

# The Design of a Simulator for the Automation Industry



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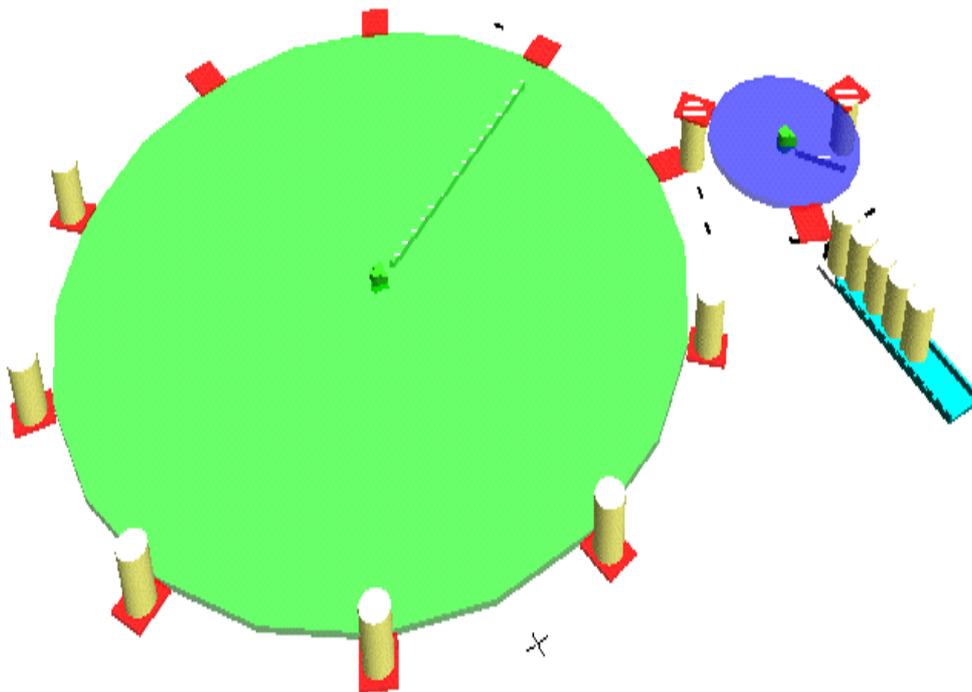
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# The design of a simulator for the automation industry



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## **Abstract**

The development of new technologies forces the industry to develop new products cheaper and faster. Every advance has its own opportunity window and if you are too late, a lot of money and time are wasted. In the automation industry the product development process can last over a year and therefore several projects are running side by side but only a few will survive to the end.

Tetra Pak R&D in Lund has studied this problem during the past few years and their aim is to find out if there is a possibility to use some kind of simulator instead of expensive test machines. This master thesis is one step in that direction and its main goal is to construct a simulation environment consisting of a soft-PLC and a mechanical visualization program. The main problem is how these two programs should communicate during a simulation. The PLC will control the model built in the visualization program and react to signals produced from the model. Therefore a simulation core has been designed and one possible solution to the communication problem is explained.

The core is developed in Visual Basic and a test model is a common part taken from any ordinary filling machine. Finally the controller program is designed in ladder code.



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## **Preface**

Finally this work has been completed and I want to thank all people involved during this project both at Tetra Pak R&D in Lund and Department of Industrial Electrical Engineering and Automation at LTH. I would like to thank Bo Hellberg and Lennart Christensson at Tetra Pak for their help during my time at Tetra Pak. A special thanks for their encouragement and patience goes to Istvan Ulvros, Tetra Pak and professor Gustaf Olsson.

Finally I would like to thank my girlfriend Tove who has been supporting me all along this work.



# 1 Introduction

## 1.1 Why building a software simulator

In the automation industry it usually takes a long time to develop new machines. There are many steps in a development cycle that all costs a lot of money. If the development time could be shortened, the costs would be reduced. Far from every machine design idea leads to a complete machine. If an idea could be rejected earlier, it would save unnecessary development costs.

In at least one stage during the development cycle it is necessary to build a test machine. This test machine is expensive and without any doubt there must be corrections made of this machine several times due to incomplete design. If the number of errors could be reduced before starting using the real machine, it will reduce the development time, spare parts and of course the costs.

