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CHAPTER 0

Background and Objectives

The current Project is developed in ACRO, Automatisering Centrum Research en Opleiding, but these acronyms are more than only words. ACRO is a Research and project Group in the field of automation and is a certified PROFIBUS COMPETENCE CENTER. This group gives PROFIBUS training in a practically-oriented industrial environment and can offer you a complete PROFIBUS service. Profibus is only one element of automation, ACRO offers a complete package of trainings and services in automation.

The topics of the research group ACRO are:

- Industrial real-time networks (fieldbus)
- Real-time vision applications
- Sensor based robotics
- Real-time camera hardware
- Real-time operating systems

This project consists in implementation of a Visual-servoing application. The application will use a robot, a conveyor and an image-analyse-system. Visual-servoing means that a robot is controlled real-time by analyses of images. In this way, data which are obtained from the image are used to implement some applications like:

- To track an object with the robot as farer as the field of action permit it.
- To track an unknown outline with the robot.
- To pick up a piece with the robot on a moveable conveyor

The available robot is a KUKA KR 3. The robot has 6 degrees of freedom, an own operating system, a PROFIBUS Interface and an Ethernet Interface to communicate with the objective world.

The vision system will consist of an USB camera “Basler Scout” or “IDS Ueye” with lens and finally lightning. The software which analyses the images will use HALCON and the computer application will be written in Visual Basic or C++.

The communication between the robot and the vision system (PC) will occur over Ethernet or PROFIBUS and the communication between the computer and the conveyor over PROFIBUS via OPC.

All these goals show an open field in which the project is developed. Because of this, all the decisions made during the project are managed by the student in order to create a final application inside of the defined objectives.

CHAPTER 1

Introduction to HALCON programming

1.1. – Introduction. Vision development environment

HALCON defines the state of the art in machine vision software. It provides an extensive vision library. HALCON solves your task so fast and with highest accuracy.

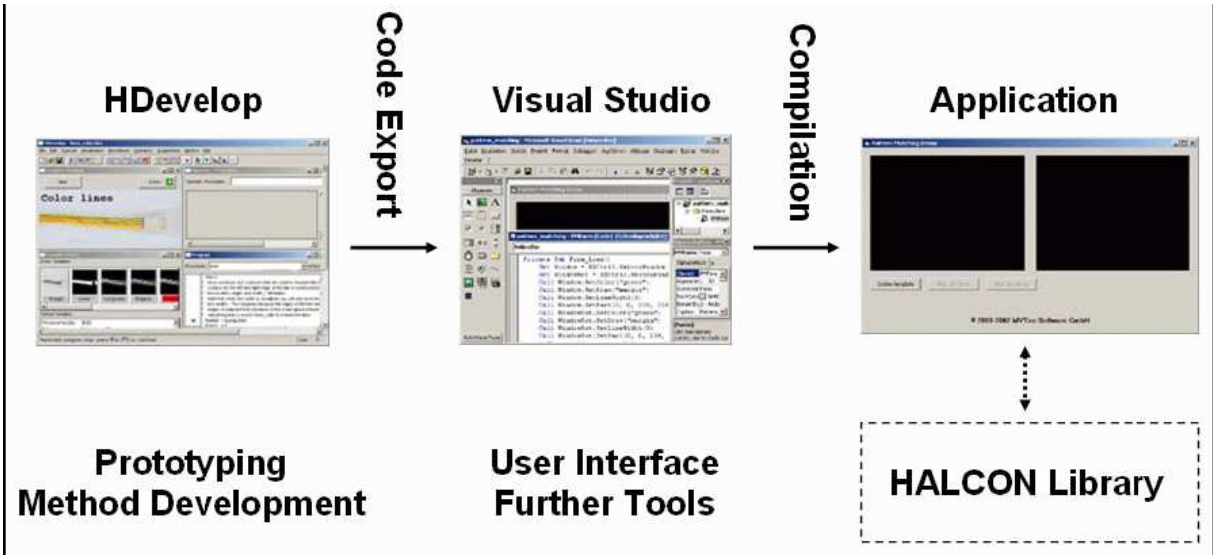
Solving image processing tasks is just one part of a complete solution, which comprises other software components like process control or database access, and hardware components from illumination to image acquisition devices and many other mechanical components. The image processing system is easy to use.

HALCON takes cares of all the important aspects:

- The software development is supported by the interactive tool HDevelop, which enables a quick development of image processing tasks combined with an easy integration into standard development environments like Microsoft Visual C++ via the automatic code export.
- The problem-oriented documentation covers all levels from a quick access to important information up to a detailed discussion of advanced topics.
- These descriptions are combined with hundreds of examples for an intuitive understanding of the solutions, which can serve as templates to shorten the development time.
- Last but not least, HALCON provides open interfaces for efficient data exchange, to integrate own operators, or to access specialized hardware round off the system.

1.2. – Develop applications with HALCON

HALCON offers many ways for the application development. But to make full use of the architecture the mode depicted in figure 1.1 is recommended.



Picture 1.1. Three-step approach for the application development.

Image inspection, prototyping of the vision method, and the final development of the vision method are done within HDevelop. Here, the program is structured into procedures in which each procedure represents one sub task, like initialization, processing, and cleanup. The main program is used only as a test environment to call the procedures by passing images and receiving the results. This program is then exported to the language of the desired programming environment.

The complete application is developed in a programming environment like Microsoft Visual Studio. The code from HDevelop is imported, e.g., via an include statement. The user interface and other necessary code is implemented using the normal mechanisms offered by the given language. Finally, the project is compiled and linked.

Together with the HALCON library, the generated program represents the solution that can, e.g., be loaded onto the destination machine or sent to a customer. An overview on the philosophy of developing with HALCON can be seen in figure 1.1. The three-step approach has several advantages:

- Whenever needed the vision part can easily be optimized or extended because HDevelop offers much better inspection and debugging facilities for image data than the standard programming environments.

- A newly exported HDevelop program can be incorporated into the programming environment quite easily because the code is included and requires modifications in the general code only if the parameters have been changed or new procedures have been introduced. This closes the development cycle in a natural manner.

- Because the vision part is separated from the general code it can easily be executed in a standalone manner. Furthermore, it can be given to others without the need to pass the whole project. Especially in the case of support questions, the HDevelop program with one or more images can quickly be sent to the distributor.

1.2.1. – Architecture and data Structures

HALCON's architecture, data structures, and internal mechanisms were developed according to the philosophy that they should be:

1) *Efficient*. Efficient means that the execution time of each HALCON operator should be as short as possible. Furthermore, the operator design has been made such that combinations that are standard sequences or more complex tasks must still remain efficient.

2) *Open*. The open architecture is important in two respects: First, it must be possible to make use of HALCON from many different languages. Here, passing of external data to HALCON and accessing internal data of HALCON must also be supported. Finally, there must be transparent interfaces to integrate user-defined operators and non-standard image acquisition devices. This open architecture allows, e.g., a simple update to a new version of a frame grabber interface without changing the installation of HALCON.

3) *Standardized*. Standardized means that the signatures, naming, and usage of operators and data strict rules. This allows a quick learning combined with few possible errors.

4) *Self-describing*. HALCON provides detailed information about each operator and their parameters not only in the documentation but also online via specialized operators.

1.2.1.1.- HALCON operators

Whenever any kind of functionality is used from the HALCON library, it is done via an operator. The current version has more than 1100 of these operators. Most of them comprise multiple methods, which are selected via parameters. A full list of all operators can be found in the Reference Manuals or in the dialog Operators of HDevelop. Important features of operators are:

- There is no hierarchy among operators. From the software architecture point of view, all operators are on the same level.

- Of course, there are logical groups of operators. This can directly be seen by the classes offered for C++ and COM, where operators processing the same data type are used as members of the corresponding classes.

- Operators have standardized rules for ordering input and output parameters.

- The design of operators follows the rules of the open architecture. Therefore, you can create your own operators and thus extend HALCON, while getting the same look-and-feel for your own operators.

- Many operators can make transparent use of automatic parallelization, which allows an easy way of speeding up the program when using large images on a multi-CPU computer.

1.2.1.2.- Parameters and Data Structures

- HALCON has two basic types of parameters: iconic data (images etc.) and control data (integers, handles, etc.).

- The parameters for each operator are arranged in a standardized order: input iconic, output iconic, input control, and output control. Not all of the groups might be needed for a given operator. However, the order remains the same.

- Each operator has a self-describing interface. This desription contains, besides the standard documentation, information about parameters like types or value lists, which can be accessed online.

- Input parameters of operators are never modified, which results in a very clear and simple sementics. There are only three operators that do not follow this principle to ensure maximum performance (namely set grayval, overpaint gray and overpaint region).

- The open architecture allows to access internal data and to integrate external data.

- All necessary data structures for 2D image processing like (multichannel) images, region, contours, tuples (a kind of array), etc. are directly supported using an extremely efficient implementation.

Images

Images belong to the iconic data.

The major part of an image are the channels, i.e., matrices containing the gray values of various pixel types.

For each image, the so-called *domain* specifies which part of the image is processed. It thus acts as a *region of interest* (ROI). The domain is a HALCON region and can therefore be defined very flexibly (from a simple rectangle to a set of unconnected pixels, see below).

Pixel data

An almost arbitrary content is possible, from standard 8-bit gray values to floating-point numbers describing derivatives. For integer values one, two, and four byte versions (with and without sign) are available. Besides this, floating point and complex images are available. Finally, special data types for describing edge direction or hue values are supported.

Image Channels

A channel corresponds to an image matrix. Each image can have an arbitrary number of channels. All channels of an image have the same size. Typical cases are: single-channel gray value image, color image with three channels (e.g., RGB), or a multichannel image from a multispectral sensor or as a result of texture filtering.

Coordinate Systems

The origin of an image is the upper left corner with coordinates (0,0). The single pixels are accessed using row and column coordinates, like in a matrix. The coordinates range from (0,0) up to (height-1, width-1). A pixel has an extent of 1, whereas the center of gravity of the first pixel of an image is (0,0). This has the effect that this pixel ranges from (-0.5, -0,5) to (0.5,0.5).

Regions

- Regions belong to the iconic data.

- A region is defined as a set of pixels, which are not necessarily limited to the coordinate range of a given image.

- The pixels of a region are not necessarily connected. This means that even an arbitrary collection of pixels can be handled as one region. If connected components as separate regions are needed, the operator connection can be called.

- Because the coordinates of pixels inside a region are not limited to the coordinates of a given image, the region can be larger than the image, possibly as the result of a dilation operation. Whether a region should be clipped to the

maximum image extents can be controlled using the operator set system with the parameter value 'clip region'.

- The implementation of regions is based on an efficient implementation of the runlength encoding. This encoding facilitates low memory consumption with efficient processing and easy use as regions of interest (domains).

- Because of the implementation based on runlength encoding, it is possible to have overlapping regions, e.g., as the result of a dilation of connected components. This would not be possible with a classical implemention based on label images.

- The number of regions for an application is virtually unlimited.

XLDs

- XLDs belong to the iconic data.

- XLD is the abbreviation for eXtended Line Description and comprises all contour and polygon based data.

- Subpixel accurate operators like edges sub pix return the contours as XLD data.

- A contour is a sequence of 2D control points, which are connected by lines.

- Typically, the distance between control points is about one pixel.

- XLD objects contain, besides the control points, so-called local and global attributes. Typical examples for these are, e.g., the edge amplitude of a control point or the regression parameters of a contour segment.

- Besides the extraction of XLD objects, HALCON supports further processing. Examples for this are the selection of contours based on given feature ranges or segmenting of a contour into lines, arcs, polygons or parallels.

Control Tuples

- Tuples are the generic data type for integer and floating point values as well as strings. A variable of type tuple can be of any of the three basic types.

- Besides single values, arrays of the basic types are supported. Therefore, one variable can contain none, one, or an arbitrary number of values, where the types of each element can be different.

- In most cases, single values are treated in the same way as multiple values. If, e.g., a feature operator is called with a single region one feature value is returned. When the operator is called with multiple regions a tuple with the corresponding number of values is returned.

- The index of tuples range from 0 to the number of values minus 1.

Handles

- Handles are references to complex data structures, e.g., models for the shape-based matching. For efficiency and data security reasons, not the entire structure but only the handle is passed to the programmer.

- All processing of data is controlled with a unique integer value. These integers are magic numbers that must not be changed and can differ from execution to execution and version to version.

- Examples where handles are used are graphics windows, files, sockets, image acquisition devices, OCR, OCV, measuring, matching, and so on.

1.2.2. – Image acquisition

Currently, HALCON provides interfaces about 40 frame grabbers in the form of dynamically loadable libraries (Windows: DLLs; UNIX: shared libraries). These libraries are installed together with the HALCON libraries. Library names start with the prefix HFG; the libraries starting with parHFG are used by Parallel HALCON.

The HALCON frame grabber interface libraries form the bridge between software provided by the frame grabber's manufacturer and HALCON. They form a common, generic interface that requires a small set of operators only.

If you successfully installed your frame grabber, all you need to do to access it from HALCON is to call the operator open framegrabber, specifying the name of the frame grabber and some additional information, e.g., regarding the connected camera. Then, images can be grabbed by calling the operator grab image (or grab image async).

1.3. – HDevelop

HDevelop is a powerful environment for both prototyping and method development. To use HDevelop you need to know just a few things. To load an example, select the menu File > Open. This will open a file section dialog that shows the main directories of the

HDevelop examples underWindows). For beginners, it is recommended to select an example from the directory Applications. As an alternative, the menu File > Open Example Program... can be used. Here, a dialog that allows you to select examples based on different categories instead of the actual location is opened.

After loading the file, the corresponding program code is displayed in the program window. The used variables - so far not instantiated - can be seen in the variable watch window. The program is now ready for execution.

Steps to run a program:

1. Press the Run button to execute the program. To continue at a stop statement, press Run again.
2. Besides the Run button, HDevelop provides a Step button, which executes only a single line and displays the results immediately afterwards. If the program contains procedures, it might be of interest to use the buttons Step Into and Step Out.
3. To rerun the complete program the Reset button can be used. To rerun parts only, simply click with the mouse to the left of the desired program line. This will reposition the program counter. When executing the program anew it will then start at the newly selected position.

Useful hints for HDevelop:

1. At the lower end of the main window, HDevelop provides a status bar. This displays useful information in many cases. Especially during the execution, when the program stops to visualize results or waits for a user interaction corresponding instructions are given.
2. Many programs will automatically display relevant data in the graphics window. Manual visualization can easily be achieved by double clicking on the icons in the variable watch window.
3. Depending on the selected installation type, not all images used in an example program might be available. In this case, we recommended to insert the HALCON CD or to install the needed images.
4. Some programs use frame grabbers for image acquisition. If the corresponding frame grabber type is not available, an error message will be raised. In this case, we recommend to either use another example or to modify the parameters to fit to the available hardware. Furthermore, if HDevelop Demo is used, no frame grabber interfaces can be used, including the File frame grabber, which reads images from files. If you want to use these programs, please use HDevelop.

1.4. – Using HALCON within Programming languages

HALCON offers three so-called language interfaces. They are libraries that enable you to call the operators and to use the data types of the HALCON library in an easy way. Two language interfaces are designed for specific languages. These are the C and the C++ interfaces. In contrast, the COM interface is independent of a given language. It can be used, e.g., with Visual Basic, C#, or Delphi.

Independent of which programming language you choose, a suitable interface library (HALCONc.*, HALCONcpp.*, HALCONx.*) together with the HALCON library (HALCON.*) must be linked to the application. In addition to this, for C and C++ the corresponding include files must be included.

For each language interface, the names of types, classes, the naming conventions of operators, etc. may differ to be compliant with the typical rules that apply for the selected language.

1.5. – Examples and applications

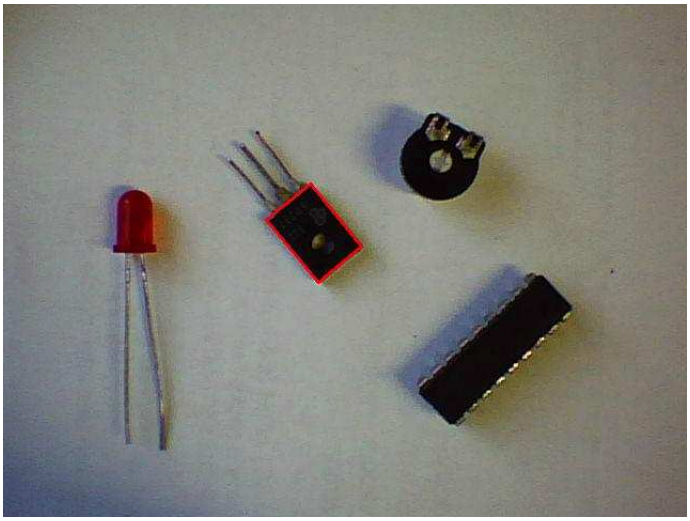
In order to explain the knowledge about the HALCON programming during the first three weeks, subsequently there are series of shorts programs as a prelude to the final program, used in the robot implementation.

First of these, it is necessary to acquire images through the camera by the following program:

```
** Image Acquisition **
*************************
dev_close_window ()
close_all_framegrabbers ()
dev_open_window (0, 0, 640, 480, 'black', WindowHandle)
open_framegrabber ('DirectShow', 1, 1, 0, 0, 0, 0, 'default', 8, 'rgb', -1, 'false', 'default', 'default',
0, -1, AcqHandle)
grab_image_start (AcqHandle, -1)
*
while (true)
   count_seconds (T1)
   grab_image_async (Image, AcqHandle, -1)

*    Do something

   count_seconds (T2)
   Result := 1/(T2-T1)
endwhile
close_framegrabber (AcqHandle)
```

The following program looks for a transistor between any electronic devices, it makes a distinction between these and it marks only the transistor. It can be seen in the picture below (Picture 1.2.):

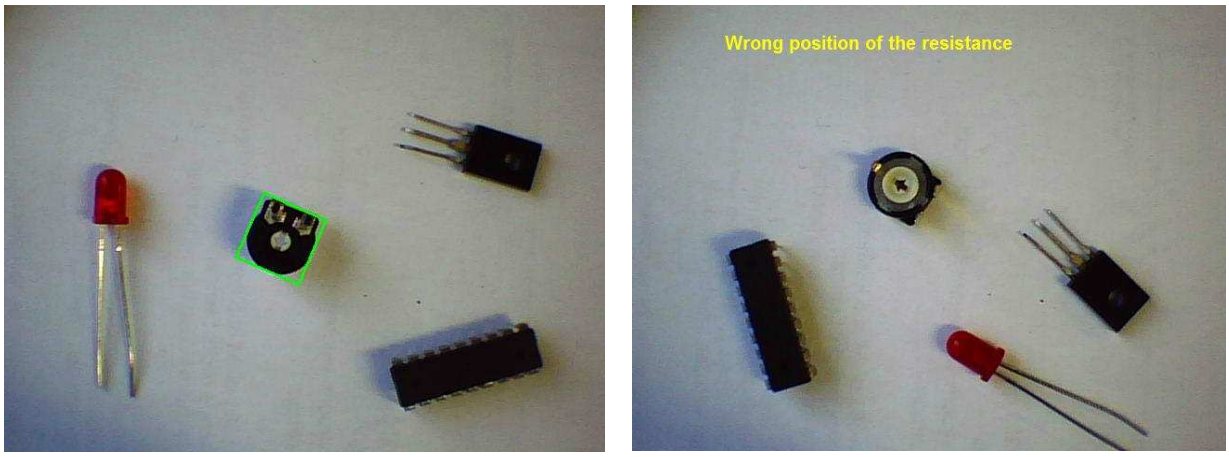
```
** Looking for a transistor **
*********************************
dev_close_window ()
close_all_framegrabbers ()
dev_open_window (0, 0, 640, 480, 'black', WindowHandle)
open_framegrabber ('DirectShow', 1, 1, 0, 0, 0, 0, 'default', 8, 'rgb', -1, 'false', 'default', 'default',
0, -1, AcqHandle)
grab_image_start (AcqHandle, -1)
*
dev_update_window ('off')

while (true)

   count_seconds (T1)
   grab_image_async (Image, AcqHandle, -1)
   count_seconds (T2)
   Result := 1/(T2-T1)
   rgb1_to_gray (Image, GrayImage)
   decompose3 (Image, r, g, b)
   threshold (r, Region, 0, 25)
   connection (Region, ConnectedRegions)
   select_shape (ConnectedRegions, SelectedRegions, ['area','compactness'], 'and', [3000,1],
    [4000,2])
   shape_trans (SelectedRegions, RegionTrans, 'rectangle2')
   boundary (RegionTrans, RegionBorder, 'inner')
   dev_set_color ('red')
   dev_set_line_width (2)
   dev_set_draw ('margin')
   dev_display (Image)
   dev_display (RegionBorder)

endwhile
close_framegrabber (AcqHandle)
```



Picture 1.2. Looking for the transistor.

In the following program, HALCON detects if the position of the reluctance (circular device) is correct. While the reluctance is on top, it marks with a green square. When it is bottom or sideway, it shows up a message “Wrong position of the reluctance”:

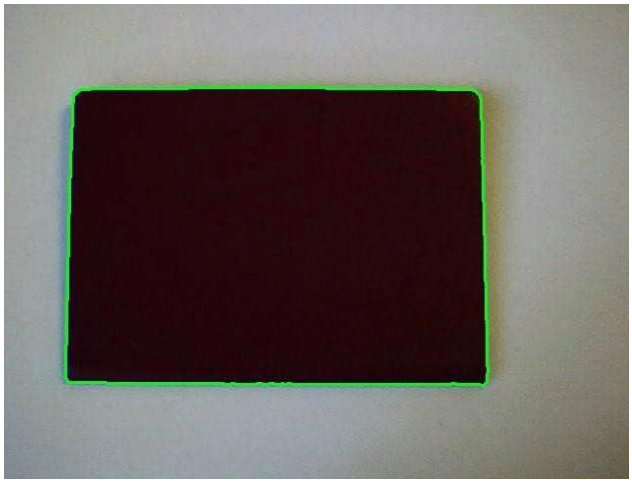
```
** Detecting the position of the reluctance **
************************************************
dev_close_window ()
close_all_framegrabbers ()
dev_open_window (0, 0, 640, 480, 'black', WindowHandle)
open_framegrabber ('DirectShow', 1, 1, 0, 0, 0, 0, 'default', 8, 'rgb', -1, 'false', 'default', 'default',
0, -1, AcqHandle)
grab_image_start (AcqHandle, -1)
*
dev_update_window ('off')

while (true)

   count_seconds (T1)
   grab_image_async (Image, AcqHandle, -1)
   count_seconds (T2)
   Result := 1/(T2-T1)
   dev_set_color ('green')
   dev_set_draw ('margin')
   dev_set_line_width (2)
   rgb1_to_gray (Image, GrayImage)
   decompose3 (Image, r, g, b)
   threshold (g, Region, 0, 53)
   connection (Region, ConnectedRegions)
   select_shape (ConnectedRegions, SelectedRegions, ['area','roundness'], 'and', [3000,0.65],
    [4250,0.75])
   shape_trans (SelectedRegions, RegionTrans, 'rectangle2')
   boundary (RegionTrans, RegionBorder, 'inner')
   area_center (RegionTrans, Area, Row, Column)
   dev_display (Image)

if (Area>0)

      dev_display (RegionBorder)

else
      set_tposition (WindowHandle, 30, 100)
      set_font (WindowHandle, '-Arial-18-*-*-*-*-1-')
      dev_set_color ('yellow')
      write_string (WindowHandle, 'Wrong position of the resistance')

endif

stop ()

endwhile

close_framegrabber (AcqHandle)
```



Picture 1.3.Position of the reluctance.

The third program extracts the outline of a single color object. For example, in the Picture 1.4, HALCON draws the outline of a passport:

```
** Drawing edges **
************************
dev_close_window ()
close_all_framegrabbers ()
dev_open_window (0, 0, 640, 480, 'black', WindowHandle)
open_framegrabber ('DirectShow', 1, 1, 0, 0, 0, 0, 'default', 8, 'rgb', -1, 'false', 'default', 'default',
0, -1, AcqHandle)
grab_image_start (AcqHandle, -1)

while (true)

    count_seconds (T1)
   grab_image_async (Image, AcqHandle, -1)
   count_seconds (T2)
   Result := 1/(T2-T1)
   threshold (Image, Region, 0, 70)
   connection (Region, ConnectedRegions)
   boundary (ConnectedRegions, RegionBorder, 'inner')
   dilation_rectangle1 (RegionBorder, RegionDilation, 10, 10)
   union1 (RegionDilation, RegionUnion)
   dev_display (Image)
   dev_set_color ('green')
   dev_set_line_width (3)
   dev_set_draw ('margin')
   reduce_domain (Image, RegionUnion, ImageReduced)
   edges_sub_pix (ImageReduced, Edges, 'lanser2', 0.5, 20, 40)
   stop ()

endwhile

close_framegrabber (AcqHandle)
```



Picture 1.4.Drawing edges

CHAPTER 2

KUKA Robot. Overview and programming over KCP

2.1. – Robot Description. KUKA KR3

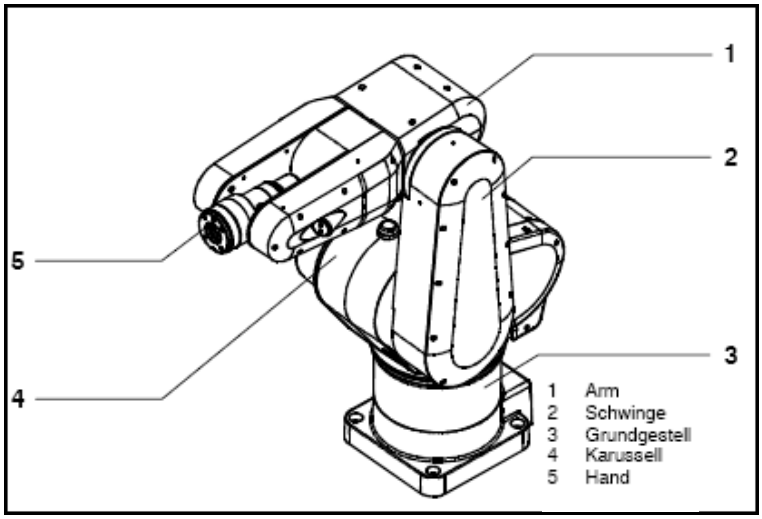
The KR3 robot and its variants are six-axis industrial robots designed for light payload applications that require articulated motion in the horizontal and vertical planes.

Their main areas of application are:
- Machine loading and parts handling
- Laboratory automation
- Product testing
- Assembly
- Adhesive application
- Training
- Arc welding
- Machining task, such as grinding, polishing and deburring

Designed for a nominal 3 Kg payload, the KR 3 provides a powerful combination of high-speed flexible automation, reliability and ease-of-use. The robot can be mounted upright or inverted, and is sealed to IP54, allowing for a wide range of possible uses.

The brushless servomotors and high-stiffness harmonic drives used in the KR3 design make it one of the fastest and most durable robots in its class. Absolute encoders built into each joint allow the KR 3 to retain positional information, making it possible to turn on the robot and be ready to go in mere seconds. Arm position parameters can be maintained in memory for up to 2 months, even when the robot and controller are disconnected.

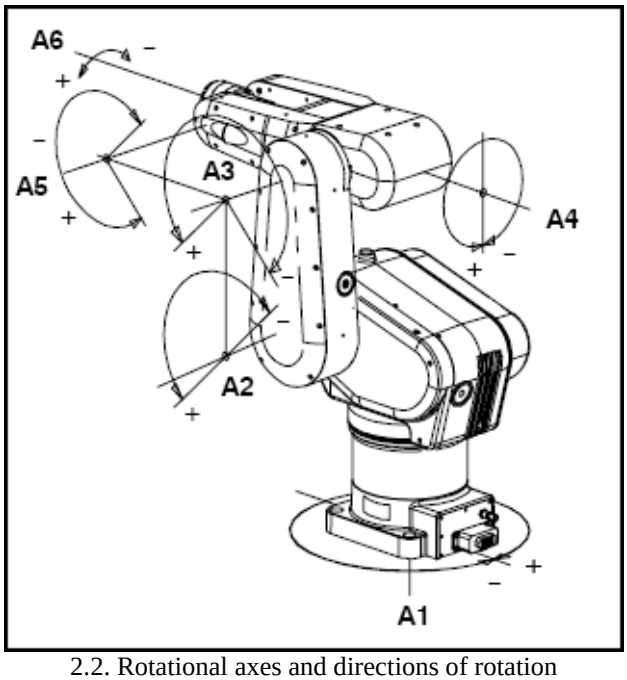
A fully integrated servo control network located within the robot makes the KR 3 virtually immune to interference from external electromagnetic radiation. This internal design also allows for a smaller controller, and reduces the complexity of umbilical cable management.



2.1. Principal components of the robot

Robot design

The ISO-standard mounting flange on the wrist allows a wide range of end effectors to be used with the KR 3. The possible movements of the robot axes are depicted in Figure 2.2



2.2. Rotational axes and directions of rotation

The working range of the robot can be limited by means of software limit switches on all axes. The working ranges of the main joints are mechanically limited by hardstops, which can be pre-adjusted at the factory.

2.2. – Technical data

Number of axes	6	
Weight	KR 3 SI	53 kg, 54 kg
Mounting position	Upright or inverted	
Nominal payload	KR 3 SI	3 kg 1.5 kg
Reach	635 mm	
Repeatability	±0.05 mm	
Encoder resolution	2048 counts per turn	
Drive system	Electromechanical, brushless motors Absolute encoders in each joint	
Transmission	Harmonic Drive	
Brakes	Brakes on joints 1, 2, 3, and 5	
Motion modes	Teach Automatic	
End-of-arm connections	ISO9409-compliant tool flange	
Energy supply	Support for pneumatic tools Up to 4 electrically isolated digital inputs and outputs on axis 5	

Axis data

Axis	Range of motion	Maximum speed
1	± 180°	240 °/s
2	−135° to +45°	210 °/s
3	± 135°	240 °/s
4	± 180°	375 °/s
5	± 135°	300 °/s
6	continuous turn[1]	375 °/s

User inputs

4 floating digital inputs with reverse voltage protection

Input voltage:	**16 V to 30 V**
Input current at 24 V:	**approx. 6 mA**
Coincidence factor.	**100%**
Filter constant:	**1 – 2 ms**

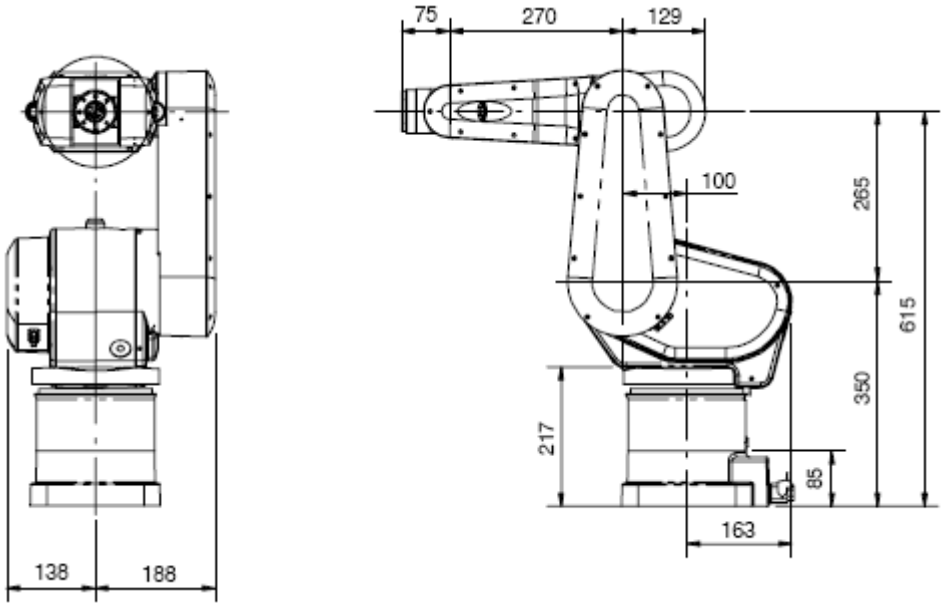
User outputs

4 floating digital inputs

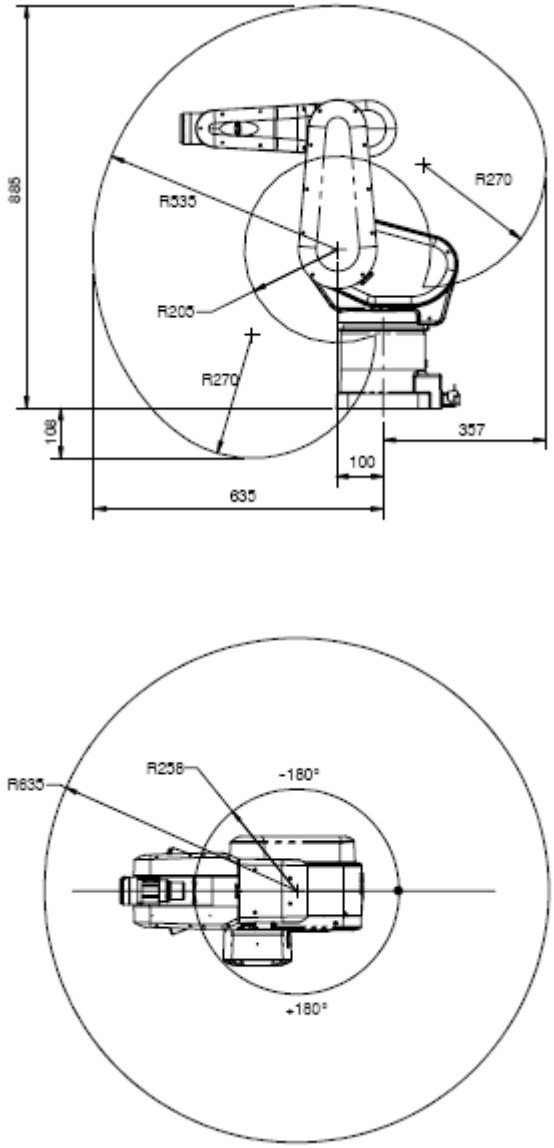
Control voltage:	**18 V to 30 V**
Voltage drop in ON state (100 mA):	**< 2 V**
Rated load:	**100 mA**
Coincidence factor:	**100%**
Load factor:	**100%**
Leakage current in OFF state:	**< 10 µA**

Switching of inductive loads is permissible with the use of free-wheeling diodes or other voltage-limiting components (VCR).

Output protection through electronic and thermal protection in case of short circuits; outputs reverse voltage proof up to 30 V.



2.3. Critical dimensions KR 3 (mm)

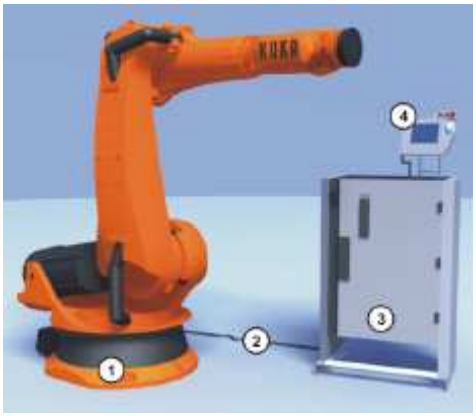


2.4. Working envelope for KR3 (mm)

2.3. – Quick description of the robot system

A KUKA robot system is made up of the following components and is depicted in the picture 2.5:

- Robot (1)
- Robot controller (3)
- KCP teach pendant (4)
- Connecting cables (2)
- Software
- Accessories



Picture 2.5. KUKA robot system

2.3.1. – KCP teach pendant

The KUKA Control Panel is the teach pendant for the robot system. The KCP has all the functions required for operating and programming the robot system.

Picture 2.6. KCP

1. *Mode selector switch.* The operating mode is selected using the mode selector switch on the KCP. The switch is activated by means of a key which can be removed. If the key is removed, the switch is locked and the operating mode can no longer be changed.

2. *Drives On.* Switches the robot drives on.

3. *Drives Off.* Switches the robot drives off.

4. *Emergency Stop button.*

5. *Space Mouse.* Jogs the robot.

6. *Right-hand status keys.* The status keys are used primarily for controlling the robot and setting values.
7. *Enter key.* The enter key is used to close an active window or inline form. Changes are saved.

8. *Arrow keys.* The arrow keys are used to jump from element to element in the user interface.

9. *Keypad.*

10. *Numeric keypad.*

11. *Softkeys.* The icons change dynamically and always refer to the active window.

12. *Start backwards key.* The start backwards key is used to start a program backwards. The program is executed step by step.

13. *Start key.* The start key is used to start a program.

14. *Stop key.* The stop key is used to stop a program that is running.

15. *Window selection key.* The window selection key is used to toggle between the main, option and message windows. The selected window is indicated by a blue background.

16. *Esc key.* The esc key is used to abort an action on the user interface.

17. *Left-hand status key.* The status keys are used for controlling the program execution and the robot movements.

18. *Menu keys.* The menu keys are used to open the menus.

The rear of KCP presents the disposition shown in Picture 2.7 (next page)

1. *Rating plate.*

2. *Start key.* The start key is used to start a program.

Picture 2.7. Rear of KCP.

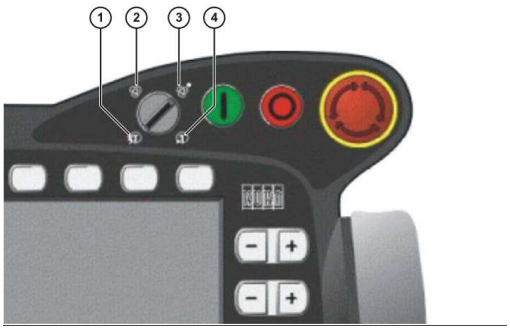
3. *Enabling switch (buttons 3, 4, 5)* The enabling switches have 3 positions:

   - Not pressed
   - Center position
   - Panic position

   The enabling switch must be held in the center position in operating modes T1 and T2 in order to be able to jog the robot. In the operating modes Automatic and Automatic External, the enabling switch has no function.

2.3.2. – Operating modes

The operating mode is selected using the mode selector switch on the KCP. The switch is activated by means of a key which can be removed. If the key is removed, the switch is locked and the operating mode can no longer be changed.



Picture 2.8. Modes in KCP

1. *Test 2 (T2)*

2. *Automatic (AUT).* For robot system without higher-level controllers. Only possible with a connected safety circuit.

3. *Automatic External (AUT EXT).* For robot system with higher-level controller, e.g. PLC. Only possible with a connected safety circuit.

4. *Test 1 (T1)*

2.3.3. – Changing user group

Different functions are available in the KSS, depending on the user group. The following user groups are available:

- User. User group for the operator

- Expert. User group for the programmer. In this user group it is possible to switch to the Windows interface.

- Administrator. The range of functions is the same as that for the user group "Expert". It is additionally possible, in this user group, to integrate plug-ins into the robot controller.

When the system is booted, the user group "User" is selected by default. The user groups "Expert" and "Administrator" are password-protected.

2.2.4. – Coordinate system

The following Cartesian coordinate systems are defined in the robot system:

WORLD
The World coordinate system is a permanently defined Cartesian coordinate system. It is the root coordinate system for the Robroot and Base coordinate systems. By default, the World coordinate system is located at the robot base.

ROBROOT
The Robroot coordinate system is a Cartesian coordinate system, which is always located at the robot base. It defines the position of the robot relative to the World coordinate system. By default, the Robroot coordinate system is identical to the World coordinate system. $Robroot allows the definition of an offset of the robot relative to the World coordinate system.

BASE
The Base coordinate system is a Cartesian coordinate system that defines the position of the workpiece. It is relative to the World coordinate system. By default, the Base coordinate system is identical to the World coordinate system. It is offset to the workpiece by the user.

2.2.5. – Tool calibration

During tool calibration, the user assigns a Cartesian coordinate system (TOOL coordinate system) to the tool mounted on the mounting flange. The TOOL coordinate system has its origin at a user-defined point. This is called the TCP (Tool Center Point). The TCP is generally situated at the working point of the tool.

Advantages of the tool calibration:

- The tool can be moved in a straight line in the tool direction.
- The tool can be rotated about the TCP without changing the position of the TCP.
- In program mode: The programmed velocity is maintained at the TCP along the path.

A maximum of 16 TOOL coordinate systems can be saved. Variable:

TOOL_DATA[1…16].

The following data are saved:

- X, Y, Z:
  Origin of the TOOL coordinate system relative to the FLANGE coordinate system.

- A, B, C:
  Orientation of the TOOL coordinate system relative to the FLANGE coordinate system

Tool calibration consists of 2 steps:

1. *Definition of the origin of the Tool coordinate system. The following methods are available:*

   TCP calibration: XYZ 4-Point method
   The TCP of the tool to be calibrated is moved to a reference point from 4 different directions. The reference point can be freely selected. The robot controller calculates the TCP from the different flange positions.

   TCP calibration: XYZ Reference method
   In the case of the XYZ Reference method, a new tool is calibrated with a tool that has already been calibrated. The robot controller compares the flange positions and calculates the TCP of the new tool.

2. *Definition of the orientation of the Tool coordinate system. The following methods are available*

Defining the orientation: ABC World method
The axes of the TOOL coordinate system are aligned parallel to the axes of the WORLD coordinate system. This communicates the orientation of the TOOL coordinate system to the robot controller.

Defining the orientation: ABC 2-Point method
The axes of the TOOL coordinate system are communicated to the robot controller by moving to a point on the X axis and a point in the XY plane.
This method is used if it is necessary to define the axis directions with particular precision.

The tool data can be entered manually.
Possible sources of data:
- CAD
- Externally calibrated tool
Tool manufacturer specifications

2.2.6. – Structure of a KRL program (KUKA Robot Language)

The picture below shows the structure of a KUKA Robot Language program:

```
1  DEF my_program( )
2  INI
3
4  PTP HOME  Vel= 100 % DEFAULT
   ...
8  LIN point_5 CONT Vel= 2 m/s CPDAT1 Tool[3] Base[4]
   ...
14 PTP point_1 CONT Vel= 100 % PDAT1 Tool[3] Base[4]
   ...
20 PTP HOME  Vel= 100 % DEFAULT
21
22 END
```

Picture 2.9. KRL program

1. *Def line*. The Def line indicates the name of the program. If the program is a function, the Def line begins with ‘Deffct’ and contains additional information.

2. *Ini line*. The Ini line contains initializations for internal variables and parameters. This line mustn’t be deleted.

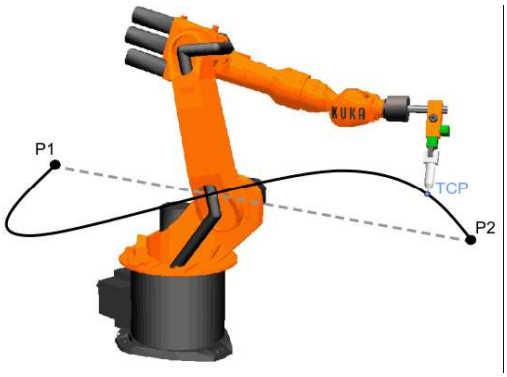
4. *Home position*. The Home position is not program-specific. It is generally used as the first and last position in the program as it is uniquely defined and uncritical. The Home position is stored by default in the robot controller.

22. *End line.* The End line is the last line in any program. If the program is a function, the wording of the End line is ‘Endfct’.

2.2.7. – Programming motions

PTP motion

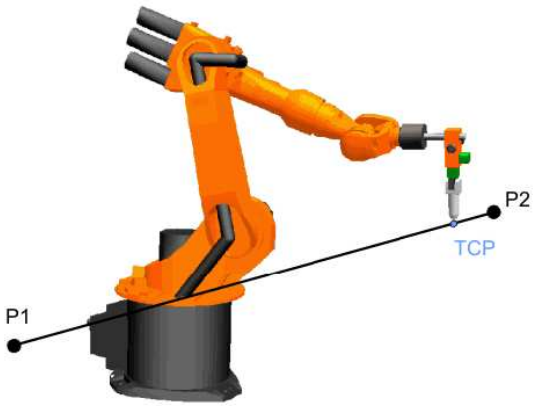
The robot guides the TCP along the fastest path to the end point. The fastest path is generally not the shortest path and is thus not a straight line. As the motions of the robot axes are rotational, curved paths can be executed faster than straight paths. The exact path of the motion cannot be predicted.



Picture 2.10. PTP motion

LIN motion

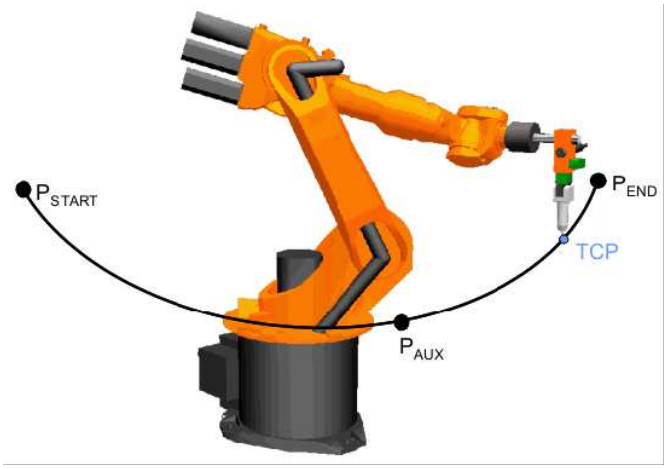
The robot guides the TCP at a defined velocity along the shortest path to the end point. The shortest path is always a straight line.



Picture 2.11. LIN motion

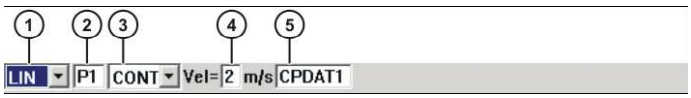
CIRC motion

The robot guides the TCP at a defined velocity along a circular path to the end point. The circular path is defined by a start point, auxiliary point and end point.