So there are several reasons why a research and development department would like to build a simulator instead of a real machine in the early stages of a development cycle. In a simulator we can build a model of the machine and we can test it without breaking anything. It is much easier to do changes in the simulator than in the real machine. By using a simulator the control program could be tested several times long before it is first tested on the real machine.

As we can see there are many reasons to build a simulator. It helps to shorten development time, reduce cost due to errors and spare parts, and makes it easier to do changes and so on. But why don't we do this every time we want to build a machine? One answer to that question is that there is no software available, designed for this purpose. So in this thesis I will try to design a simple simulator out of known software and make it work.

## 1.2 Goals of the thesis

The main goal was to make a simulator and to simulate a part taken from a filling machine. The simulator must handle signals both ways between itself and a controller. The simulator must also contain some kind of visualisation and this is done by some software supplied with graphical tools. This means that the visualiser must allow to be controlled from outside and be able to send signals back when some certain criteria are met. To achieve this there were a few other minor problems that had to be solved first.

Programs use different ways of communication with other programs. Therefore a communication link between them must be designed. The programs can't work together in real time, since they are located on the same computer. The time must be divided between them and this must be controlled in some way.

An object must be constructed to simulate different parts of a real machine. How these objects are designed depends on several things but the most important thing is that we must be able to reuse all objects and that there must not be any limitations to add new objects to the model. In other words, the simulation core should not have to be changed when a new object is added.

## **1.3 Limitations and methods**

The simulator was limited to two programs available in the commercial market, one being the controller and the other the simulation of the machine. The two programs are FrameworkX from GE-Fanuc, (FX) which is a soft PLC and Working Model 3D Motion from MSC Working Knowledge, (WM3) which is a mechanical motion simulation software.

As the work went along, it turned out to be difficult to establish communication between the programs. The main reason of this was that in the early stages in my work, FrameworkX was only available in a beta version without proper manuals. Especially the OLE Automations for Process Control, OPC, documentation was missing which made it very difficult to connect the two programs together. Another problem was that the final version of Working Model 3D was delivered very late during the limited thesis working time. Therefore the work had to be focused on the minor problems and there were no time left in the end to build a complete machine simulator as intended.

The thesis is limited to establish communication between the programs, control the data flow between them and build a small demonstration model to show how the simulator is supposed to work.

In the beginning of the work, time had to be spent to learn and understand the basics around FrameworkX and Working Model 3D. Internet was used to find information about OPC. Missing a lot of primary information trial and error had to be used a lot during the work. When documentation then was available it became easier and the communication was improved quite fast. Then it was possible to focus on building a few objects and test model so it became possible to demonstrate the simulator function. It finally worked!

### **1.3.1 Results**

The main goal was to build a complete simulator and that goal was achieved. However, to build a complete machine part as intended, failed. But the principles are shown in the small test model and it is only a question of available time to build a more complex test model.

### **1.3.2 Report outline**

The report is divided into three parts. The first part describes briefly the software used and the communication protocols. This is done in Chapters 2 and 3. The second part, Chapters 4 and 5, deals with simulation methods and test model. Finally the last chapter summarises the result of the work.

To fully understand how this simulation works the reader should have some knowledge about object orientated programming in Visual Basic. Those just interested in the simulation method may look directly at Chapter 5

During the second part there will be some written code among the text. This code is taken from the final code created in Visual Basic. But some details are left out and sometimes there is no real code, just some text notes. However, the complete code is printed in appendices A2-10.

# 2 Simulation environment

## 2.1 Total structure

The simulator consists of a soft-PLC, communication link and a mechanical simulation program. The control program resides inside the PLC and it communicates with OPC, OLE Automations for Process Control through an OPC-server. The soft-PLC used is FX-Control from FrameworkX, GE-Fanuc and from now on, called FX. But the simulator is not bound to FX and it can be replaced by any other soft-PLC that uses OPC to communicate. But FX has an advantage in having a built-in OPC-server and all communication between FX and the OPC-server is handled automatically by FX. Therefore, when referring to FX the OPC-server is included.

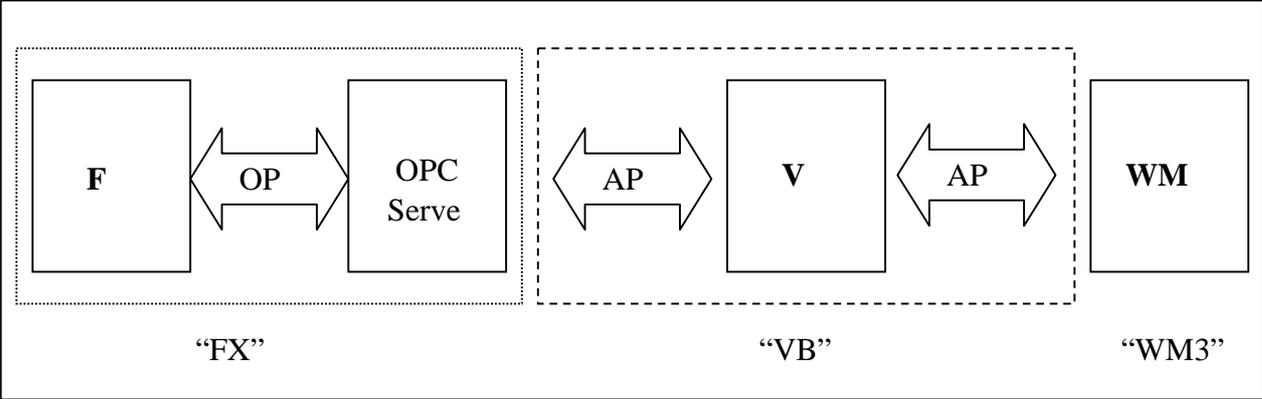


Figure 2.1 The model consist of three parts. To the left: The soft-PLC and an OPC-server, from now on called FX. Middle: Visual Basic and both API, referred as VB. To the right: Working model 3D, shorten toWM3.

The communication link consists of two OLE Automation interfaces, refereed as API and the simulator core written in Visual Basic, hereafter named VB. The main task for the communication link is to transfer and translate signals from FX to the mechanical simulation program, but it also contains functions, such as starting and stopping the simulator. Finally it also has a monitoring function, which allows us to se how the signals change during a simulation.

One API is providing VB with an interface to communicate between OPC and VB. Through the interface object is created and connected between FX and VB. All signals controlling the simulation come from FX and are transferred to mechanical simulation, except from a few simulator signals.

The other API is providing VB with an interface to the mechanical simulation program. Through these interface signals is collected from the mechanical model and transferred to FX. Of course the interface also provides the model with signals sent from FX.

Finally the mechanical simulation program is built to visualise the machine movements. This simulator is using Working Model 3D Motion from MSC Working Knowledge. This program will be referred to as WM3 from now on. WM3 has a large number of possibilities to build advanced models but our model is very simple and its main purpose is to show the idea behind the simulator

## 2.2 Components

As mentioned in the previous sections there are totally six components in the simulator. They can be divided into three parts according to fig 2.1. The “FX” part consist of FX and the OPC-server as shown in the left box in the figure. Below in this chapter there is an overview of FX and the OPC-server is discussed in chapter 3. The “VB” part or the core of the simulator consists of all written code in VB. Both API are imported and used in the code so they are treated as a one in VB. The middle box contains both API and VB. Both API will be described a bit further in chapter three and below a very brief overview to VB. The third part consists only of WM3 that also will be discussed later in this chapter.

### 2.2.1 FrameworX (FX)

FX is a soft-PLC, which integrates development and execution of a controller. It also provides a graphical tool to build a HMI that can monitor the process.

The program supports tools such as Ladder and SFC according to IEEE 1131. It also has a tool chest where many predefined objects are stored. Most of them has a graphical interface and can be used when building a HMI.