Picture 2.12. CIRC motion

2.2.7.1.- Inline form for motions

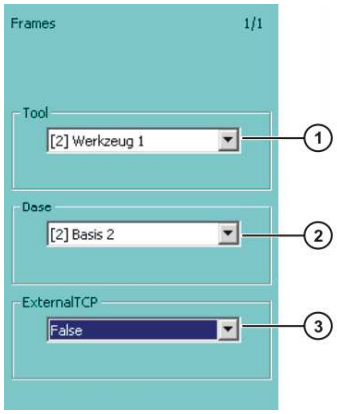


Picture 2.13. Inline form for LIN motions

1. Type of motion (PTP, LIN, CIRC)
2. Name of the end point. The system automatically generates a name. The name can be overwritten.
3. CONT: end point is approximated; [blank]: the motion stops exactly at the end point
4. Velocity (0.001… 2 m/s)
5. Name for the motion data set. The system automatically generates a name. The name can be overwritten.

If is chosen a CIRC motion additionally appears another auxiliary point what defines the coordinates of the auxiliary point to describe de circle.

Option window "Frames"

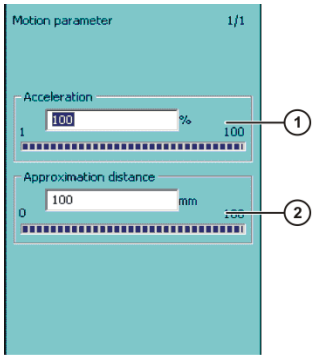


Picture 2.14. Frames

1. Tool selection. Range of values [1-16]
2. Base selection. Range of values [1-32]
3. External TCP. False: Tool on mounting flange

   True: Fixed tool

Option window "Motion parameter" (in PTP motions)



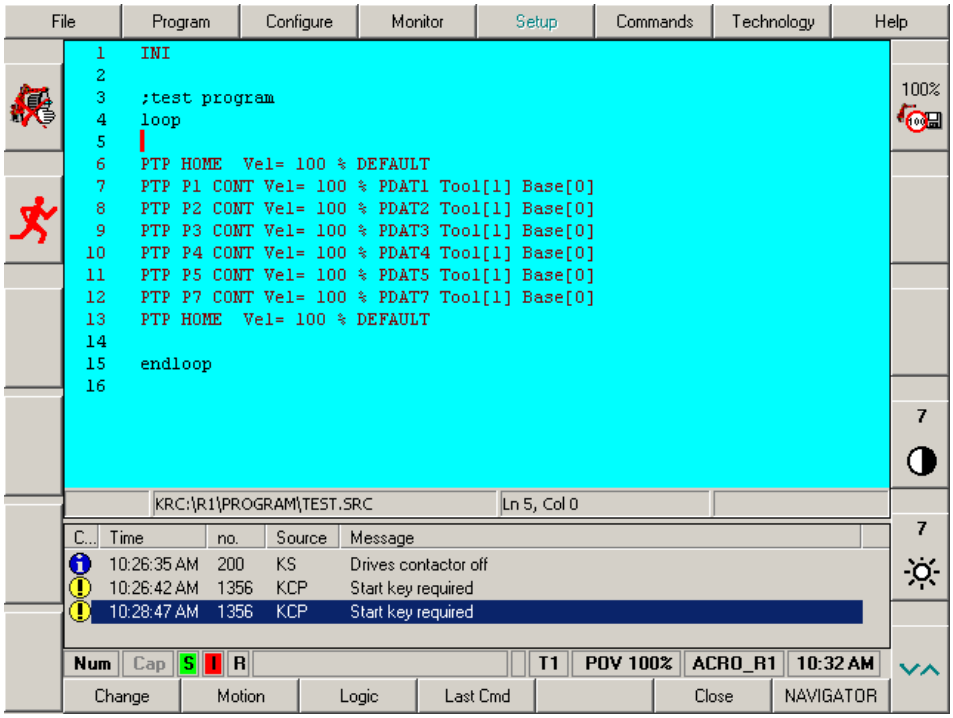
Picture 2.15. Motion parameter

1. Acceleration. Refers to the maximum value specified in the machine data [1-100%]
2. Furthest distance before the end point at which approximate positioning can being. This box is only displayed if CONT has been selected in the inline form [0-100%]

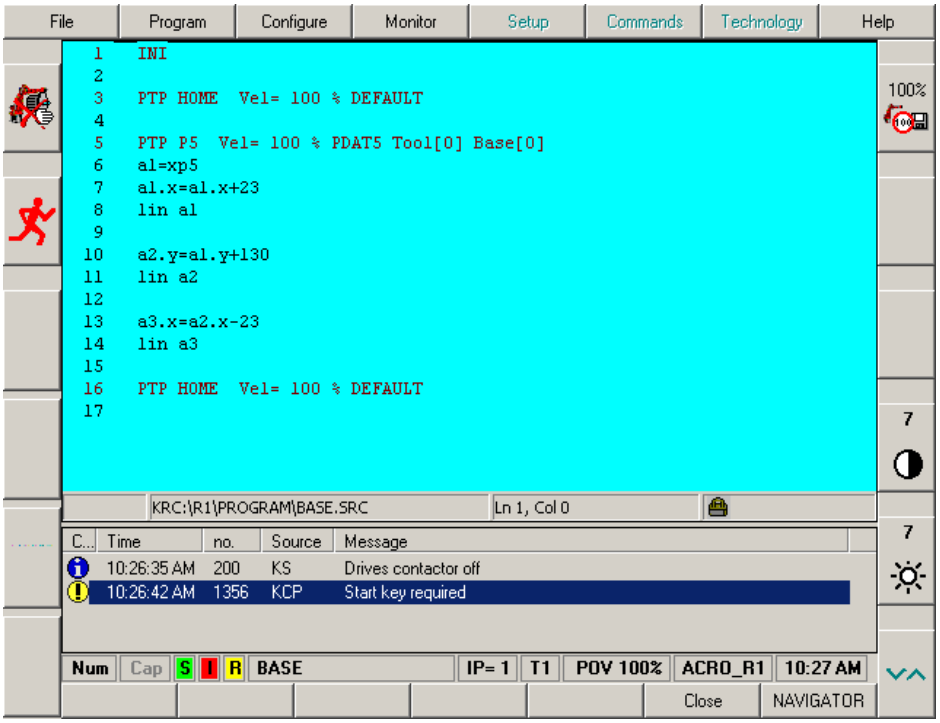
In CIRC and LIN motions the orientation of a tool can be different at the start point and end point of a motion. It can be selected by a new option called "Orientated Control Selection". There are several different types of transition from the start orientation to the end orientation. Three options are available: Standard, Wrist PTP and Constant.

2.4. – Initial programs

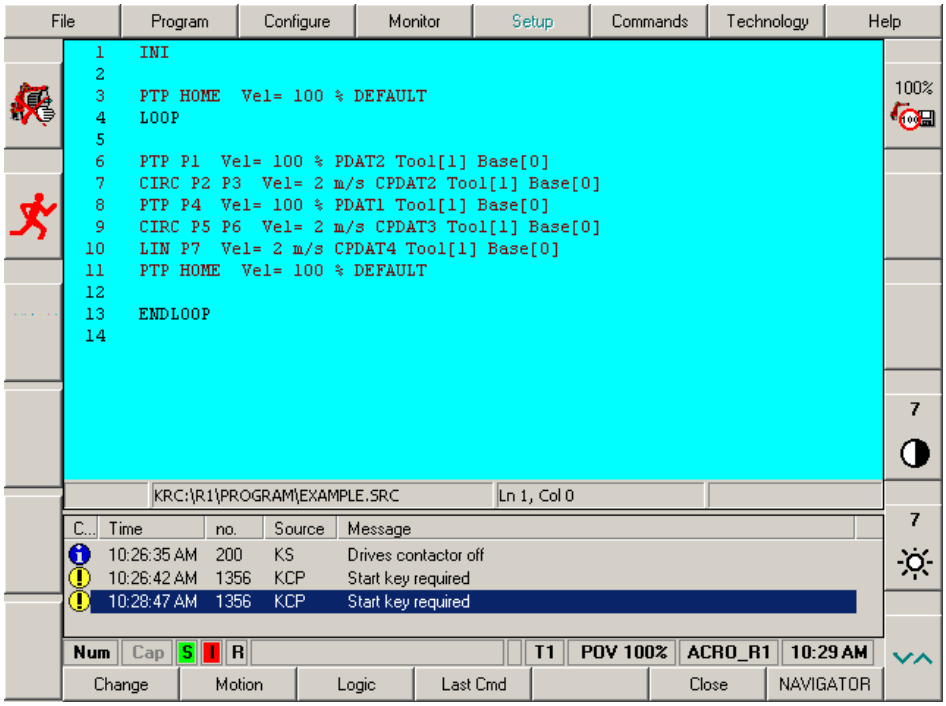
The programs below show the structure of an easy program using point to point motion, circular, linear and some coordinates given by the user to move the robot some distances in millimeters (Picture 2.17).



Picture 2.16. First program



Picture 2.17. Second program



Picture 2.18. Third program

CHAPTER 3

Manufacturing the surface of work

3.1. – Surface work and possible alternatives

The robot has its own support but it needs an additional surface to work, where are situated the conveyor, the camera, etc. This involves thinking about different ways to get the best solution.

Firstly was chosen a metal plate fixed on the base of the robot. But it wasn't a good idea because the robot could produce movements on the plate, it could make errors while the camera is grabbing images and even it would be an unstable structure.

Afterwards was decided that the best choice was to design a table, more stable and robust than previous plate. To design this, at the beginning it was necessary to take measures about the maximum length that the robot can reach during the movements. The work surface will be on the same level as the robot base. Take into account that the working envelope measures displayed in the previous chapter (Picture 2.4), the required table needs the following dimensions:

- Length: 1220 mm
- Width: 780 mm
- Height: 865 mm

The next step is to check if there are enough materials which are necessary to make the table (1220 x 780) in the workplace.

3.2. – Features and reasons

Looking at the robot scope, it is common to think that the table is enough to implement the process (too big), but it's thought to hold another future process.

The color of the table is white to help and simplify the images later collected through the camera. In this way Halcon programming is more efficient and it reduces the mistakes. The steel structure of the table is colored brown to conserve the esthetic form of the remaining tables inside the department.

The table legs are adjustable in height to allow a fine-regulation.

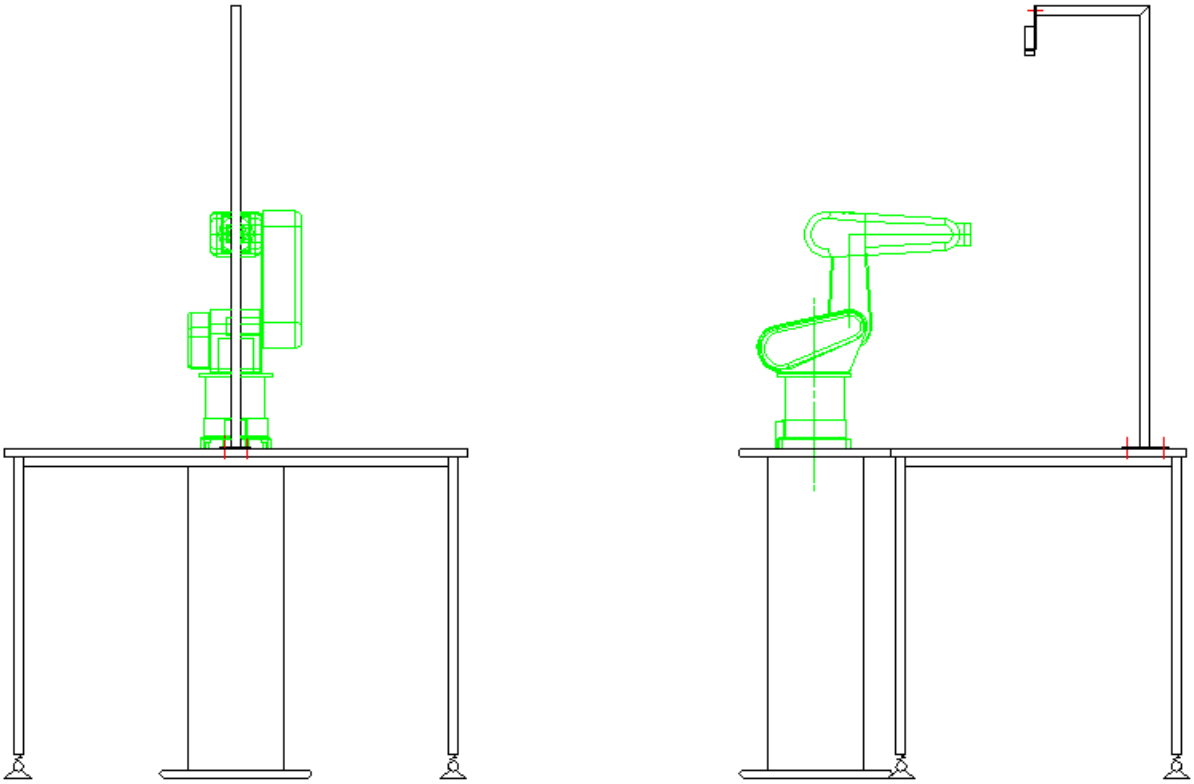
3.3. – Camera support

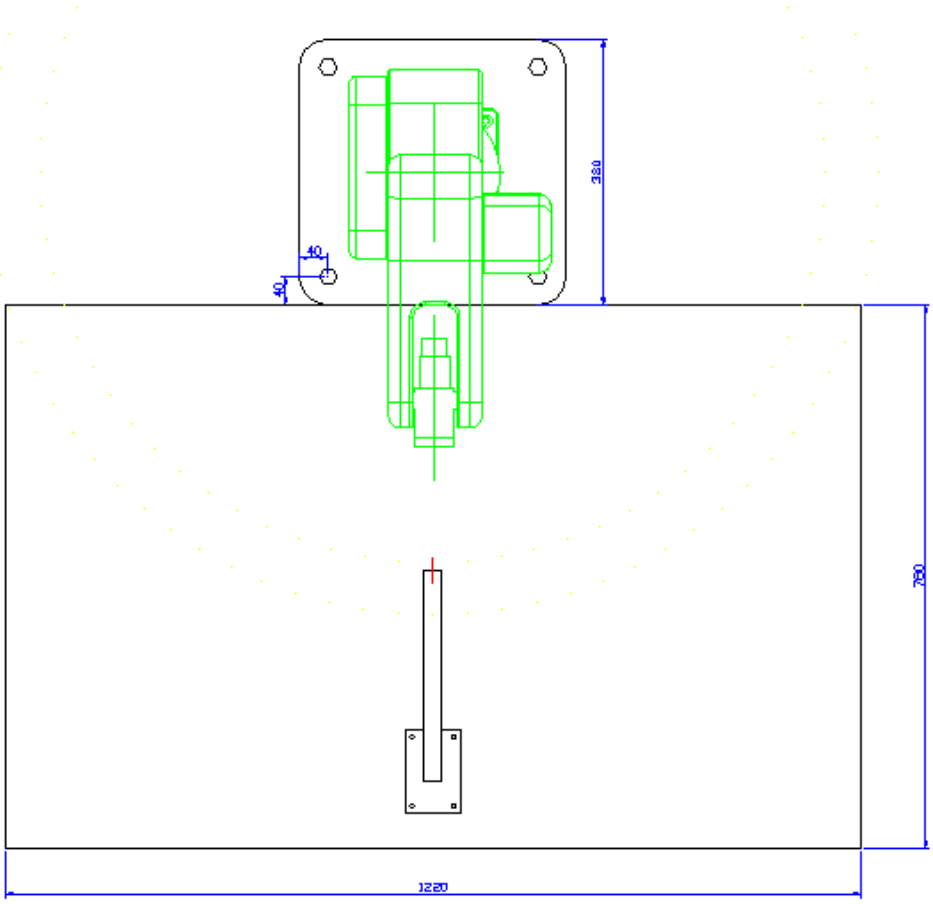
The camera presents a new problem. The best position to place it is above the robot in the central part of the table, but it has to keep a certain distance to not crash the robot while it is moving.

In consequence of this, the camera support has an L shape to avoid a collision with the robot. By tudying the robot movements and by considering the security distances, the final shape of the support is obtained.

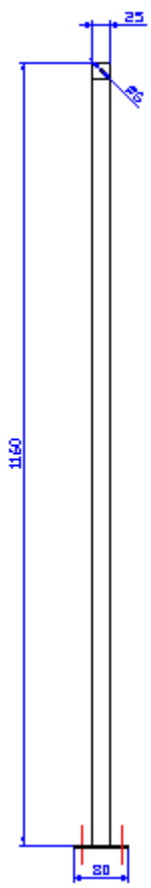
3.4. – Plans

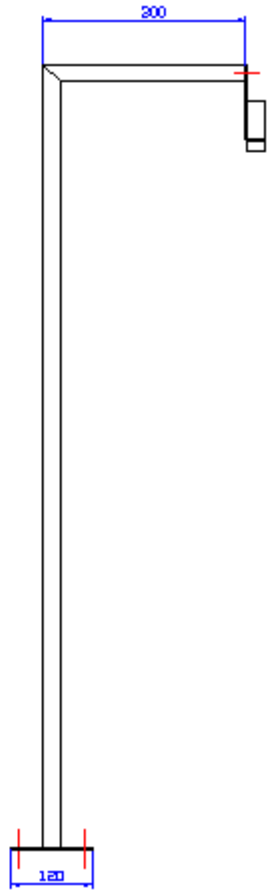
The following pages show the plans made in AUTOCAD in order to know how the layout of the project is going to be and to know the real measures of the elements.

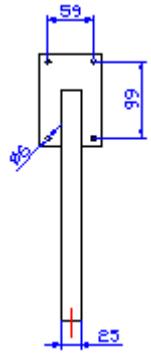




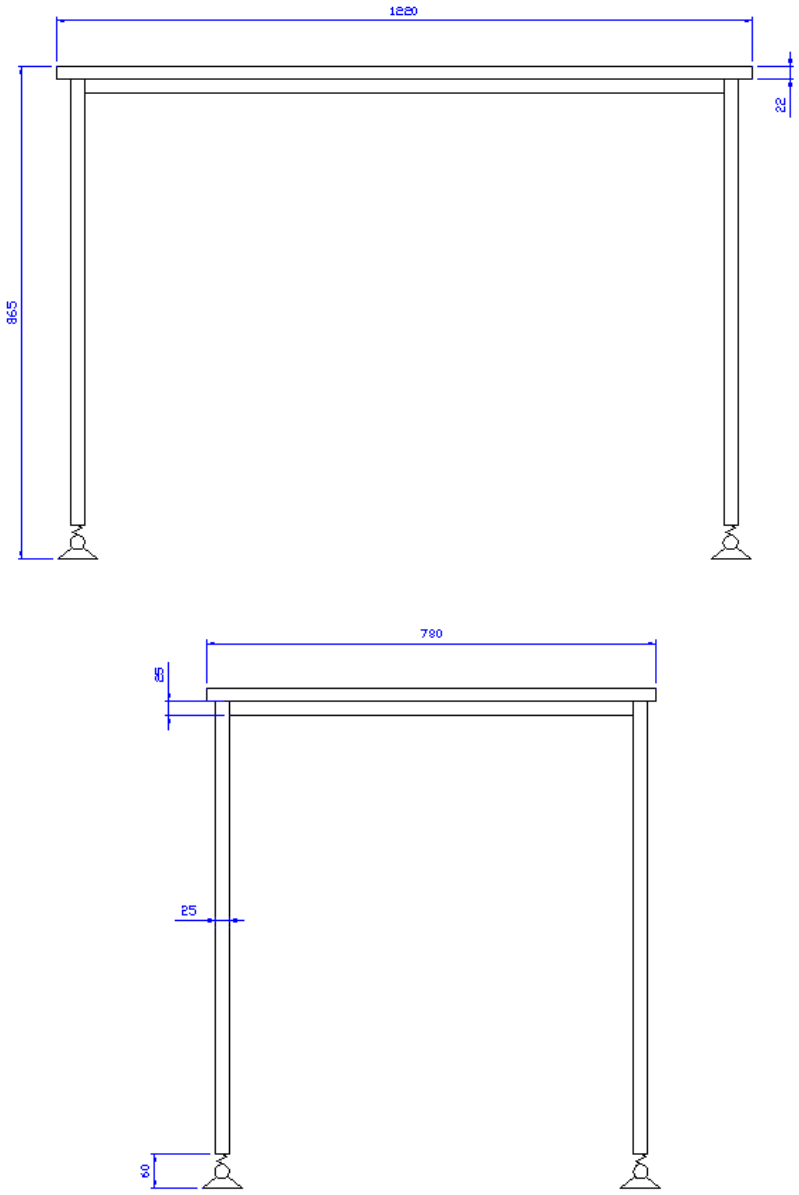
General plan







Camera Support



Work table

CHAPTER 4

Visual Basic programming

4.1. – A brief description of Visual Basic

Visual Basic is a high level programming language evolved from the earlier DOS version called Basic. Basic means Beginners' All-purpose Symbolic instruction Code. It is a fairly easy programming language to learn. The codes look a bit like English Language. Different software companies produced different version of Basic, such as Microsoft QBasic, QuickBasic, GWBasic and so on.

Visual Basic is a visual and events driven Programming Language. These are the main divergence from the old Basic. In Basic, programming is done in a text-only environment and the program is executed sequentially. In Visual Basic, programming is done in a graphical environment. Because users may click on a certain object randomly, so each object has to be programmed independently to be able to response to those actions (events). Therefore, a Visual Basic Program is made up of many subprograms, each has its own program codes, and each can be executed independently and at the same time each can be linked together in one way or another.

You can choose to start a new project, open an existing project or select a list of recently opened programs. A project is a collection of files that make up your application. There are various types of applications we could create; however, we shall concentrate on creating Standard EXE programs (EXE means executable program).

The Visual Basic Environment consists of the:

- A Blank Form for you to design your application's interface.
- The Project window which displays the files that are created in your application.
- The Properties window which displays the properties of various controls and objects that are created in your applications.

It also includes a Toolbox that consists of all the controls essential for developing a VB Application. Controls are tools such as text box, command button, label, combo box, picture box, image box, timer and other objects that can be dragged and drawn on a form to perform certain tasks according to the events associated with them. Additional objects can be added by clicking on the project item on the menu and click on components on the drop-down list.

4.2. – Drawing the user interface

There are three primary steps involved in building a Visual Basic application:

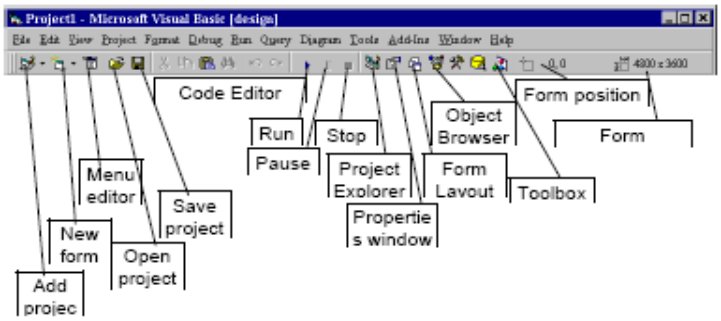
1. Draw the user interface
2. Assign properties to controls
3. Attach code to controls

Visual Basic operates in three modes

⇒ Design mode - used to build application
⇒ Run mode - used to run the application
⇒ Break mode - application halted and debugger is available

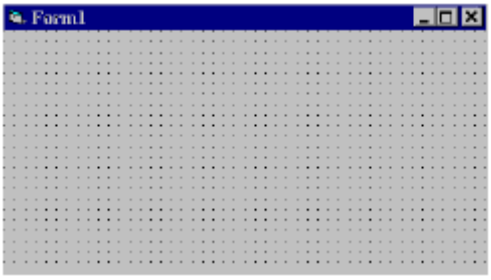
Six windows appear when you start Visual Basic

The Main Window consists of the title bar, menu bar, and toolbar. The title bar indicates the project name, the current Visual Basic operating mode, and the current form. The menu bar has dropdown menus from which you control the operation of the Visual Basic environment. The toolbar has buttons that provide shortcuts to some of the menu options. The main window also shows the location of the current form relative to the upper left corner of the screen and the width and length of the current form.



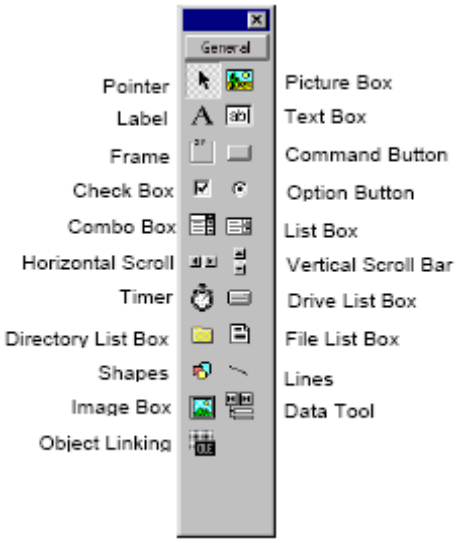
Picture 4.1. Title bar, menu bar and toolbar

The Form Window is central to developing Visual Basic applications. It is where you draw your application.



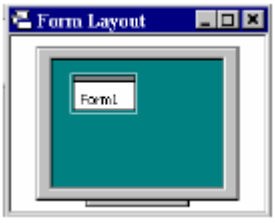
Picture 4.2. Form window

The Toolbox is the selection menu for controls used in your application.



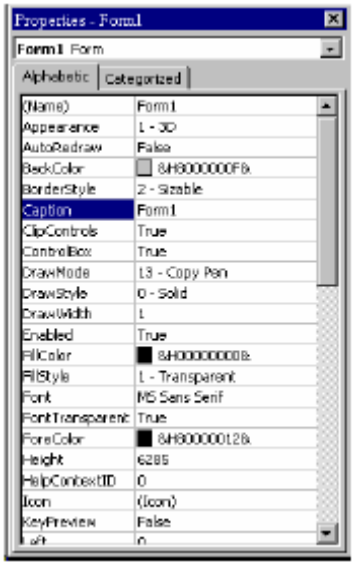
Picture 4.3. Toolbox

The Form Layout Window shows where (upon program execution) your form will be displayed relative to your monitor's screen:



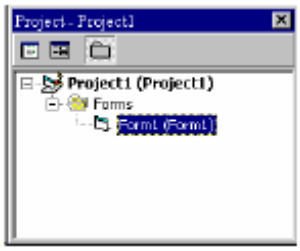
Picture 4.4. Form layout window

The Properties Window is used to establish initial property values for objects. The drop-down box at the top of the window lists all objects in the current form. Two views are available: Alphabetic and Categorized. Under this box are the available properties for the currently selected object.



Picture 4.5. Properties window

The Project Window displays a list of all forms and modules making up your application. You can also obtain a view of the Form or Code windows (window containing the actual Basic coding) from the Project window.



Picture 4.6. Project window

4.3. – Learning to program in Visual Basic

In order to make a program that contains the process followed by the robot over the camera, the first step is to start programming some simple programs and then, with the knowledge acquired, make the last application program for the project.

In this way, the programs made during the period of learning to program in Visual Basic are attached in the Appendix 1 (the window program and the code of each one).

CHAPTER 5

Motor-PLC connection via PROFIBUS

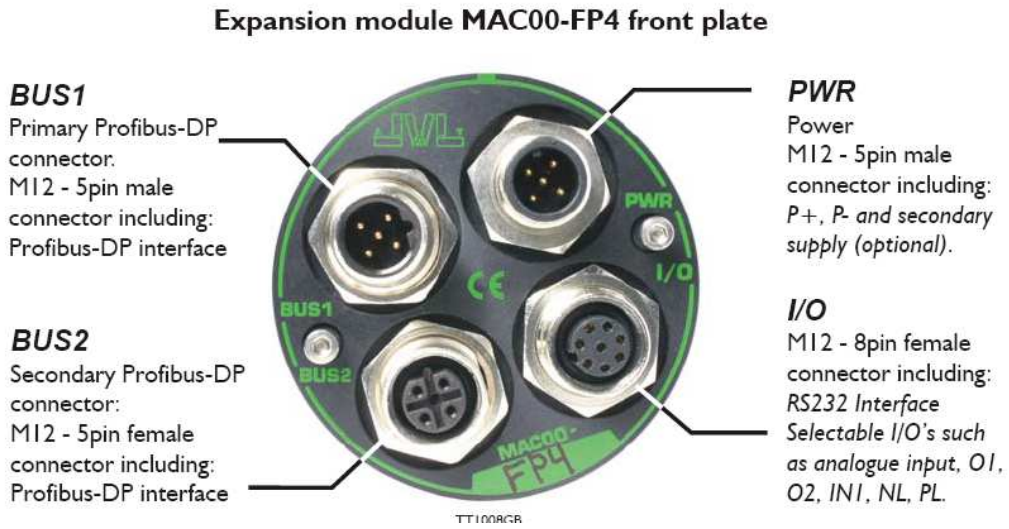
5.1. – Components and connection cables

The goal of the project includes a conveyor which moves one object on the table. The conveyor needs a step motor to run. The power to move the conveyor is supplied by a motor of the MAC's family, specifically the motor MAC95 FP4 (datasheet in the Appendix 4).

The motor has a PROFIBUS connection and it requires a PLC to be commanded. The PLC is from Siemens, specifically from the family S7-300 (S7 CPU 314-6CG03-0AB0).

The motor has two connections; one is the power input and the other is the PROFIBUS connector. The power is provided by a power supply which supplies the necessary voltage to the motor (between 12 and 48 VDC). The maximum voltage in the power supply is 30 V which is used.

The pin connections are detailed in the pictures below:



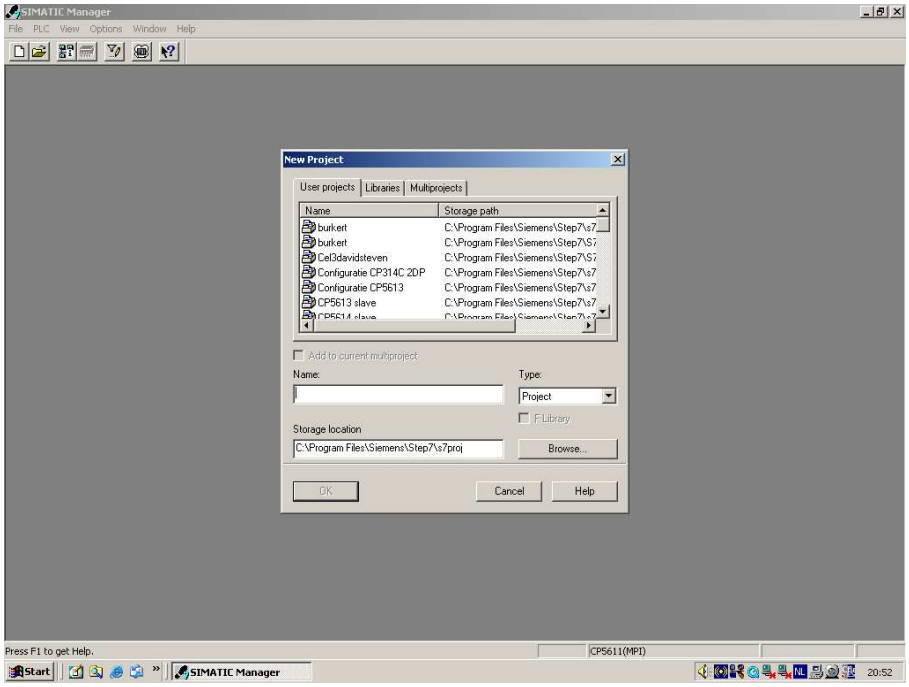
Picture 5.1. MAC00 FP4 connectors

"PWR" - Power input. M12 - 5-pin male connector				
Signal name	**Description**	**Pin no.**	**JVL Cable WI1000M12 F5A05N**	**Isolation group**
P+	Main supply +12-48VDC. Connect with pin 2 *	1	Brown	1
P+	Main supply +12-48VDC. Connect with pin 1 *	2	White	1
P-	Main supply ground. Connect with pin 5 *	3	Blue	1
CV	Control voltage +12-48VDC.	4	Black	1
P-	Main supply ground. Connect with pin 3 *	5	Grey	1
* Note: P+ and P- are each available at 2 terminals. Make sure that both terminals are connected in order to split the supply current in 2 terminals and thereby avoid an overload of the connector.				
"BUS1" - Profibus-DP interface. M12 - 5-pin male connector				
Signal name	**Description**	**Pin no.**	**Cable: user supplied**	**Isolation group**
-	Reserved for future purpose - do not connect	1	-	2
A-	Terminal A (Siemens syntax) for the Profibus-DP interface	2	-	2
DGND	Profibus-DP interface ground	3	-	2
B+	Terminal A (Siemens syntax) for the Profibus-DP interface	4	-	2
SHIELD	Cable shield. Internally conn. to the motor housing.	5	-	2

Table 5.1. Detailed pin connections

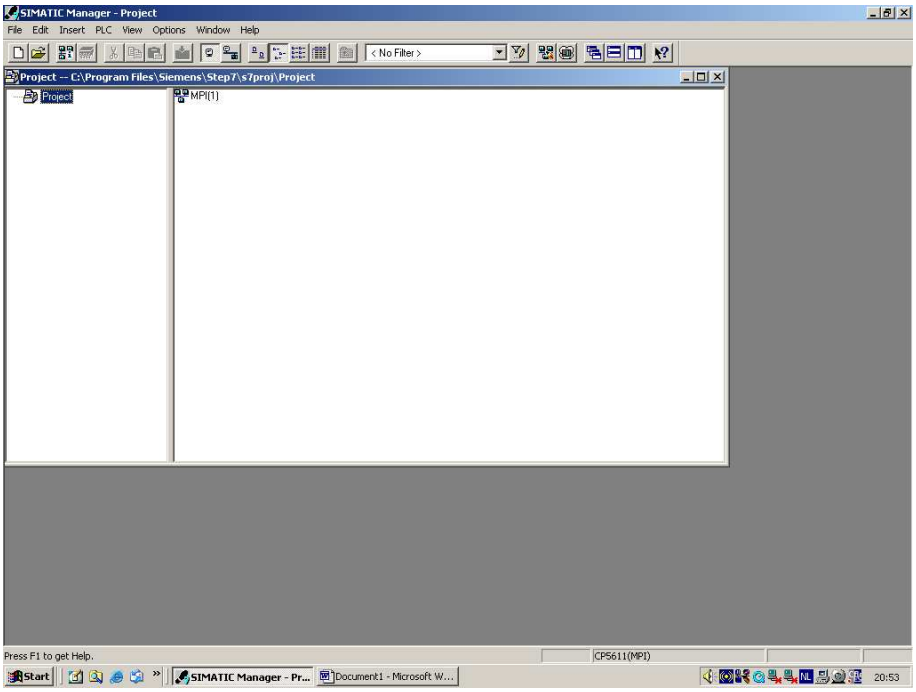
5.2. – PROFIBUS network configuration

The PROFIBUS network configuration is used to connect the motor (slave) and the PLC (master) by the program of Siemens, Simatic Step 7. Each step is detailed below:



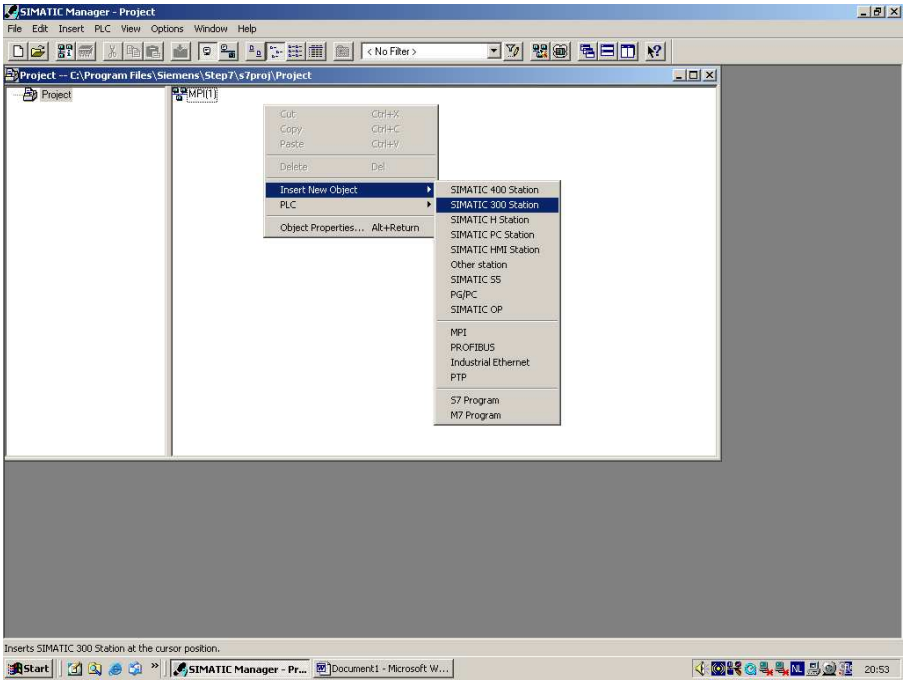
Picture 5.1. First picture in PROFIBUS network configuration

1. Open the program Simatic Step 7 and create a new project. The following window will appear (Picture 5.2)



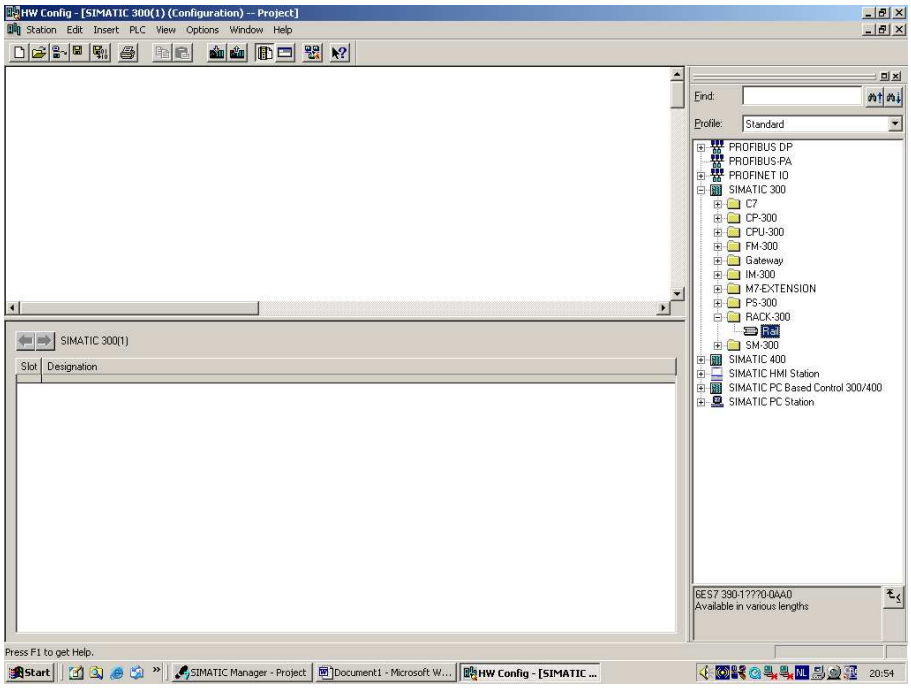
Picture 5.2. Second picture in PROFIBUS network configuration

2. Insert a new object, in this case the PLC is from the family S7-300



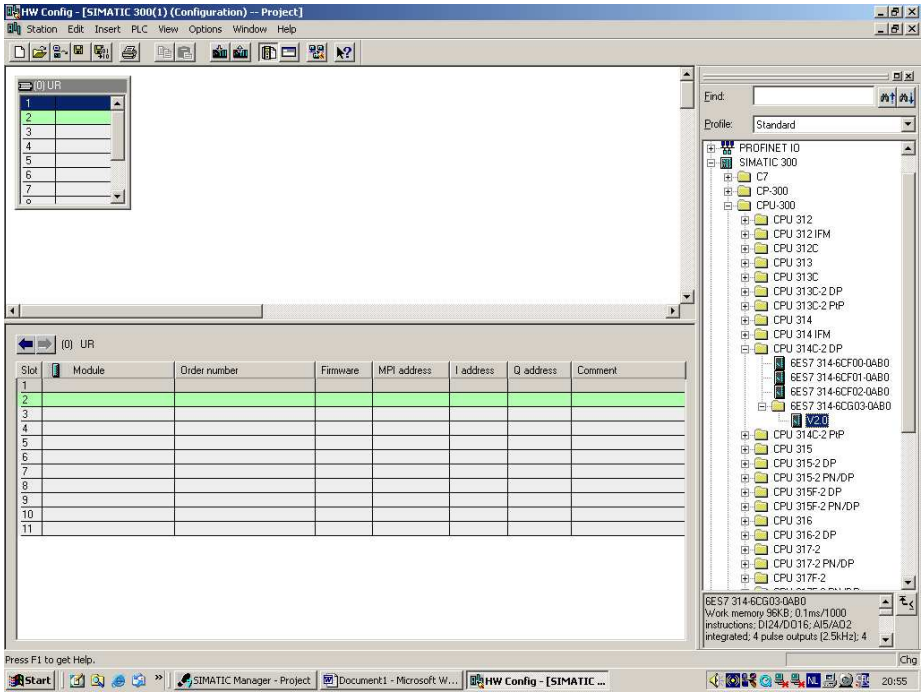
Picture 5.3. Third picture in PROFIBUS network configuration

3. Access into SIMATIC 300(1) on the left side, the program shows the next window (Picture 5.4). Choose the rail in Rack-300 and do double click



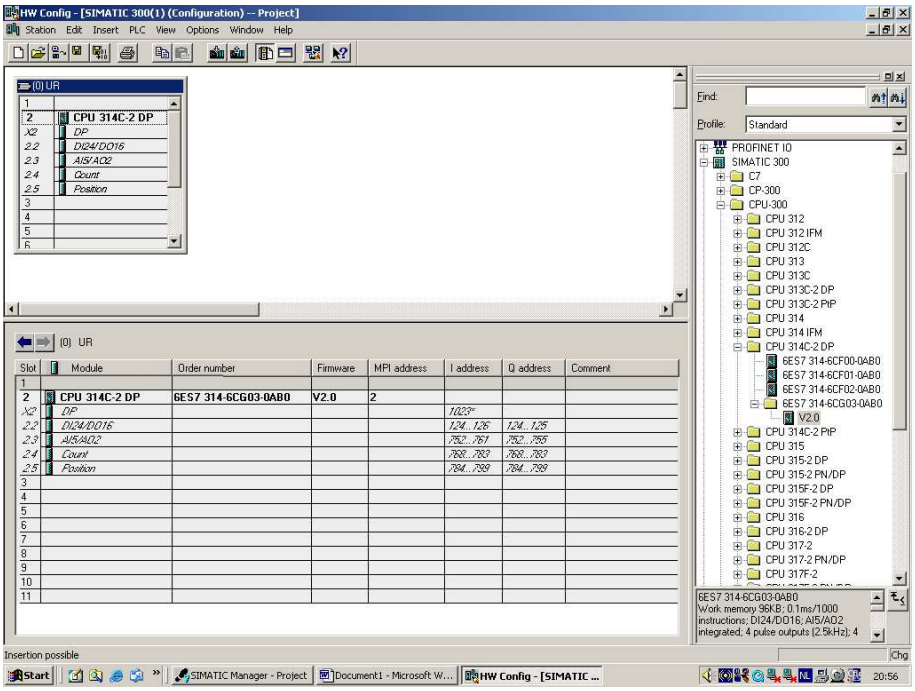
Picture 5.4. Fourth picture in PROFIBUS network configuration

4. Then is necessary to look for the exact PLC in the list on the right side (S7 CPU 314-6CG03-0AB0)



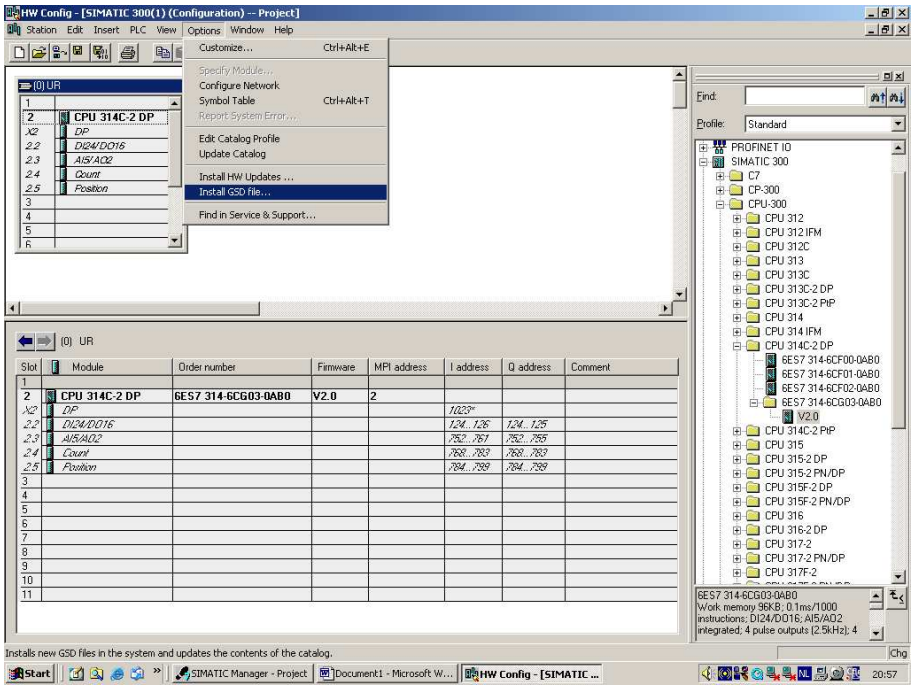
Picture 5.5. Fifth picture in PROFIBUS network configuration

5. The program shows a window with properties in which is necessary to indicate the MPI address, in this case is the number 2.