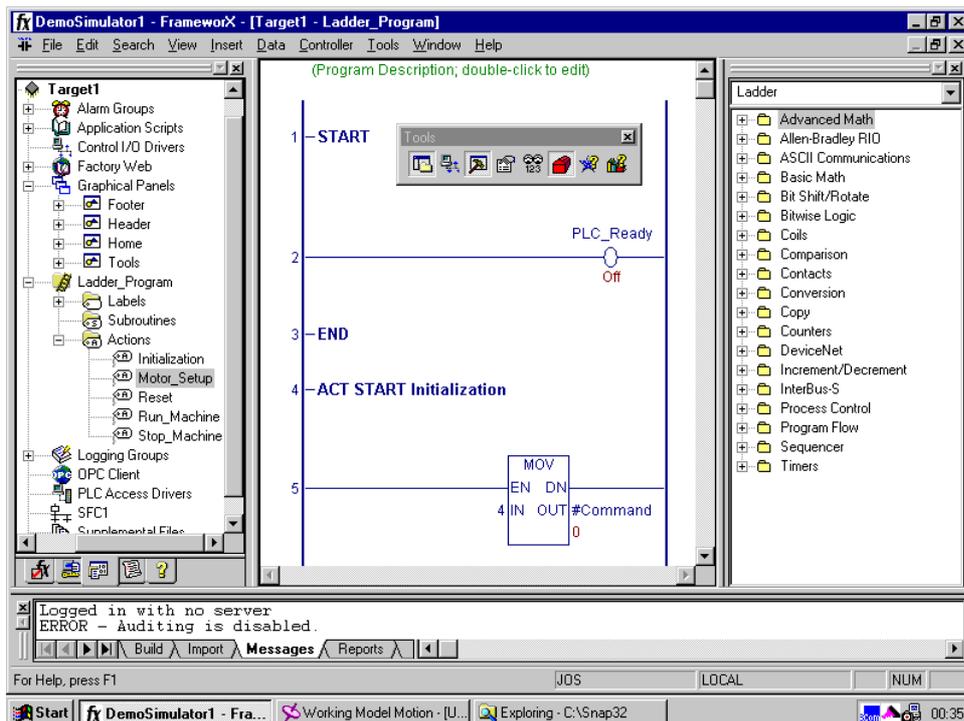


Figure 2.2 Screenshot of FX-control.

In the very early stage of the thesis the graphical tool was explored to reveal if it could be used as a visualisation tool of the machine. But then the model would only consist of a schematic model and most important only in two dimensions. Also add some advanced algebra to solve all mechanical properties and it would be a thesis of it own.

Actually there are two different programs that can be executed, FX-control or FX-view. The differences between them are that FX-control contains the development environment and FX-View consists only of the HMI and the executing controller. It is said before that there is a built-in OPC-server to FX, actually there are two of them, one each to FX-control and FX-view. Every time any of those programs is started the corresponding OPC-server is also started.

### 2.2.2 Working Model 3D (WM3)

WM3 is a 3- dimensional simulation program for mechanical models in motion. It's a pure simulator tool where the model of the "real" machine is simulated. The model is build by many different bodies and constraints with different degrees of freedom. Each body can have different geometrical and physical properties and they can also have initial speed and acceleration. Movements are described by functions and tables and of course the impact the environment consisting of all other bodies. There are also some defined objects such as motors, springs and pistons that can be used to create more dynamic models. Momentum and forces can be applied anywhere and can be used as initial conditions. Other greater feature is that it is possible to import models form other CAD-tools and convert them into WM3 models.