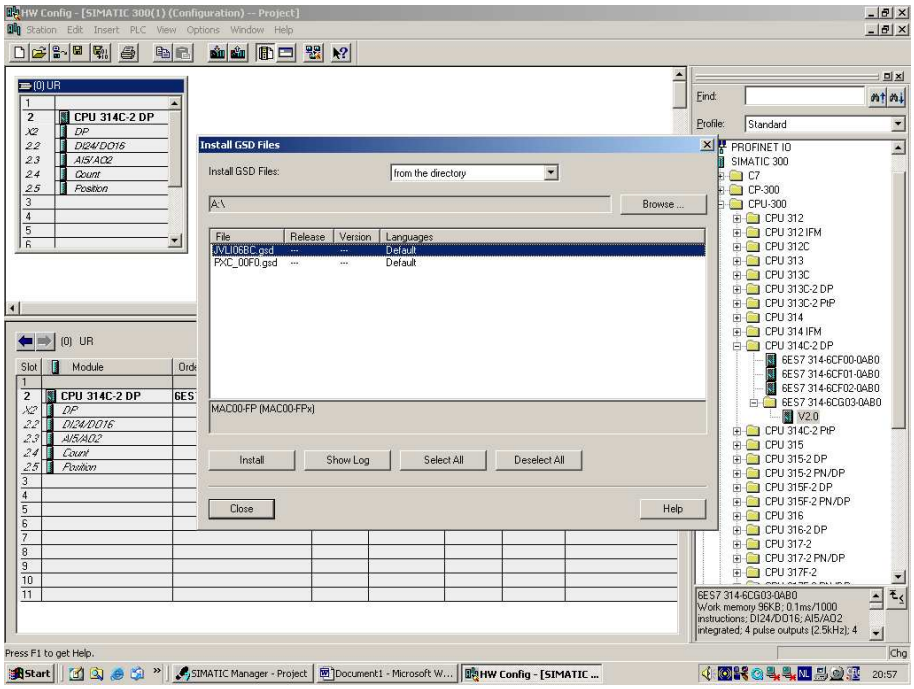
Picture 5.6. Sixth picture in PROFIBUS network configuration

6. Afterwards the program has to recognize the motor, so it needs a *.gsd file of the motor which has to be installed.



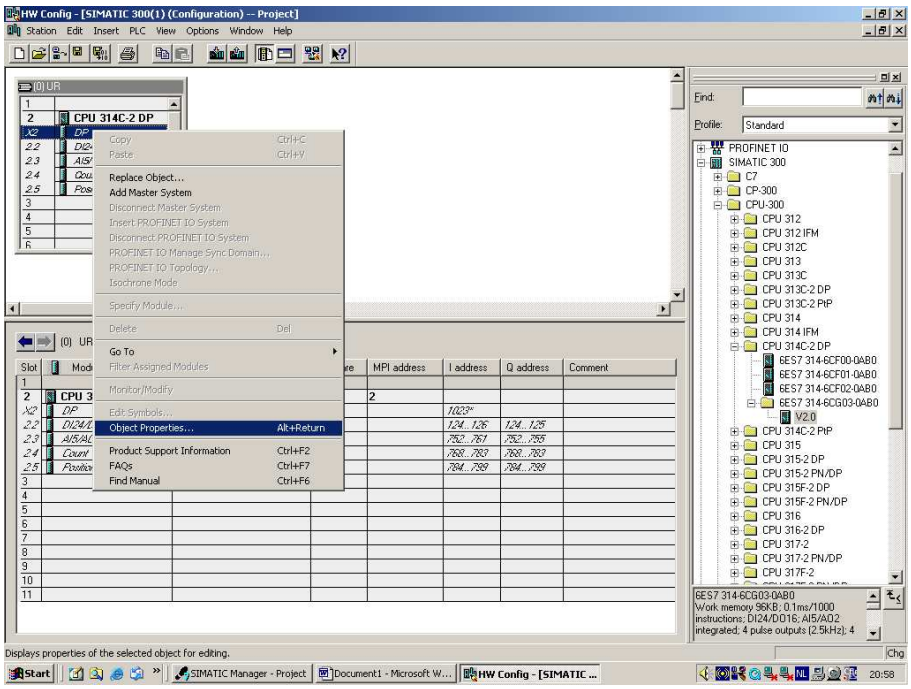
Picture 5.7. Seventh picture in PROFIBUS network configuration

7. The gsd-file can be downloaded from internet in the website. The name of this is JVLI06BC.gsd



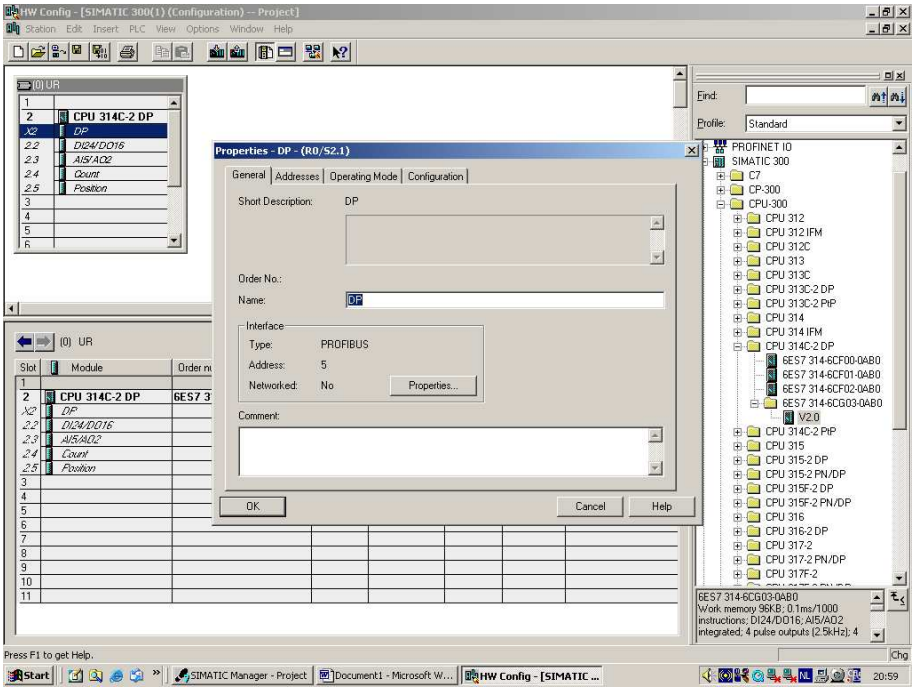
Picture 5.8. Eighth picture in PROFIBUS network configuration

8. Open the object properties clicking with the right button on DP.



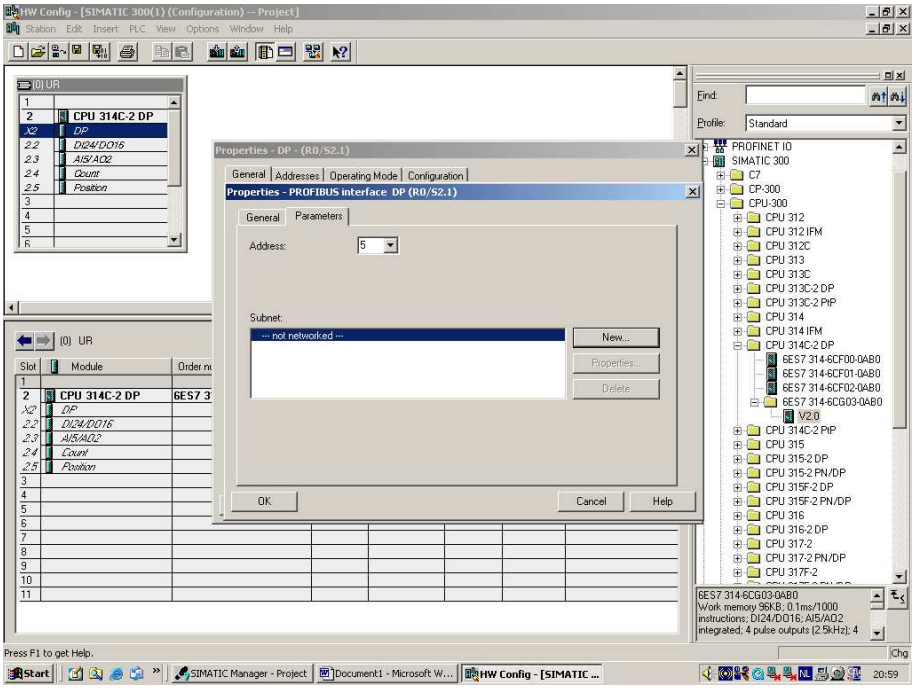
Picture 5.9. Ninth picture in PROFIBUS network configuration

9. In the object properties window click on properties.



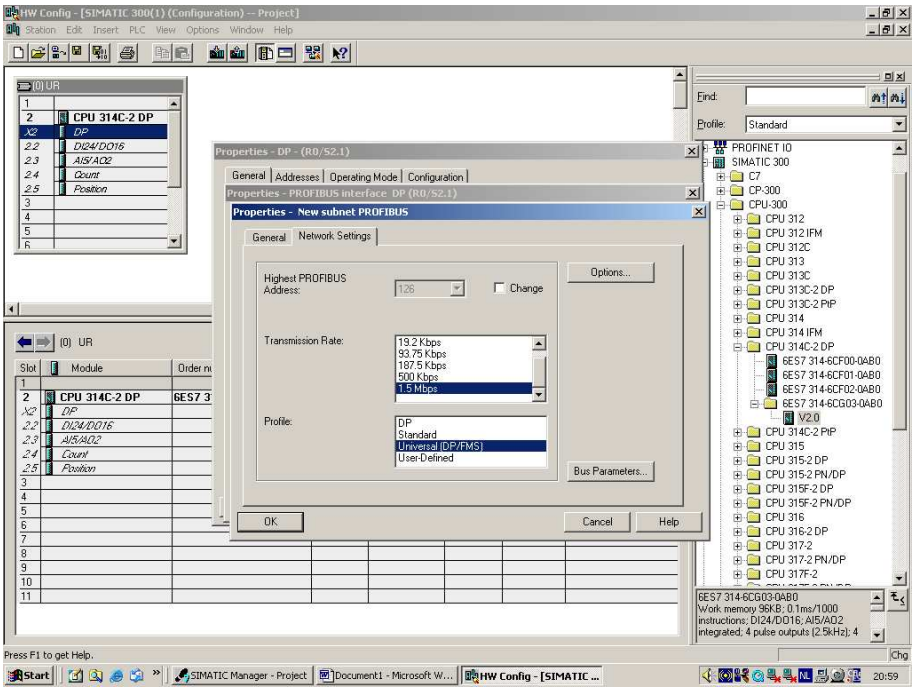
Picture 5.9. Ninth picture in PROFIBUS network configuration

10. Afterwards select in the menu bar Parameters, the address is just the number which identify the network (realize that this address is not the same as the MPI address). Revise if it's correct and click on New.



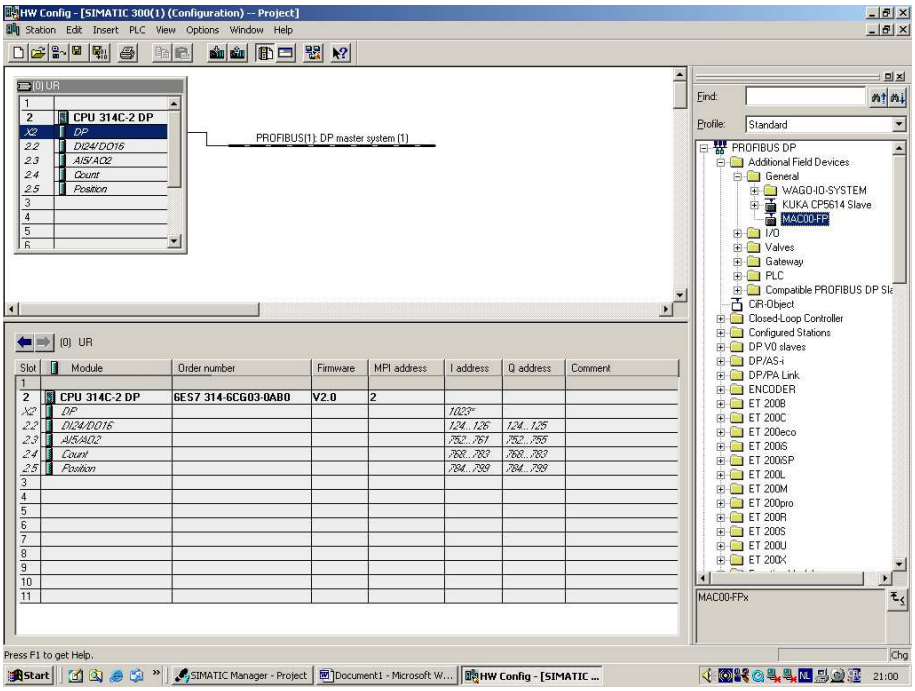
Picture 5.10. Tenth picture in PROFIBUS network configuration

11. Select Transmission Rate 1.5Mbps and Profile Universal (DP/MFS) and click Ok, the new network appears in the last window.



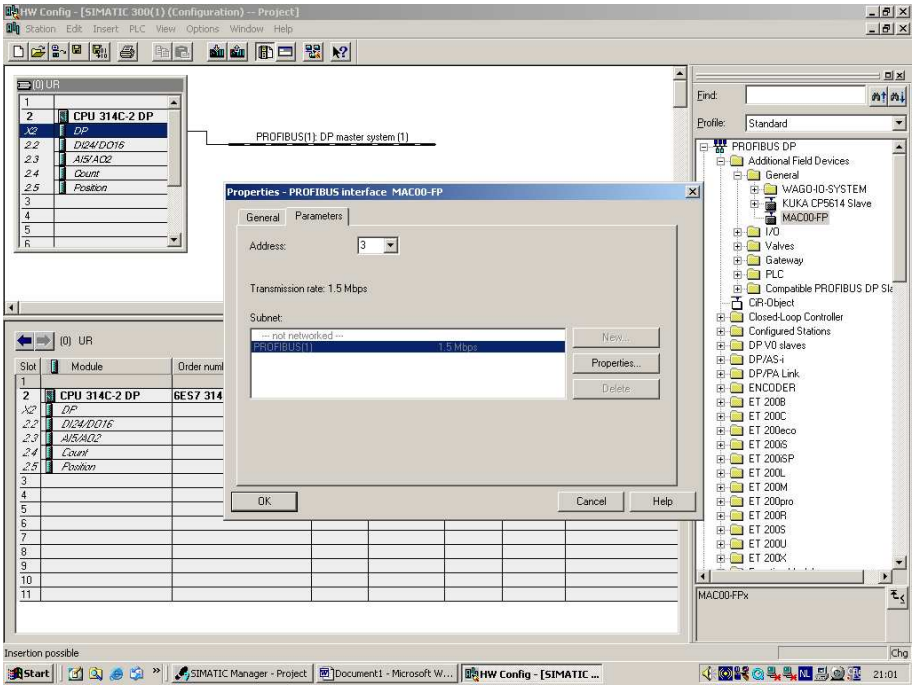
Picture 5.11. Eleventh picture in PROFIBUS network configuration

12. The network is already configured like in the picture below. Find on the right side the motor file (MAC00-FP) and select it.



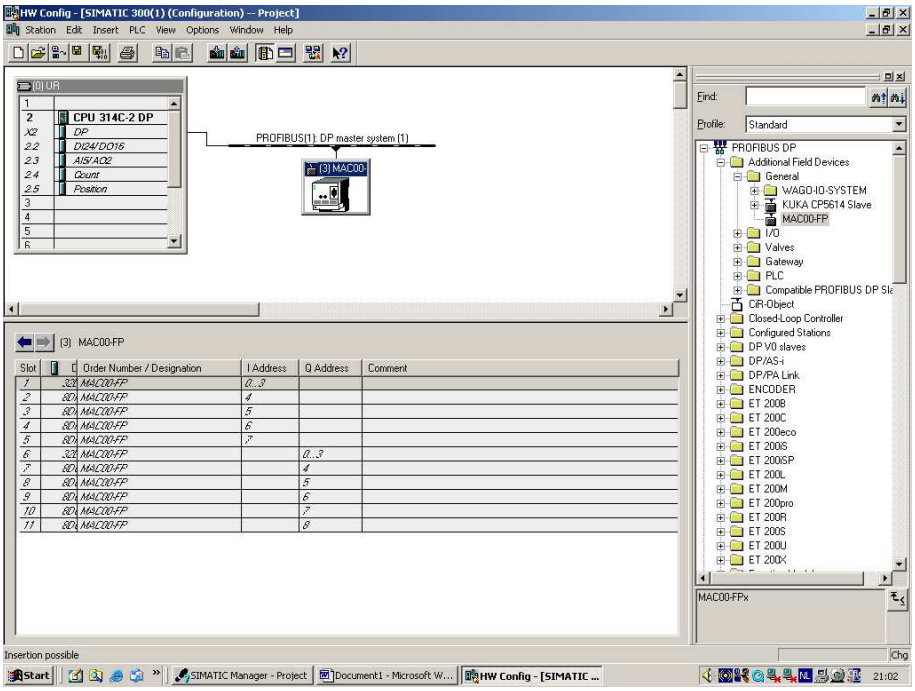
Picture 5.12.Twelveth picture in PROFIBUS network configuration

13. Write the motor address which was selected in the switches inside the motor (for more information, see the motor datasheet in the Appendix 4). In this case the first and second switches are on, so it indicates the address 3.



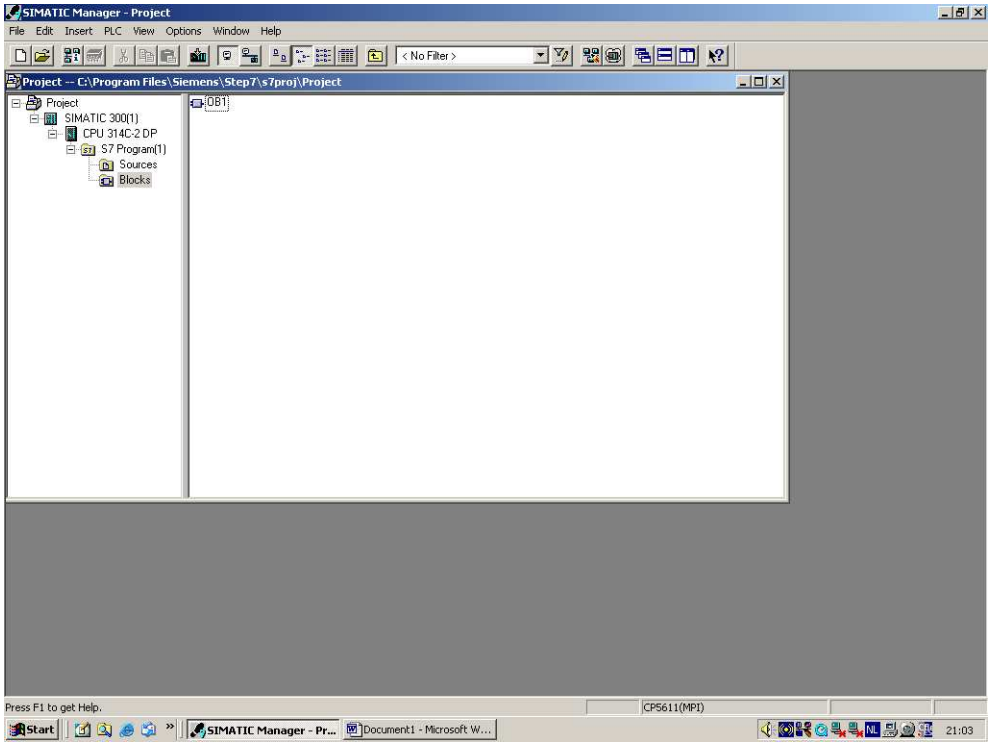
Picture 5.13. Thirteenth picture in PROFIBUS network configuration

14. Finally, the connection is made, see the picture below.



Picture 5.14. Fourteenth picture in PROFIBUS network configuration

15. The main program has the next appearance.



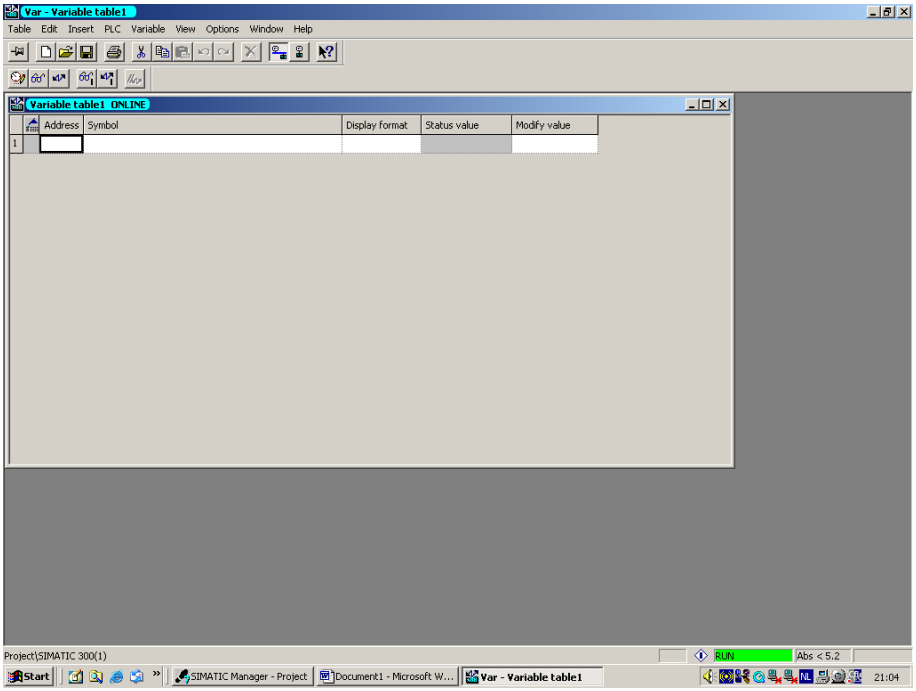
Picture 5.15. Fifteenth picture in PROFIBUS network configuration

5.3. – Testing the motor variable values

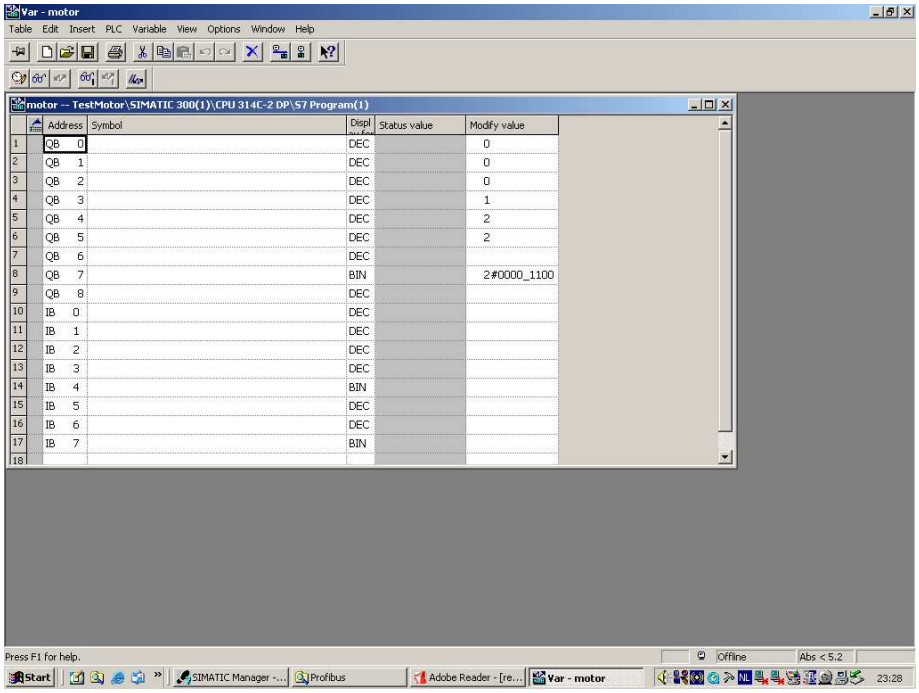
To test the motor and to select the best values of the variables which provide a good working of it. The program Simatic Step 7 offers a tool to monitor and modify the parameters of the motor. It is possible to use this tool with the motor datasheet and the different kind of registers which the motor has programmed. All this information is attached in Appendix 4.

To access in modifying/monitoring variables, click in the toolbar “PLC” and then in “Monitor/Modify Variables”. The window in the picture 5.16 appears. Afterwards introduce the inputs and outputs defined in the motor. In this case there are 9 outputs and 8 inputs shown in the picture 5.17. After some tests it would be clear which registers and values of each parameter like velocity, acceleration, torque, etc. are used. Those values will be initially introduced in the motor.

Decisions about every value are detailed in the following chapter. Also the problems with the link between the motor and the conveyor are discussed.



Picture 5.16. Variable table



Picture 5.17. Motor inputs and outputs

CHAPTER 6

Step 7 program for the conveyor

6.1. – Requirements

Firstly the motor is joined directly with the conveyor in one side. The motor is used for applications of high velocity, so it may have some problems when it is connected directly to the conveyor due to the velocity of this has to be slow. To solve this problem in the test mode explained in the previous chapter, many register were tested to adjust the best values of each one. After many tests these values were chosen but the motor had a strange comportment because it worked in low velocity and high torque. So it's impossible to move the conveyor itself. For this reason, afterwards the connection will be modified adding a component which reduces the velocity. The initials data will be shown in this chapter. Maybe these won't be the latest data.

The program in Step 7 for the conveyor consists in a start/stop program controlled by some switches connected in the PLC. The data that has to be included the first time in the motor to control the velocity, acceleration…

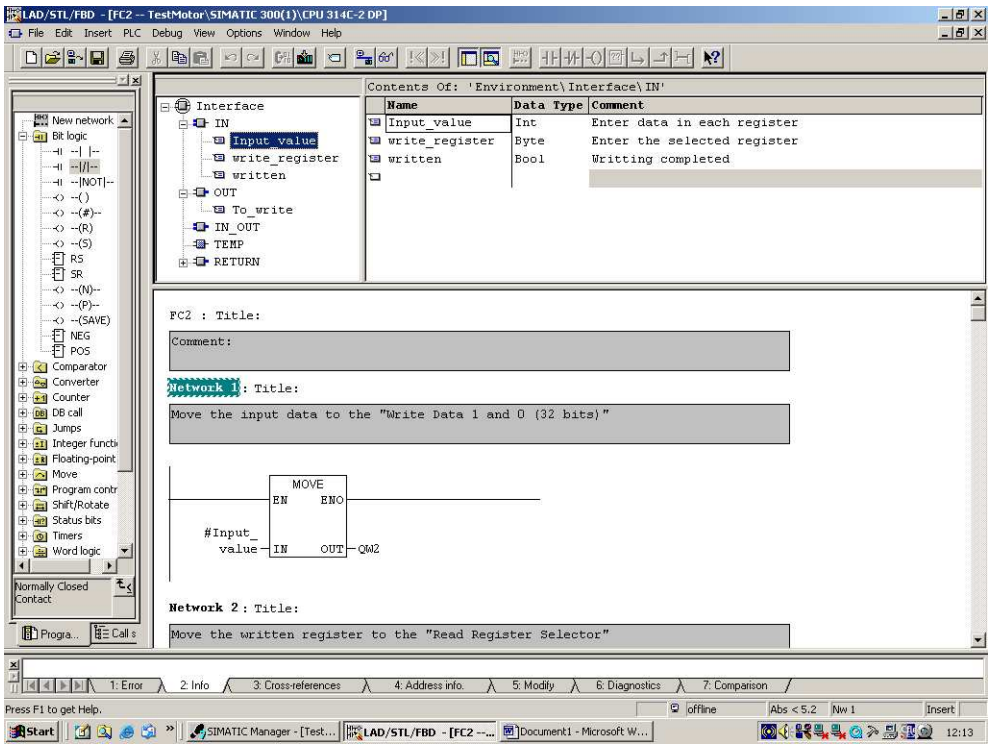
The software of the motor has some registers that can be selected in order to choose one of them depending on the application (see Appendix 2). The used registers are:

- Register 2 (with value 1 to start the motor)
- Register 5 (to select the velocity)
- Register 6 (to select the acceleration)
- Register 7 (to select the torque)
- Register 13 (to select the inertia)

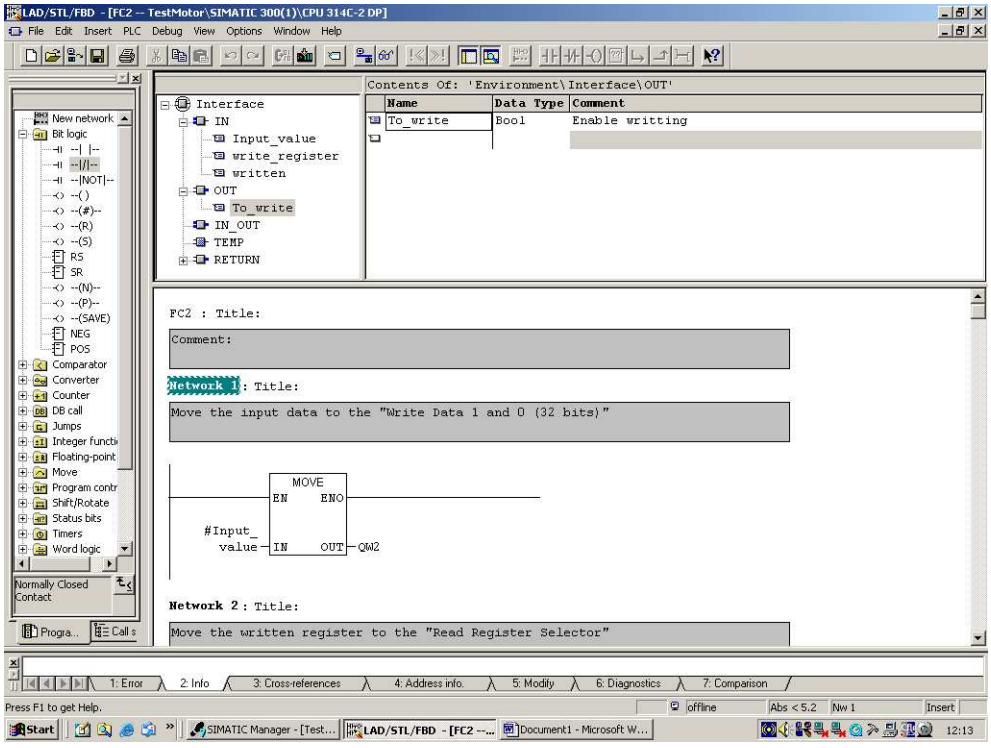
6.2. – Step 7 program

Subsequently is explained the program in Step 7 which is used in the application for moving the conveyor:

1. Open the OB1 and write the required inputs and outputs.

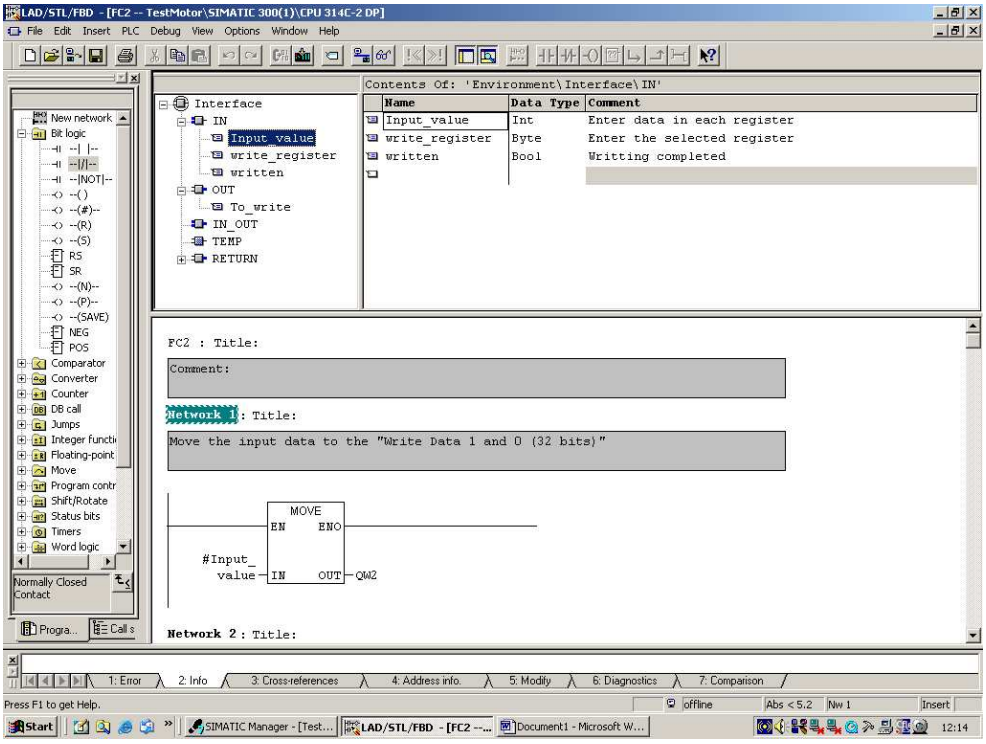


Picture 6.1. Inputs

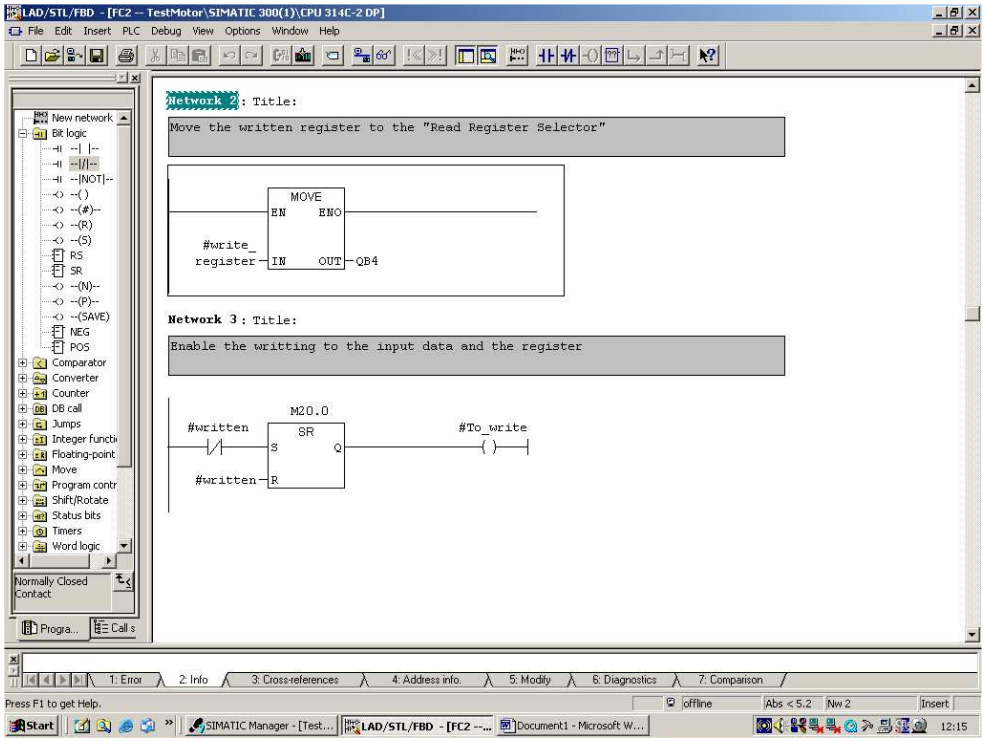


Picture 6.2. Outputs

2. Move each data to the correct input/output of the motor.

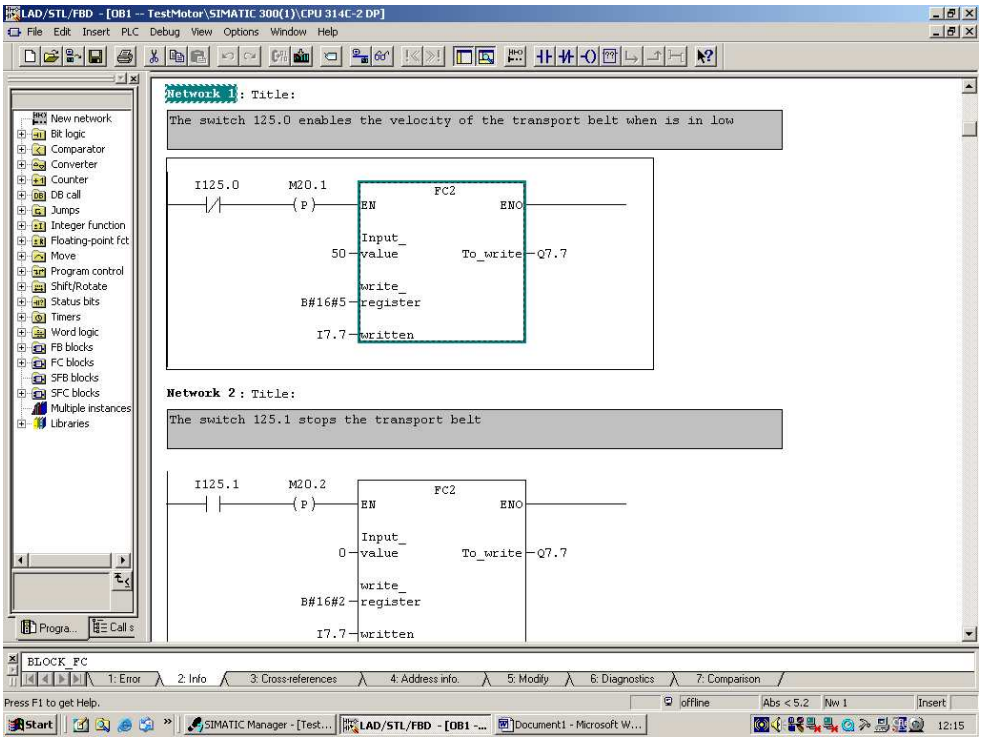


Picture 6.3. Move data

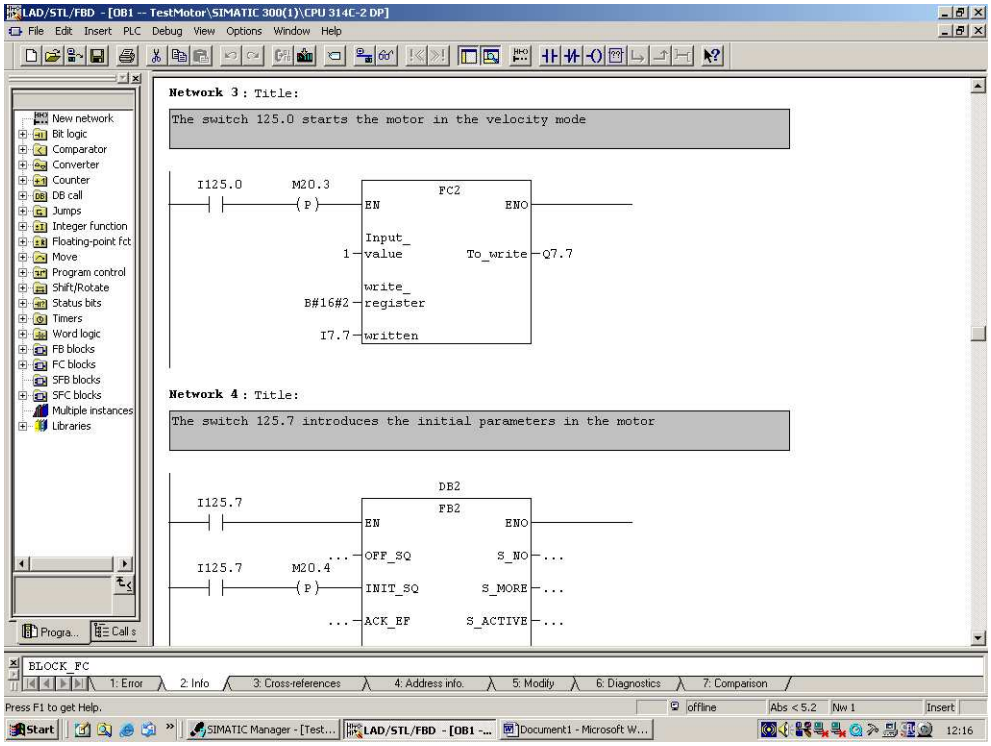


Picture 6.4. Move data

3. Introduce Function Blocks with the inputs and outputs made. Include also their equivalent switches which enable each one. Write the correct values in each data, it means, with the switch 125.0 in low, in register 5 the value 50 is introduced (value of speed) and after it is sent over the PLC to the motor.

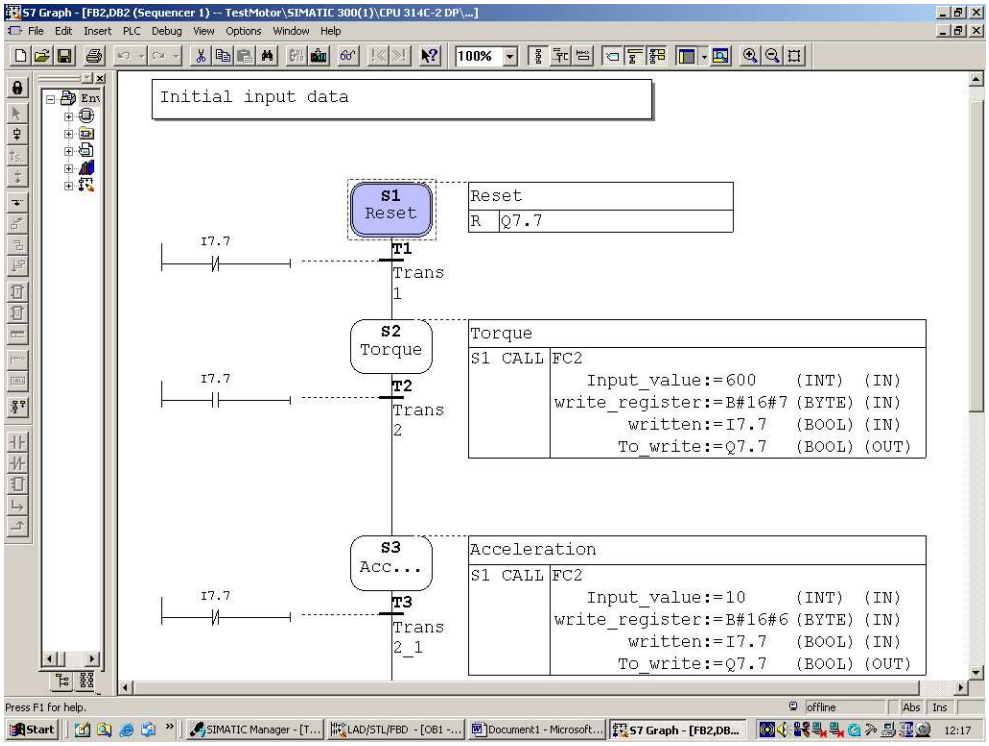


Picture 6.5. Two function blocks

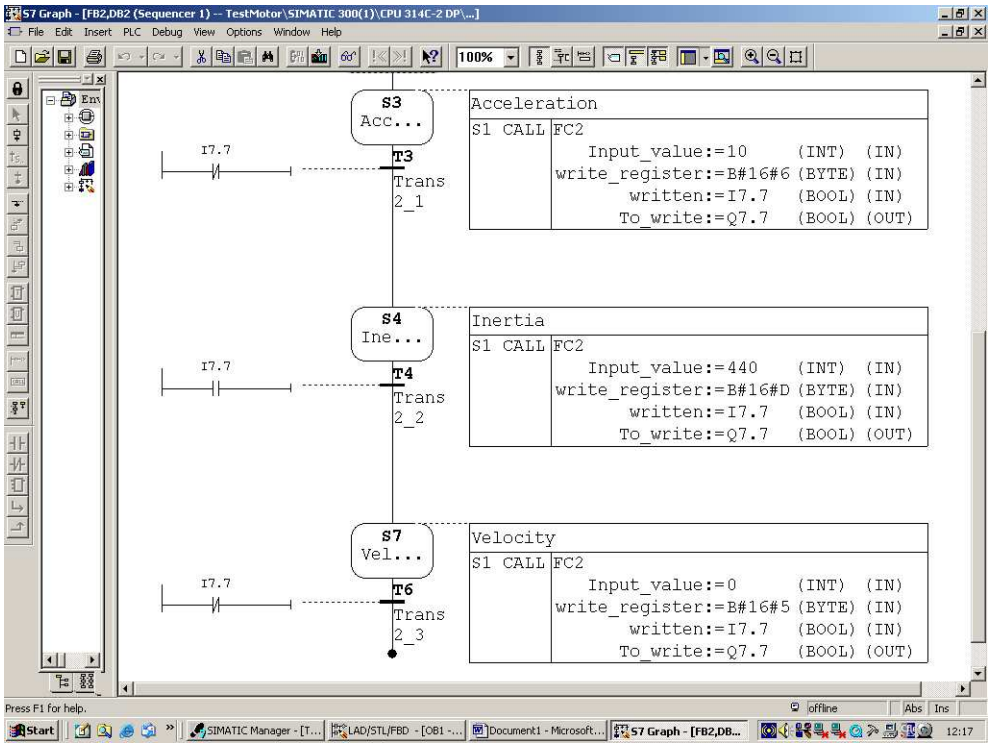


Picture 6.6. One function block and one function graph

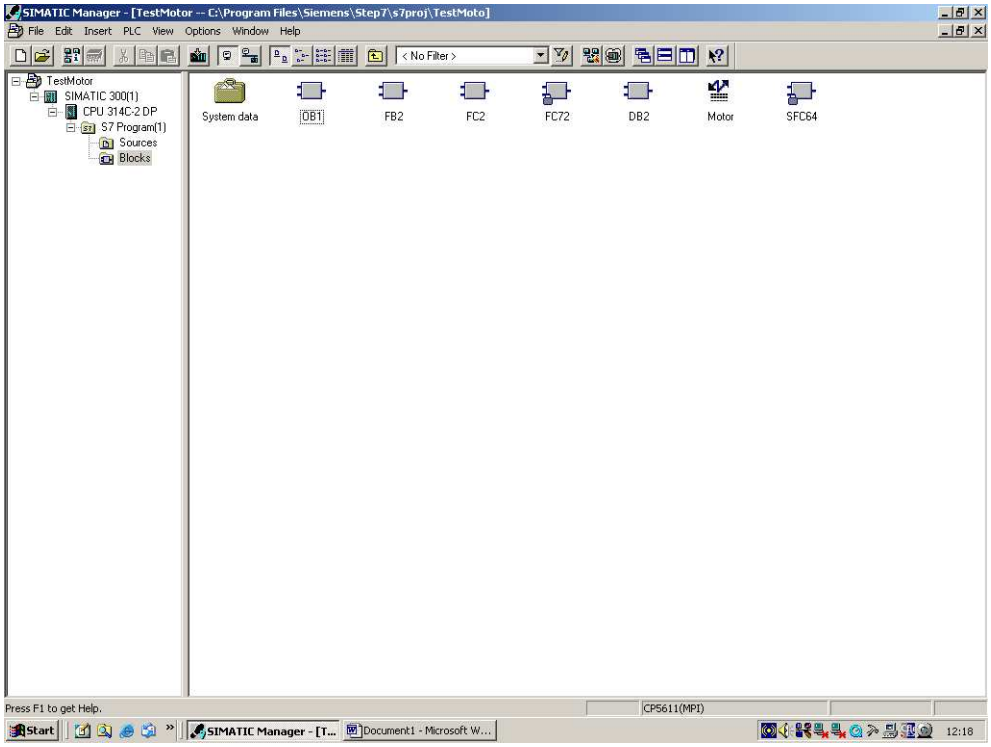
4. The initial input data has to be made in a specific function of Step 7, this function is the S7 Graph, in the way of the pictures below. It consists in a “grafcet” that allows to introduce the written value in each register.