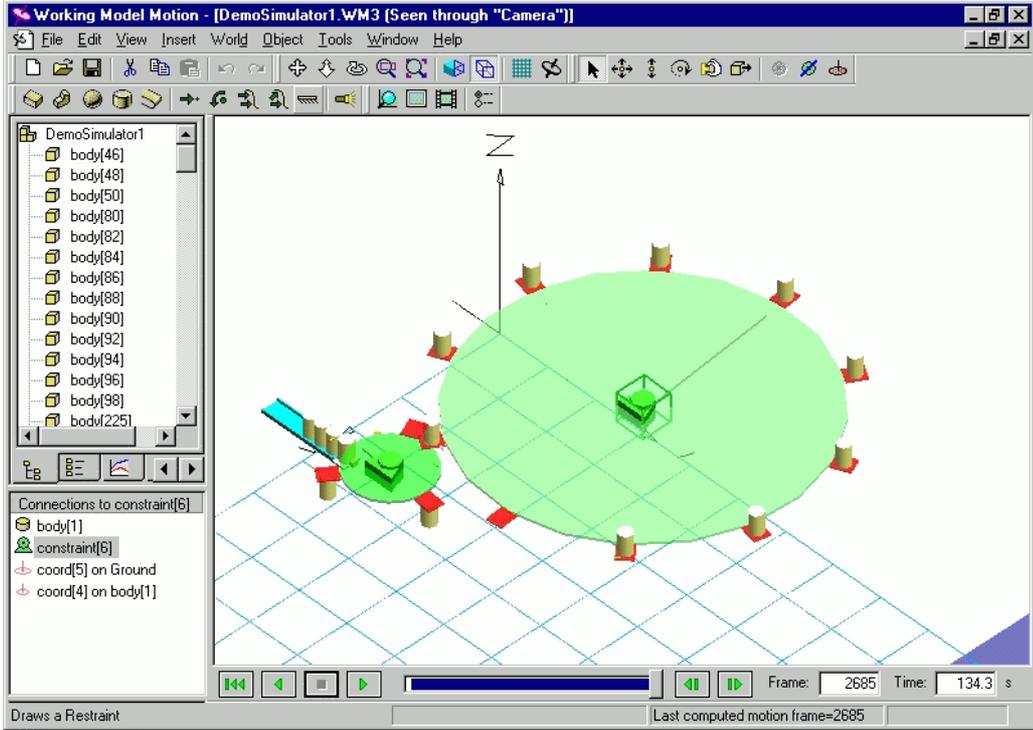


Figure 2.3 Screenshot of WM3

Several properties can be controlled during the simulation through inputs. It is actually this feature that makes it possible to control the model from an outside source i.e. a controller. WM3 has a very simple script language, which mainly consists of the if-function, mathematical function and some signal generators. But together with inputs it is quite simple to control properties during the simulation of the model.

It is also possible to collect information from the model or, as we see it, signals that can be sent to the controller. This is done by using an output that is an object that calculates a value during each frame using information from the model properties together with the script language. Here the signal generator functions that can extend a signals duration are especially helpful. But, even if outputs give us a way to get a certain information from the model, they are not used in the simulator. The reason is that it is easier to directly use the API and acquire the information from the model.

Visualisation of the model is very powerful. It is possible to look at the model from anywhere and zooming down to small details. When a simulation is performed it remains in the memory until a new simulation is done or if it is deleted. Rerunning the simulation will increase the visualisation speed and it can be done from any angle and zooming. Finally it is possible to export a simulation as a video clip that can be shown in other tools.

However, one major feature is missing in WM3 which was a part of its predecessor Working Model 2D. Instead of giving a value to the side of a cube and let other bodies refer to that side, it must be set to a numerical value. This makes it very time consuming to edit fundamental body values in a model and the whole model must be revisited. The same problem occurs when objects are placed in the model. For example if two objects should be three radiuses apart it would be very helpful to use the first objects reference point and then add three radiuses for the second one.

One other thing to understand is that WM3 is not currently powerful enough to perform real-time simulation even if it is working stand-alone. Of course this is also a hardware issue and therefore there are a great possibilities to improve performance in the future.

### **2.2.3 Visual Basic (VB)**

The simulator core is written in Microsoft Visual Basic 6 as a part of Microsoft Excel tool. The core serves as a “glue” between WM3 and FX, taking care of timing issues and signal handling, but also has a simple monitor window where the user can follow the signal flow between FX and WM3

VB is an object-orientated language with is focused on the user and his interaction with the program. In an application it is the user who controls the flow by actions throw the GUI, normally by the mouse or keyboard. VB contains classes, which has methods and properties that can perform operations and set attributes in the object. VB works with three components, class modules (classes), modules and forms. Each class contains information about an object and its methods and properties. The modules contain a set of procedures that should be executed each time they are called. Finally, the forms represent the visible part in VB. We can create buttons, textboxes, and lists and so on in order to communicate with the program.

Besides this, there are several APIs that can be added to the VB-environment that can be used to create objects to control other applications without implementing that object. We just create an instance of the object and it is ready to use.

## 3 Use of communication mechanism

### 3.1 What is OPC

OPC stands for OLE for Process Control and it is a standard protocol to transmit data and I/O-signals between programs running within the Windows environment. OPC is built upon two of Microsoft's technologies, OLE and DCOM and it's also designed and optimised for industrial applications. It is developed by a non-profit organisation, the OPC-Foundation, which provides free specifications for developers.

The main reason behind OPC was to create a protocol, which allows different automation applications to work together independent of any manufacture specifications. There are many benefits, both for consumers and manufactures. The consumers are no longer limited to one manufacturer and the system they provide. The consumer can freely change the controller and choose one that suits his needs without changing the whole system. The manufacturers only have to provide one communication-interface and therefore their development process will be shortened. Thus they can concentrate on the application and compete with their products in a larger market.

OPC uses the concept of servers and clients. The server is connected to a controller and provides data to the system throughout clients on their request. Since the server simply is a program it can run in parallel on the same computer as the controller. The clients are data-consumers but they can also send information to the server, typically trough a HMI to control a process.

There are two ways a client can get information from the server. The easiest but an inefficient way is polling. The client asks the server and will receive an answer directly. But the client doesn't know when a value has changed so it has to ask repeatedly. Another way is to let the server notify the client when a value has changed. Then the client can respond by acquiring the value form the server or by reading all values of interest at the moment.

### 3.2 FrameworX built-in OPC-server and its OLE Automation interface

As mentioned earlier FX has a built-in OPC-server. The advantage of this is that every signal defined in the controller is registered in the server directly. The only thing VB needs to know is the name of the server and some additional information if they are located on different machines.

Lets take a closer look how we connect the OPC-server from VB. Of course the API must be installed and registered in VB before any of the code below will work.

First an object that will handle the OPC-server at the client is created. It is then connected to the OPC-server named "fxControl.OPCServer.1" which is the name of the server started by FX-Control. The third row in the code below creates an OPC-Groups object. Each signal in the server must belong to a group. The advantage with groups is that you can create an event to each group that will fire as soon as one of the signals in the group changes its value. This is a very useful way to notify the client that something has happened among all the signals in a specific group. The

object OPC\_Groups handles all groups created in the program and before we can do anything a group must be created.

```
...  
Set OPC_Server = New OPCServer  
OPC_Server.Connect ("fxControl.OPCServer.1")  
  
Set OPC_Groups = OPC_Server.OPCGroups  
Set myGroup = OPC_Groups.Add("myGroup ")  
...
```

After the group two properties are added, IsActive and IsSubscribed must be set to *true* in order to acquire data from the OPC-server, continuously. Before we can register the signals we have another level of object in the OPC-server to handle. OPCItems is an object that keeps a collection of items together inside a specific group.

```
...  
myGroup.IsActive = True  
myGroup.IsSubscribed = True  
  
Set myItems = myGroup.OPCItems  
Set myCommand = myItems.AddItem("#Command", myGroup.ClientHandle)  
...
```

Then finally the signal is added to the OPCItems object. Here it is important that the signal name is spelled exactly as in the server i.e. case sensitive. Otherwise a signal is registered in the server but if there is no corresponding signal name in the server, no error is reported.

Now we can use the signal in our program and we can read and write to the signal. Writing to the signal is simple. We use the method write and the value is written to the OPC-server. Of course a value must be of correct type i.e. Boolean, integer, char but otherwise it's easy.

```
myCommand.Write (setValue)  
  
myCommand.Read  
k = k+ myCommand.Value
```

Reading a value is done in two steps. When the read method is called it collects the value from the OPC-server and stores it in the object in a property named value. After that the value is accessed by calling the property. The value will remain the same until the read method is called again.

### 3.3 Working Models OLE Automation interface

In this section we will take a closer look at WM3 and the API we are using to communicate between VB and WM3. Before we can read or write to WM3 we must create an object in VB so we can access its properties. Following code does this.

```
Set App = GetObject( "WM3D.Application")  
Set Doc = App.ActiveDocument
```

The App object contains a reference to the WM3 program and the Doc object contains a reference to the model in WM3. The Doc object is our link to the model and through this we can access almost everything in the model. We can control the whole simulation or the colour of any body in the model. But to do this we must create a link to each specific object we want to control. In the simulator we are most interested to get values from bodies and to set new values to inputs.