Picture 6.7. Graph of the data values



Picture 6.8. Graph of the data values



Picture 6.9. Main program aspect

CHAPTER 7

Camera: location, lighting and calibration

7.1. – Camera. Properties and location

The camera which is chosen is a camera of the IDS company (Imaging Development Systems), specifically an uEye UI-146xLE model, SXGA (2048x1536).

The uEye LE 146x models are equipped with a light-sensitive 1/2". Sensor with rolling shutter which acquires 11 frames per second in fullframe-mode.

Characteristics: max. 11 fps, 220 fps in AOI-mode with 320x240 pixels 1/2" CMOS sensor, rolling shutter, progressive scan Exposure: 57 µs - 1,75 s (freerun mode) Binning horizontal and vertical Subsampling horizontal and vertical AOI horizontal and vertical

Picture 7.1. Camera uEye

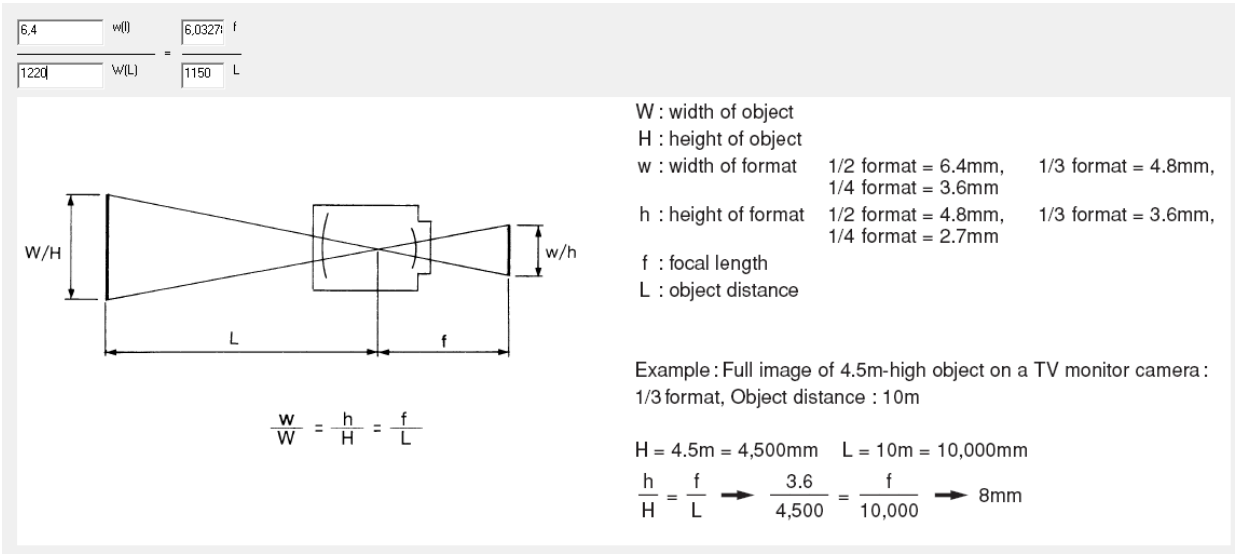
This camera is perfect for the process because it reduces size and it has a high resolution, as well as a progressive scan grabbing images.

Taking into account the maximum reach of the robot as well as the tool length and the camera lens length. The support of the camera was made in order to not to damage it. The camera is situated on the top of the workspace, just in the middle of the table and at an altitude of 1160 mm. The camera is joined with the support by a screw with two nuts, one to fix in the support and another to fix the camera and not let movements in the camera.

7.2. – Choosing the correct lens

The lens is as important as the illumination of the process. It defines the vision field of the camera which will be the robot “eye”. To calculate the correct lens a program in Visual Basic is used which includes the equation with the relations between the focus and the dimensions on the surface of work.

The picture below shows the result of the program and the appropriate lens used in the camera:



Picture 7.2. Calculating the focus

The data include in the equation are:

- Length from the table to the camera = 1150 mm
- Width of the table = 1120 mm
- ½ format = 6.4 mm

So, the focus is 6.0327 mm and then the camera requires is a **6 mm lens**

7.3. – Lighting the surface

Lighting is the most important paragraph when cameras are used. A good illumination enable to recognize each object in an easier way. Some parameters like brightness, contrast… need to be controlled.

The first step is to choose the best for the project and to check which location is the best.

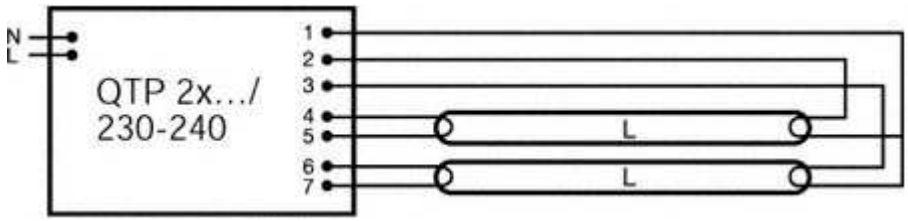
After some tests, the lighting selected is provided by two fluorescent tubes located on the support of the camera, far away from the robot reach. These fluorescent tubes have to run with high frequency. The camera grabs more than 50 frames per second and because of this some dimming parts can appear.

The two fluorescent tubes are 13 W each one with a length of 530 mm; they emit a uniform lighting without too brightness in the center, otherwise the white color of the surface would reflex the light and the quality of the images would be bad.

For the tubes it is necessary to use another piece holding up these. In this case the support will be made of wood. The measures and location of this are selected by the user but these setting don't need a high precision.

A Quicktronic Intelligent QTi dimmable is a device which ensures flicker-free operation of the lamps throughout the entire dimming range from 100 to 1%; specifically the device Quicktronic Intelligent QTP 2x18/230-240 is utilized in the project. The picture below shows the physical form of this, the next picture expose it the electric diagram to make the connection between the lamps, the Quicktronic and the electric network.

Picture 7.3. Quicktronic Intelligent QTP 2x18/230-240



Picture 7.4. Electric diagram

The cables have two colors, one for each lamp (white and red) and they are hold in the camera support by bridges. The Quicktronic is also holding up here too.

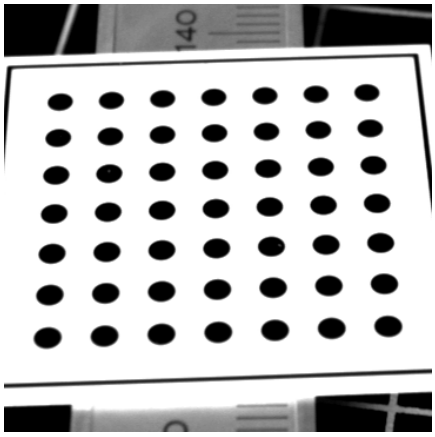
7.4. – Calibrating the coordinates on the work area

When the lighting and the lens are correct and connected, the next step consists in adjust the data of the camera in the program HALCON, modifying some parameters to get the best quality during the recording.

```
** Adjusting new parameters in uEye camera **
*******************************************************
close_all_framegrabbers ()
open_framegrabber ('uEye', 2, 2, 0, 0, 0, 0, 'default', 8, 'gray', -1, 'false', 'UI146xLE-C',      '1',   0,
-1, AcqHandle)
set_framegrabber_param (AcqHandle, 'contrast', 256)
set_framegrabber_param (AcqHandle, 'exposure', 10.3157)
set_framegrabber_param (AcqHandle, 'frame_rate', 27.542)
set_framegrabber_param (AcqHandle, 'gain_master', 35)
grab_image_start (AcqHandle, -1)
while (true)
   grab_image_async (Image, AcqHandle, -1)

*    Do something
endwhile
close_framegrabber (AcqHandle)
```

The function set_framegrabber_param modify some parameters; in this case the parameters changed are: contrast, exposure, frame rate and gain master. On the other hand, in the function open_framegrabber the camera has been selected to record only half the pixels. All this changes allows a faster image acquisition with an optimal image quality.

Once parameters are adjusted, the calibration can start. The calibration is done by a tool like a calibration plate called “caltab” (see it in the picture below), it’s a tool designed by HALCON Company for calibrating surfaces in real coordinates. Therefore, a program is made which takes pictures with the caltab in different positions around the table.

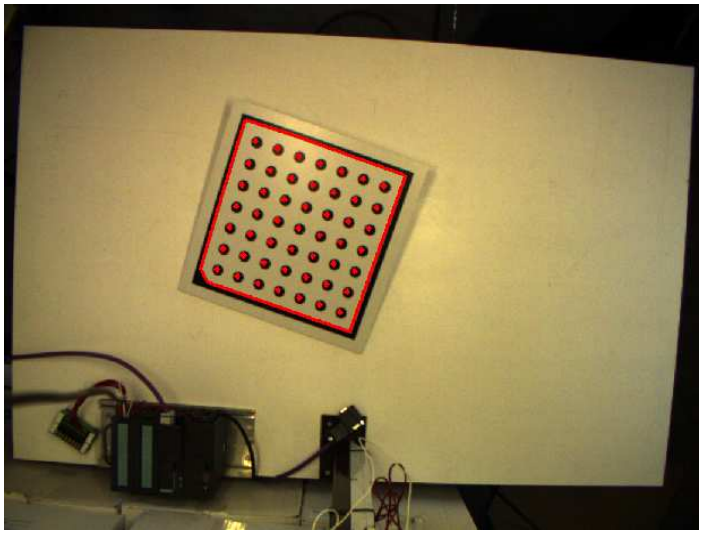


Picture 7.5. Caltab

The next program takes pictures and it records one image in the map “images2” with a three number from 000. Then the program could be executed once, the caltab is situated in another position and execute again following this process. The pictures would be a .tiff file:

```
**  Logging images for calibration **
*****************************************
close_all_framegrabbers ()
dev_close_window ()
open_framegrabber ('uEye', 2, 2, 0, 0, 0, 0, 'default', 8, 'rgb', -1, 'false', 'UI146xLE-C', '1', 0, -1,
AcqHandle)
dev_open_window (0, 0, 512, 380, 'black', WindowHandle)
set_framegrabber_param (AcqHandle, 'contrast', 256)
set_framegrabber_param (AcqHandle, 'exposure', 10.3157)
set_framegrabber_param (AcqHandle, 'frame_rate', 27.542)
set_framegrabber_param (AcqHandle, 'gain_master', 30)
* set_framegrabber_param (AcqHandle, 'white_balance', 'auto')
Counter := 0
while (true)
   grab_image_start (AcqHandle, -1)
   grab_image_async (Image, AcqHandle, -1)
   write_image (Image, 'tiff', 0, './images2/' + (Counter$'03') + '.tiff' )
   Counter := Counter + 1
   stop ()
endwhile
```

Subsequently, one of the images taken during the calibration are seen as well as the caltab’s contour and dots that the program HALCON has drawn.



Picture 7.6. Calibration picture

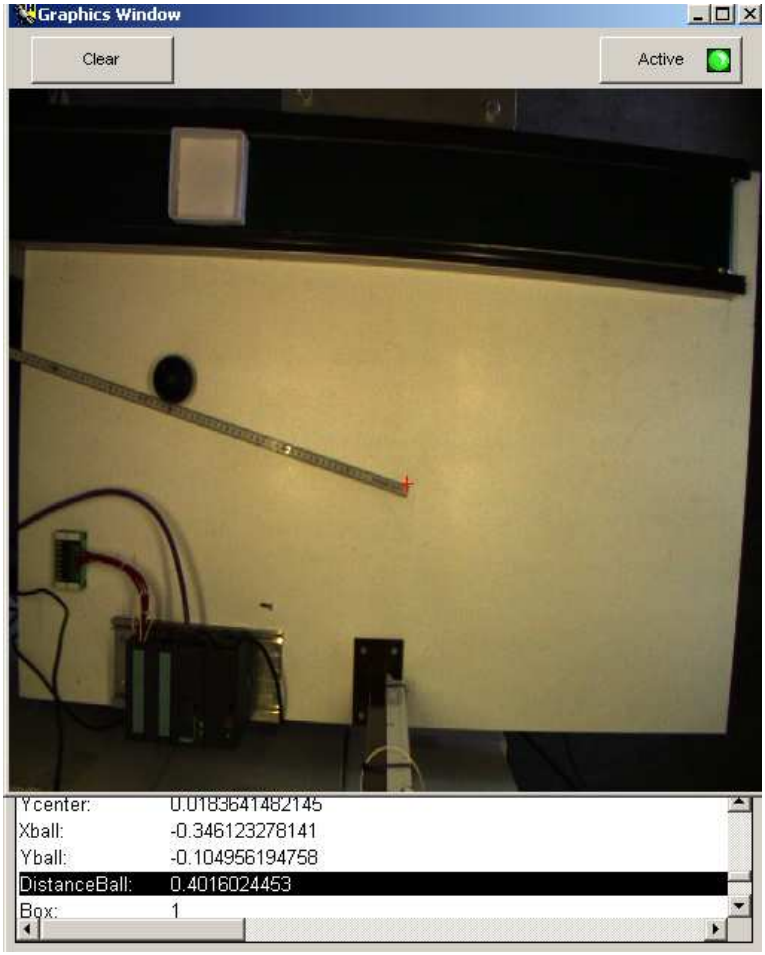
The following program opens each picture and recognizes the caltab in each position on the table. Important data in the program which could change for detecting the caltab are the data the functions find_caltab and find_marks_and_pose.

The function camera_calibration is a powerful tool in HALCON and it computes the final calibration and usually it takes several seconds to be executed. In the last part of this there are two functions which create two files with the calculated parameters.

```
** Calibrating the surface of work **
****************************************
read_image (Image, './images2/000.tiff')
get_image_pointer1 (Image, Pointer, Type, Width, Height)
dev_close_window ()
dev_open_window (0, 0, Width*0.60, Height*0.60, 'black', WindowHandle)
dev_update_window ('on')
StartCampar := [0.006,0,0.0000032,0.0000032,512,384,1024,768]
* Calibration
Counter := 0
NRows := []
NCols := []
NStartpose := []
caltab_points ('caltab.descr', X, Y, Z)
for i := 0 to 26 by 1
   read_image (Image, './images2/' + (i$'03') + '.tiff' )
   dev_set_draw ('margin')
   dev_set_line_width (3)
   find_caltab (Image, Caltab, 'caltab.descr', 3, 90, 3)
   find_marks_and_pose (Image, Caltab, 'caltab.descr', StartCampar, 100, 10, 18, 0.5, 15, 100,
RCoord, CCoord, StartPose)
   dev_set_color ('red')
   disp_cross (WindowHandle, RCoord, CCoord, 6, 0)
   tuple_concat (NRows, RCoord, NRows)
   tuple_concat (NCols, CCoord, NCols)
   tuple_concat (NStartpose, StartPose, NStartpose)
endfor
stop ()
dev_open_window (0, 0, 512, 512, 'black', WindowHandle)
camera_calibration (X, Y, Z, NRows, NCols, StartCampar, NStartpose, 'all', CamParam,
NFinalPose, Errors)
write_cam_par (CamParam, 'campar.dat')
tuple_select_range (NFinalPose, 0, 6, Pose)
write_pose (Pose, 'campose.dat')
```

After the calibration, the program necessary for the project can be made and with it takes measures from a central point defined in the program and another object situated on the work area.

To show this, in the next picture there is a meter to measure the distance between the center considered by the camera (red point) and the center of the black ball. The program shows the distance between this center and the ball on the bottom. Can be checked than the coordinates are exact because the center of the ball is just in a distance of 40 mm and the program returns this value.



Picture 7.7. First real coordinates

7.5. – HALCON program for the real process of the project

The process to implement consists in a black ball placed everywhere on the table, the ball has to be picked up by the robot and put down inside the white box situated on the conveyor. For this are going to be defined two regions in order to recognize easily each object on each surface. In Chapter 3 the color of the table white was chosen to help and simplify the images later collected. For this reason a black ball and a dark conveyor are used. So it is easier to recognize the white box on the conveyor (Picture 7.7)

The edges of the conveyor have a soft gray color and it's a problem to recognize just the box. To solve this problem, these edges are covered with black isolate tape.

After that, HALCON program can confuse itself when it is detecting the ball and this is quite near to the conveyor. The best way to answer the problem is leaving a small strip without isolate tape in the side of the table, with this strip there isn't problems with none object.

For the last application will be necessary to get the coordinates of the central point of the ball and the box. As each one has its own surface to be placed, two regions are going to be defined. The box region is defined like a rectangle which contains the conveyor and the ball region like an ellipse which contains the area of the maximum reach of the robot in correct position to pick up objects. Additionally the program needs to be able to store the point where the user wants to stop the conveyor.

So there are three steps, first to know if ball and box are inside the area permitted, second to know when box is in position defined by the user and third to get the real coordinates (X axis and Y axis). The HALCON program for all of these steps is:

```
**Final HALCON program (regions, positions and coordinates)**
************************************************************************
dev_open_window (0, 0, 512, 512, 'black', WindowHandle)
read_cam_par ('campar01.dat', CamParam1)
read_pose ('campose01.dat', Pose1)
set_origin_pose (Pose1, 0, 0, 0, PoseNewOrigin1)
close_all_framegrabbers ()
open_framegrabber ('uEye', 2, 2, 0, 0, 0, 0, 'default', 8, 'rgb', -1, 'false', 'UI146xLE-C', '1', 0, -1,
            AcqHandle)
set_framegrabber_param (AcqHandle, 'frame_rate', 27.542)
set_framegrabber_param (AcqHandle, 'contrast', 256)
set_framegrabber_param (AcqHandle, 'exposure', 10.3157)
set_framegrabber_param (AcqHandle, 'gain_master', 35)
grab_image_start (AcqHandle, -1)
dev_update_window ('off')
while (1)

    ** Looking for the ball **
    grab_image_async (Image, AcqHandle, -1)
    set_origin_pose (Pose1, 0.077595, 0.03263, 0, PoseNewOrigin1)
    dev_display (Image)
    decompose3 (Image, red, green, blue)
    rgb3_to_gray (red, green, blue, ImageGray)
    disp_cross (WindowHandle, 350, 540, 6, 0)
    gen_ellipse (Ellipse, 0, 510, -0.07, 480, 410)
    reduce_domain (ImageGray, Ellipse, ImageReduced1)
    threshold (ImageReduced1, Region, 0, 15)
    connection (Region, ConnectedRegions)
    select_shape (ConnectedRegions, SelectedRegions, 'area', 'and', 1200, 5000)
    select_shape (SelectedRegions, SelectedRegions1, 'roundness', 'and', 0.5, 1)
```

```
  fill_up (SelectedRegions1, RegionFillUp)

Ball := |RegionFillUp|
  if (Ball =1)
     area_center (RegionFillUp, Area, Row, Column)
     image_points_to_world_plane (CamParam1, PoseNewOrigin1, 350, 540, 'm', Xcenter,
          Ycenter)
     image_points_to_world_plane (CamParam1, PoseNewOrigin1, Row, Column, 'm', Xball,
          Yball)
     distance_pp (Xcenter, Ycenter, Xball, Yball, DistanceBall)
     disp_cross (WindowHandle, Row, Column, 6, 0)
  else
     ** When ball is not inside the robot reach, it shows a message **
     dev_display (Ellipse)
     dev_set_draw ('margin')
     set_tposition (WindowHandle, 640, 640)
     set_font (WindowHandle, '-Arial-14-*-*-*-*-1-')
     dev_set_color ('yellow')
     write_string (WindowHandle, 'Ball out of the robot reach')
  endif

  ** Looking for the box **
  gen_rectangle2 (Rectangle2, 110, 480, -0.05, 500, 70)
  reduce_domain (red, Rectangle2, ImageReduced)
  threshold (ImageReduced, Region1, 45, 255)
  connection (Region1, ConnectedRegions1)
  select_shape (ConnectedRegions1, SelectedRegions2, 'area', 'and', 9000, 12000)
  fill_up (SelectedRegions2, RegionFillUp1)
  Box := |RegionFillUp1|
  if (Box = 1)
     area_center (RegionFillUp1, Area1, Row1, Column1)
     image_points_to_world_plane (CamParam1, PoseNewOrigin1, 350, 540, 'm', Xcenter,
          Ycenter)
     image_points_to_world_plane (CamParam1, PoseNewOrigin1, Row1, Column1, 'm', Xbox,
          Ybox)
     disp_cross (WindowHandle, Xcenter, Ycenter, 6, 0)
     disp_cross (WindowHandle, Row1, Column1, 6, 0)
     distance_pp (Xcenter, Ycenter, Xbox, Ybox, DistanceBox)
     if (Column1>=370)
        ** When box is in the column selected, a message appears **
        set_tposition (WindowHandle, 640, 640)
        set_font (WindowHandle, '-Arial-14-*-*-*-*-1-')
        dev_set_color ('yellow')
        write_string (WindowHandle, 'Box in correct position')
     endif
  else
     set_tposition (WindowHandle, 640, 640)
     set_font (WindowHandle, '-Arial-14-*-*-*-*-1-')
     dev_set_color ('yellow')
     write_string (WindowHandle, 'Box out of conveyor')
```

```
    endif
endwhile
```

At the beginning of the program there are two new commands read_cam_par and read_pose, these are utilized to read the files created during the calibration. The central point of the image is selected by the user, in this case (Row: 350, Column: 540); to adjust it in the program, with set_origin_pose, the initial point Pose1 defined as the central dot in the first image acquired with the caltab can be changed as follows: set_origin_pose (Pose1, 0.077595, 0.03263, 0, PoseNewOrigin1). Those values were taken with the program to prevent errors.

The following code has two parts clearly defined, in the first one it is trying to detect if ball is inside or outside of the robot reach. With the command gen_ellipse and after with reduce_domain the work area available by the robot is defined, the program only works in this specific area. After this with the select_shape command, it recognizes the ball and then it takes the area_center. An important function is image_points_to_world_plane because this function transforms points in the image to real coordinates in the world. The second part is similar, only changes the region (a rectangle) and it includes the position where the box is in the correct position.

CHAPTER 8

OPC communication

8.1. – OPC overview

OPC is open connectivity in industrial automation and the enterprise systems that support industry. Interoperability is assured through the creation and maintenance of open standards specifications. There are currently seven standards specifications completed or in development.

Based on fundamental standards and technology of the general computing market, the OPC Foundation adapts and creates specifications that fill industry-specific needs. OPC will continue to create new standards as needs arise and to adapt existing standards to utilize new technology.

OPC Server DP enables easy access to Profibus DP devices. Profibus networks can automatically be configured and diagnosed. This ensures extremely easy network administration and enables flexible access to individual components.

8.2. – OPC sever via Profibus connection

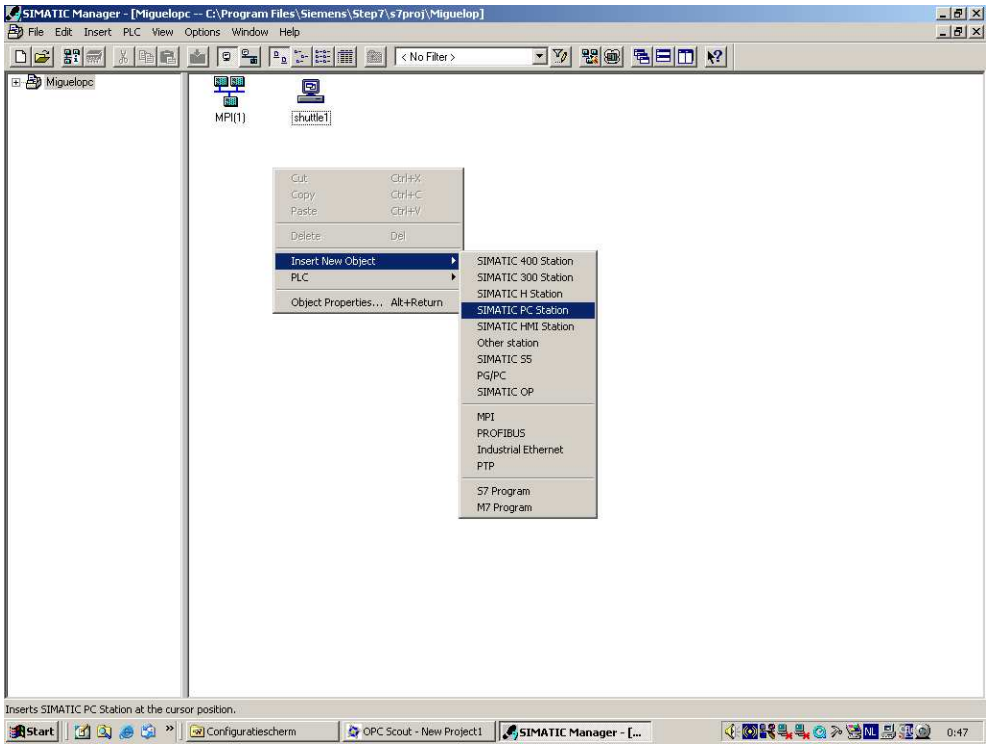
Standard OPC is utilized to make communication between the motor and a CP 5611 card (integrated on the PC). This card is used to connect programming devices and PCs to Profibus up to 12 Mbit/s and to the multipoint MPI interface of Simatic S7.

OPC will connect with the PLC, the computer and the motor; that integration could be commanded by Visual Basic later, following an OPC protocol in a Visual Basic program.

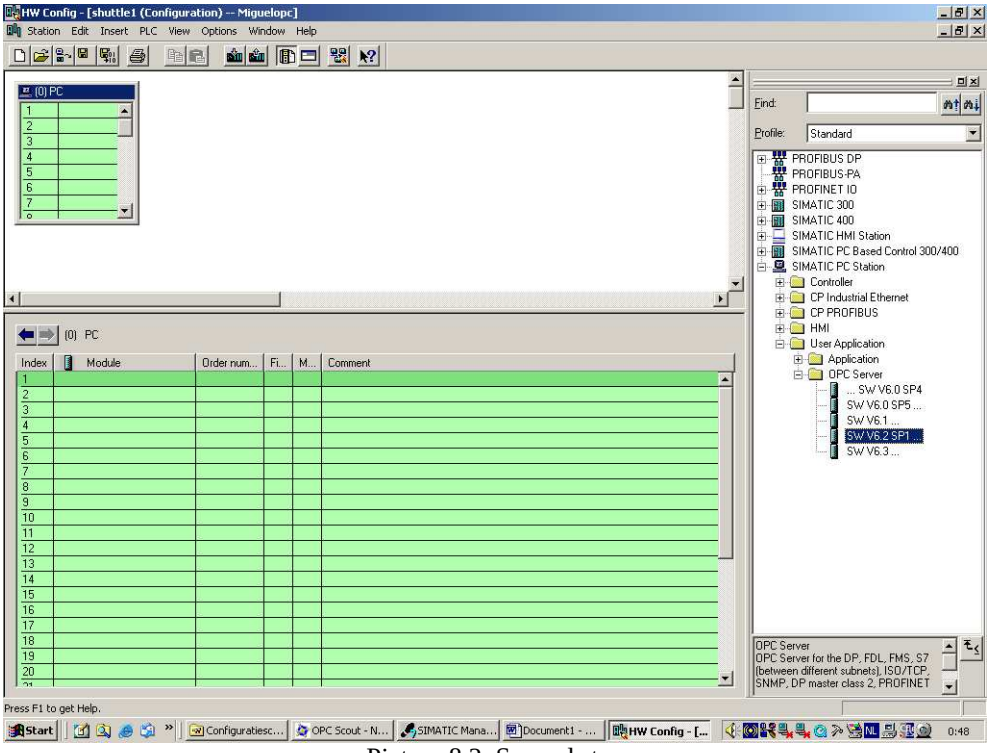
Next pictures show how to make the OPC connection over Profibus in order to get a flexible access of each device as well as integrate everything in a final program made in Visual Basic (remember that HALCON programs can be used in Visual Basic).

8.2.1. – Create an OPC connection

Open a new Simatic project, add a new PC station and include the OPC Server indicated in Picture 8.2

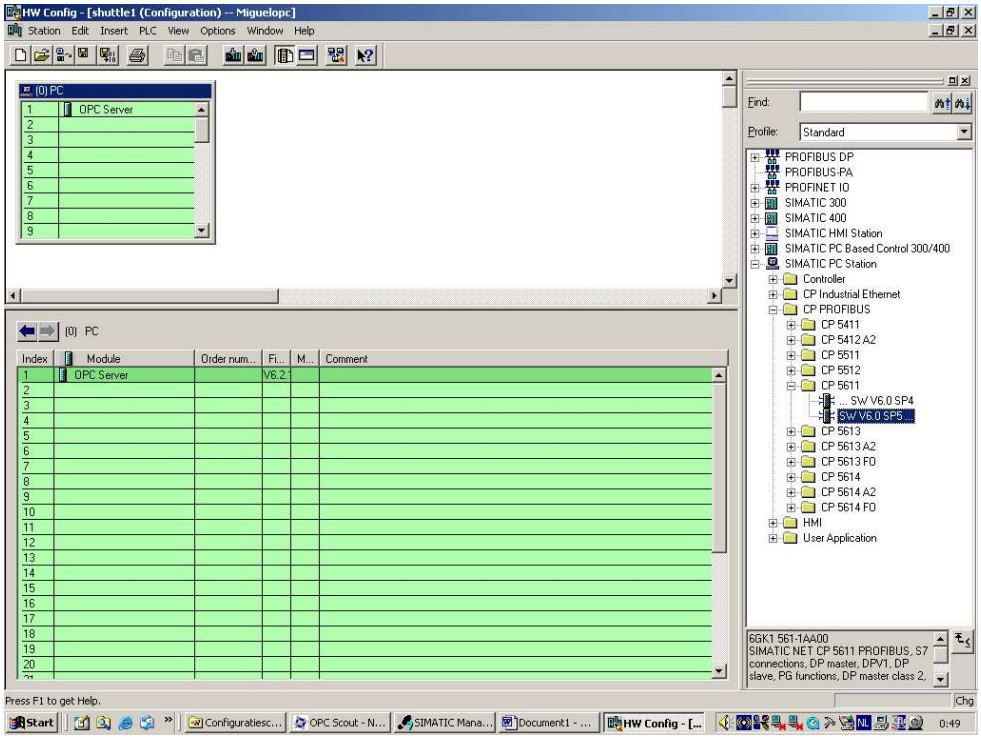


Picture 8.1. First Step

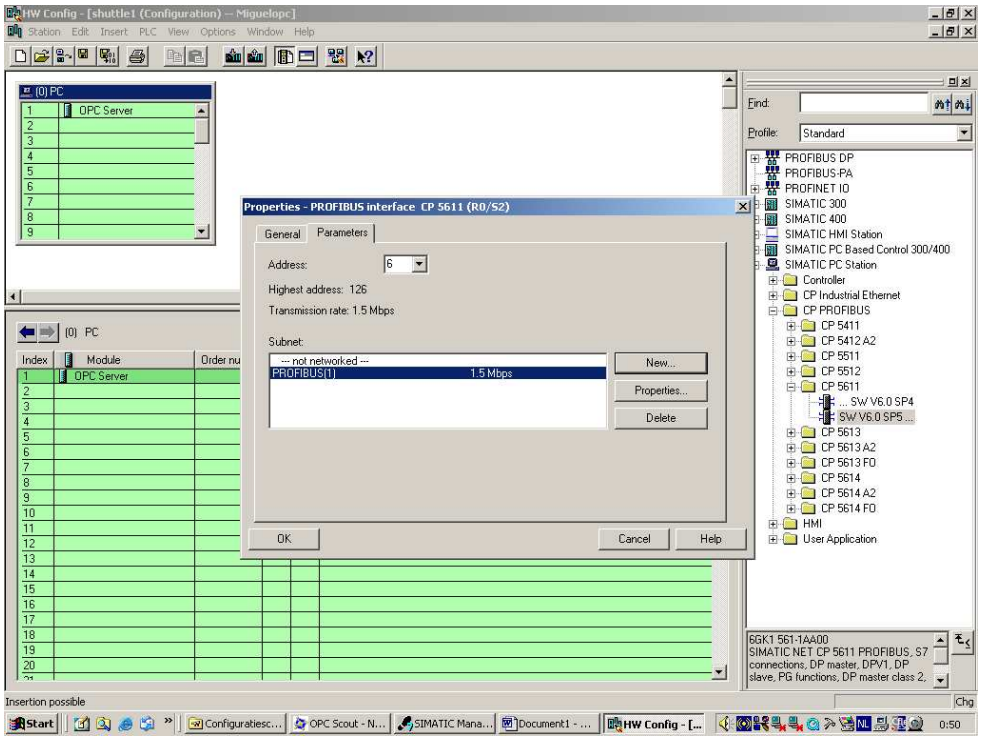


Picture 8.2. Second step

Insert the file corresponding to the CP card integrated in the computer, in this case CP5611. Set an address for the new device (in this case 6, remember that the PLC has address 2, the motor address 3)

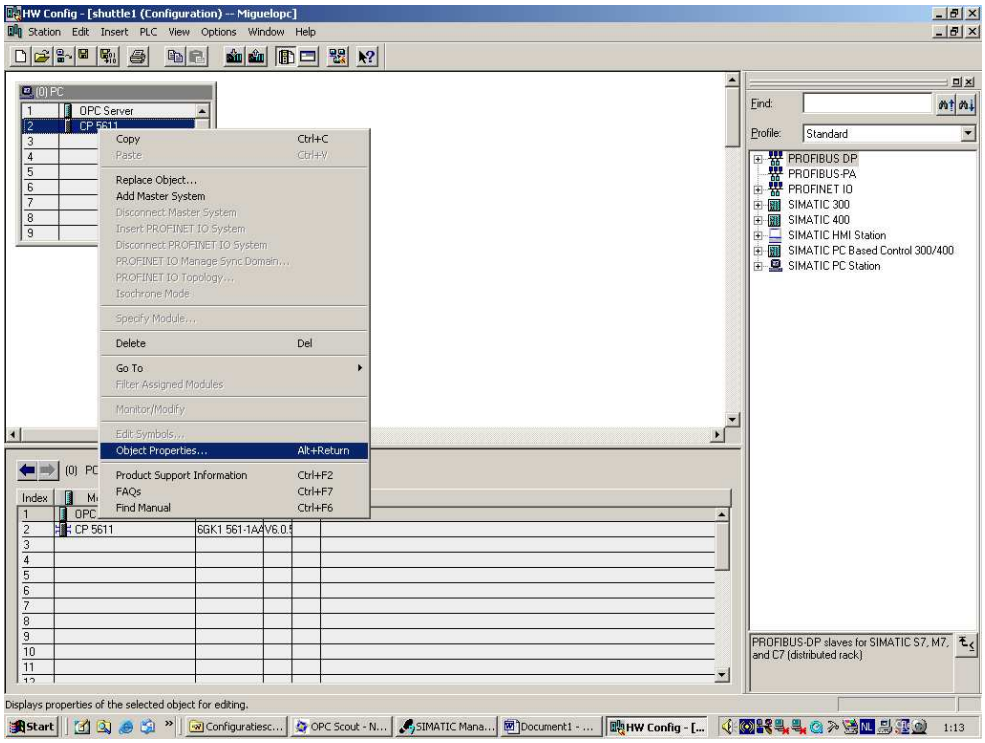


Picture 8.3. Third step

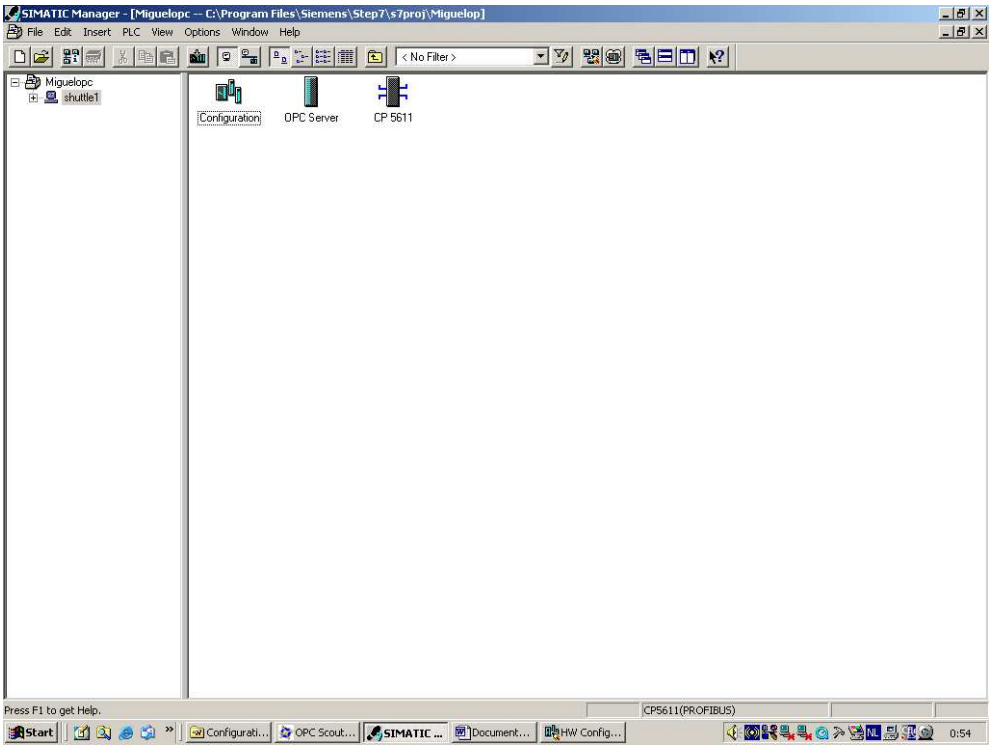


Picture 8.4. Fourth step

In “object properties”, include the new network done like it was explained in chapter 5. The program has the following appearance (Picture 8.6):



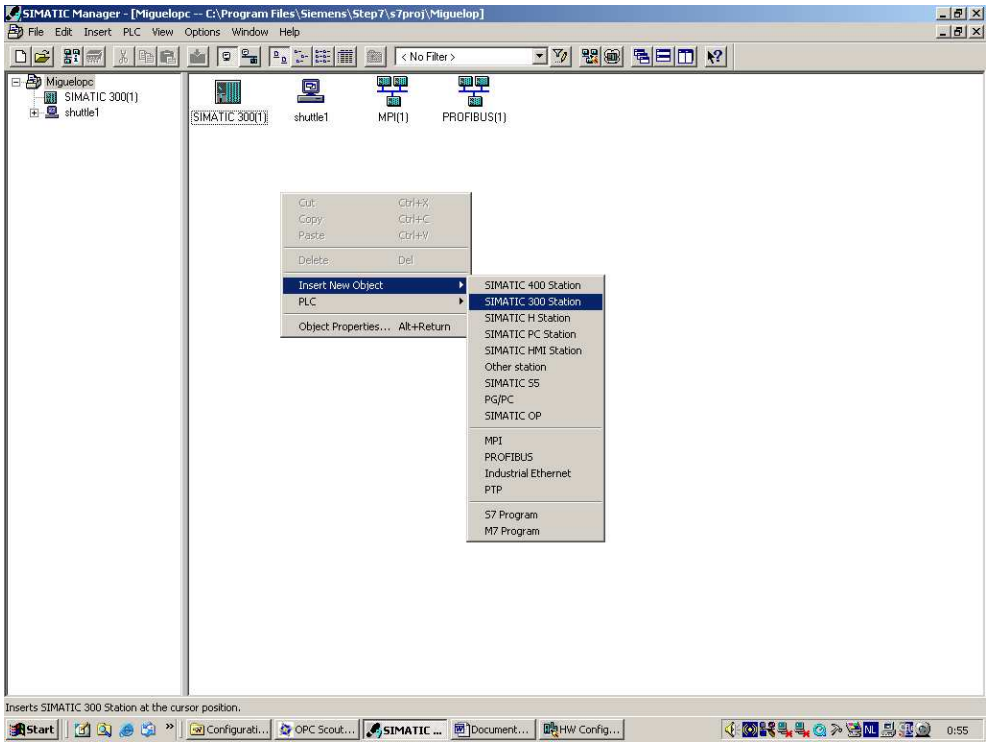
Picture 8.5. Fifth step



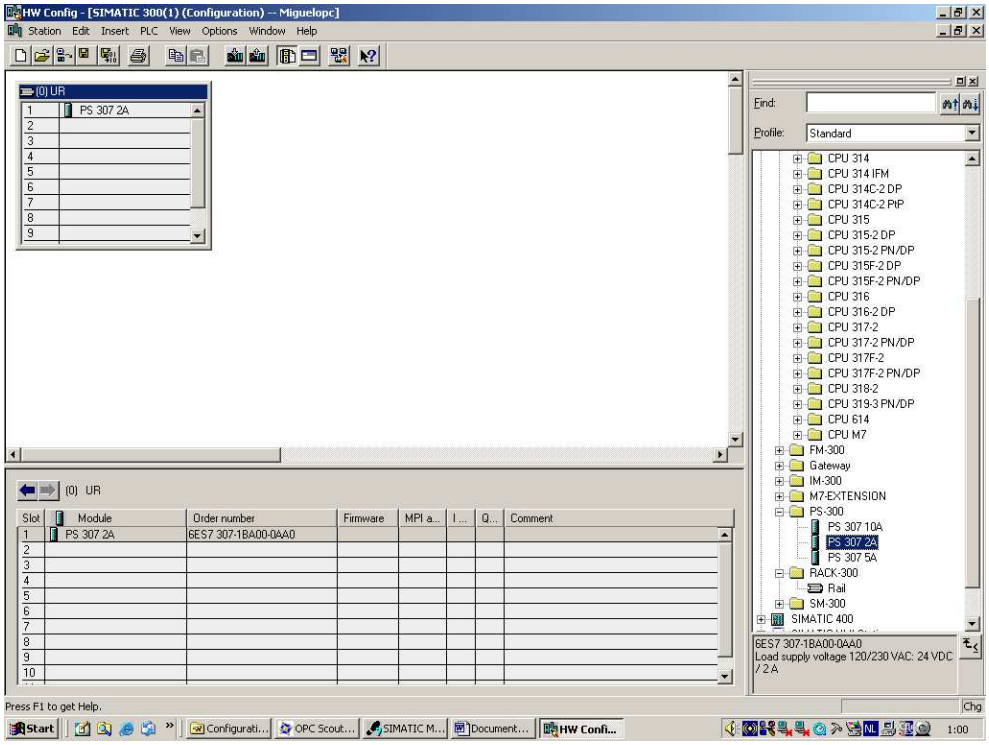
Picture 8.6. Sixth step

Until here, OPC configuration is almost done. Now it is time to make the network with the motor and the PLC. These steps are shown in chapter 5 but there are some pictures to explain the process followed in order to know the final addresses and remember again.

At first, add “Rail” and afterwards the PLC like in the picture 8.8.

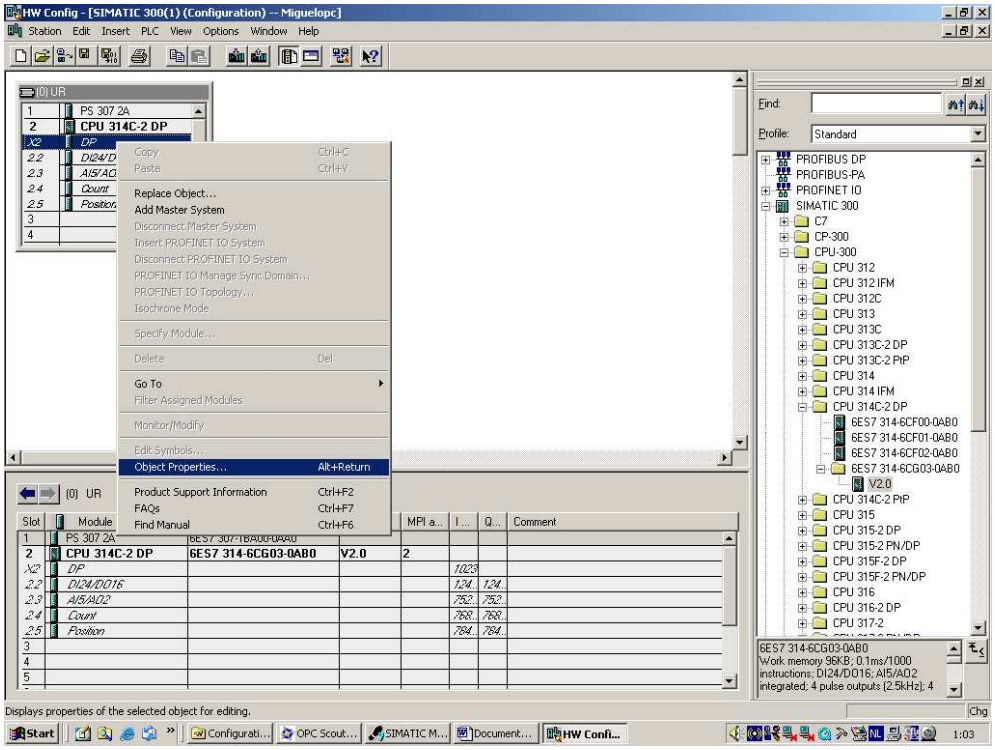


Picture 8.7. Seventh step

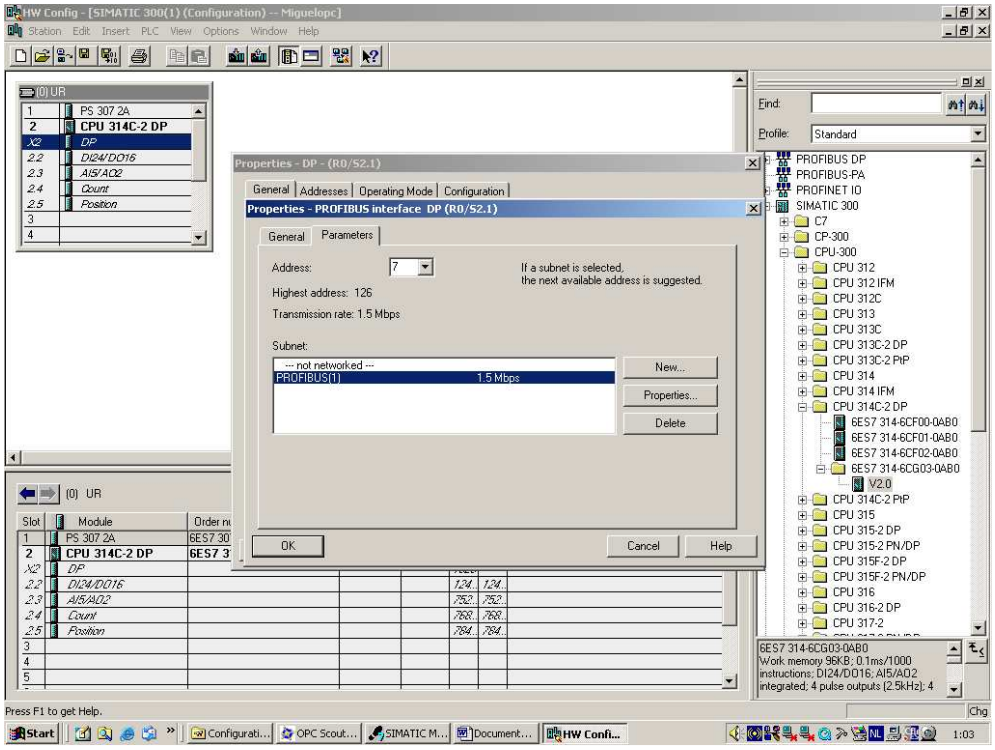


Picture 8.8. Eighth step

Include the CPU for the PLC and create a new network (in this case with address 7). This network will connect the motor.

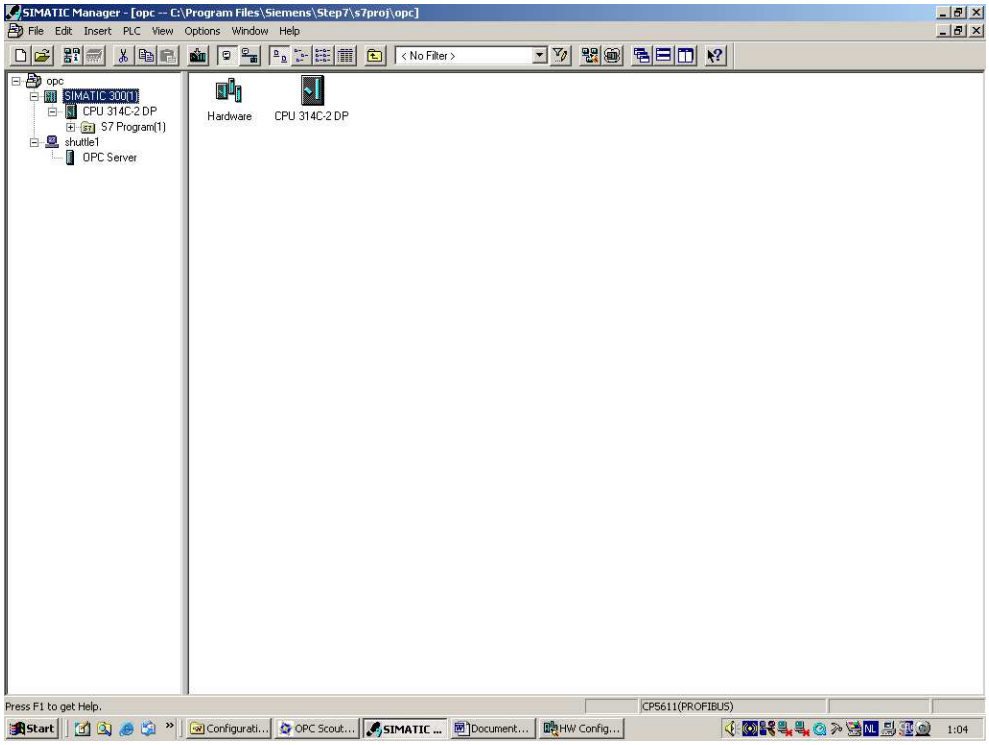


Picture 8.9. Ninth step



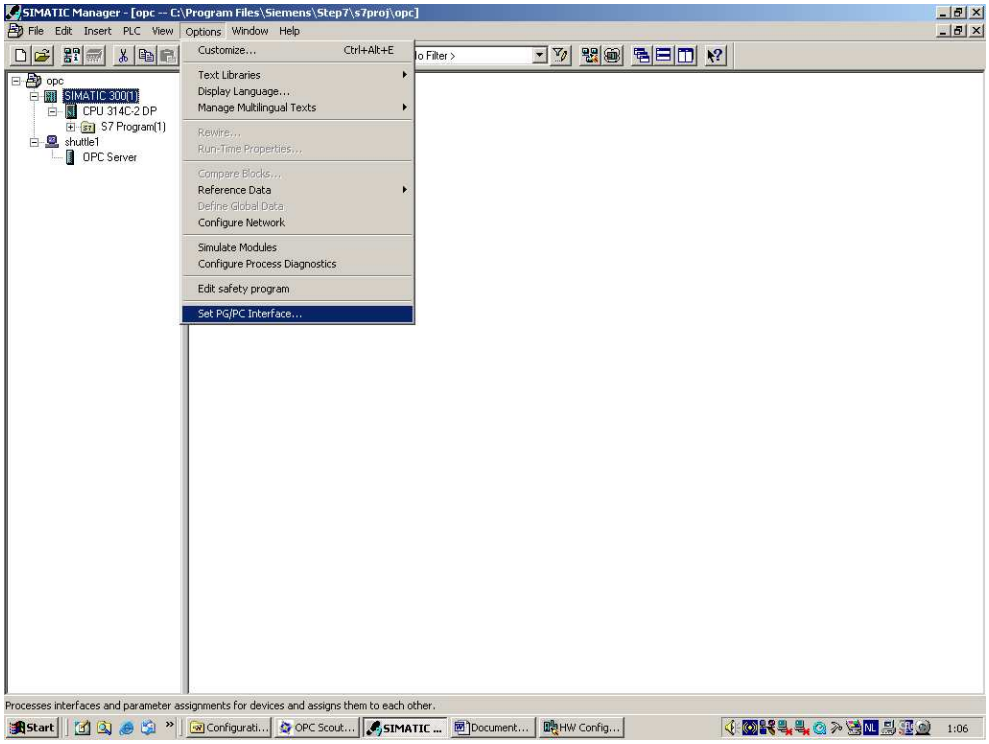
Picture 8.10. Tenth step

OPC server via Profibus is already made. The final configuration is shown in the next picture.

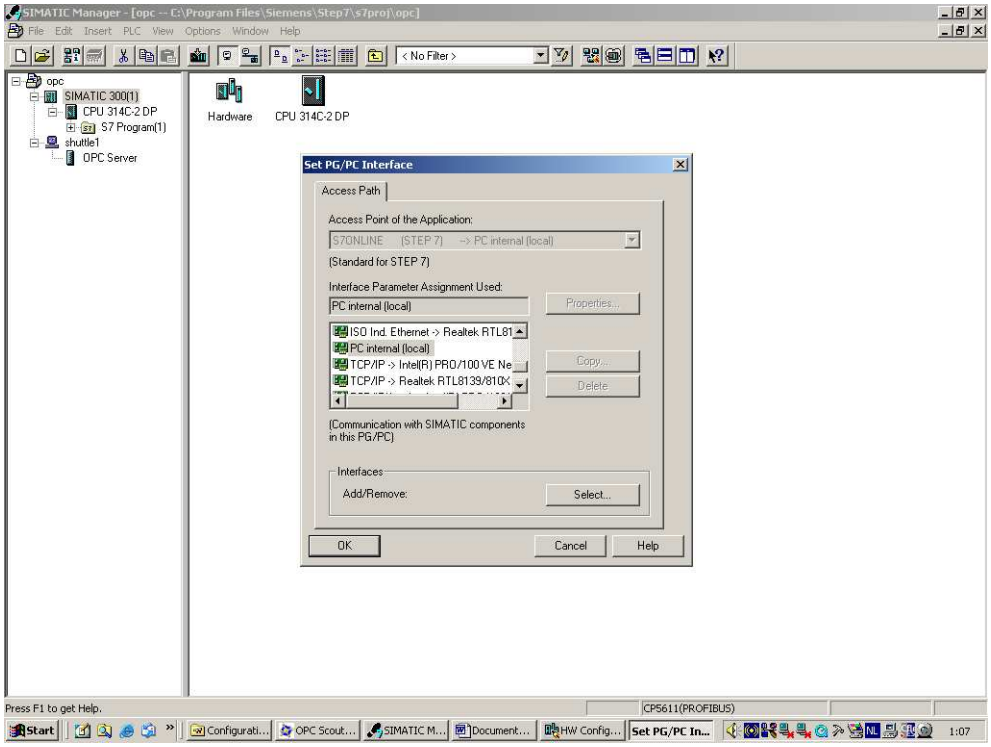


Picture 8.11. Eleventh step

To download in the PLC is necessary to make some changes. To download the PC Station (shuttle1): select options, set PG/PC interface and select PC internal (local).

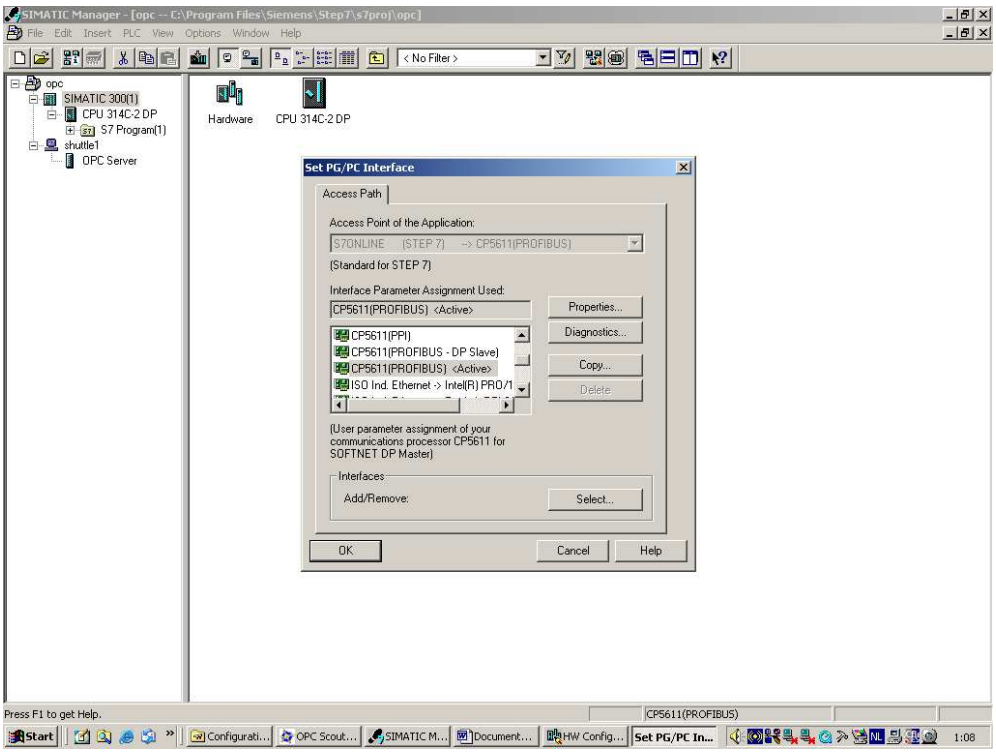


Picture 8.12. Twelfth step



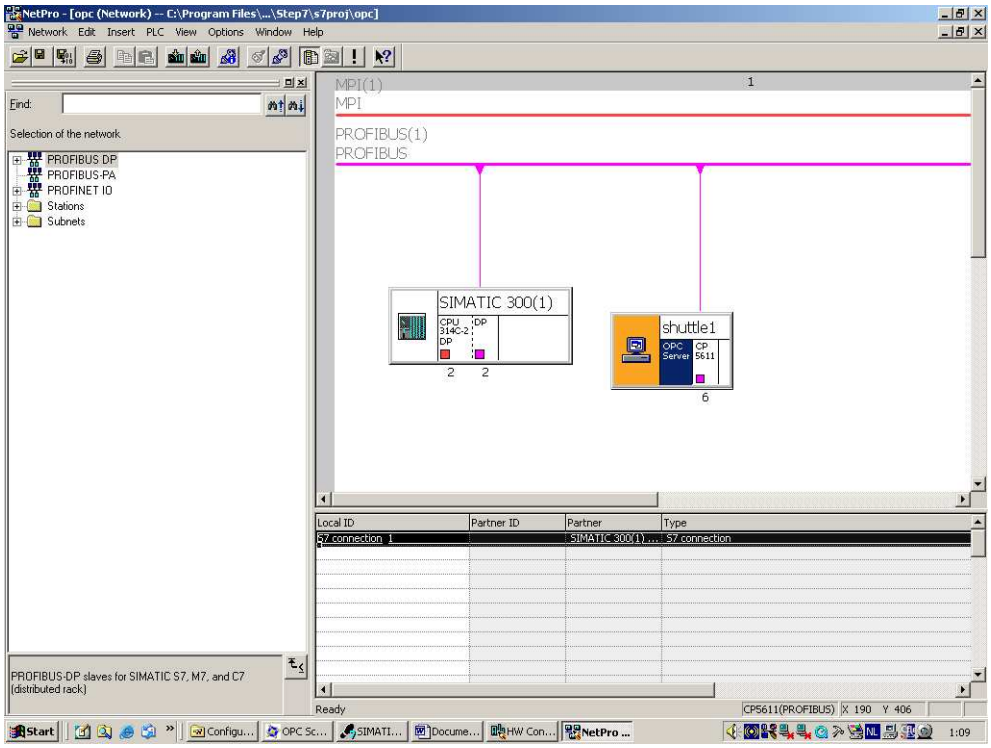
Picture 8.13. Thirteenth step

To download Simatic 300: select options, set PG/PC interface and select CP5611 (Profibus)

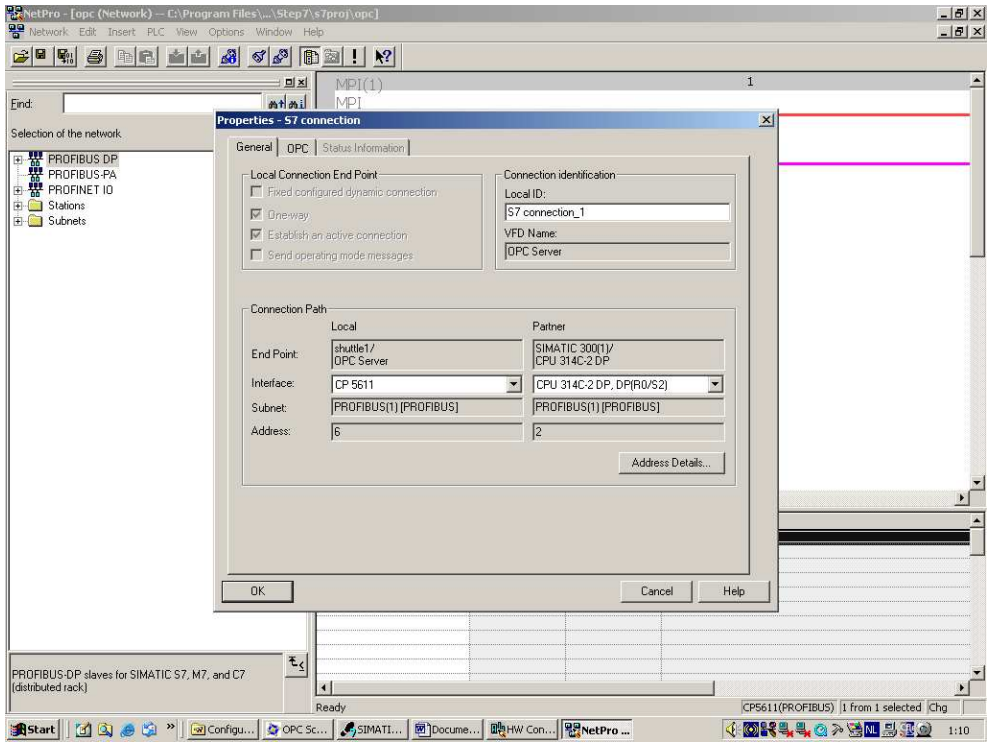


Picture 8.14. Fourteenth step

Select network and configure a S7 connection in shuttle1 clicking on OPC server. The window in the picture 8.16 appears.



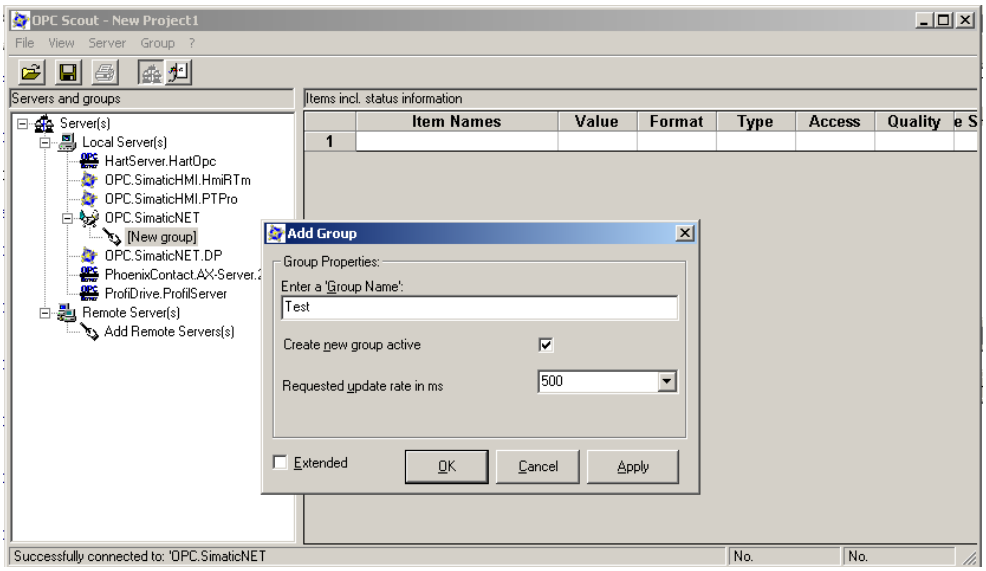
Picture 8.15. Fifth step



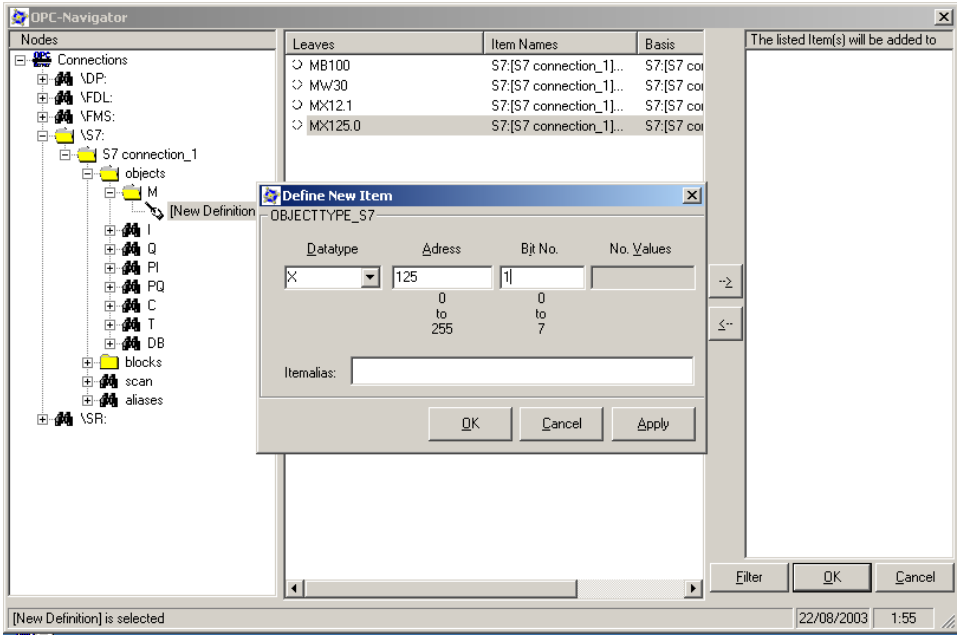
Picture 8.16. Sixteenth step

8.2.2. – Check OPC connection

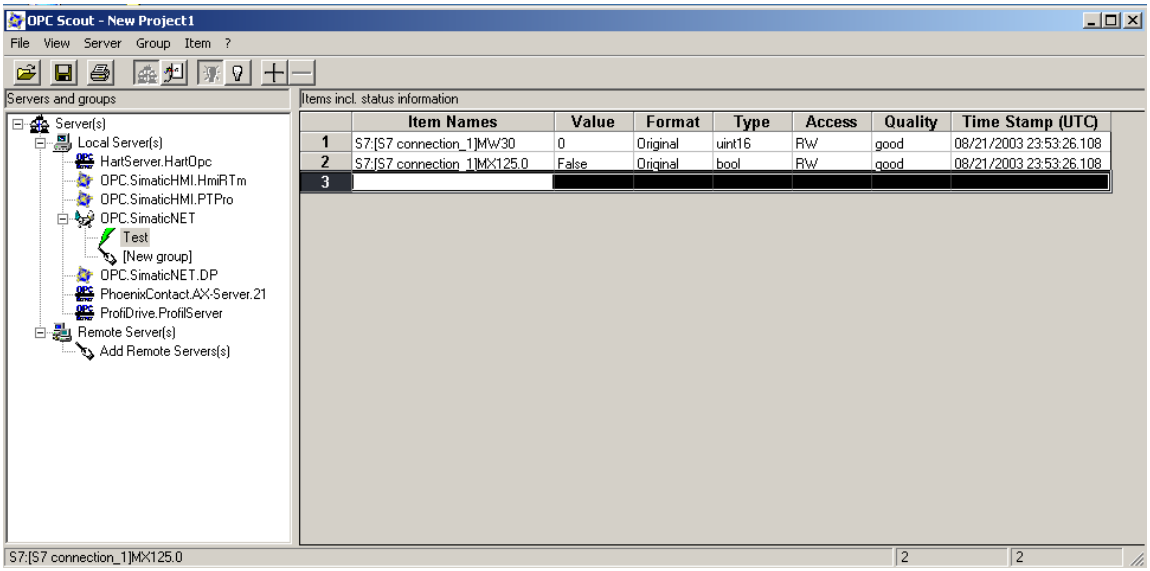
OPC scout is a tool of Simatic which allows the user to know in each moment the value, format, and state of the variables that has been included. Next pictures show the way for making this.



Picture 8.17. OPC Scout



Picture 8.18. Define new item

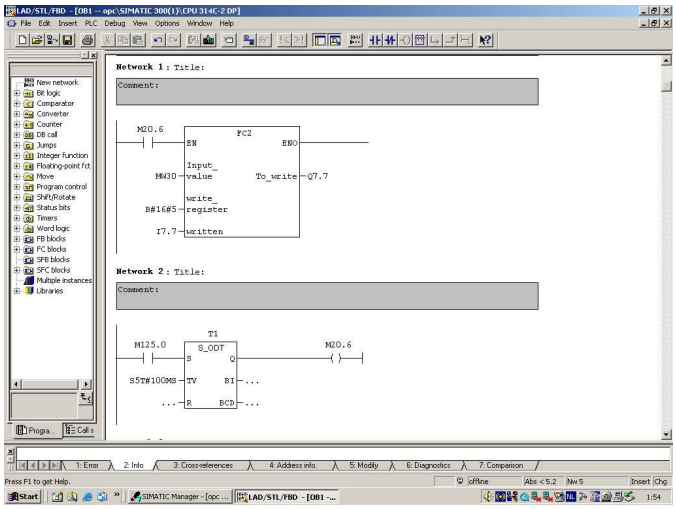


Picture 8.19.Items state

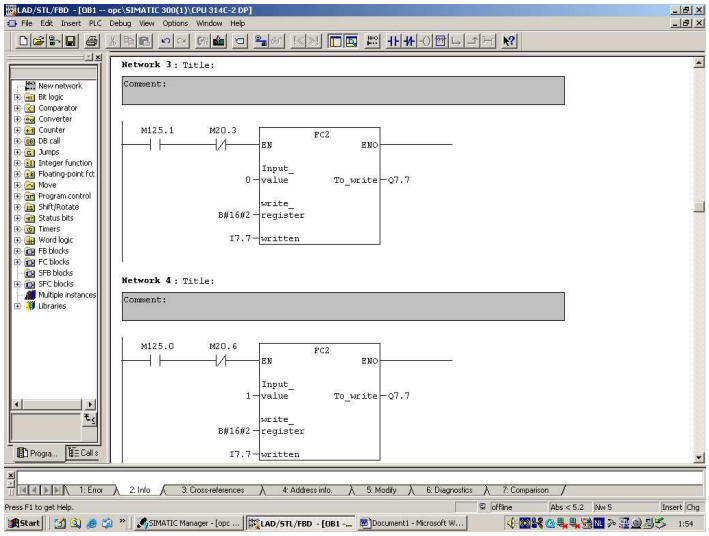
8.3. – New S7 program for the conveyor with OPC

The last S7 program was controlled by switches. To integrate everything in one application with Visual Basic, all the inputs and outputs which were commanded by switches, are stored in a memory variable (M). The program has been modified to not include the initial data at the same time as the velocity is being changed.

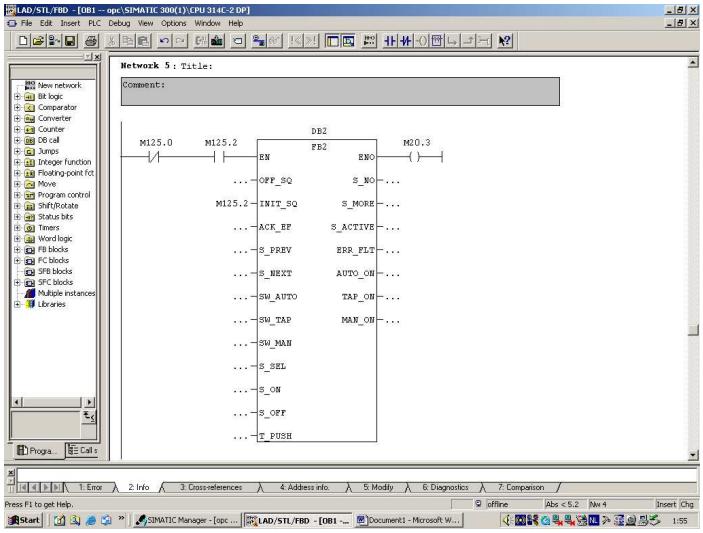
At first, the initial data are introduced (Network 5) therefore the motor will start (Network 4 and 2). The program changes from the start register to the velocity register. In the Visual Basic program, speed has to be changed any time (Network 1). The belt can be stopped at any time (Network 3). New S7 program is displayed in the pictures below.



Picture 8.20. New S7 program (1)



Picture 8.21. New S7 program (2)



Picture 8.22. New S7 program (3)

CHAPTER 9

Communication and Visual Basic programs

9.1. – Summary

At the moment all the components of the project are connected and the elements which take part in the project are done. Now it's time to make the final Visual Basic program which will command everything. It's not easy to do at simultaneous because each part has to be tested in order to check the errors in an easiest way.

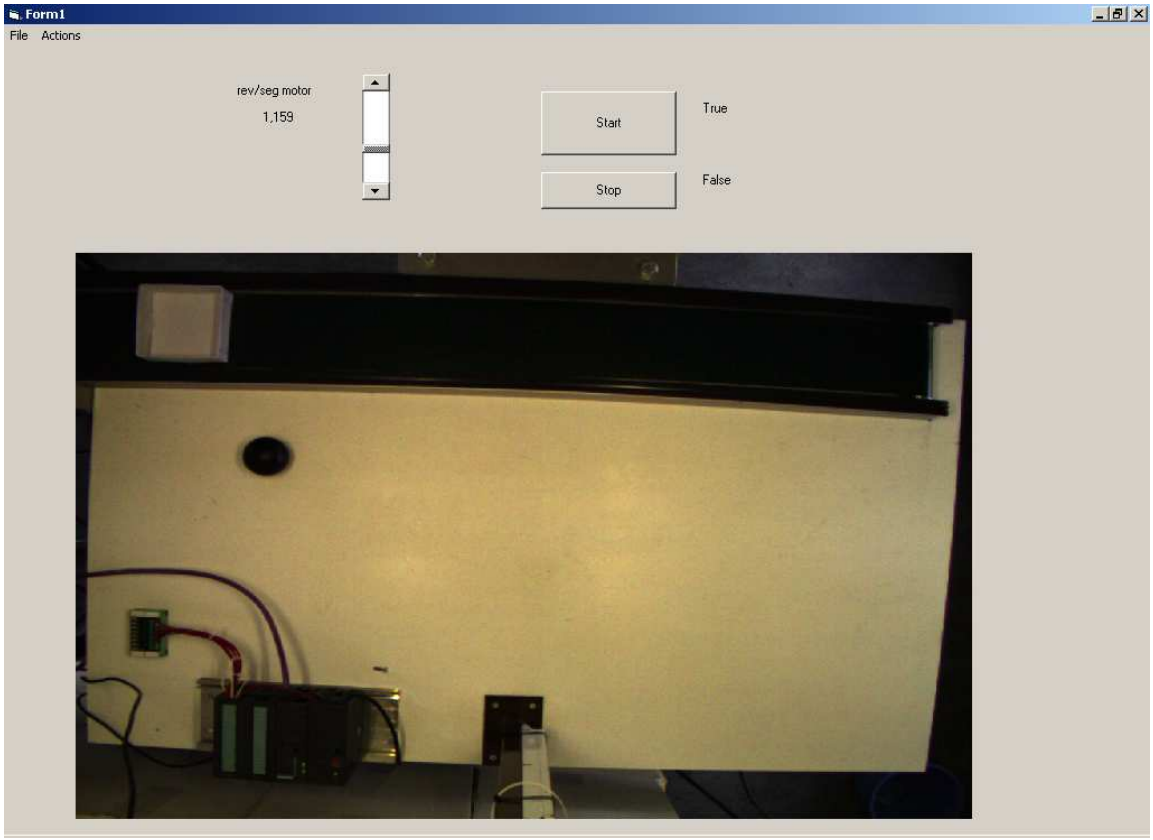
For this reason, the current chapter will explain the different programs made in this project. The first is to control the conveyor, and the next is to create the communication between the computer and the robot.

After this, a flowchart will be necessary to make with the process to follow in order to integrate these programs and to add the required code to finish it.

9.2. – Program that controls the belt over PROFIBUS

This program consists in a simple window which shows the images acquired by the camera in each moment as well as two buttons for start/stop the belt by the user. It even allows adjusting the velocity of the motor displaying the speed in rev/seg. This program also includes a menu bar with some options like introduce the initial data (acceleration, torque…) in the motor.

Subsequently, in the picture 9.1 is displayed the window created in Visual Basic, and later is the code used in the program for controlling the conveyor. Realize that this program integrates OPC server and HALCON. To include a HALCON program is necessary to save the program with .bas extension and add it in the Visual Basic project like a module. After this, the code can be added in the main program. Picture 9.1 shows the program made. The programming code for this application is in Appendix 2, paragraph A2.1.



Picture 9.1. Program to control the conveyor

9.3. – Robot-PC Ethernet communication and VB programs

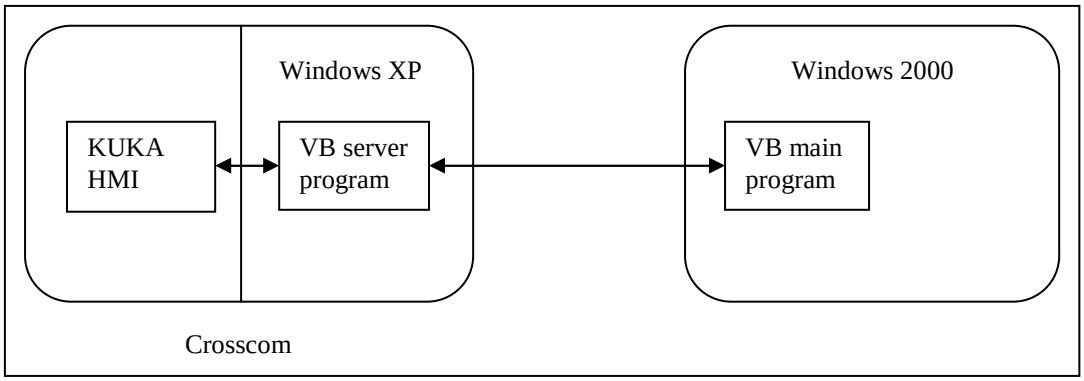
9.3.1. – General aspects

Until now, PROFIBUS has been used in the communication, but between the robot and the main PC will be utilized an Ethernet connection for the reason that this method has been used successfully before in the department and it is even easier than PROFIBUS connection to send data instead of the coordinates. This way just has the problem of a reduced speed while data are being sent.

The cable used is a crossover cable. Ethernet communication needs an IP address and a remote port adjusted as the user wants. These data should be the same in each computer to transfer information. The communications has been done with the following data:

- IP address: 136.129.165.4
- Remote port: 10101

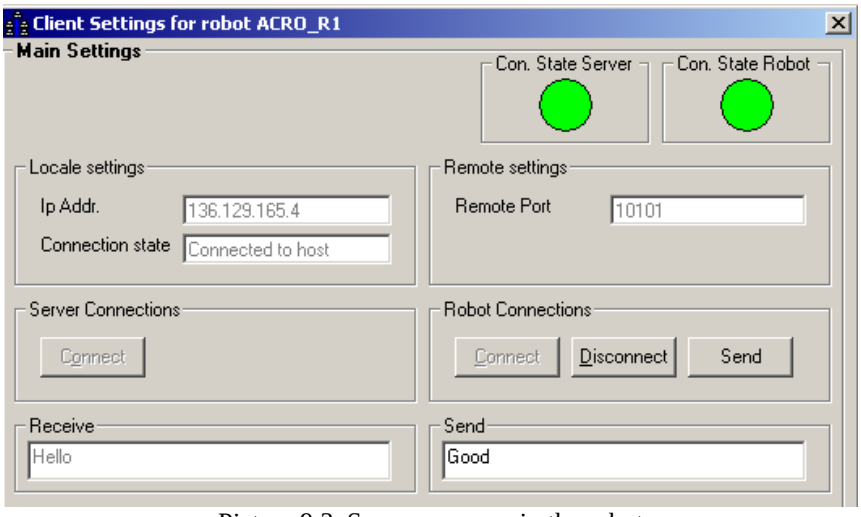
The KUKA robot has an own operating system (KUKA HMI 1.2) and it also has a special version of Windows XP. Because of this the communication between the robot and the main computer needs two steps for the final communication. Due to this it will be necessary to make a Visual Basic program in the computer of the robot as well as in the main computer. Communication between the robot and Windows is called Crosscom.



Picture 9.2. Communication scheme

9.3.2. – First version of the server program in the robot

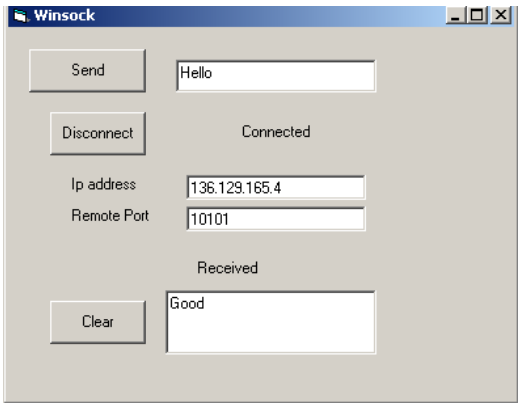
The following program is the first version of the Visual Basic application made for Windows XP of the robot computer. Two different parts are mentioned, on the left side there are parameters needed for Ethernet connection running like a server, on the right side there is the connection with the robot via Crosscom. In addition, the program includes two state lights and two texts where data sent and received are shown. When both connections are good, the lights have a green color, if not they change into red. Sometimes the state of the server is listening when the application in the main computer is not correct. An example, the following two pictures show a correct sending and reception.



Picture 9.3. Server program in the robot

9.3.3. – Program in the main PC

The current section, like section 9.2, displays a small program which will take part in the final program. The aim of the program is completely different. This application is just to demonstrate that communication can be possible and to check that data sent and received are correct, without mistakes.



Picture 9.4. Program to communicate with the robot

The programming code of both program used for the communication is in Appendix 2 at the end of the current report, section A2.2 and A2.3. These programs are not explained in the current chapter because it will be added in the final program and it will be explained in one of the last chapters of the project report.

CHAPTER 10

Robot settings: suction system and calibration

10.1. – Robot suction system

The next step is to include the robot suction system necessary to complete the project. The object which would be picked up is a small black ball with a diameter approx. 500 mm. So the best tool to get the ball is a suction cup tool with a diameter smaller than the diameter of the object; in this way, the power of suction is higher.

Besides the cup tool, other components are needful even more important than the tool itself. These components are the following:

- Compressor
- Valve
- Vacuum sensor (Pneumatic Converter)
- Vacuum generator
- Suction cup tool

Each one has its own function. It's going to be explained in the next section.

10.1.1. – Compressor (Panther - Werther International)

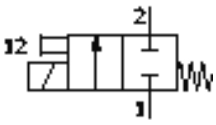
One of the most important components in the suction system is the compressor; the first part in this system. A gas compressor is a mechanical device that increases the pressure of gas by reducing its volume, with this is obtained air with a high velocity. It is explained because the pressure and after the vacuum generator create the suction in the final point, which means, in the cup tool. The picture 10.1 shows the compressor that takes part in the project application.

Picture 10.1. Compressor

10.1.2. – Solenoid valve MFH-2-M5 - 4573

The valve is connected directly with the compressor with a tube. This valve has the function of start/stop the suction. It actuates through an electrical signal and is connected to the PLC to be commanded by OPC and to be supplied.

The address in the PLC for this device is the output Q125.0 and as can be seen in the picture, the normal position is closed.



Picture 10.2. Valve

10.1.3. – PE converter PEN-M5 - 8625

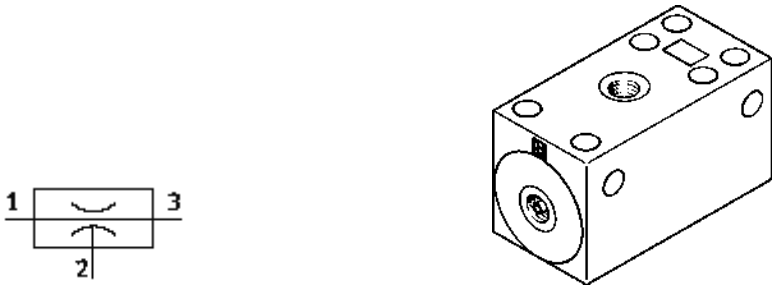
This device is connected after the valve and it detects when there is vacuum or not. The device uses 3 cables, all of them connected to the PLC, when vacuum is created, the device sends an electrical signal to the PLC to the input address I124.7; the others two are the power and the ground.

Picture 10.3. Vacuum sensor

10.1.4. – Vacuum generator VAD-M5 - 19293

As was mentioned in one of the previous sections, the vacuum generator creates the suction necessary for the application by the Venturi Effect. It is the drop in fluid pressure that results when an incompressible fluid flows through a constricted section of pipe. The fluid velocity must increase through the constriction, while the pressure decreases due to conservation of energy. The gain in kinetic energy is supplied by a drop in pressure or a pressure gradient force.

In the picture below the component and the schematic drawing are presented, the pneumatic connection 1 is joined with the vacuum sensor and connection 2 is joined with the tool creating the needed vacuum for the suction.



Picture 10.4. Vacuum generator

10.1.5. – Suction cup tool

The suction cup is the last component in the suction system and it has the shape showed in the next picture.

Picture 10.5. Suction cup

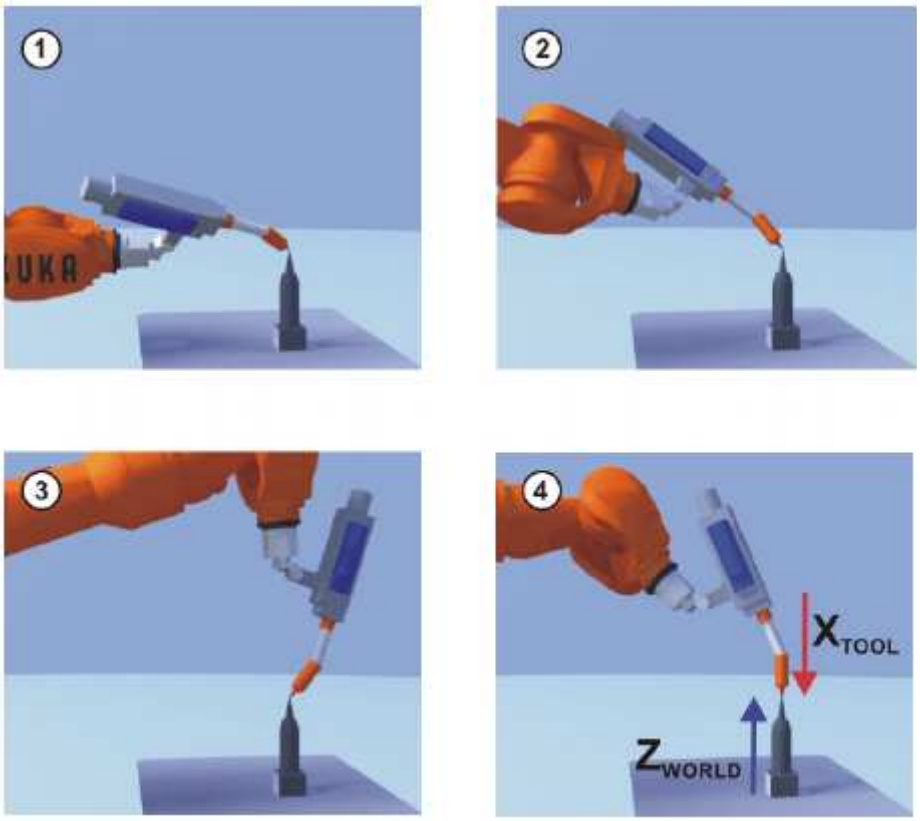
10.2. – Robot calibration

10.2.1. – Tool calibration

The method used for the tool calibration is TCP calibration: XYZ 4-Point method. The TCP of the tool to be calibrated is moved to a reference point from 4 different directions. The reference point can be freely selected. The robot controller calculates the TCP from the different flange positions. The tool to be calibrated is mounted on the mounting flange. The operating mode has to be T1 or T2.

1. Select the menu **Setup** > **Measure** > **Tool** > **XYZ 4-Point**.
2. Assign a number and a name for the tool to be calibrated. Confirm with **OK**.
3. Move the TCP to a reference point. Confirm with **OK**.
4. Move the TCP to the reference point from a different direction. Confirm with **OK**.
5. Repeat step 4 twice.
6. Press **Save**.

The name of the tool is “aspirate tool” and it has the number [1].



Picture 10.6. Tool calibration

10.2.2. – Base calibration

The method used for the base calibration is 3-point method**.** The robot moves to the origin and 2 further points of the new base. These 3 points define the new base. A previously calibrated tool is mounted on the mounting flange. Operating mode T1 or T2

1. Select the menu **Setup** > **Measure** > **Base** > **ABC 3-Point**.
2. Assign a number and a name for the base. Confirm with **OK**.
3. Enter the number of the mounted tool. Confirm with **OK**.
4. Move the TCP to the origin of the new base. Confirm with **OK**.
5. Move the TCP to a point on the positive X axis of the new base. Confirm with **OK**.
6. Move the TCP to a point in the XY plane with a positive Y value. Confirm with **OK**.
7. Press **Save**.

The name of the base is “project” and it has the number [1].

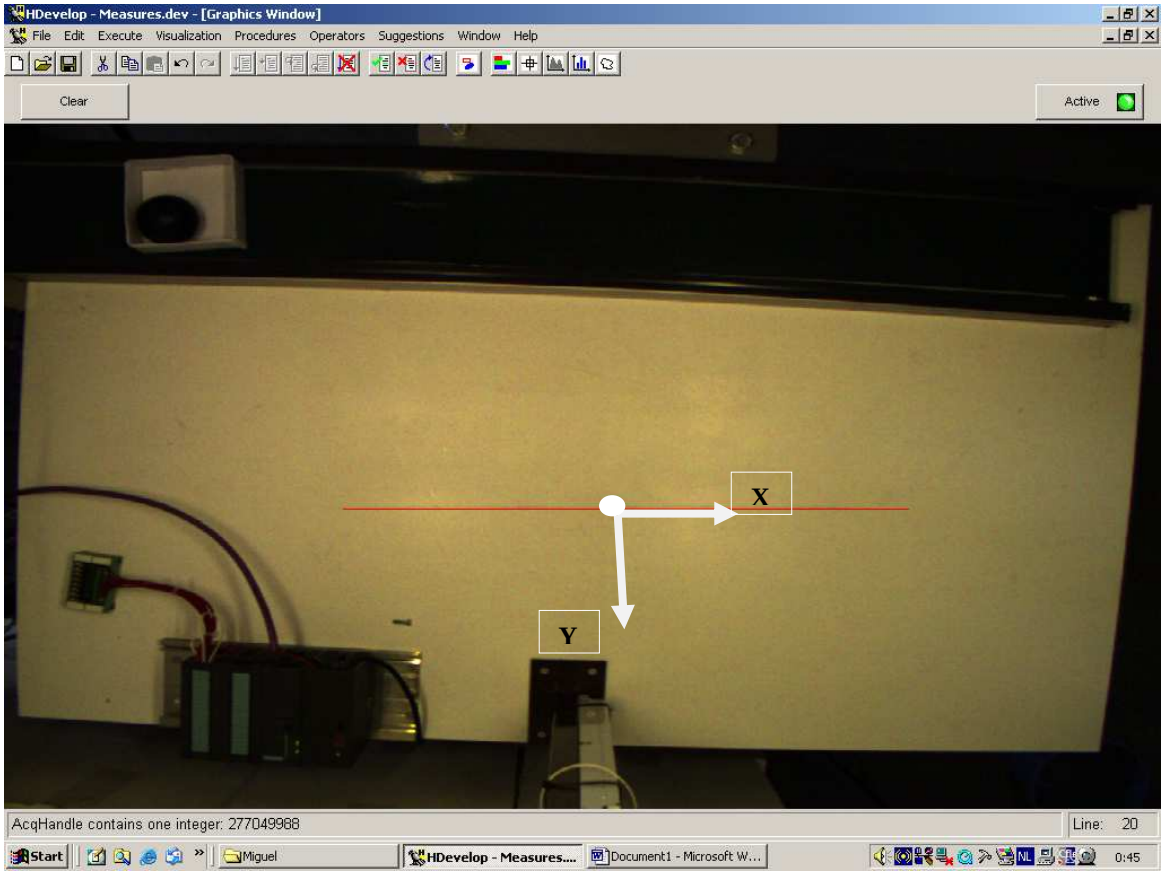
To make a good calibration, the robot has to have the same axis than the camera because the camera is the eyes of the robot. But a straight line in the camera is not the same as in the robot. For this reason and to send to the robot the real coordinates in the same plane, the best way to solve this is drawing a straight line in the program Halcon (red line in the Picture 10.7) to know what are the real axis for the camera and then, to draw this line on the table. This line is utilized after to calibrate the base in the robot as was explained before.