Lets take a closer look how we acquire a reference to a specific body object. The first step is to get references to every body from the Doc object. Then we must know the name of the body in WM3. Here are two possibilities, first we can use WM3 predefined name for each body which is "body[index]" where index corresponds to the order the bodies were created in WM3. Second we can give each object in WM3 a name and use that name to find it from VB.

```
Set CollectionOfBodies = Doc.Bodies  
Set myBody = CollectionOfBodies.Item(myName)
```

In the code above myBody now contains a reference to a specific object named myName in WM3. There is no need to go into each detail of each property but a body object has 4 methods and 6 properties. Two of these methods are GetConfig and SetConfig, which can be used to change the three-dimensional configuration of the body object. However one of the properties is of great importance to the simulator. This is the IsInterferingWith property that returns *true* or *false* if the body is interfering with any other body i.e. this property alone acts as a sensor. Unfortunately this property requires a name of an other body to check if they are interfering. This means that one has to loop through every body of interest before one knows the answer. But the great benefit is that there is no need to calculate any geometry to reveal the answer.

Besides bodies there are motors, inputs and outputs that are of interest, but they all work in a similar way so there is no need to go deeper into that.

Now let's go back to the Doc object. In order to control the simulation there is a method RunTo(FrameNumber) which is very helpful when simulating. Upon calling the method the simulation will start and continue until it reaches the frame number. During this time VB is halted and will resume first when WM3 is done. The frame number is kept by the Doc object, so in order to make a good simulation you increase the frame number by one each simulation cycle and the precision in the simulation is mainly determined by the frame rate i.e. frames per second.



# 4 Simulator design

## 4.1 Description of the simulator

To begin with, we have two industrial programs running on the same computer and using the same resource, the CPU. A third program is also executing in the same environment and is responsible for synchronising information between the programs. When we are simulating we need to calculate how it would be in a real machine and extract information from those calculations and pass the information between the two programs. If we knew from the beginning what we want to do and have all the inputs ready then it would be best to run and complete the first program. The information could then be passed to the second program and after it is completed we would have the result of the simulation. But, this is not sufficient for simulations in the automation industry where we want to pass information between the programs several times during runtime. So instead of running each program completely, we run them a little bit at a time and in between information are shared. So, the main idea behind the simulator is that the available time in the computer is divided in small fractions and that each simulation program is running in parallel. Between the time periods the third program executes and transfers parameters between the programs.

Though, it is interesting to know how a computer handles several programs at the same time we should not concern us anymore about that. Instead we will look how the different programs work together and thereby understand more about the simulation method. At first, we will look at them, as we would like to do in a simulation.

Let us start with the simulator. Before the VB-script can be executed we must start WM3 and FX-View and load the simulation model into the environment. After that we start the VB-script and we are then ready to run the simulation from FX-View.