The code of this program is easy:

```
**Straight line in the camera for the calibration**
*****************************************************
dev_open_window (0, 0, 512, 512, 'black', WindowHandle)
read_cam_par ('campar.dat', CamParam1)
read_pose ('campose.dat', Pose1)
set_origin_pose (Pose1, 0, 0, 0, PoseNewOrigin1)
close_all_framegrabbers ()
open_framegrabber ('uEye', 2, 2, 0, 0, 0, 0, 'default', 8, 'rgb', -1, 'false', 'UI146xLE-C',       '1',   0,
  -1, AcqHandle)
set_framegrabber_param (AcqHandle, 'frame_rate', 27.542)
set_framegrabber_param (AcqHandle, 'contrast', 256)
set_framegrabber_param (AcqHandle, 'exposure', 10.3157)
set_framegrabber_param (AcqHandle, 'gain_master', 35)
grab_image_start (AcqHandle, -1)
dev_update_window ('off')



while (1)
```

```
    dev_set_color ('red')
    gen_region_line (RegionLines, 432, 300, 432, 800)
    dev_display (RegionLines)
    grab_image_async (Image, AcqHandle, -1)
    set_origin_pose (Pose1, 0, 0, 0, PoseNewOrigin1)
    dev_display (Image)
    disp_cross (WindowHandle, 432, 540, 6, 0)
endwhile
```

In the next picture are displayed the real axis and the central point used in the base calibration.



Picture 10.7. Axis in the camera for the base calibration

CHAPTER 11

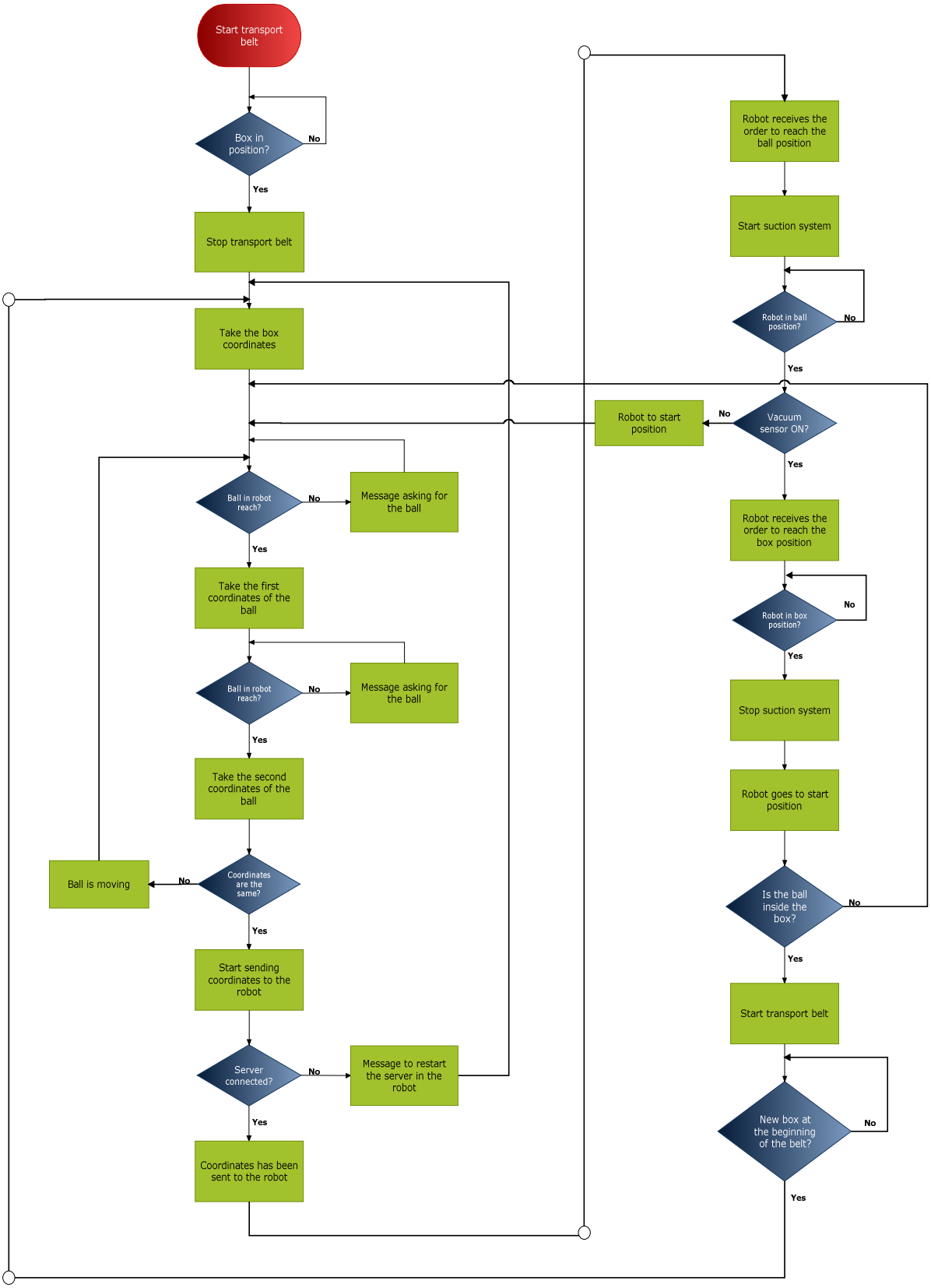
Flowchart and final programs

11.1. – Flowchart

This chapter describes the final process exactly like it has been programmed as well as the code used to make it. The first part is a flowchart of the process. It describes all the steps to implement but before it is necessary to explain the process in general.

The project consists of a conveyor and robot application controlled by a camera. The user can put a box wherever he wants on the conveyor, the robot picks up a ball situated somewhere on the surface of work and put the ball down inside the box. After this, the camera checks if everything is perfect therefore the conveyor will start. When a new box appears on the conveyor, the process will start again.

On the following is the whole flowchart with the process. It is the structure of the main program. The most difficult part is how to make the communication between the main program, the server in the robot and the robot program itself. The data sent in the process will be explained in the next paragraph in order to understand it in an easiest way.



Picture 11.1. Flowchart

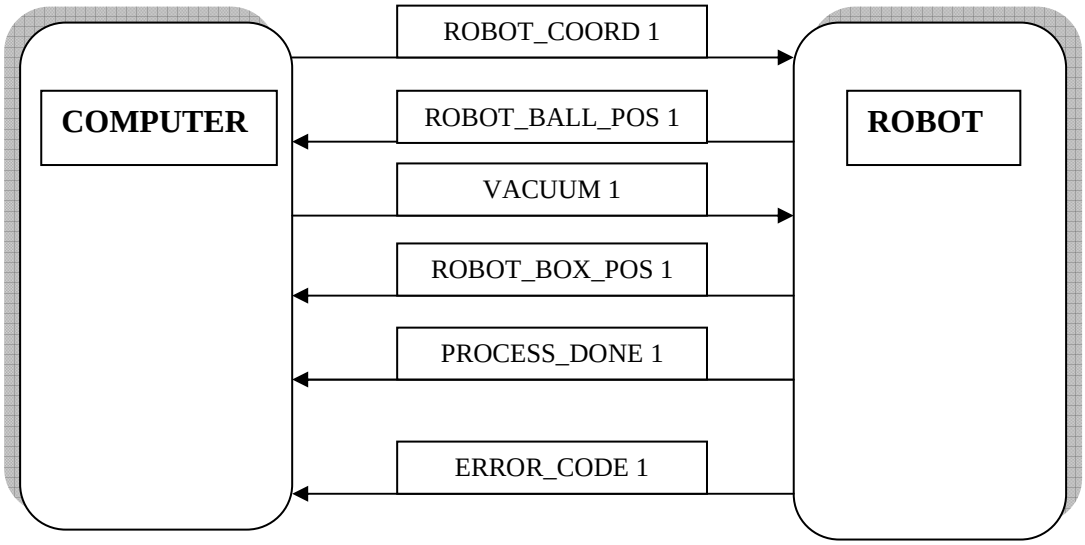
11.2. – Final programs

11.2.1. – General aspects in the communication

Firstly the data needed in the communication should be declared in the robot. These data have to be declared as global because they should be changed by the main program but even by the robot.

In the communication the data sent are strings. With this kind of data there aren't problems during the communication, because in an Ethernet connection you select each one by the name (see the picture below) followed by the state (1 if true or 0 if false). So is very easy to detect data arrival.

The process is the next: when coordinates has been sent, the main program send also "ROBOT_COORD 1". When the robot detects it, he starts running. With "ROBOT_BALL_POS 1", the main program enables the suction system if after some seconds the vacuum sensor is "on" the program sends "VACUUM 1", if not the robot sends to the main computer "ERROR_CODE 1" the process starts again and the value of the strings changes to 0. If the process follows normally, when the robot is in the box position it sends "ROBOT_BOX_POS 1" and when it is in his initial position sends "PROCESS_DONE 1". The scheme of this process is shown in the following picture.



Picture 11.2. Data exchange in the communication

11.2.2. – Main program

The current section will try to explain some parts of the programming code in order to make it easier. The form load is one of the most important parts; here is code from OPC server, code to initialize the camera and to communicate with the robot.

- Code corresponding to OPC connection:

```
'opc connection
Set ConnectOPCServer = New OPCServer
ConnectOPCServer.Connect "OPC.SimaticNet"
Set ConnectOPCGroups = ConnectOPCServer.OPCGroups
Set ConnectOPCGroup = ConnectOPCGroups.Add("connectie")
ConnectOPCGroup.UpdateRate = 250
Set ConnectOPCItems = ConnectOPCGroup.OPCItems
ConnectOPCItems.DefaultIsActive = True
Set bit_start = ConnectOPCItems.AddItem("S7:[S7 connection_1]MX125.0", 1)
```

- Code corresponding to the camera settings:

```
'open framegrabber
Call Op.ReadCamPar("campar.dat", hv_CamParam1)
Call Op.ReadPose("campose.dat", hv_Pose1)
Call Op.SetOriginPose(hv_Pose1, 0.0326, -0.0776, 0, hv_PoseNewOrigin1)
Call Op.CloseAllFramegrabbers
Call Op.OpenFramegrabber("uEye", 2, 2, 0, 0, 0, 0, "default", 8, "rgb", -1, "false", "UI146xLE-C",
"1", 0, -1, hv_AcqHandle)
Call Op.SetFramegrabberParam(hv_AcqHandle, "frame_rate", 27.542)
Call Op.SetFramegrabberParam(hv_AcqHandle, "contrast", 256)
Call Op.SetFramegrabberParam(hv_AcqHandle, "exposure", 10.3157)
Call Op.SetFramegrabberParam(hv_AcqHandle, "gain_master", 35)
Call Op.GrabImageStart(hv_AcqHandle, -1)


'start grabbing images and go to the steps menu
Timer4.Enabled = True
```

Code that makes the connection possible:

```
'connection with PC from robot
Winsock1.Close
Winsock1.RemoteHost = "136.129.165.4"
Winsock1.RemotePort = "10101"
Winsock1.Connect
```

This main program is made by steps programmed as functions; each step is the same as in the flowchart (Picture 11.1). It also takes the images each moment that is executed. Subsequently a small piece of code is shown; look that timer4 was initialized in the form load:

```
Private Sub Timer4_Timer()

'**main program wich calls each step in the process**
'*************************************************************
Call Op.GrabImageAsync(ho_Image, hv_AcqHandle, -1)
Call Op.DispObj(ho_Image _
    , hv_ExpDefaultWinHandle)
Timer4.Enabled = False

Select Case Step

Case "check_box"
   If findbox = True Then Step = "check_box1"

Case "check_box1"
   If findbox1 = True Then Step = "check_ball1"
```

When the application is looking for the box until the prefix position, in the first function (check_box) it stops the conveyor and after it takes a new image and gets the coordinates (check_box1). So the coordinates are more correct because there are a little time until the belt is stopped. It is not important due to it grabs a new image.

Another problem that can appear is when the ball is moving. This problem is solved grabbing two images in two instants separated by “Sleep (250)” and after comparing the coordinates of both. But coordinates are in millimeters, these can be always different. For that reason, when the coordinates are approximately the same; the program takes the condition true. This comparison is made as follows:

```
BallX1 = Format(Round(hv_Xball, "000"))
BallY1 = Format(Round(hv_Yball, "000"))

BallX2 = Format(Round(hv_Xball, "000"))
BallY2 = Format(Round(hv_Yball, "000"))

If BallY1 = BallY2 Then
      If BallX1 = BallX2 Then
         findball2 = True
      Else
         Step = "ball_moving"
      End If
   Else
      Step = "ball_moving"
 End If
```

After this, the coordinates are changed to microns because in the communication can’t be sent variables with a comma, and in this way the exactitude is higher.

As was explained in the previous section the communication uses strings data. In these strings the name of the variable and the value are included. The value of the coordinates have to be without comma, otherwise the robot software shows error messages. And even the communication gave another problem; the variables in the robot were declared as “real” and from Halcon are declared as “variant”. These kinds of data are incompatible but, for example an integer is not a good variable because it rounds the values and the coordinates would be incorrect. After some test, the kind of data chosen was “long”. For this, see the following code:

```
longXball = CLng(hv_Xball)
CoordXball = "X_BALL" + " " + CStr(longXball)
Winsock1.SendData CoordXball
```

The protocol of communication when the coordinates are being sent is the next: the first coordinate is the X axis of the ball, when the server program receives it will send “Xball” to the main computer as the communication was successfully. After this, the main program start sending the next coordinate and the server answers again. This process is followed until the server sends “done”. In this way both programs are coordinated.

An important function in the program is DataArrival. This function is called when data is coming in Ethernet communication. In the programming code can be made a distinction between the received data. The first part, when n = 0, is for the coordinates and the second part is utilized during the robot running.

```
Private Sub Winsock1_DataArrival(ByVal bytesTotal As Long)

Dim Strdata2() As String
Dim n As Integer

'get data from the robot
Winsock1.GetData strData


Strdata2() = Split(strData, " ")

n = UBound(Strdata2)

If n = 0 Then
txtDone.Text = strData
End If

'data during the robot movement
If n = 1 Then
   Select Case Strdata2(0)
      Case "ROBOT_BALL_POS"
         robot_ball_pos = Strdata2(1)
      Case "ROBOT_BOX_POS"
         robot_box_pos = Strdata2(1)
```

```
        Case "PROCESS_DONE"
            robot_process_done = Strdata2(1)
        Case "ERROR_CODE"
            error_robot = Strdata2(1)
            txtBoxInPos.Text = ""
            txtXball.Text = ""
            txtYball.Text = ""
            txtXbox.Text = ""
            txtYbox.Text = ""
            txtDone.Text = ""
        Case Else
            MsgBox ("Error sending data")
    End Select
End If

End Sub
```

In the main program the velocity of the belt and the position where the box has to stop in real time can be modified. To change the velocity is very simple with the scroll bar. It changes the speed easily, but it causes a problem with the position of the box. When the user leaves the box near to the robot, in the movement to reach the box, the robot stops due to a blockade. This can be solved by not allowing that the box can be stopped in this area.

```
Private Sub hsbBoxPos_Change()

If (hsbBoxPos.Value >= 300 And hsbBoxPos.Value <= 670) Then
    MsgBox "Value is not valid because of a possible blockade of robot, please select in the
     permitted area"
    hsbBoxPos.Value = box_position
Else
    box_position = hsbBoxPos.Value
End If

End Sub


Private Sub vsbVelocity_Change()
velocity.Write vsbVelocity.Value
End Sub
```

The full programming code can be seen in the Appendix 3, section A3.1. The window created for this application is displayed in the picture below while the program has been running.

Picture 11.3. Main program

11.2.3. – Client sever program in the robot

This program is used to get and send data between computers and to send and receive data from the robot. The way that the coordinates arrive is the same as in the main program, but here these data are sent at the same time to the robot. It can be done by the command "CrossCommands.SetVar()". Next to this there is a small piece of code:

```
If n = 1 Then

   Select Case Strdata2(0)
      Case "X_BALL"
         bool1 = CrossCommands.SetVar("X_BALL", Strdata2(1))
         TcpClient.SendData "Xball"
```

To display in the program some variables from the robot, the command to use is "CrossCommands.ShowVar()" like in the next piece of code:

```
Label1.Caption = CrossCommands.ShowVar("X_BALL", str_Xball)
Label1.Caption = str_Xball
```

Ethernet connection in this program is the same as in the main program, which means, the code to include in the form load is just the same as in the previous paragraph.

To connect the program with the robot there is a piece of code specific for that as follows:

```
Public Sub ConnectRob()

'Create object for the robot
Set CrossCommands = CreateObject("CrossCommEXE.CrossCommand")
CrossCommands.Init Me

    CrossCommands.ConnectToCross vValue
    Connected = True
    StrBofVer = GetBOFVer

End Sub
```

These commands used to connect the server program with the robot are declared in another file added in the Visual Basic project which is called “Module”. The code of this program can be seen also in Appendix 3, section A3.3.

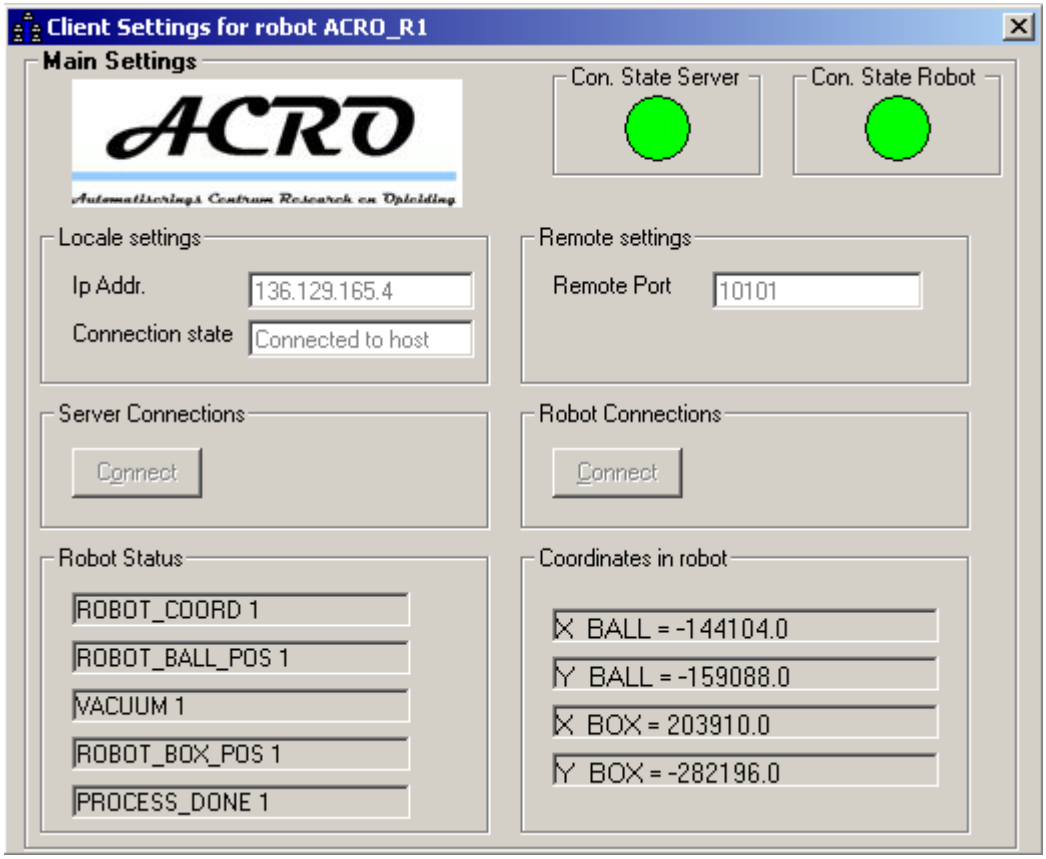
When the robot is running, it is necessary to create a kind of protocol in the communication in order to have a good synchronization between the three programs. The problem is that in this server it is impossible to make a main program with steps because it is an application that is receiving and sending data and it can’t implement any process defined to follow. For this reason, there is a part which checks the variables when the robot is running to know the state of the robot at each moment. Here is the code where the steps are defined with Boolean variables. When one step has finished, it allows the execution of the next. It can be seen as follows:

```
Private Sub Timer2_Timer()

If boolBall = True Then

Dim str_RobotBallPos As String
Dim dataRobot1() As String
Dim sendBallPos As String

lblBallPos.Caption = CrossCommands.ShowVar("ROBOT_BALL_POS", str_RobotBallPos)
dataRobot1() = Split(str_RobotBallPos, " ")
lblBallPos.Caption = dataRobot1(0) + " " + dataRobot1(2)
sendBallPos = "ROBOT_BALL_POS" + " " + "1"
```

```
If dataRobot1(2) = 1 Then
   TcpClient.SendData sendBallPos
   boolError = True
   boolBall = False
End If

End If
```

The picture below displays the window of this program. On the top there are two circular lights that show the state of the connection with the main computer and the robot. On the bottom are all the variables declared in the robot and the value of them in real time. As was mentioned in other paragraph, the coordinates are in microns. These will be converted to millimeters in the robot program. On the left side in the bottom of the window are the variables that show the state of the robot while it is running in real time.

The programming code of the current program can be seen in Appendix 3, section A3.2.



Picture 11.4. Server program in the robot computer

11.2.4. – Robot program

The program of the robot is a short program. To understand it is better to look back to Picture 11.2 and to see the direction of each variable in the communication process while the robot is running. In this program there are some steps:

- Firstly before than start making the program is necessary to declare the global variables. For this go to C:\KRC\ROBOTER\KRC\R1\System and access to $config.dat. The variables that have been declared are the next:

  ```
  DECL REAL X_BALL
  DECL REAL Y_BALL
  DECL REAL X_BOX
  DECL REAL Y_BOX
  DECL INT ROBOT_COORD
  DECL INT ROBOT_BALL_POS
  DECL INT ROBOT_BOX_POS
  DECL INT VACUUM
  DECL INT ERROR_CODE
  ```

  When these variables have been typed on the bottom of the file and after saving, the computer should be restarted in the program. It means “shut down” the computer to configure the changes.

- Now, in the program, can be declared another variables and positions. The variables utilized to give the position to the robot should be “integer”. The coordinates are given in microns and the robot works in millimeters. Each variable must be divided by 1000. Realize that the entire program is a “loop” and the robot is always waiting ROBOT_COORD = 1 to start working.

- When the robot receives this data from the main program, the first step to go to the selected point P6 (it is like the home position). After this point it needs another, if not it shows an error, this is the reason because there is another: P4. Realize that every point has the reference of the tool and the base fixed.

- Set all the axis of the point P4 on 0 is the best way to give after the exact value of the coordinates, because the coordinates have the reference of the camera. So in the position “a1” can be set the coordinates X and Y of the ball and the Z axis is given manually because it is the same for the whole process. The movement is commanded with lin a1.

- ROBOT_BALL_POS is set on 1 before the movement because, in this way, the suction system is faster and the process doesn't have to wait.

- When the robot is in the ball position, there is a wait time because the main program has to send if the vacuum sensor is ON or not. If the robot doesn't receive this data, after this half a second, the robot sends ERROR_CODE 1 and goes to the initial position. So when the main program detects this code, it takes again the coordinates and sends again.

- If the sensor is set in ON, the main program sends VACUUM 1 and the robot goes to reach the box coordinates. When it is on the top of the box, the data ROBOT_BOX_POS 1 is sent and the main program disconnects the suction system. For this, the robot waits for 2 seconds to be sure that the ball has been released inside the box. After this, the robot goes to its initial position (out of the vision range) and sends PROCESS_DONE 1. With this the main program knows that the robot has finished and then the camera process start again checking if the ball is really in the box.

The robot program is executed in Automatic Mode. To execute this mode it needs to push the start button to run and even the first motion (until the point P6) has to be executed manually by the user each time when the program has been stopped. For this reason the user is always sure that when the application is started, the robot is never going to crash with the table or another object because it has to be moved by the user manually and he takes visual contact with this.

Note: Realize that before putting a new value to a variable, there is a function "wait", it is because the robot follows executing the program until the next function while it is executing a movement. Realize also that this "waits" are for a little time.

```
DEF Test3( )

decl int Xball
decl int Yball
decl int Xbox
decl int Ybox
pos a1        ;position of the ball
pos a2        ;position of the box

LOOP
  ;change coordinates to mm
  Xball = X_BALL/1000
  Yball = Y_BALL/1000

  Xbox = X_BOX/1000
  Ybox = Y_BOX/1000
```

```
  IF ROBOT_COORD == 1 THEN
    PROCESS_DONE = 0
    ERROR_CODE = 0

PTP P6  Vel= 100 % PDAT6 Tool[1]:Aspirate tool Base[1]:Project
    ;give coordinates to the next point, robot needs initial point
    xp4.x = xp6.x
    xp4.y = xp6.y
    xp4.z = xp6.z

PTP P4  Vel= 100 % PDAT4 Tool[1]:Aspirate tool Base[1]:Project
    ;to situate center of tool in central point of the base
    xp4.x = 0
    xp4.y = 0
    xp4.z = 0

    ;to take coordinates of the ball, z axis is given by the user
    a1=xp4
    a1.z = a1.z + 10
    a1.x = a1.x + Xball
    a1.y = a1.y + Yball

    WAIT SEC 1/100     ;to add values robot needs wait function
    ROBOT_BALL_POS = 1
    ROBOT_COORD = 0
    lin a1
    WAIT SEC 1/5       ;short time to wait vacuum data


    IF VACUUM == 1 THEN

      a1.z = a1.z - 120 ;z axis position for the box
      lin a1

      a2 = xp4
      xp4.x = 0
      xp4.y = 0
      xp4.z = 0
      a2.z = -120

      ;new point with box reference
      a2.x = a2.x + Xbox + 20
      a2.y = a2.y + Ybox + 20
      lin a2
      WAIT SEC 1/1000
      ROBOT_BALL_POS = 0
      ROBOT_BOX_POS = 1
      WAIT SEC 2         ;wait suction off and go to first position
```

```
PTP P11  Vel= 100 % PDAT11 Tool[1]:Aspirate tool Base[1]:Project
      WAIT SEC 1/1000
      VACUUM = 0
      PROCESS_DONE = 1
    ELSE

      ;when vacuum is off then go to first position and send error
PTP P10  Vel= 100 % PDAT10 Tool[1]:Aspirate tool Base[1]:Project
      WAIT SEC 1/1000
      ERROR_CODE = 1
      ROBOT_COORD = 0
      ROBOT_BALL_POS = 0
    ENDIF
  ENDIF

ENDLOOP
END
```

11.3. – Picture of the final process

Picture 11.5. Final process

CHAPTER 12

Conclusions: improvements and future applications

12.1. – Conclusions

At the beginning the project was a very big challenge because my knowledge in the field of robotics and artificial vision were reduced. When I accepted the project it was a risk, but at the end it is finished.

The current project is considered as the first step in Visual-servoing applications. It implements a small but important application in the field of real-time vision and automation processes. However implement new applications on the basis of this project is an easy task. Therefore is necessary to think about the new process and to make some changes in the code of the main program and the robot program. But the project, of course, can be improved in some ways and it is open to possible extensions. The next paragraph will try to explain some improvements that can be taken into account, but these could be even more.

12.2. – Improvements and future applications

Subsequently are mentioned some possible extensions and modifications in order to improve the current project.

One of the most important aspects in industry is efficiency which means something like more work in the same time. For this reason, efficiency could be equivalent to the speed of the process. In this way most of the possible improvements are going to follow this way:

- The motor which moves the conveyor is connected with PROFIBUS over OPC with the PLC and both with the computer. OPC as was explained in previous chapter is a standard of communication, it is a powerful tool in automation. But the velocity when data are sent is not fast. Due to that a new extension could be make the connection between the computer and the PLC over Ethernet and after, with the other devices like the motor, over PROFIBUS.

- Between the robot and the main computer there is an Ethernet connection. This connection during the working of the robot is not so fast. When the main program is sending the coordinates to the robot, it needs almost 3 or 4 seconds. One option could be send another kind of data, because the protocol of communication designed by me uses “string” data and these data are longer than another. But this kind of communication was chosen because of it didn’t have mistakes by the way of creating a safe communication.
  Another option would be to make a PROFIBUS connection between the PLC and the robot, this option is the best. The KUKA robot has PROFIBUS connection and it can be made, but this subject takes part of another big project that can be developed in the future in ACRO.

Leaving aside the improvement of the communication, the most important improvement is the calibration of the surface of work. There are some possible motives to explain this. One of this is that the calibration was made with a tool from Halcon 8.0 and the project has utilized Halcon 7.0 to make it. On the other hand, the problem is the quality of the lens because it has some distortions, more on the side. The error in the distances is higher when the object is further from the center of the table. Another option could be to choose a lens with less focus distance to watch more field of work and exclude from the application the side area.

CHAPTER 13

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- **"Working with an agent from the KUKA Company from 20/11/2007 to 22/11/2007", slides and documentation.**
- **"Programación en Visual Basic. NET" – Luis Miguel Blanco, 2002. Grupo EIDOS Consultaría y Documentación Informática, S.L., 2002.**
- **"Integrated Servo Motors, Technical Manual" - JVL Industri Elektronik A/S, Denmark.**
- **"Using Visual Basic (VB) to communicate with the DS100 and EM100" version: 2.0a - Tibbo Technology, Inc. 2001, 2002.**

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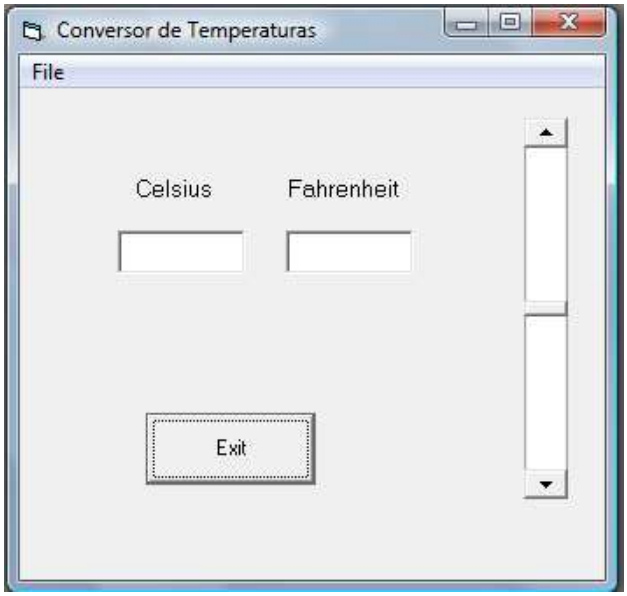
APPENDIX 1

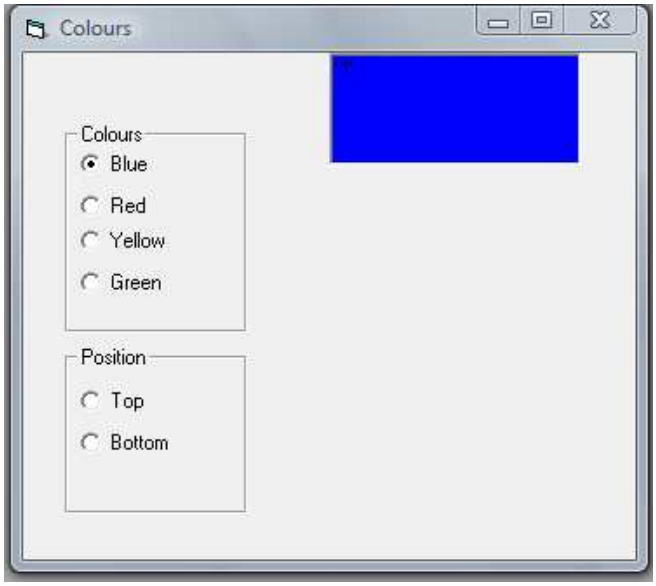
Visual Basic learning programs

First program




```
Option Explicit

Private Sub gff_Click()
End Sub

Private Sub cmdExit_Click()
End
End Sub

Private Sub mnuFileExit_Click()
End
End Sub

Private Sub vsbTemp_Change()
txtCelsius.Text = vsbTemp.Value
txtFahr.Text = vsbTemp.Value * 1.8 + 32
End Sub
```

Second program




```
Private Sub Option1_Click()
End Sub
Option Explicit
```

```
Private Sub Form_Load()
txtBox.Top = 0
End Sub
```

```
Private Sub optBottom_Click()
txtBox.Top = frmColours.ScaleHeight - txtBox.Height
End Sub
```

```
Private Sub optYellow_Click()
txtBox.BackColor = vbYellow
End Sub
```

```
Private Sub optTop_Click()
txtBox.Top = 0
End Sub
```

```
Private Sub optBlue_Click()
txtBox.BackColor = vbBlue
End Sub
```

```
Private Sub optRed_Click()
txtBox.BackColor = vbRed
End Sub
```

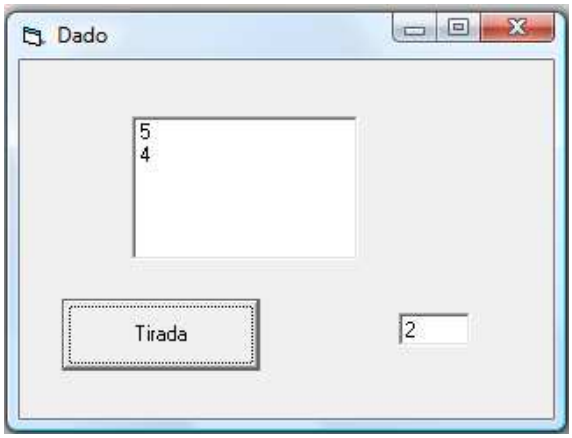
```
Private Sub optGreen_Click()
txtBox.BackColor = vbGreen
End Sub
```

Third program


```
Const Yes = 6
Const No = 7
Option Explicit
```

```
Private Sub cmdInsert_Click()
Dim Answer As Integer
Answer = MsgBox("Are you sure adding text to the list?", 291, "Question")
If Answer = Yes Then
    List.AddItem txtText.Text
End If
If Answer = No Then MsgBox "The text isn't added to the list", 0, "Message"
End Sub
```

Fourth program

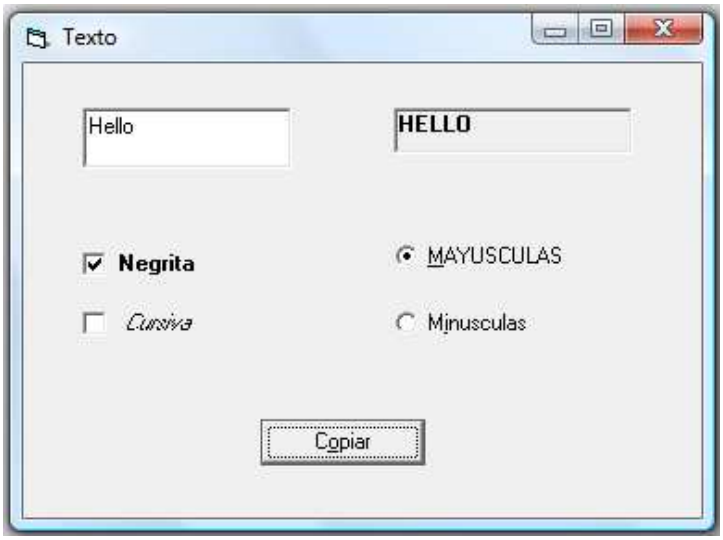


```
Option Explicit

Private Sub NumTiradas_KeyPress(KeyAscii As Integer)
If (KeyAscii < 48 Or KeyAscii > 57) Then
    If (KeyAscii <> 8) Then KeyAscii = 0
End If
End Sub

Private Sub Tirada_Click()
Dim Contador As Integer
Dado.Clear
For Contador = 1 To NumTiradas.Text
    Dado.AddItem (Int(6 * Rnd) + 1)
'Formula: Int([Valor superior]-[Valor inferior]+1)Rnd+[Valor inferior]
'Resolviendo: tipo integer--> Int(6-1+1*Rnd)+1
Next Contador
End Sub
```

Fifth program

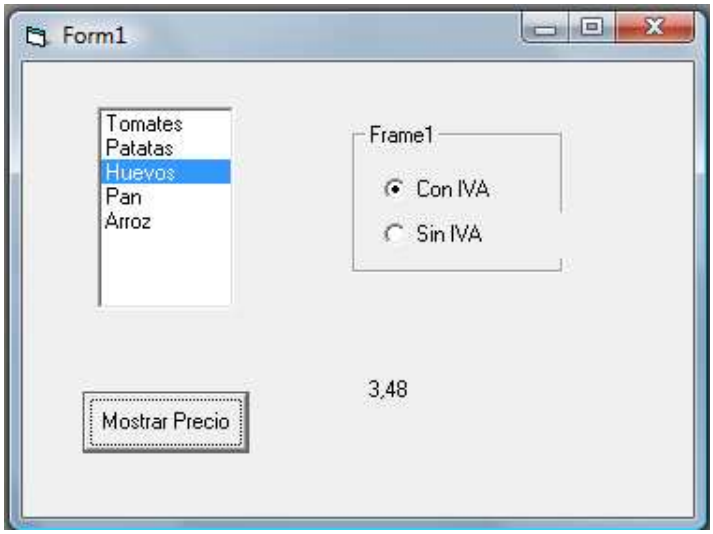

```
Option Explicit
Private Sub cmdDiv_Click()
txtResult.Text = Val(txtOper1.Text) / Val(txtOper2.Text)
lblOp.Caption = "/"
End Sub

Private Sub cmdMult_Click()
txtResult.Text = Val(txtOper1.Text) * Val(txtOper2.Text)
lblOp.Caption = "*"
End Sub

Private Sub cmdResta_Click()
txtResult.Text = Val(txtOper1.Text) - Val(txtOper2.Text)
lblOp.Caption = "-"
End Sub

Private Sub cmdSuma_Click()
txtResult.Text = Val(txtOper1.Text) + Val(txtOper2.Text)
lblOp.Caption = "+"
End Sub
```

Sixth program




```
Option Explicit

Private Sub cmdCopiar_Click()
lblEtiqueta.Caption = txtTexto.Text

If chbNegrita.Value = 1 Then
    lblEtiqueta.FontBold = True
Else
    lblEtiqueta.FontBold = False
End If

If chbCursiva.Value = 1 Then
    lblEtiqueta.FontItalic = True
Else
    lblEtiqueta.FontItalic = False
End If

If optMayusc.Value = True Then
    lblEtiqueta.Caption = UCase(lblEtiqueta.Caption)
Else
    lblEtiqueta.Caption = LCase(lblEtiqueta.Caption)
End If
End Sub
```

Seventh program




```
Option Explicit
```

```
Private Sub MostrarPrecio_Click()
Dim Precios As Integer
Select Case ListaObjetos.ListIndex
    Case 0
      Precios = 1
    Case 1
      Precios = 2
    Case 2
      Precios = 3
    Case 3
      Precios = 4
    Case 4
      Precios = 5
End Select

If sinIVA.Value = True Then
   Precio.Caption = Precios
  Else
   Precio.Caption = Precios * 0.16 + Precios
End If
End Sub
```

Eigth program


```
Option Explicit
```

```
Private Sub ListaBorrarElem_Click()
If ListaNombres.ListIndex = -1 Then
    MsgBox "Debes seleccionar algún elemento"
Else
    ListaNombres.RemoveItem (ListaNombres.ListIndex)
End If
End Sub
```

```
Private Sub ListaNombres_MouseUp(Button As Integer, Shift As Integer, X As Single, Y As Single)
If Button = 2 Then PopupMenu Lista
End Sub
```

```
Private Sub NombreAñadir_Click()
ListaNombres.AddItem (txtNombre.Text)
Lista.Enabled = True
End Sub
```

```
Private Sub NombreBorrar_Click()
txtNombre.Text = ""
End Sub
```

```
Private Sub ListaBorrar_Click()
Dim Respuesta As Integer
Respuesta = MsgBox("¿Estas seguro?", 36, "Pregunta")
If Respuesta = vbYes Then
    ListaNombres.Clear
    Lista.Enabled = False
End If
End Sub
```

```
Private Sub ListaProteger_Click()
ListaNombres.Enabled = Not (ListaNombres.Enabled)
ListaProteger.Checked = Not (ListaProteger.Checked)
NombreAñadir.Enabled = Not (NombreAñadir.Enabled)
ListaBorrar.Enabled = Not (ListaBorrar.Enabled)
ListaBorrarElem.Enabled = Not (ListaBorrarElem.Enabled)
ListaTamaño.Enabled = Not (ListaTamaño.Enabled)
End Sub
```

```
Private Sub ListaTamaño12_Click()
ListaTamaño8.Checked = False
ListaTamaño12.Checked = True
ListaTamaño18.Checked = False
ListaNombres.FontSize = 12
End Sub
```

```
Private Sub ListaTamaño18_Click()
ListaTamaño8.Checked = False
ListaTamaño12.Checked = False
ListaTamaño18.Checked = True
ListaNombres.FontSize = 18
End Sub
```

```
Private Sub ListaTamaño8_Click()
ListaTamaño8.Checked = True
ListaTamaño12.Checked = False
ListaTamaño18.Checked = False
ListaNombres.FontSize = 8
End Sub
```

```
Private Sub txtNombre_Change()
If Len(txtNombre.Text) <> 0 Then
    Nombre.Enabled = True
Else
    Nombre.Enabled = False
End If
End Sub
```

Ninth program


```
Const Elementos = 8
Dim Contador As Integer
Dim Tabla(1 To Elementos) As Integer
Option Explicit
```

```
Private Sub Form_Load()
Randomize
Crear 'Llamamos a la rutina Private Sub Crear()
End Sub
```

```
Private Sub Nueva_Click()
Lista.Clear
For Contador = 1 To Elementos
    Tabla(Contador) = Int((9 * Rnd) + 1)
    Lista.AddItem Tabla(Contador)
Next Contador
End Sub
```

```
Private Sub Ordenar_Click()
Dim I As Integer
Dim J As Integer
Dim Cambio As Integer
I = 1
Do
    For J = 1 To Elementos - I
        If Tabla(J) >= Tabla(J + 1) Then
          Cambio = Tabla(J)
          Tabla(J) = Tabla(J + 1)
          Tabla(J + 1) = Cambio
        End If
          Next J
          I = I + 1
        Loop Until I > (Elementos - 1)
        Lista.Clear
        For Contador = 1 To Elementos
          Lista.AddItem Tabla(Contador)
        Next Contador
End Sub
```

```
Private Sub Crear()
For Contador = 1 To Elementos
    Tabla(Contador) = Int((9 * Rnd) + 1)
    Lista.AddItem Tabla(Contador)
Next Contador
End Sub
```

APPENDIX 2

Visual Basic communication programs

A2.1 – Code of program to control the belt

```
'**opc variables**
‘**********************
 Public ConnectOPCServer As OPCServer
 Public ConnectOPCGroup As OPCGroup
 Public ConnectOPCGroups As OPCGroups
 Public ConnectOPCItems As OPCItems
 Public bit_start As OPCItem
 Public bit_stop As OPCItem
 Public velocity As OPCItem
 Public initial_data As OPCItem

 '**same for all programs**
‘********************************
  Dim Op As New HOperatorSetX
  Dim Tuple As New HTupleX
  Dim hv_ExpDefaultWinHandle As Variant

  Dim Window1 As HWindowX
  Dim WindowHandle1 As Variant

 '**more variables for bigger programs**
‘***********************************************
  Dim hv_AcqHandle As Variant
  Dim ho_Image As HUntypedObjectX, ho_Region As HUntypedObjectX



Private Sub Command1_Click()
bit_start.Write 1
bit_stop.Write 0
initial_data.Write 0
End Sub
```

```
Private Sub Command3_Click()
bit_stop.Write 1
bit_start.Write 0
End Sub


Private Sub Exit_Click()
bit_stop.Write 1
End
End Sub


Private Sub Form_Load()

'**window declaration**
‘**************************
Set Window1 = HWindowXCtrl1.HalconWindow
hv_ExpDefaultWinHandle = Window1.HalconID

'**opc connection**
‘***********************
Set ConnectOPCServer = New OPCServer
ConnectOPCServer.Connect "OPC.SimaticNet"
Set ConnectOPCGroups = ConnectOPCServer.OPCGroups
Set ConnectOPCGroup = ConnectOPCGroups.Add("connectie")
ConnectOPCGroup.UpdateRate = 250
Set ConnectOPCItems = ConnectOPCGroup.OPCItems
ConnectOPCItems.DefaultIsActive = True
Set bit_start = ConnectOPCItems.AddItem("S7:[S7 connection_1]MX125.0", 1)
Set bit_stop = ConnectOPCItems.AddItem("S7:[S7 connection_1]MX125.1", 1)
Set velocity = ConnectOPCItems.AddItem("S7:[S7 connection_1]MW30", 1)
Set initial_data = ConnectOPCItems.AddItem("S7:[S7 connection_1]MX125.2", 1)




'**open framegrabber**
‘****************************
Call Op.CloseAllFramegrabbers
Call Op.OpenFramegrabber("uEye", 2, 2, 0, 0, 0, 0, "default", 8, "rgb", -1, "false", "UI146xLE-C", "1", 0,
-1, hv_AcqHandle)
Call Op.SetFramegrabberParam(hv_AcqHandle, "contrast", 256)
Call Op.SetFramegrabberParam(hv_AcqHandle, "exposure", 10.3157)
Call Op.SetFramegrabberParam(hv_AcqHandle, "frame_rate", 27.542)
Call Op.SetFramegrabberParam(hv_AcqHandle, "gain_master", 35)
Call Op.GrabImageStart(hv_AcqHandle, -1)

'**start grabbing images**
‘******************************
Timer2.Enabled = True
```

```
End Sub


Private Sub Form_Unload(Cancel As Integer)
Call Op.CloseAllFramegrabbers
End Sub

Private Sub Initialvalues_Click()
initial_data.Write 1
End Sub

Private Sub Startbelt_Click()
bit_start.Write 1
bit_stop.Write 0
End Sub

Private Sub Stopbelt_Click()
bit_stop.Write 1
bit_start.Write 0

End Sub

Private Sub Timer1_Timer()

'**reading opc items from plc**
‘************************************
bit_start.Read (1)
Label1.Caption = bit_start

bit_stop.Read (1)
Label2.Caption = bit_stop

velocity.Read (1)
Label3.Caption = Format(Round(1600 / 60 * velocity / 4096, 3), "0.000")
End Sub

Private Sub Timer2_Timer()

'**grabbing images, make the halcon program**
‘******************************************************
Call Op.GrabImageAsync(ho_Image, hv_AcqHandle, -1)
Call Op.DispObj(ho_Image, hv_ExpDefaultWinHandle)
End Sub

Private Sub VScroll1_Change()
velocity.Write VScroll1.Value
End Sub
```

A2.2 – Code of server program in the robot

```
Option Explicit

Private Sub CmdConRob_Click()

‘**Connect with robot**
**************************
ConnectRob

End Sub


Private Sub CmdDisconRob_Click()

'**Disconnect from robot**
********************************
DisconnectRob

End Sub

Private Sub cmdSend_Click()


‘**Send data over Ethernet**
*********************************
TcpClient.SendData txtSendData.Text

End Sub



Private Sub Form_Load()

'**Setup Form**
******************
TxtGate.Enabled = False
TxtPoort.Enabled = False
txtconnectstat.Enabled = False
txtSendData.Enabled = True
txtOutput.Enabled = False
TxtPoort.Text = "10101"
TxtGate.Text = TcpClient.LocalIP

ConStateRobot.Visible = False
ConStateServer.Visible = False


'**Read out robot name and set as form title**
*****************************************************
QueryValue HKEY_LOCAL_MACHINE,
"System\CurrentControlSet\Control\ComputerName\ComputerName", "ComputerName"
frmClient.Caption = "Client Settings for robot" & " " & vValue

End Sub
```

```
Private Sub cmdConnect_Click()

‘**Connect with the main computer**
*****************************************
'Declare Variables
Dim Answer As String

TxtGate.Enabled = False
TxtPoort.Enabled = False

Answer = MsgBox("Are these settings correct ?", vbQuestion + vbYesNo, "Connect")

If Answer = vbYes Then

   '**Copy Port number data**
   ********************************
   If TcpClient.State = sckClosed Then
      TcpClient.LocalPort = TxtPoort.Text
   Else
      MsgBox ("The connection state is not 'closed'")
   End If

   'Copy server data
   If TcpClient.State <> sckError Then
      If TcpClient.State = sckConnected Then
        MsgBox ("Not possible while connected to server")
      Else
         'Nothing
      End If
   Else
      MsgBox ("Not possible while error on port")
   End If

   '**Invoke the Connect method to initiate a connection**
   ******************************************************************
   If TcpClient.State <> sckError Then
     TcpClient.Listen
   Else
     MsgBox ("Connecting not possible while error on socket!")
   End If
End If

End Sub

Private Sub Form_Unload(Cancel As Integer)

End

End Sub

Private Sub TcpClient_ConnectionRequest(ByVal requestID As Long)

'**Accept connection**
*************************
TcpClient.Close
TcpClient.Accept requestID

End Sub
```

```
Private Sub TcpClient_SendComplete()

'**Clear sended message**
*******************************
txtSendData.Text = ""

End Sub

Private Sub Timer1_Timer()

'**Do connection test and show message in taskbar**
*************************************************************
connectiontest

End Sub

Private Sub tcpClient_DataArrival(ByVal bytesTotal As Long)

'Declare Variables
Dim n As Integer


'**Check for arriving data**
*******************************
TcpClient.GetData Strdata


txtOutput.Text = Strdata


'**Only empty data when variable has been read**
*********************************************************
Strdata = Empty

End Sub

Private Sub connectiontest()

'**Do a connection test and fire message**
************************************************
Select Case TcpClient.State

   Case sckClosed
      txtconnectstat.Text = "Socket closed"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed
   Case sckListening
      txtconnectstat.Text = "Listening"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbYellow
   Case sckConnectionPending
      txtconnectstat.Text = "Connection pending"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed
   Case sckResolvingHost
      txtconnectstat.Text = "Resolving host"
      ConStateServer.Visible = True
```

```
        ConStateServer.FillColor = vbRed
    Case sckHostResolved
        txtconnectstat.Text = "Host resolved"
        ConStateServer.Visible = True
        ConStateServer.FillColor = vbRed
    Case sckConnecting
        txtconnectstat.Text = "Connecting host"
        ConStateServer.Visible = True
        ConStateServer.FillColor = vbRed
    Case sckConnected
        txtconnectstat.Text = "Connected to host"
        cmdConnect.Enabled = False
        ConStateServer.Visible = True
        ConStateServer.FillColor = vbGreen
    Case sckClosing
        txtconnectstat.Text = "Closing socket"
        ConStateServer.Visible = True
        ConStateServer.FillColor = vbRed
        TcpClient.Close
        TcpClient.Listen
    Case sckError
        txtconnectstat.Text = "Error on socket"
        ConStateServer.Visible = True
        ConStateServer.FillColor = vbRed

End Select

'**Check connection with the robot**
****************************************
If Connected = False Then
    CmdConRob.Enabled = True
    CmdDisconRob.Enabled = False
    ConStateRobot.Visible = True
    ConStateRobot.FillColor = vbRed
Else
    If Connected = True Then
        CmdConRob.Enabled = False
        CmdDisconRob.Enabled = True
        ConStateRobot.Visible = True
        ConStateRobot.FillColor = vbGreen
    End If
End If

End Sub

Public Sub ConnectRob()

'**Connect the robot**
**************************
Set CrossCommands = CreateObject("CrossCommEXE.CrossCommand")

CrossCommands.Init Me

        CrossCommands.ConnectToCross vValue
        Connected = True
        StrBofVer = GetBOFVer

End Sub
```

A2.3 – Code for Ethernet communication in the main PC

```
Dim strData As String

Private Sub cmdClear_Click()

txtReceive.Text = ""

End Sub

Private Sub cmdConnect_Click()

'**connect/disconnect with server**
****************************************
If Winsock1.State = 0 Then
   Winsock1.Connect
Else
   Winsock1.Close
End If

End Sub

Private Sub cmdSend_Click()

‘**send data to the server**
*******************************
Winsock1.SendData txtSend.Text

End Sub

Private Sub Form_Load()

‘**Setup form**
******************
Winsock1.Close
Winsock1.RemoteHost = "136.129.165.4"
Winsock1.RemotePort = "10101"
Winsock1.Connect

End Sub

Private Sub Timer1_Timer()

'**connection state**
************************
Select Case Winsock1.State
   Case 0: lblState.Caption = "Closed"
   Case 1: lblState.Caption = "Open"
   Case 2: lblState.Caption = "Listening"
   Case 3: lblState.Caption = "Connection pending"
   Case 4: lblState.Caption = "Resolving host"
   Case 5: lblState.Caption = "Host resolved"
   Case 6: lblState.Caption = "Connecting"
   Case 7: lblState.Caption = "Connected"
   Case 8: lblState.Caption = "Peer closing"
   Case Else: lblState.Caption = "Error"
End Select
```

```
'**set caption of "connect" button**
****************************************
If Winsock1.State = 0 Then
   cmdConnect.Caption = "Connect"
Else
   cmdConnect.Caption = "Disconnect"
End If

'**enable/disable "send" button**
**************************************
If Winsock1.State = 7 Then
   cmdSend.Enabled = True
Else
   cmdSend.Enabled = False
End If

End Sub

Private Sub Winsock1_DataArrival(ByVal bytesTotal As Long)

'**get data and write in the text box**
****************************************
Winsock1.GetData strData
txtReceive.Text = txtReceive.Text + strData

End Sub
```

APPENDIX 3

Visual Basic final programs

A3.1 – Code of the main progam

```
'**opc variables**
‘**************
Public ConnectOPCServer As OPCServer
Public ConnectOPCGroup As OPCGroup
Public ConnectOPCGroups As OPCGroups
Public ConnectOPCItems As OPCItems
Public bit_start As OPCItem
Public bit_stop As OPCItem
Public velocity As OPCItem
Public initial_data As OPCItem
Public suction As OPCItem
Public vacuum As OPCItem

'**halcon variables**
‘*****************
Dim hv_WindowHandle As Variant, hv_CamParam1 As Variant
Dim hv_Pose1 As Variant, hv_PoseNewOrigin1 As Variant
Dim hv_AcqHandle As Variant, hv_Ball As Variant
Dim hv_Area As Variant, hv_Row As Variant
Dim hv_Column As Variant, hv_Xcenter As Variant
Dim hv_Ycenter As Variant, hv_Xball As Variant
Dim hv_Yball As Variant, hv_DistanceBall As Variant
Dim hv_Box As Variant, hv_Area1 As Variant
Dim hv_Row1 As Variant, hv_Column1 As Variant
Dim hv_Xbox As Variant, hv_Ybox As Variant
Dim ho_Image As HUntypedObjectX, ho_red As HUntypedObjectX
Dim ho_green As HUntypedObjectX, ho_blue As HUntypedObjectX
Dim ho_ImageGray As HUntypedObjectX, ho_Circle As HUntypedObjectX
Dim ho_ImageReduced1 As HUntypedObjectX, ho_Region As HUntypedObjectX
Dim ho_ConnectedRegions As HUntypedObjectX, ho_SelectedRegions As HUntypedObjectX
Dim ho_SelectedRegions1 As HUntypedObjectX, ho_RegionFillUp As HUntypedObjectX
Dim ho_Rectangle2 As HUntypedObjectX, ho_ImageReduced As HUntypedObjectX
Dim ho_Region1 As HUntypedObjectX, ho_ConnectedRegions1 As HUntypedObjectX
Dim ho_SelectedRegions2 As HUntypedObjectX, ho_RegionFillUp1 As HUntypedObjectX
```

```
Dim ho_Ellipse As HUntypedObjectX

'**same for all programs**
‘*********************
Dim Op As New HOperatorSetX
Dim Tuple As New HTupleX
Dim hv_ExpDefaultWinHandle As Variant
Dim Window1 As HWindowX
Dim WindowHandle1 As Variant

'**program variables**
‘*******************
Dim Answer As Integer
Dim n As Integer
Dim strData As String
Dim Step As String
Dim BallX1 As Long
Dim BallY1 As Long
Dim BallX2 As Long
Dim BallY2 As Long
Dim robot_ball_pos As Integer
Dim robot_box_pos As Integer
Dim robot_process_done As Integer
Dim error_robot As Integer
Dim box_position As Integer
Private Declare Sub Sleep Lib "Kernel32" (ByVal dwMilliseconds As Long)


Private Sub cmdConnect_Click()

'**connect/disconnect ethernet connection**
‘************************************
If Winsock1.State = 0 Then
   Winsock1.Connect
Else
   Winsock1.Close
End If

End Sub

Private Sub cmdStart_Click()

bit_start.Write 1
bit_stop.Write 0
initial_data.Write 0

End Sub
```

```
Private Sub cmdStop_Click()

bit_stop.Write 1
bit_start.Write 0

End Sub

Private Sub Exit_Click()

bit_stop.Write 1
bit_start.Write 0
velocity.Write 0
End

End Sub

Private Sub Form_Load()

'**window declaration**
‘********************
Set Window1 = HWindowXCtrl1.HalconWindow
hv_ExpDefaultWinHandle = Window1.HalconID


'**opc connection**
‘******************
Set ConnectOPCServer = New OPCServer
ConnectOPCServer.Connect "OPC.SimaticNet"
Set ConnectOPCGroups = ConnectOPCServer.OPCGroups
Set ConnectOPCGroup = ConnectOPCGroups.Add("connectie")
ConnectOPCGroup.UpdateRate = 250
Set ConnectOPCItems = ConnectOPCGroup.OPCItems
ConnectOPCItems.DefaultIsActive = True
Set bit_start = ConnectOPCItems.AddItem("S7:[S7 connection_1]MX125.0", 1)
Set bit_stop = ConnectOPCItems.AddItem("S7:[S7 connection_1]MX125.1", 1)
Set velocity = ConnectOPCItems.AddItem("S7:[S7 connection_1]MW30", 1)
Set initial_data = ConnectOPCItems.AddItem("S7:[S7 connection_1]MX125.2", 1)
Set suction = ConnectOPCItems.AddItem("S7:[S7 connection_1]QX125.0", 1)
Set vacuum = ConnectOPCItems.AddItem("S7:[S7 connection_1]IX124.7", 1)

'**open framegrabber**
‘********************
Call Op.ReadCamPar("campar.dat", hv_CamParam1)
Call Op.ReadPose("campose.dat", hv_Pose1)
Call Op.SetOriginPose(hv_Pose1, 0.0326, -0.0776, 0, hv_PoseNewOrigin1)
Call Op.CloseAllFramegrabbers
Call Op.OpenFramegrabber("uEye", 2, 2, 0, 0, 0, 0, "default", 8, "rgb", -1, "false", "UI146xLE-C", "1", 0,
-1, hv_AcqHandle)
Call Op.SetFramegrabberParam(hv_AcqHandle, "frame_rate", 27.542)
Call Op.SetFramegrabberParam(hv_AcqHandle, "contrast", 256)
```

```
Call Op.SetFramegrabberParam(hv_AcqHandle, "exposure", 10.3157)
Call Op.SetFramegrabberParam(hv_AcqHandle, "gain_master", 35)
Call Op.GrabImageStart(hv_AcqHandle, -1)


'**start grabbing images and go to the steps menu**
'****************************************
Timer4.Enabled = True

'**connection with PC from robot**
'****************************
Winsock1.Close
Winsock1.RemoteHost = "136.129.165.4"
Winsock1.RemotePort = "10101"
Winsock1.Connect
lblIP.Caption = Winsock1.LocalIP

Step = "check_box"
box_position = 200

End Sub

Private Sub Form_Unload(Cancel As Integer)

Call Op.CloseAllFramegrabbers
bit_stop.Write 1
bit_start.Write 0
velocity.Write 0
suction.Write 0

End Sub


Private Sub hsbBoxPos_Change()

If (hsbBoxPos.Value >= 300 And hsbBoxPos.Value <= 670) Then
   MsgBox "Value is not valid because of a possible blockade of robot, please select in the permitted
area"
   hsbBoxPos.Value = box_position
Else
   box_position = hsbBoxPos.Value
End If

End Sub

Private Sub Initialvalues_Click()

initial_data.Write 1

End Sub
```

```
Private Sub Startbelt_Click()

bit_start.Write 1
bit_stop.Write 0

End Sub

Private Sub Stopbelt_Click()

bit_stop.Write 1
bit_start.Write 0

End Sub

Private Sub Timer1_Timer()

'**reading opc items from plc**
‘************************
bit_start.Read (1)
Label1.Caption = bit_start

bit_stop.Read (1)
Label2.Caption = bit_stop

velocity.Read (1)
Label3.Caption = Format(Round(1600 / 60 * velocity / 4096, 3), "0.000")

vacuum.Read (1)
lblVacuum.Caption = vacuum

End Sub

Private Sub Timer3_Timer()

'**display connect state**
‘*********************
Select Case Winsock1.State
   Case 0: lblState.Caption = "Closed"
   Case 1: lblState.Caption = "Open"
   Case 2: lblState.Caption = "Listening"
   Case 3: lblState.Caption = "Connection pending"
   Case 4: lblState.Caption = "Resolving host"
   Case 5: lblState.Caption = "Host resolved"
   Case 6: lblState.Caption = "Connecting"
   Case 7: lblState.Caption = "Connected"
   Case 8: lblState.Caption = "Peer closing"
   Case Else: lblState.Caption = "Error"
End Select
```

```
'**set caption of "connect" button**
'*****************************
If Winsock1.State = 0 Then
   cmdConnect.Caption = "Connect"
Else
   cmdConnect.Caption = "Disconnect"
End If

End Sub


Public Function findbox() As Boolean

cmdConnect.Enabled = True
hsbBoxPos.Enabled = True

'**follow central point of the box**
'*****************************
Call Op.Decompose3(ho_Image, ho_red, ho_green, ho_blue)
Call Op.Rgb3ToGray(ho_red, ho_green, ho_blue, ho_ImageGray)
Call Op.SetColor(hv_ExpDefaultWinHandle, "yellow")
Call Op.DispCross(hv_ExpDefaultWinHandle, 350, 540, 6, 0)
Call Op.GenRectangle2(ho_Rectangle2, 100, 480, -0.05, 500, 70)
Call Op.ReduceDomain(ho_red, ho_Rectangle2, ho_ImageReduced)
Call Op.Threshold(ho_ImageReduced, ho_Region1, 45, 255)
Call Op.Connection(ho_Region1, ho_ConnectedRegions1)
Call Op.SelectShape(ho_ConnectedRegions1, ho_SelectedRegions2, "area", "and", 9000, 12000)
Call Op.FillUp(ho_SelectedRegions2, ho_RegionFillUp1)
Call Op.CountObj(ho_RegionFillUp1, hv_Box)

'**detect if the box is in the transport belt and stop this in a specific region**
'*************************************************************
If Tuple.TupleEqual(hv_Box, 1) Then
   txtBoxOut.Text = ""
   Call Op.AreaCenter(ho_RegionFillUp1, hv_Area1, hv_Row1, hv_Column1)
   Call Op.DispCross(hv_ExpDefaultWinHandle, 350, 540, 6, 0)
   Call Op.DispCross(hv_ExpDefaultWinHandle, hv_Row1, hv_Column1, 6, 0)

   If hv_Column1 >= 300 Then
      hsbBoxPos.Enabled = False   'prevent robot blockade
   End If

   If Tuple.TupleGreaterEqual(hv_Column1, box_position) Then
      bit_stop.Write 1
      bit_start.Write 0
      txtAgain.Text = ""
      'disable some options
      cmdStart.Enabled = False
      cmdStop.Enabled = False
      Stopbelt.Enabled = False
```

```
      Startbelt.Enabled = False
      txtBoxInPos.Text = "Box in correct position"
      Sleep (50)
      findbox = True

   Else
      txtBoxInPos.Text = ""
   End If

Else
   txtBoxOut.Text = "Box out of transport belt"
End If

End Function

Public Function findbox1() As Boolean

'**take the coordinates after belt stopped**
‘**********************************
Call Op.Decompose3(ho_Image, ho_red, ho_green, ho_blue)
Call Op.Rgb3ToGray(ho_red, ho_green, ho_blue, ho_ImageGray)
Call Op.DispCross(hv_ExpDefaultWinHandle, 350, 540, 6, 0)
Call Op.ReduceDomain(ho_red, ho_Rectangle2, ho_ImageReduced)
Call Op.Threshold(ho_ImageReduced, ho_Region1, 40, 255)
Call Op.Connection(ho_Region1, ho_ConnectedRegions1)
Call Op.SelectShape(ho_ConnectedRegions1, ho_SelectedRegions2, "area", "and", 8000, 12000)
Call Op.FillUp(ho_SelectedRegions2, ho_RegionFillUp1)
Call Op.CountObj(ho_RegionFillUp1, hv_Box)
Call Op.ImagePointsToWorldPlane(hv_CamParam1, hv_PoseNewOrigin1, 350, 540, "microns",
hv_Xcenter, hv_Ycenter)
Call Op.ImagePointsToWorldPlane(hv_CamParam1, hv_PoseNewOrigin1, hv_Row1, hv_Column1,
"microns", hv_Xbox, hv_Ybox)
Call Op.DispCross(hv_ExpDefaultWinHandle, hv_Row1, hv_Column1, 6, 0)

findbox1 = True

End Function

Public Function findball1() As Boolean

'**reset data from the robot**
‘************************
robot_ball_pos = 0
robot_box_pos = 0
robot_process_done = 0
error_robot = 0

cmdConnect.Enabled = True
cmdStart.Enabled = False
cmdStop.Enabled = False
```

```
Stopbelt.Enabled = False
Startbelt.Enabled = False
hsbBoxPos.Enabled = False

'**look for the ball and detect if is inside or outside of the robot range**
‘*********************************************************
Call Op.DispObj(ho_Image _
   , hv_ExpDefaultWinHandle)
Call Op.Decompose3(ho_Image, ho_red, ho_green, ho_blue)
Call Op.Rgb3ToGray(ho_red, ho_green, ho_blue, ho_ImageGray)
Call Op.DispCross(hv_ExpDefaultWinHandle, 350, 540, 6, 0)
Call Op.GenEllipse(ho_Ellipse, 0, 510, -0.07, 480, 410)
Call Op.ReduceDomain(ho_ImageGray, ho_Ellipse, ho_ImageReduced1)
Call Op.Threshold(ho_ImageReduced1, ho_Region, 0, 18)
Call Op.Connection(ho_Region, ho_ConnectedRegions)
Call Op.SelectShape(ho_ConnectedRegions, ho_SelectedRegions, "area", "and", 1200, 5000)
Call Op.SelectShape(ho_SelectedRegions, ho_SelectedRegions1, "roundness", "and", 0.5, 1)
Call Op.FillUp(ho_SelectedRegions1, ho_RegionFillUp)
Call Op.CountObj(ho_RegionFillUp, hv_Ball)

'**take the first coordinates of the ball**
‘*******************************
   If Tuple.TupleEqual(hv_Ball, 1) Then
      txtBallOut.Text = ""
      Call Op.AreaCenter(ho_RegionFillUp, hv_Area, hv_Row, hv_Column)
      Call Op.ImagePointsToWorldPlane(hv_CamParam1, hv_PoseNewOrigin1, 350, 540, "mm",
          hv_Xcenter, hv_Ycenter)
      Call Op.ImagePointsToWorldPlane(hv_CamParam1, hv_PoseNewOrigin1, hv_Row, hv_Column,
          "mm", hv_Xball, hv_Yball)
      Call Op.DispCross(hv_ExpDefaultWinHandle, hv_Row, hv_Column, 6, 0)
      BallX1 = Format(Round(hv_Xball, "000"))
      BallY1 = Format(Round(hv_Yball, "000"))
      Sleep (250)
      findball1 = True
   Else
      Call Op.SetDraw(hv_ExpDefaultWinHandle, "margin")
      Call Op.DispObj(ho_Ellipse _
         , hv_ExpDefaultWinHandle)
      Call Op.SetColor(hv_ExpDefaultWinHandle, "yellow")
      txtBallOut.Text = "Ball out of the robot reach"
      MsgBox ("Put the ball within the range of the robot to follow")
   End If

End Function
```

```
Public Function findball2() As Boolean

'**take the second coordinates of the ball**
'*********************************
Call Op.DispObj(ho_Image _
   , hv_ExpDefaultWinHandle)
Call Op.Decompose3(ho_Image, ho_red, ho_green, ho_blue)
Call Op.Rgb3ToGray(ho_red, ho_green, ho_blue, ho_ImageGray)
Call Op.DispCross(hv_ExpDefaultWinHandle, 350, 540, 6, 0)
Call Op.ReduceDomain(ho_ImageGray, ho_Ellipse, ho_ImageReduced1)
Call Op.Threshold(ho_ImageReduced1, ho_Region, 0, 18)
Call Op.Connection(ho_Region, ho_ConnectedRegions)
Call Op.SelectShape(ho_ConnectedRegions, ho_SelectedRegions, "area", "and", 1200, 5000)
Call Op.SelectShape(ho_SelectedRegions, ho_SelectedRegions1, "roundness", "and", 0.5, 1)
Call Op.FillUp(ho_SelectedRegions1, ho_RegionFillUp)
Call Op.CountObj(ho_RegionFillUp, hv_Ball)

   If Tuple.TupleEqual(hv_Ball, 1) Then
      txtBallOut.Text = ""
      Call Op.AreaCenter(ho_RegionFillUp, hv_Area, hv_Row, hv_Column)
      Call Op.ImagePointsToWorldPlane(hv_CamParam1, hv_PoseNewOrigin1, 350, 540, "mm",
          hv_Xcenter, hv_Ycenter)
      Call Op.ImagePointsToWorldPlane(hv_CamParam1, hv_PoseNewOrigin1, hv_Row, hv_Column,
          "mm", hv_Xball, hv_Yball)
      Call Op.DispCross(hv_ExpDefaultWinHandle, hv_Row, hv_Column, 6, 0)
      BallX2 = Format(Round(hv_Xball, "000"))
      BallY2 = Format(Round(hv_Yball, "000"))
   Else
      Call Op.SetDraw(hv_ExpDefaultWinHandle, "margin")
      Call Op.DispObj(ho_Ellipse _
         , hv_ExpDefaultWinHandle)
      Call Op.SetColor(hv_ExpDefaultWinHandle, "yellow")
      txtBallOut.Text = "Ball out of the robot reach"
      MsgBox ("Put the ball within the range of the robot to follow")
   End If

'**Check if the coordinates in two different moments are the same**
'*****************************************************
   If BallY1 = BallY2 Then
      If BallX1 = BallX2 Then
         findball2 = True
      Else
         Step = "ball_moving"
      End If
   Else
      Step = "ball_moving"
   End If
```

```
'**take the real coordinates in "microns" for sending to the robot**
‘*****************************************************
Call Op.AreaCenter(ho_RegionFillUp, hv_Area, hv_Row, hv_Column)
Call Op.ImagePointsToWorldPlane(hv_CamParam1, hv_PoseNewOrigin1, 350, 540, "microns",
hv_Xcenter, hv_Ycenter)
Call Op.ImagePointsToWorldPlane(hv_CamParam1, hv_PoseNewOrigin1, hv_Row, hv_Column,
"microns", hv_Xball, hv_Yball)
Call Op.DispCross(hv_ExpDefaultWinHandle, hv_Row, hv_Column, 6, 0)

End Function

Public Function moving() As Boolean

'**function called when the ball is moving for taking the coordinates again**
‘************************************************************
moving = True

End Function

Public Function XballSent() As Boolean

'**sending X coordinate of the ball**
*****************************
Dim CoordXball As String
Dim longXball As Long

longXball = CLng(hv_Xball)
CoordXball = "X_BALL" + " " + CStr(longXball)

'**checking ethernet connection**
‘***************************
If Winsock1.State = 7 Then
   If txtDone.Text = "" Then
     Winsock1.SendData CoordXball
     txtXball.Text = Format(hv_Xball / 1000, "000.000")
     XballSent = True
   End If
Else
   Answer = MsgBox("Server not connected, do you want to connect it?", 36, "Question")
      If Answer = vbYes Then
         MsgBox "Please restart the robot server, and then click ok"
         Winsock1.Close
         Winsock1.Connect
         Step = "check_box"
       Else
         MsgBox "Please restart the robot server, and click 'yes' to follow"
         Step = "check_box"
      End If
End If
End Function
```

```
Public Function YballSent() As Boolean

'**sending Y coordinate of the ball**
'*****************************
Dim CoordYball As String
Dim longYball As Long

cmdConnect.Enabled = False

longYball = CLng(hv_Yball)
CoordYball = "Y_BALL" + " " + CStr(longYball)

'checking ethernet connection
If Winsock1.State = 7 Then
   If strData = "Xball" Then
      Winsock1.SendData CoordYball
      txtYball.Text = Format(hv_Yball / 1000, "000.000")
      YballSent = True
   End If
Else
'Nothing
End If

End Function
Public Function XboxSent() As Boolean

'**sending X coordinate of the box**
'*****************************
Dim CoordXbox As String
Dim longXbox As Long

longXbox = CLng(hv_Xbox)
CoordXbox = "X_BOX" + " " + CStr(longXbox)

'checking ethernet connection
If Winsock1.State = 7 Then
   If strData = "Yball" Then
      Winsock1.SendData CoordXbox
      txtXbox.Text = Format(hv_Xbox / 1000, "000.000")
      XboxSent = True
   End If
Else
'Nothing
End If
End Function
```

```
Public Function YboxSent() As Boolean

'**sending Y coordinate of the box**
‘*****************************
Dim CoordYbox As String
Dim longYbox As Long

longYbox = CLng(hv_Ybox)
CoordYbox = "Y_BOX" + " " + CStr(longYbox)

'**checking ethernet connection**
‘*************************
If Winsock1.State = 7 Then
   If strData = "Xbox" Then
      Winsock1.SendData CoordYbox
      txtYbox.Text = Format(hv_Ybox / 1000, "000.000")
      txtDone.Text = "Ybox"
      YboxSent = True
   End If
Else
'Nothing
End If

End Function

Public Function ball_pos() As Boolean

'**ROBOT_COORD allows starting the robot when is in 1**
‘*********************************************
Dim robot_coord As String
Call Op.GrabImageAsync(ho_Image, hv_AcqHandle, -1)

robot_coord = "ROBOT_COORD" + " " + "1"
Winsock1.SendData robot_coord
ball_pos = True

End Function

Public Function ball_aspirated() As Boolean

'**start aspirating when robot is in position**
‘***********************************
Dim vacuum_on As String

vacuum.Read (1)
lblVacuum.Caption = vacuum

If robot_ball_pos = 1 Then
   suction.Write 1  'OPC item
End If
```

```
'**if vacuum sensor is "on", the process follows**
'*************************************
If lblVacuum.Caption = "True" Then
   vacuum_on = "VACUUM" + " " + "1"
   Winsock1.SendData vacuum_on
   ball_aspirated = True
Else
   If error_robot = 1 Then
      suction.Write 0
      Step = "check_ball1"
   End If
End If

End Function

Public Function ball_in_box() As Boolean

'**to leave the ball in the box**
'*************************
If robot_box_pos = 1 Then
   suction.Write 0
   vacuum.Read (1)
   lblVacuum.Caption = vacuum
   ball_in_box = True
End If

End Function

Public Function check_ball_in_box() As Boolean

'**check if the ball is inside the box and then start the belt**
'***********************************************
If robot_process_done = 1 Then
   bit_stop.Write 0
   cmdStart.Enabled = True
   cmdStop.Enabled = True
   Startbelt.Enabled = True
   Stopbelt.Enabled = True
   Call Op.DispObj(ho_Image _
      , hv_ExpDefaultWinHandle)
   Call Op.Decompose3(ho_Image, ho_red, ho_green, ho_blue)
   Call Op.Rgb3ToGray(ho_red, ho_green, ho_blue, ho_ImageGray)
   Call Op.ReduceDomain(ho_red, ho_Rectangle2, ho_ImageReduced)
   Call Op.Threshold(ho_ImageReduced, ho_Region1, 45, 255)
   Call Op.Connection(ho_Region1, ho_ConnectedRegions1)
   Call Op.SelectShape(ho_ConnectedRegions1, ho_SelectedRegions2, "area", "and", 4000, 9000)
   Call Op.FillUp(ho_SelectedRegions2, ho_RegionFillUp1)
   Call Op.CountObj(ho_RegionFillUp1, hv_Box)
```

```
   If Tuple.TupleEqual(hv_Box, 1) Then
      txtBoxInPos.Text = ""
      txtBallInBox.Text = "Ball inside the box"
      bit_start.Write 1
      hv_Column1 = 0
      check_ball_in_box = True
   Else
      'if ball is not in box, take the coordinates again
      txtBoxInPos.Text = ""
      txtBallInBox.Text = "Ball out of the box"
      txtXball.Text = ""
      txtYball.Text = ""
      txtXbox.Text = ""
      txtYbox.Text = ""
      txtDone.Text = ""
      Step = "check_ball1"
   End If

End If

End Function

Public Function process_again() As Boolean
txtDone.Text = ""
hsbBoxPos.Enabled = True

'**when another box is detected in the first part of the belt, process start again**
*****************************************************************
If Tuple.TupleGreaterEqual(hv_Column1, 55) Then
   txtBallInBox.Text = ""
   txtAgain.Text = "New process"
   process_again = True
Else
   Call Op.DispObj(ho_Image _
   , hv_ExpDefaultWinHandle)
   Call Op.Decompose3(ho_Image, ho_red, ho_green, ho_blue)
   Call Op.Rgb3ToGray(ho_red, ho_green, ho_blue, ho_ImageGray)
   Call Op.SetColor(hv_ExpDefaultWinHandle, "yellow")
   Call Op.DispCross(hv_ExpDefaultWinHandle, 350, 540, 6, 0)
   Call Op.GenRectangle2(ho_Rectangle2, 100, 0, -0.05, 200, 70)
   Call Op.ReduceDomain(ho_red, ho_Rectangle2, ho_ImageReduced)
   Call Op.Threshold(ho_ImageReduced, ho_Region1, 40, 255)
   Call Op.Connection(ho_Region1, ho_ConnectedRegions1)
   Call Op.SelectShape(ho_ConnectedRegions1, ho_SelectedRegions2, "area", "and", 9000, 12000)
   Call Op.FillUp(ho_SelectedRegions2, ho_RegionFillUp1)
   Call Op.CountObj(ho_RegionFillUp1, hv_Box)
   Call Op.AreaCenter(ho_RegionFillUp1, hv_Area1, hv_Row1, hv_Column1)
End If

End Function
```

```
Private Sub Timer4_Timer()

'**main program wich calls each step in the process**
'****************************************
Call Op.GrabImageAsync(ho_Image, hv_AcqHandle, -1)
Call Op.DispObj(ho_Image _
   , hv_ExpDefaultWinHandle)

Timer4.Enabled = False

Select Case Step

Case "check_box"
   If findbox = True Then Step = "check_box1"

Case "check_box1"
   If findbox1 = True Then Step = "check_ball1"

Case "check_ball1"
   If findball1 = True Then Step = "check_ball2"

Case "check_ball2"
   If findball2 = True Then Step = "coord_Xball"

Case "ball_moving"
   If moving = True Then Step = "check_ball1"

Case "coord_Xball"
   If XballSent = True Then Step = "coord_Yball"

Case "coord_Yball"
   If YballSent = True Then Step = "coord_Xbox"

Case "coord_Xbox"
   If XboxSent = True Then Step = "coord_Ybox"

Case "coord_Ybox"
   If YboxSent = True Then Step = "reach_ball"

Case "reach_ball"
   If ball_pos = True Then Step = "aspirate"

Case "aspirate"
   If ball_aspirated = True Then Step = "reach_box"

Case "reach_box"
   If ball_in_box = True Then Step = "ball_inside_box"

Case "ball_inside_box"
   If check_ball_in_box = True Then Step = "process_ended"
```

```
Case "process_ended"
   If process_again = True Then Step = "check_box"

End Select

Timer4.Enabled = True

End Sub

Private Sub vsbVelocity_Change()

'**change the velocity of the trasnport belt**
'************************************
velocity.Write vsbVelocity.Value

End Sub


Private Sub Winsock1_DataArrival(ByVal bytesTotal As Long)

Dim Strdata2() As String
Dim n As Integer

'**get data from the robot**
'**********************
Winsock1.GetData strData


Strdata2() = Split(strData, " ")

n = UBound(Strdata2)

If n = 0 Then
txtDone.Text = strData
End If

'**data during the robot movement**
'*****************************
If n = 1 Then
   Select Case Strdata2(0)
      Case "ROBOT_BALL_POS"
         robot_ball_pos = Strdata2(1)
      Case "ROBOT_BOX_POS"
         robot_box_pos = Strdata2(1)
      Case "PROCESS_DONE"
         robot_process_done = Strdata2(1)
      Case "ERROR_CODE"
         error_robot = Strdata2(1)
         txtBoxInPos.Text = ""
```

```
        txtXball.Text = ""
        txtYball.Text = ""
        txtXbox.Text = ""
        txtYbox.Text = ""
        txtDone.Text = ""
      Case Else
        MsgBox ("Error sending data")
  End Select
End If

End Sub
```

A3.2 – Code of server program in the robot

```
Option Explicit
Dim boolBall As Boolean
Dim boolError As Boolean
Dim boolBox As Boolean
Dim boolDone As Boolean

Private Sub CmdConRob_Click()

ConnectRob

End Sub

Private Sub Form_Load()

'**Setup Form**
‘**************
TxtGate.Enabled = False
TxtPoort.Enabled = False
txtconnectstat.Enabled = False
TxtPoort.Text = "10101"
TxtGate.Text = TcpClient.LocalIP

ConStateRobot.Visible = False
ConStateServer.Visible = False


'**Read out robot name and set as form title**
‘************************************
QueryValue HKEY_LOCAL_MACHINE,
"System\CurrentControlSet\Control\ComputerName\ComputerName", "ComputerName"
frmClient.Caption = "Client Settings for robot" & " " & vValue

End Sub
```

```
Private Sub cmdConnect_Click()

'Declare Variables
Dim Answer As String

TxtGate.Enabled = False
TxtPoort.Enabled = False

Answer = MsgBox("Are these settings correct ?", vbQuestion + vbYesNo, "Connect")

If Answer = vbYes Then

   'Copy Port number data
   If TcpClient.State = sckClosed Then
      TcpClient.LocalPort = TxtPoort.Text
   Else
      MsgBox ("The connection state is not 'closed'")
   End If

   'Copy server data
   If TcpClient.State <> sckError Then
      If TcpClient.State = sckConnected Then
        MsgBox ("Not possible while connected to server")
      Else
         'Nothing
      End If
   Else
      MsgBox ("Not possible while error on port")
   End If

   'Invoke the Connect method to initiate a connection.
   If TcpClient.State <> sckError Then
     TcpClient.Listen
   Else
     MsgBox ("Connecting not possible while error on socket!")
   End If

Else
   'Nothing
End If

End Sub

Private Sub Form_Unload(Cancel As Integer)

'**End program**
‘**************
End

End Sub
```

```
Private Sub TcpClient_ConnectionRequest(ByVal requestID As Long)

'**Accept connection**
‘********************
TcpClient.Close
TcpClient.Accept requestID

End Sub

Private Sub Timer1_Timer()

'**Do connection test and show message in taskbar**
‘****************************************
connectiontest

End Sub

Private Sub tcpClient_DataArrival(ByVal bytesTotal As Long)

'**Declare Variables**
‘******************
Dim bool1 As Boolean
Dim bool2 As Boolean
Dim bool3 As Boolean
Dim bool4 As Boolean
Dim bool5 As Boolean
Dim bool6 As Boolean
Dim bool_reset1 As Boolean
Dim bool_reset2 As Boolean
Dim bool_reset3 As Boolean
Dim bool_reset4 As Boolean


Dim Strdata2() As String
Dim n As Integer
Dim xball As Integer

'Check for arriving data
TcpClient.GetData Strdata
Strdata2() = Split(Strdata, " ")

n = UBound(Strdata2)

If n = 0 Then
MsgBox ("Incorrect data")
End If
```

```
If n = 1 Then

   Select Case Strdata2(0)
      Case "X_BALL"
         bool1 = CrossCommands.SetVar("X_BALL", Strdata2(1))
         bool_reset1 = CrossCommands.SetVar("ROBOT_COORD", "0")
         TcpClient.SendData "Xball"
         boolBall = False
         boolError = False
         boolBox = False
         boolDone = False
         lblDone.Caption = ""
         lblVacuum.Caption = ""
         lblCoord.Caption = ""
         lblBallPos.Caption = ""
         lblBoxPos.Caption = ""
      Case "Y_BALL"
         bool2 = CrossCommands.SetVar("Y_BALL", Strdata2(1))
         bool_reset2 = CrossCommands.SetVar("ROBOT_BALL_POS", "0")
         TcpClient.SendData "Yball"
      Case "X_BOX"
         bool3 = CrossCommands.SetVar("X_BOX", Strdata2(1))
         bool_reset3 = CrossCommands.SetVar("ERROR_CODE", "0")
         TcpClient.SendData "Xbox"
      Case "Y_BOX"
         bool4 = CrossCommands.SetVar("Y_BOX", Strdata2(1))
         bool_reset4 = CrossCommands.SetVar("ROBOT_BOX_POS", "0")
         TcpClient.SendData "Done"
         boolBall = True
      Case "ROBOT_COORD"
         bool5 = CrossCommands.SetVar("ROBOT_COORD", Strdata2(1))
         lblCoord.Caption = Strdata2(0) + " " + Strdata2(1)
      Case "VACUUM"
         bool6 = CrossCommands.SetVar("VACUUM", Strdata2(1))
         lblVacuum.Caption = Strdata2(0) + " " + Strdata2(1)
      Case Else
         MsgBox ("Error")
   End Select

End If

'**Only empty data when variable has been read**
'***************************************
Strdata = Empty


'**coordinates in the robot**
'**********************
Dim str_Xball As String
Dim str_Yball As String
```

```
Dim str_Xbox As String
Dim str_Ybox As String

Label1.Caption = CrossCommands.ShowVar("X_BALL", str_Xball)
Label1.Caption = str_Xball

Label2.Caption = CrossCommands.ShowVar("Y_BALL", str_Yball)
Label2.Caption = str_Yball

Label3.Caption = CrossCommands.ShowVar("X_BOX", str_Xbox)
Label3.Caption = str_Xbox

Label4.Caption = CrossCommands.ShowVar("Y_BOX", str_Ybox)
Label4.Caption = str_Ybox


End Sub

Private Sub connectiontest()

'**Do a connection test and fire message**
‘*********************************
Select Case TcpClient.State

   Case sckClosed
      txtconnectstat.Text = "Socket closed"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed
   Case sckListening
      txtconnectstat.Text = "Listening"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbYellow
      cmdConnect.Enabled = False
      lblCoord.Caption = ""
      lblBallPos.Caption = ""
      lblBoxPos.Caption = ""
      lblVacuum.Caption = ""
      lblDone.Caption = ""
   Case sckConnectionPending
      txtconnectstat.Text = "Connection pending"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed
   Case sckResolvingHost
      txtconnectstat.Text = "Resolving host"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed
   Case sckHostResolved
      txtconnectstat.Text = "Host resolved"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed
```

```
   Case sckConnecting
      txtconnectstat.Text = "Connecting host"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed
   Case sckConnected
      txtconnectstat.Text = "Connected to host"
      cmdConnect.Enabled = False
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbGreen
   Case sckClosing
      txtconnectstat.Text = "Closing socket"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed
      TcpClient.Close
      TcpClient.Listen
   Case sckError
      txtconnectstat.Text = "Error on socket"
      ConStateServer.Visible = True
      ConStateServer.FillColor = vbRed

End Select

'**Check connection with the robot**
'*****************************
If Connected = False Then
   CmdConRob.Enabled = True
   'CmdDisconRob.Enabled = False
   ConStateRobot.Visible = True
   ConStateRobot.FillColor = vbRed
Else
   If Connected = True Then
      CmdConRob.Enabled = False
      'CmdDisconRob.Enabled = True
      ConStateRobot.Visible = True
      ConStateRobot.FillColor = vbGreen
   End If
End If

End Sub

Public Sub ConnectRob()

'**Create object for the robot**
'************************
Set CrossCommands = CreateObject("CrossCommEXE.CrossCommand")
CrossCommands.Init Me
      CrossCommands.ConnectToCross vValue
      Connected = True
      StrBofVer = GetBOFVer
End Sub
```

```
Private Sub Timer2_Timer()

‘**making the steps while the robot is running**
‘************************************
If boolBall = True Then

Dim str_RobotBallPos As String
Dim dataRobot1() As String
Dim sendBallPos As String

lblBallPos.Caption = CrossCommands.ShowVar("ROBOT_BALL_POS", str_RobotBallPos)
dataRobot1() = Split(str_RobotBallPos, " ")
lblBallPos.Caption = dataRobot1(0) + " " + dataRobot1(2)
sendBallPos = "ROBOT_BALL_POS" + " " + "1"

If dataRobot1(2) = 1 Then
   TcpClient.SendData sendBallPos
   boolError = True
   boolBall = False
End If

End If


If boolError = True Then

Dim str_Error As String
Dim dataRobot2() As String
Dim sendError As String

lblDone.Caption = CrossCommands.ShowVar("ERROR_CODE", str_Error)
dataRobot2() = Split(str_Error, " ")
lblDone.Caption = dataRobot2(0) + " " + dataRobot2(2)
sendError = "ERROR_CODE" + " " + "1"
If dataRobot2(2) = 1 Then
   TcpClient.SendData sendError
   lblCoord.Caption = ""
   lblBallPos.Caption = ""
   lblBoxPos.Caption = ""
   lblVacuum.Caption = ""
   boolError = False
End If

If lblVacuum.Caption = "VACUUM 1" Then
   boolBox = True
   boolError = False
End If

End If
```

```
If boolBox = True Then

Dim str_RobotBoxPos As String
Dim dataRobot3() As String
Dim sendBoxPos As String

lblBoxPos.Caption = CrossCommands.ShowVar("ROBOT_BOX_POS", str_RobotBoxPos)
dataRobot3() = Split(str_RobotBoxPos, " ")
lblBoxPos.Caption = dataRobot3(0) + " " + dataRobot3(2)
sendBoxPos = "ROBOT_BOX_POS" + " " + "1"

If dataRobot3(2) = 1 Then
   TcpClient.SendData sendBoxPos
   boolDone = True
   boolBox = False
End If

End If


If boolDone = True Then

Dim str_RobotDone As String
Dim dataRobot4() As String
Dim sendDone As String

lblDone.Caption = CrossCommands.ShowVar("PROCESS_DONE", str_RobotDone)
dataRobot4() = Split(str_RobotDone, " ")
lblDone.Caption = dataRobot4(0) + " " + dataRobot4(2)
sendDone = "PROCESS_DONE" + " " + "1"

If dataRobot4(2) = 1 Then
   TcpClient.SendData sendDone
   boolDone = False
End If

End If

End Sub
```

A3.3 – Code of Module added in server program

```
'Declare variables to connect with the robot
Public CrossCommands As Object
Public KRC1 As Boolean
Public KRC2 As Boolean
Public Connected As Boolean
Public Strresult As String
Public strtest As String
Public Strdata As String
Public StrBofVer As String
Public LogInfo As String
Public Fs

'Declare variables to read out robot name
Public Const REG_SZ As Long = 1
Public Const REG_DWORD As Long = 4

Public Const HKEY_CLASSES_ROOT = &H80000000
Public Const HKEY_CURRENT_USER = &H80000001
Public Const HKEY_LOCAL_MACHINE = &H80000002
Public Const HKEY_USERS = &H80000003

Public Const ERROR_NONE = 0
Public Const ERROR_BADDB = 1
Public Const ERROR_BADKEY = 2
Public Const ERROR_CANTOPEN = 3
Public Const ERROR_CANTREAD = 4
Public Const ERROR_CANTWRITE = 5
Public Const ERROR_OUTOFMEMORY = 6
Public Const ERROR_ARENA_TRASHED = 7
Public Const ERROR_ACCESS_DENIED = 8
Public Const ERROR_INVALID_PARAMETERS = 87
Public Const ERROR_NO_MORE_ITEMS = 259

Public Const KEY_QUERY_VALUE = &H1
Public Const KEY_SET_VALUE = &H2
Public Const KEY_ALL_ACCESS = &H3F

Public Const REG_OPTION_NON_VOLATILE = 0
Public vValue As Variant

Declare Function RegCloseKey Lib "advapi32.dll" (ByVal hKey As Long) As Long
Declare Function RegCreateKeyEx Lib "advapi32.dll" Alias "RegCreateKeyExA" (ByVal hKey As Long,
ByVal lpSubKey As String, ByVal Reserved As Long, ByVal lpClass As String, ByVal dwOptions As
Long, ByVal samDesired As Long, ByVal lpSecurityAttributes As Long, phkResult As Long,
lpdwDisposition As Long) As Long
Declare Function RegOpenKeyEx Lib "advapi32.dll" Alias "RegOpenKeyExA" (ByVal hKey As Long,
ByVal lpSubKey As String, ByVal ulOptions As Long, ByVal samDesired As Long, phkResult As Long)
As Long
Declare Function RegQueryValueExString Lib "advapi32.dll" Alias "RegQueryValueExA" (ByVal hKey
As Long, ByVal lpValueName As String, ByVal lpReserved As Long, lpType As Long, ByVal lpData As
String, lpcbData As Long) As Long
Declare Function RegQueryValueExLong Lib "advapi32.dll" Alias "RegQueryValueExA" (ByVal hKey
As Long, ByVal lpValueName As String, ByVal lpReserved As Long, lpType As Long, lpData As Long,
lpcbData As Long) As Long
```

```
Declare Function RegQueryValueExNULL Lib "advapi32.dll" Alias "RegQueryValueExA" (ByVal hKey
As Long, ByVal lpValueName As String, ByVal lpReserved As Long, lpType As Long, ByVal lpData As
Long, lpcbData As Long) As Long
Declare Function RegSetValueExString Lib "advapi32.dll" Alias "RegSetValueExA" (ByVal hKey As
Long, ByVal lpValueName As String, ByVal Reserved As Long, ByVal dwType As Long, ByVal
lpValue As String, ByVal cbData As Long) As Long
Declare Function RegSetValueExLong Lib "advapi32.dll" Alias "RegSetValueExA" (ByVal hKey As
Long, ByVal lpValueName As String, ByVal Reserved As Long, ByVal dwType As Long, lpValue As
Long, ByVal cbData As Long) As Long


'Read out bof version used
Public Function GetBOFVer()

   'Declare Variables
   Dim TempVar As String

   Set Fs = CreateObject("Scripting.FileSystemObject")
   TempVar = Fs.GetFileVersion("c:\KRC\HMI\Kuka_HMI.exe")
   Set Fs = Nothing
   GetBOFVer = TempVar

End Function
'Deconnect from Kuka cross KRC2
Public Sub DisconnectRob()
   Connected = False
   CrossCommands.CrossComm.ServerOff
   Set CrossCommands = Nothing
End Sub

'To read a vaiable in the Kuka KRC2
Public Function getVar(varName)
   getVar = CrossCommands.CrossComm.getVarValue(varName)
End Function

'To make communication with the kuka cross
Public Function ConnectToCross(ByVal sConnectName As String, Optional nC_Mode As Integer) As
Boolean
End Function

'To read a variable in the Kuka KRC1
Public Function ShowVar(ByVal sVariableName As String, ByRef sResult As String, Optional
vTimeOut) As Boolean
End Function

'To set a variable in the Kuka KRC1
Public Function SetVar(ByVal sVariableName As String, ByVal sNewValue As String, Optional
vTimeOut) As Boolean
End Function

'Deconnect from Kuka cross KRC1
Public Sub ServerOff()
End Sub

'Check Connection with Kuka Cross KRC1
Public Property Get CrossIsConnected() As Boolean
End Property
```

```
Public Function SetValueEx(ByVal hKey As Long, sValueName As String, lType As Long, vValue As
Variant) As Long

'Declare Variables
Dim lValue As Long
Dim sValue As String

Select Case lType
   Case REG_SZ
      sValue = vValue & Chr$(0)
      SetValueEx = RegSetValueExString(hKey, sValueName, 0&, lType, sValue, Len(sValue))
   Case REG_DWORD
      lValue = vValue
      SetValueEx = RegSetValueExLong(hKey, sValueName, 0&, lType, lValue, 4)
End Select

End Function
Function QueryValueEx(ByVal lhKey As Long, ByVal szValueName As String, vValue As Variant) As
Long

'Declare Variables
Dim cch As Long
Dim lrc As Long
Dim lType As Long
Dim lValue As Long
Dim sValue As String

On Error GoTo QueryValueExError

' Determine the size and type of data to be read
lrc = RegQueryValueExNULL(lhKey, szValueName, 0&, lType, 0&, cch)
If lrc <> ERROR_NONE Then Error 5

Select Case lType
   ' For strings
   Case REG_SZ:
      sValue = String(cch, 0)
      lrc = RegQueryValueExString(lhKey, szValueName, 0&, lType, sValue, cch)
         If lrc = ERROR_NONE Then
            vValue = Left$(sValue, cch - 1)
         Else
            vValue = Empty
         End If
   ' For DWORDS
   Case REG_DWORD:
      lrc = RegQueryValueExLong(lhKey, szValueName, 0&, lType, lValue, cch)
         If lrc = ERROR_NONE Then vValue = lValue
   Case Else
   'all other data types not supported
      lrc = -1
End Select

QueryValueExExit:
QueryValueEx = lrc
Exit Function

QueryValueExError:
Resume QueryValueExExit
```

```
End Function
Public Sub QueryValue(Where As Long, sKeyName As String, sValueName As String)

'Declare Variables
Dim lRetVal As Long
Dim hKey As Long

lRetVal = RegOpenKeyEx(Where, sKeyName, 0, KEY_QUERY_VALUE, hKey)
lRetVal = QueryValueEx(hKey, sValueName, vValue)
RegCloseKey (hKey)

End Sub
```

APPENDIX 4

Datasheet of the motor

4.5 Expansion Module MAC00-FP2/FP4

MAC00-FP2
With cable glands

MAC00-FP4
With M12 connectors

TT1010GB

4.5.1 Profibus module MAC00-FP2 and FP4 Introduction

The MAC00-FP2 and FP4 are Profibus-DP slaves. They are capable of running at baud rates up to 12Mbit.
All the registers[1] of the MAC motor can be read and written.

The modules include 6 inputs, 2 of which are end-limit inputs. These can be read from the Profibus-DP. The end-limit inputs can automatically halt the motor. The other inputs can be used to activate different movements.

The MAC motor is controlled by writing to the input data (9 bytes).

The expansion modules MAC00-FP2 and FP4 can be mounted on standard MAC motors MAC50, MAC95, MAC140, MAC141, MAC400 and MAC800.

Both modules offer the same functions but with the following hardware differences:

Type	Protection class	Connectors		
		I/O and interface	Power supply	Bus interface
MAC00-FP2	IP67	Cable glands (Mini crimp connectors internally	Cable glands (Screw terminals internally)	Cable glands x 2 (Screw terminals internally)
MAC00-FP4	IP67	M12	M12	M12 B-coded (x2)

Both modules are delivered without any cables as standard.
Optionally the MAC00-FP2 module can be delivered with cable in selected lengths. Also cables for the MAC00-FP4 with M12 connectors are available.
The first part of this section deals with the common features of both modules. Please see the latter pages for specific information about each module, such as example connection diagrams.

[1] A list of the typically used registers can be found in *Serial Quick Guide (MacTalk protocol)*, page 167.
[2] The FlexMac commands are described in *FlexMac commands, page 111*.

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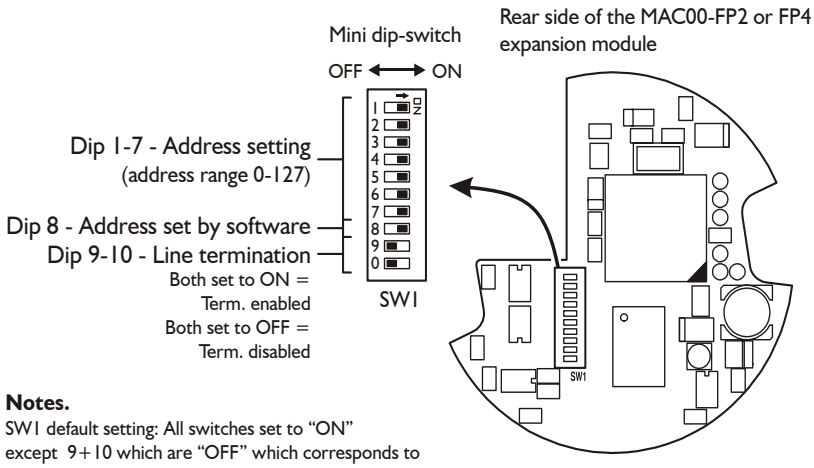
4.5 Expansion Module MAC00-FP2/FP4

4.5.2 MAC00-FP2 and FP4 Address and Termination setup

Each unit connected to the Profibus must be set up with a unique address.
The illustration below shows how the address and termination can be set on the internal dip switch. The dip switch is located on the internal circuit board.

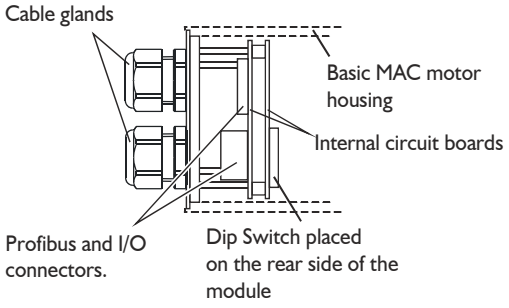
MAC00-FP2 and FP4 Dip switch settings



Notes.
SW1 default setting: All switches set to "ON" except 9+10 which are "OFF" which corresponds to
- Address is set by software / - Termination disabled

"Address set by software" (DIP8) means that the profibus address will automatically be set to the same value as the motor address

Dip switch location on the MAC00-FP2 Expansion module



4.5.3 Output data (Master->Slave)

The MAC00-FP2/FP4 module contains 9 bytes of output data.

Address	Name	Description
0	Write data 3 (MSB)	Data to write to register
1	Write data 2	--- " ---
2	Write data 1	--- " ---
3	Write data 0 (LSB)	--- " ---
4	Write register selector	The register to write
5	Read register selector	The register to read
6	Direct register	Direct FlexMac command
7	Command	Bits for commanding reads/write
8	Input setup	Bits for input setup

Write data

For 16 bit registers, the data must be placed in Write data 0 and Write data 1.
For 32 bit registers, the data must be placed in Write data 0-3.

Write register selector

The number of the register to write to should be placed here. The register must be in the range 1-255.

Read register selector

The number of the register to read from should be placed here. The register must be in the range 1-255.

Direct register

This register can be used to execute a FlexMac^2 command. When writing to this Register, the command will be executed immediately. The bit 0-6 is the command, and bit 7 is not used. If the same command is to be executed twice, bit 7 can be toggled. The command is accepted when the "Last direct register", in the output data, has the same value as this register.

4.5 Expansion Module MAC00-FP2/FP4

Command

Bit	7	6	5	4	3	2	1	0
Function	Write Toggle	Read Toggle	Write 32 bit	Read 32 bit	Auto write	Auto read	Reserved	Reserved

Bit 7 (Write toggle) is used for writing data to the selected register (Write register selector). When this bit is toggled, writing is executed. The write command is accepted when Bit 7 in the command status (output data byte 7) is equal to this bit.

Bit 6 (Read toggle) is used for reading data from the selected register (Read register selector). When this bit is toggled, reading is executed. The read command is accepted when Bit 6 in the command status (output data byte 7) is equal to this bit.

Bit 5 (Write 32 bit) Set this to 1 if writing to a 32 bit register and 0 if writing to a 16 bit register.

Bit 4 (Read 32 bit) Set this to 1 if reading from a 32 bit register and 0 if reading from a 16 bit register.

Bit 3 (Auto write) When this bit is 1, the data written in write data 0-3, is transferred to the MAC motor immediately, regardless of the write toggle bit.

Bit 2 (Auto read) When this bit is 1, the data in read data 0-3 is updated all the time, regardless of the read toggle bit.

Bit 1and Bit 0 should be 0.

Input setup

Bit	7	6	5	4	3	2	1	0
Function	-	Reset end limit	PL Enable	NL Enable	Input mode			

Bit 6 (Reset end-limit) When this bit is 1, the end limit condition is reset, if no end limits are activated.

Bit 5 (PL Enable) When this bit is 1, the positive end-limit is enabled.

Bit 4 (NL Enable) When this bit is 1, the negative end-limit is enabled.

Bit 3-0 (Input mode) these bits select the current input mode. See section *Input modes*, page 109 for details.

4.5 Expansion Module MAC00-FP2/FP4

4.5.4 Input data (Slave->Master)

The MAC00-FP2/4 contains 8 bytes of input data.

Address	Name	Description
0	Read data 3 (MSB)	Data read from register register
1	Read data 2	--- " ---
2	Read data 1	--- " ---
3	Read data 0	--- " ---
4	Motor status	Status bits for the motor
5	Input status	Status of inputs
6	Last direct register	Last accepted direct FlexMac command
7	Command Status	Status bits for commands

Read Data

For 16 bit registers, the read value will be placed in Read data 0 and Read data 1.
For 32 bit registers, the read value will be placed in Read data 0-3.

Motor status

Bit	7	6	5	4	3	2	1	0
Function	-	Decelerating	Accelerating	In position	-	-	-	Error

Bit 6 (Decelerating) this bit is 1 when the motor is decelerating.

Bit 5 (Accelerating) this bit is 1 when the motor is accelerating.

Bit 4 (In position) this bit is 1 when the motor has reached its commanded position.

Bit 0 (Error) this bit is 1 when a motor error has occurred.

Input status

Bit	7	6	5	4	3	2	1	0
Function	-	-	PL	NL	IN4	IN3	IN2	IN1

Bit 5 (PL) Positive limit input.

Bit 4 (NL) Negative limit input.

Bit 3-0 (INx) user inputs.

Last direct register

See *Direct register*, page 106 for details.

Command status

Bit	7	6	5	4	3	2	1	0
Function	Write Toggle	Read Toggle	-	-	Status			

Bit 7 (Write Toggle) this bit indicates when writing is completed. See *Command*, page 107 for details.

Bit 6 (Read Toggle) this bit indicates when reading is completed. See *Command*, page 107 for details.

Bit 3-0 (Status) These bits indicate the status of the MAC00-FP2/FP4. The following status codes are possible:

Code	Description
0	OK – Idle
1	Executing Input
2	Executing Output
3	Limit switch active
4	Profi error
5	Connecting to MAC motor

4.5.5 Input modes

The 4 user inputs can be used to execute different move commands.
The following input modes can be selected:

Mode	Description
0	Passive
1	Absolute+Relative
2-14	Reserved
15	Custom

Passive mode (0)

When this mode is selected, the user inputs are ignored.
The inputs can be read in output data 5 for other purposes.

Absolute + Relative mode (1)

When this mode is selected. the inputs have the following functions:

IN1: Selects the absolute position in position register 1.
IN2: Selects the absolute position in position register 2.
IN3: Moves relative the distance in position register 3.
IN4: Moves relative the distance in position register 4.

The action is executed when an inactive-to-active transition is detected on the input.

Custom mode (15)

When this mode is selected, the action of each input can be selected with the slave parameters. See “Slave parameters” on page 110.

4.5.6 Slave parameters

When configuring the profibus, it is possible to set some parameters for the slave. These parameters are setup during startup and cannot be changed during operation.

XX Input level

Using these parameters, the input level of the inputs IN1, IN2, IN3, IN4, NL and PL can be selected.

Possible values:

Active high	: The input will be active, when a signal is applied.
Active low	: The input will be active, when no signal is applied.

End-limit action

Using this parameter, the action taken when an end limit is activated can be selected.

Possible values:

Velocity = 0 :	When the end-limit is activated, the velocity will be set to 0 and the motor will decelerate and stop. If the motor should run again, the user must manually set a new velocity.
Passive mode :	When the end-limit is activated, the actual mode will be changed to passive. In passive mode the motor is short-circuited and can be rotated.

In firmware version 1.4 or higher, the “end-limit action" is also active if the Profibus is going off-line but it needs to be online before it goes off line before the feature is enabled.

Input debounce

Using this parameter, an input filter can be activated.

Possible values:

Disabled	No filtering will be done on the inputs.
Enabled	The inputs are filtered, resulting in better noise immunity but slower response. When the filter is enabled, there will be a delay at the input of about 5ms.

Input x action

Using these parameters, up to 3 actions can be assigned to each input.
These actions are used when the custom input mode is selected. See “Input modes” on page 109.
The action is defined by a FlexMac command. See “FlexMac commands” on page 111.

Possible values are 0-127, where 0 represents no action.

4.5 Expansion Module MAC00-FP2/FP4

4.5.7 FlexMac commands

Using the FlexMac commands, it is possible to activate a set of registers and set the mode of the motor using a single command. The command is composed of two parts. The first part is the mode that the motor will use.
The following 4 modes can be selected:

Value	Motor mode after command	Format
0	Passive	Command = 0 + Register N
32	Velocity	Command = 32 + Register N
64	Position	Command = 64 + Register N
96	<No change>	Command = 96 + Sub-command N

The second part of the command is a register number or sub-command number.
The following table shows the register numbers:

N	Register	N	Register	N	Register	N	Register
0	P1	8	V1	16	A1	24	L1
1	P2	9	V2	17	A2	25	L2
2	P3	10	V3	18	A3	26	L3
3	P4	11	V4	19	A4	27	L4
4	P5	12	V5	20	T1	28	Z1
5	P6	13	V6	21	T2	29	Z2
6	P7	14	V7	22	T3	30	Z3
7	P8	15	V8	23	T4	31	Z4

The following table shows the sub-commands:

N	Command	N	Command
0	No operation	16	Start search zero
1	Reset error	17	No operation
2	P_SOLL = 0	18	No operation
3	P_IST = 0	19	Reserved
4	P_FNC = 0	20	Select absolute position mode
5	V_SOLL = 0	21	Select relative position mode using P_SOLL
6	T_SOLL = 0	22	Select relative position mode using P_FNC
7	Reset IN_POS, ACC,DEC	23	No operation
8	P_FNC = (FLWERR - P7) * 16	24	No operation
9	P_FNC = (FLWERR - P8) * 16	25	No operation
10	Reserved	26	No operation
11	Reserved	27	No operation
12	Activate P0,V0,A0,T0,L0,Z0	28	No operation
13	Activate P1,V1,A1,T1,L1,Z1	29	No operation
14	Activate P2,V2,A2,T2,L2,Z2	30	Reserved
15	Activate P3,V3,A3,T3,L3,Z3	31	Reserved

Examples of FlexMac commands

Change velocity mode and activate register V1 :
32 + 8= FlexMac command 40

Activate register P5 and change to position mode
64 + 4 = FlexMac command 68

Activate register T3 and change to position mode
64 + 22 = FlexMac command 86

Activate P0,V0,A0,T0,L0 and Z0 without changing the mode:
96 + 12 = FlexMac command 108

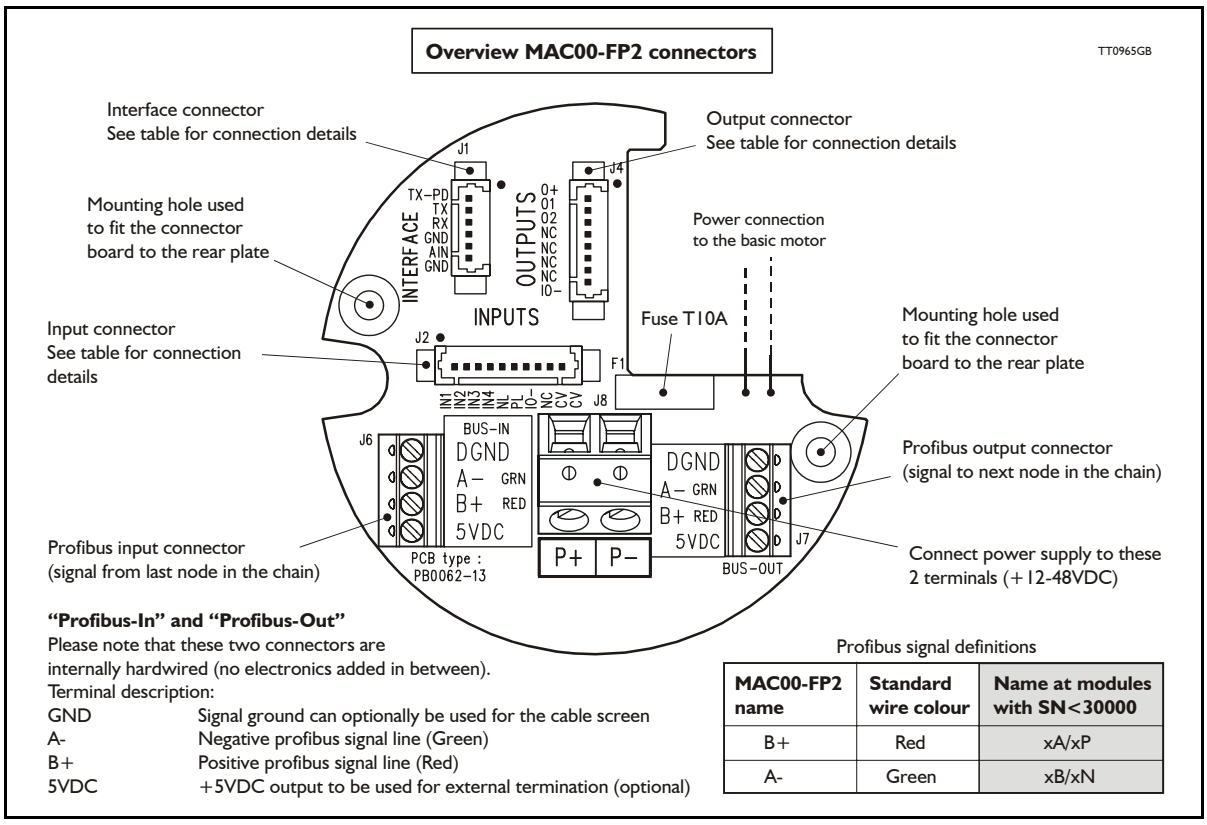
4.5 Expansion Module MAC00-FP2/FP4

4.5.8 MAC00-FP2 and FP4 description of connections

The following pages describe the different aspects of connecting the modules MAC00-FP2 and FP4.

4.5.9 MAC00-FP2 Connectors

MAC00-FP2 rear plate layout:
The illustration below shows all the internal connectors in the module. The profibus and power connectors are easy-to-use screw terminals. If the I/Os are used, they require a JVL cable type WG0402 (2m), WG0410 (10m) or WG0420 (20m). See also the appendix for cable and connector accessories.



"Profibus-In" and "Profibus-Out"
Please note that these two connectors are internally hardwired (no electronics added in between).
Terminal description:

GND	Signal ground can optionally be used for the cable screen
A-	Negative profibus signal line (Green)
B+	Positive profibus signal line (Red)
5VDC	+5VDC output to be used for external termination (optional)

Profibus signal definitions

MAC00-FP2 name	Standard wire colour	Name at modules with SN<30000
B+	Red	xA/xP
A-	Green	xB/xN

4.5 Expansion Module MAC00-FP2/FP4

4.5.10 MAC00-FP2 option with cables (optional)

The MAC00-FP2 type number only covers the basic module, i.e. without any cables. If a number is added after the basic type number, for example MAC00-B2-10, this suffix indicates that the module is fitted with 10 m of cable in the I/O. The I/O cable covers all the signal lines, i.e. RS232, Digital input 1-4, Limit inputs NL and PL and the Digital outputs 1-4.
Please note the WG0420 table below is not valid for cables delivered before 1.10.2002.
See *WG0420 (old versions delivered before 1.10.2002), page 176*

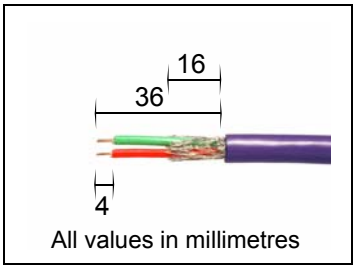
Digital Inputs - Internal connector J2			
Signal name	**Pin no.**	**Description**	**Wire colour**
IN1	1	Digital input 1	Red/black
IN2	2	Digital input 2	Green/black
IN3	3	Digital input 3	Violet
IN4	4	Digital input 4	Violet/white
NL	5	Negative limit input - If not used, do not connect.	Grey
PL	6	Positive limit input - If not used, do not connect.	Grey/black
IO-	7	I/O ground. Shared with the output ground (O-)	Pink/black
NC	8	(Reserved)	Black/white
CV	9	Secondary supply. Used during emergency stop *	Light green **
CV	10	Secondary supply. Used during emergency stop *	White
Digital Outputs - Internal connector J4			
Signal name	**Pin no.**	**Description**	**Wire colour**
O+	1	Supply for outputs - Must be connected to an ext. supply.	Red/white
O1	2	Digital output 1 - PNP output - Max. 25mA	Green/white
O2	3	Digital output 2 - PNP output - Max. 25mA	Yellow/black
NC	4	(Reserved)	Blue/white
NC	5	(Reserved)	Orange/white
NC	6	(Reserved)	Brown/white
NC	7	(Reserved)	Pink
IO-	8	I/O ground. This ground is shared with the input ground	Black
Interface - including analogue input - Internal connector J1			
Signal name	**Pin no.**	**Description**	**Wire colour**
TXPD	1	Transmit pull-down (Connect to TX if addr. not used)	Red
TX	2	RS232 Transmit (Connect to TXPD if addr. not used).	Green **
RX	3	RS232 Receive (connect to GND if not used).	Yellow
GND	4	Ground for RS232	Blue
AIN	5	Analogue input +/-10V or Zero sensor input	Orange
GND	6	Ground for AIN	Brown
Cable Screen			
The cable-screen is internally connected to motor housing. Externally it must be connected to earth.			
Unused wire			
Orange/Black - is not used internally. It must be left unconnected.			

* : The VC terminals are only available on modules with serial number >25000
** : The light green wire (CV) can be difficult to distinguish from the green wire (TX) on some cables.

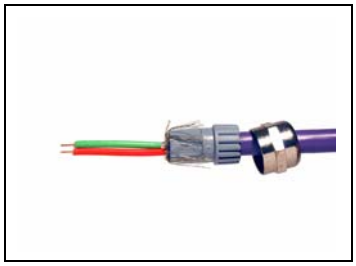
Important: Please note that the cables are a standard type. They are not recommended for use in cable chains or where the cable is repeatedly bent. If this is required, use a special robot cable (2D or 3D cable).

4.5.11 Assembly instructions for profi cables

Remove the insulation from the cable, as shown in the accompanying picture.

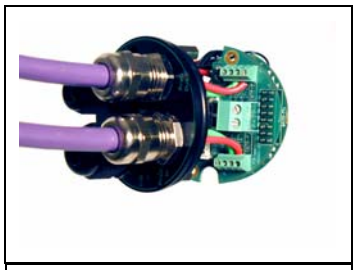


Fit the plastic part of the gland on the cable, and fold the screen around it. Remember to first feed the cable through the nut.



Feed the cables through the cable glands in the rear plate of the module and tighten the nuts.

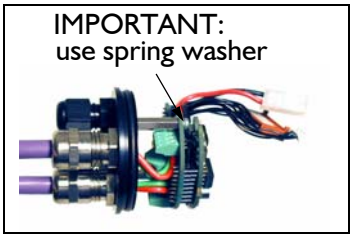
Screw the wires into the module. The red wire must go into the B+ terminal, and the green must go into the A- terminal.
The input and output terminals can be swapped if required. The is no difference between input and output on the board which means that it is purely hard-wired.



Attach the circuit board to the rear plate with the two screws. REMEMBER to use the spring washers included.

The table below shows the difference between Siemens naming conventions and the naming on the MAC00-FPx.

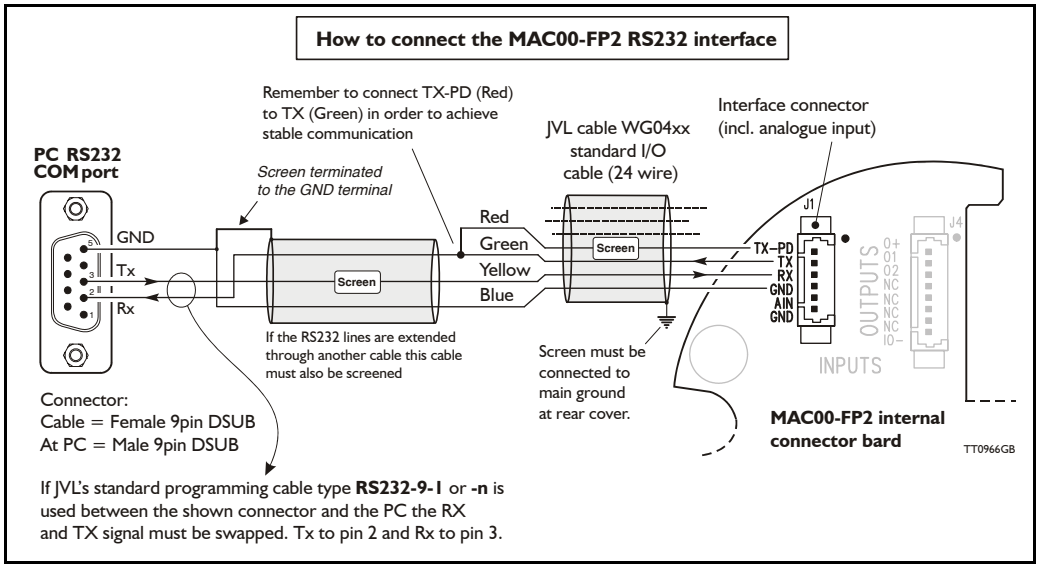
MAC00-FPx name	Siemens name	Standard wire colour
B+	B	Red
A-	A	Green



4.5 Expansion Module MAC00-FP2/FP4

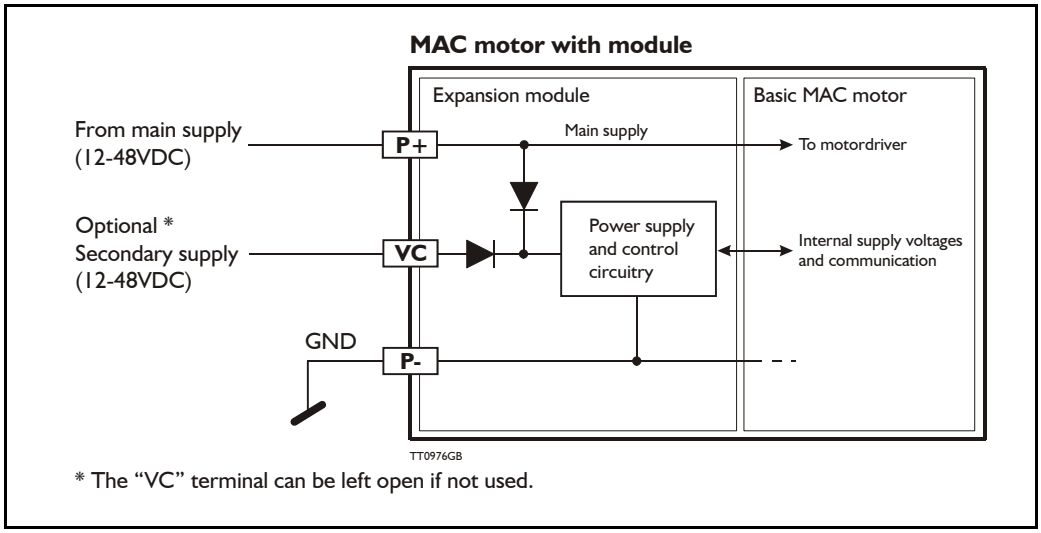
4.5.12 MAC00-FP2 - How to connect the RS232 interface

The illustration below shows how to connect the MAC00-FP2 directly to a PC COM port. The drawing is based on standard cables from JVL, type WG0402, WG0410 or WG0420. See also *Accessories, page 174* for a complete list of cables and connectors. If the MAC motor is connected to the same RS232 line as other motors, the terminal TX-PD should only be connected at one of the motors. If one of JVL's standard RS232 cables (RS232-9-1 or -n) is used between the DSUB connector shown and the PC com port, the RX and TX pins must be swapped since they cross in these standard cables.



4.5.13 Operation with dual supply for emergency situations

In many applications it is intended that positional data and other setup information is retained during an emergency situation. It is however also required by law in many countries that the main power for energizing the motor is removed in such a situation.
To meet both of these requirements, the MAC motor equipped with a MAC00-FPx module offers a secondary supply input called "VC". If the main supply at the P+ terminal is removed, the internal control circuitry can be kept "alive" by maintaining a supply at the "VC" terminal.



4.5 Expansion Module MAC00-FP2/FP4

Expansion module MAC00-FP4 front plate

BUS1
Primary Profibus-DP connector.
M12 - 5pin male connector including:
Profibus-DP interface

BUS2
Secondary Profibus-DP connector:
M12 - 5pin female connector including:
Profibus-DP interface

TT1008GB

PWR
Power
M12 - 5pin male connector including:
P+, P- and secondary supply (optional).

I/O
M12 - 8pin female connector including:
RS232 Interface
Selectable I/O's such as analogue input, O1, O2, IN1, NL, PL.

4.5.14 Expansion MAC00-FP4 hardware description

The MAC00-FP4 offers IP67 protection and M12 connectors which make it ideal for automation applications where no additional protection is desired. The M12 connectors offer solid mechanical protection and are easy to unplug compared to the FP2 module which has cable glands. The signals available are restricted compared to the FP2 module since only 4 I/O terminals are available. The I/Os connected to these 4 terminals must be selected by a small dip-switch.

The connector layout:

"PWR" - Power input. M12 - 5-pin male connector				
Signal name	**Description**	**Pin no.**	**JVL Cable WI1000M12 F5A05N**	**Isolation group**
P+	Main supply +12-48VDC. Connect with pin 2 *	1	Brown	1
P+	Main supply +12-48VDC. Connect with pin 1 *	2	White	1
P-	Main supply ground. Connect with pin 5 *	3	Blue	1
CV	Control voltage +12-48VDC.	4	Black	1
P-	Main supply ground. Connect with pin 3 *	5	Grey	1
* Note: P+ and P- are each available at 2 terminals. Make sure that both terminals are connected in order to split the supply current in 2 terminals and thereby avoid an overload of the connector.				
"BUS1" - Profibus-DP interface. M12 - 5-pin male connector				
Signal name	**Description**	**Pin no.**	**Cable: user supplied**	**Isolation group**
-	Reserved for future purpose - do not connect	1	-	2
A-	Terminal A (Siemens syntax) for the Profibus-DP interface	2	-	2
DGND	Profibus-DP interface ground	3	-	2
B+	Terminal A (Siemens syntax) for the Profibus-DP interface	4	-	2
SHIELD	Cable shield. Internally conn. to the motor housing.	5	-	2

(Continued next page)

4.5 Expansion Module MAC00-FP2/FP4

"BUS2" - Profibus-DP Interface. M12 - 5-pin female connector

Signal name	Description	Pin no.	Cable: user supplied	Isolation group
5VDC	5V output. Can be used for ext. termination (Max 40mA)	1	-	2
A-	Terminal A (Siemens syntax) for the Profibus interface	2	-	2
DGND	Profibus-DP interface ground	3	-	2
B+	Terminal B (Siemens syntex) for the Profibus interface.	4	-	2
SHIELD	Cable shield. Internally connected to the motor housing.	5	-	2

"IO" - I/Os and RS232 interface. M12 - 8-pin female connector.

Signal name	Description	Function	Pin no.	JVL Cable WI1000-M12 M8A05N	Isolation group
IOC	I/O terminal C.	DIP 5 = OFF : *PL* input DIP 5 = ON : O1 *(PNP 25mA)*	1	White	3
Tx	RS232 interface - transmit output Important !: DIP1 must be turned ON. If addressing is used it must be turned ON at minimum one of the connected motors.		2	Brown	1
Rx	RS232 interface - receive input		3	Green	1
GND	RS232 Ground - also used with analogue input		4	Yellow	1
IOA	I/O terminal A.	DIP 2 = ON and DIP3 = OFF : *AIN* (Analogue input) DIP2 = OFF and DIP 3 = ON : *O2* (output 2 / PNP 25mA) (*AIN* is the analogue input. Remember to use the GND terminal with AIN !).	5	Grey	3 (1 when used as AIN)
IOB	I/O terminal B.	DIP 4 = OFF : *IN1* (input 1) DIP 4 = ON : *O1 (PNP 25mA)* (output 1)	6	Pink	3
IO-	I/O ground to be used with IN1, NL, PL, O1, O2		7	Blue	3
IOD	I/O terminal D.	DIP 6 = OFF : *NL* (negative limit input) DIP 6 = ON : *O+* (output supply)	8	Red	3

Cable Screen

Some standard cables with M12 connector offer a screen around the cable. This screen on some cables is fitted to the outer metal at the M12 connector. When fitted to the MAC00-FP4 module, this means that the screen will have contact with the complete motor housing and thereby also the power ground (main ground).

Isolation groups

The MAC00-FP4 offers optical isolation at the digital inputs and outputs (IN1, NL, PL and O1-2). The table shows a number for each pin. This number refers to the isolation group to which the pin is connected.
Isolation group 1 means that the terminal refers to the main ground (P-, GND and the motor housing).
Isolation group 2 means that the terminal refers to the Profibus-DP interface ground (DGND).
Isolation group 3 means that the terminal refers to the I/O ground (IO-)

4.5 Expansion Module MAC00-FP2/FP4

4.5.15 Cables for the MAC00-FP4

The following cables equipped with M12 connector can be supplied by JVL.

MAC00-FP4 Connectors				Description	JVL Order no.	Photo
"BUS1" 5-pin Male B-coded	"BUS2" 5-pin Female B-coded	"I/O" 8-pin Female	"PWR" 5-pin Male			
		X		RS232 Interface cable. Connects directly from MAC00-FP4 to PC Length: 5m (197 inch)	**RS232-M12-1-5-8**	
			X	Cable (Ø5.5mm) with M12 **female** 5 pin 90 degree connector loose ends 0.35mm² (22AWG) and foil screen. Length: 5m (197 inch)	**WI1000-M12F5A05N**	
			X	Same as above but 20m (787 inch)	**WI1000-M12F5A20N**	
		X		Cable with M12 **male** 8-pin 90 degree connector loose ends 0.22mm² (24AWG) and foil screen. Length: 5m (197 inch)	**WI1000-M12M8A05N**	
		X		Same as above but 20m (787 inch)	**WI1000-M12M8A20N**	
	X			Profibus DP cable with M12 male 5-pin connector B-coded, loose ends and screen. Length: 5m (197 inch).	**WI1026-M12M5S05R**	
	X			Same as above but 15m (591 inch)	**WI1026-M12M5S15R**	
X				Profibus DP cable with M12 female 5-pin connector B-coded, loose ends and screen. Length: 5m (197 inch)	**WI1026-M12F5S05R**	
X				Same as above but 15m (591 inch)	**WI1026-M12F5S15R**	
Loose connectors and termination resistor						
	X			Loose Profibus DP **male** M12 connector. B-coded. Internal screw terminals.	**WI1028-M12M5VC1**	
X				Loose Profibus DP **female** M12 connector. B-coded. Internal screw terminals.	**WI1028-M12F5VC1**	
	X			Profibus DP **male** M12 termination resistor. B-coded.	**WI1028-M12M4STR3**	
Protection caps. Optional if connector is not used, to protect from dust / liquids.						
	X	X		IP67 protection cap for M12 **female** connector.	**WI1000-M12FCAP1**	
X			X	IP67 protection cap for M12 **male** connector.	**WI1000-M12MCAP1**	

Important: Please note that the cables are a standard type. They are not recommended for use in cable chains or where the cable is repeatedly bent. If this is required, use a special robot cable (2D or 3D cable). See also *Accessories, page 174* where additional M12 connectors are shown.

4.5 Expansion Module MAC00-FP2/FP4

4.5.16 GSD file for the MAC00-FP2 and FP4

The GSD file must be used to configure the PLC or master controller used for the Profibus communication. The file is shown here but is also available on disc. Please contact your nearest JVL representative.

GSD file:

```
; COM PROFIBUS V 3.3, GSD'-Xport
; Time Stamp: 01/31/00, 12:36:39
#Profibus_DP
; <Unit-Definition-List>
GSD_Revision=1
Vendor_Name="JVL IND EL"
Model_Name="MAC00-FP"
Revision="0.0"
Ident_Number=0x06BC
Protocol_Ident=0
Station_Type=0
Hardware_Release="1.1"
Software_Release="1.2"
9.6_supp=1
19.2_supp=1
93.75_supp=1
187.5_supp=1
500_supp=1
1.5M_supp=1
3M_supp=1
6M_supp=1
12M_supp=1
MaxTsdr_9.6=60
MaxTsdr_19.2=60
MaxTsdr_93.75=60
MaxTsdr_187.5=60
MaxTsdr_500=100
MaxTsdr_1.5M=150
MaxTsdr_3M=250
MaxTsdr_6M=450
MaxTsdr_12M=800
Implementation_Type="VPC3"
Bitmap_Device="DPLINK_"

; Slave-Specification:
Freeze_Mode_supp=0
Sync_Mode_supp=0
Auto_Baud_supp=1
Min_Slave_Intervall=1
Max_Diag_Data_Len=8
Modul_Offset=0
Slave_Family=0
OrderNumber="MAC00-FPx"
```

```
; UserPrmData: Length and Preset:
PrmText=1
Text(0)="Active low"
Text(1)="Active high"
EndPrmText

PrmText=2
Text(0)="Velocity = 0"
Text(1)="Passive mode"
EndPrmText

PrmText=3
Text(0)="Disabled"
Text(1)="Enabled"
EndPrmText

ExtUserPrmData=1 "IN1 Input level"
Bit(0) 1 0-1
Prm_Text_Ref=1
EndExtUserPrmData

ExtUserPrmData=2 "IN2 Input level"
Bit(1) 1 0-1
Prm_Text_Ref=1
EndExtUserPrmData

ExtUserPrmData=3 "IN3 Input level"
Bit(2) 1 0-1
Prm_Text_Ref=1
EndExtUserPrmData

ExtUserPrmData=4 "IN4 Input level"
Bit(3) 1 0-1
Prm_Text_Ref=1
EndExtUserPrmData

ExtUserPrmData=5 "NL Input level"
Bit(4) 1 0-1
Prm_Text_Ref=1
EndExtUserPrmData

ExtUserPrmData=6 "PL Input level"
Bit(5) 1 0-1
Prm_Text_Ref=1
EndExtUserPrmData

ExtUserPrmData=7 "Endlimit action"
Bit(0) 0 0-1
Prm_Text_Ref=2
EndExtUserPrmData

ExtUserPrmData=8 "Input 1 Action"
UnSigned8 0 0-255
EndExtUserPrmData
```

```
ExtUserPrmData=9 "Input 2 Action"
UnSigned8 0 0-255
EndExtUserPrmData

ExtUserPrmData=10 "Input 3 Action"
UnSigned8 0 0-255
EndExtUserPrmData

ExtUserPrmData=11 "Input 4 Action"
UnSigned8 0 0-255
EndExtUserPrmData

ExtUserPrmData=12 "Input debounce"
Bit(1) 0 0-1
Prm_Text_Ref=3
EndExtUserPrmData

ExtUserPrmData=13 "Input noise filter"
Bit(2) 0 0-1
Prm_Text_Ref=3
EndExtUserPrmData

Max_User_Prm_Data_Len=15
User_Prm_Data_Len=15
User_Prm_Data=0x0,0x3F,0x0,0,0,0,0,0,0,0,0,0,0,0,0

Ext_User_Prm_Data_Const(0) = 0x0,0x3F,0x0,0,0,0,0,0,0,0,0,0,0,0,0
Ext_User_Prm_Data_Ref(1)=1
Ext_User_Prm_Data_Ref(1)=2
Ext_User_Prm_Data_Ref(1)=3
Ext_User_Prm_Data_Ref(1)=4
Ext_User_Prm_Data_Ref(1)=5
Ext_User_Prm_Data_Ref(1)=6
Ext_User_Prm_Data_Ref(2)=7
Ext_User_Prm_Data_Ref(2)=12
Ext_User_Prm_Data_Ref(2)=13
Ext_User_Prm_Data_Ref(3)=8
Ext_User_Prm_Data_Ref(4)=8
Ext_User_Prm_Data_Ref(5)=8
Ext_User_Prm_Data_Ref(6)=9
Ext_User_Prm_Data_Ref(7)=9
Ext_User_Prm_Data_Ref(8)=9
Ext_User_Prm_Data_Ref(9)=10
Ext_User_Prm_Data_Ref(10)=10
Ext_User_Prm_Data_Ref(11)=10
Ext_User_Prm_Data_Ref(12)=11
Ext_User_Prm_Data_Ref(13)=11
Ext_User_Prm_Data_Ref(14)=11

; <Module-Definition-List>
Module="MAC00-FP" 0x13,0x10,0x10,0x10,0x10,0x23,0x20,0x20,0x20,0x20,0x20
EndModule
```