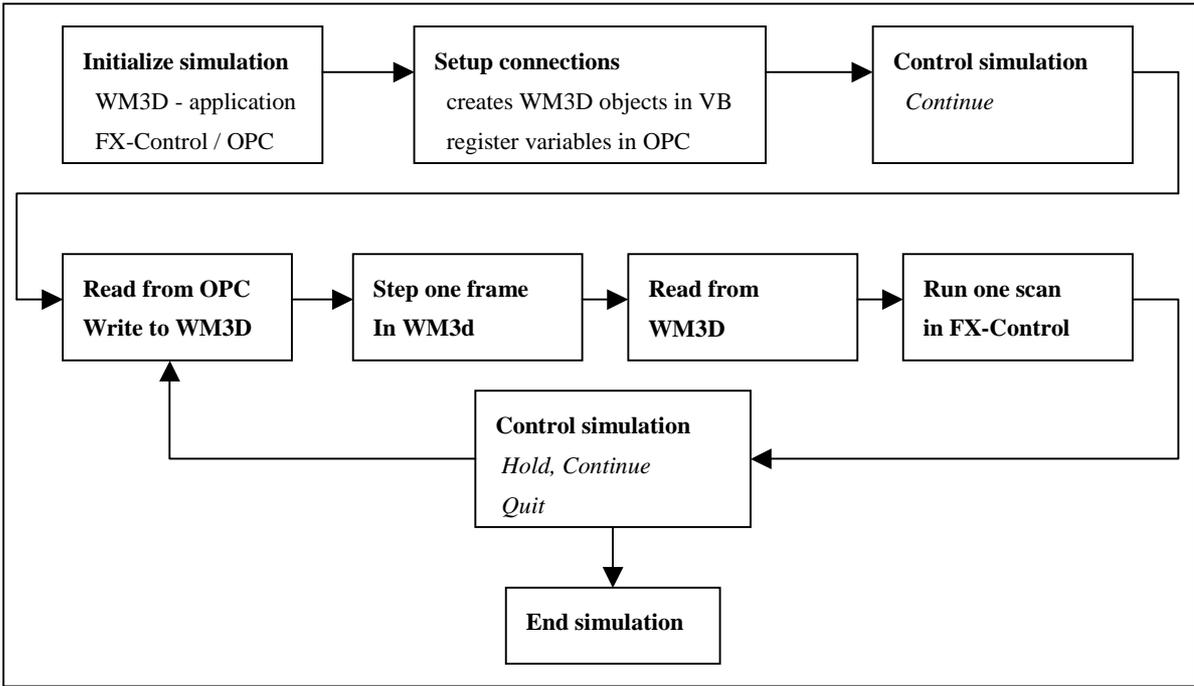


Figure. 4.1 The simulator structure

When the VB-script is started it begins with initialising two objects, one, which is the WM3D application and the other, is the OPC-server in FX. These objects are necessary because they contain the simulation variables that must be transferred between the programs to make the simulation work.

The WM3D-application object contains the whole model and every object can be manipulated from the VB-script. However, most of the manipulation is done during the second stage, set-up connections, before the actual simulation begins. During simulation the only external changes in the model are changing colours at some objects i.e. turning their visibility on or off. But to be able to read some values from the applications object we must create a corresponding object in VB. Of course we must send control signals, inputs, to the simulation but those signals should not be treated as a part of the model.

If we look at the OPC-Server we have a similar problem. But instead of creating a corresponding object in VB we only have to register a variable in the OPC-Server and connect it to the corresponding variable in the controller. So before the actual simulation can start we must initialise all objects and register all variables that we need for the simulator to work. This is also done in the VB-script in two separate modules, which are executed in the set-up connection phase.

Now we are ready to run the simulation. Each cycle in the simulator consists of one scan in the controller and one frame calculation in WM3D. We also have to transfer control signals in both directions during one cycle. In the model we begin each cycle by reading the current controller value in the OPC-server. They are then transferred to WM3D, which then executes one simulation frame. Next, we read the out signals from WM3D and write them to the OPC-server. Finally, we execute one scan in the controller.

The question that should be raised after this, is how we can assure that only one scan is executed in the controller and how do we know when it is done? The answer is that the controller is equipped with a command option which allows us to run only one scan in the controller and then freeze it. After this scan, it also changes a value of one of its internal variables, #command. This variable is accessible throughout the OPC server and connected to a VB-variable during connection-connection phase. When the controller executes, VB is idle and is waiting for an event from the OPC-server. This event is triggered each time the controller changes the value of #command. To summarise: the controller is signalling when one scan is done and VB will continue to execute. Actually we have the same problem for WM3D but it is solved much easier and was discussed in 3.3.

## 4.2 Code design in Visual Basic

The simulator consists of several different components, but the main functionality lies in the VB-script. Therefore we will take a closer look at the structure and code in VB. The complete code is in Appendix A2-10, but some extracts are shown below to make it easier to understand the design and functionality.

In previous chapters we have talked about objects and how we need to create them to be able to run the simulation. But before we can create them they must be designed and programmed in VB. We also need to know which objects are needed and how they work together, which also can be seen in figure 4.2.

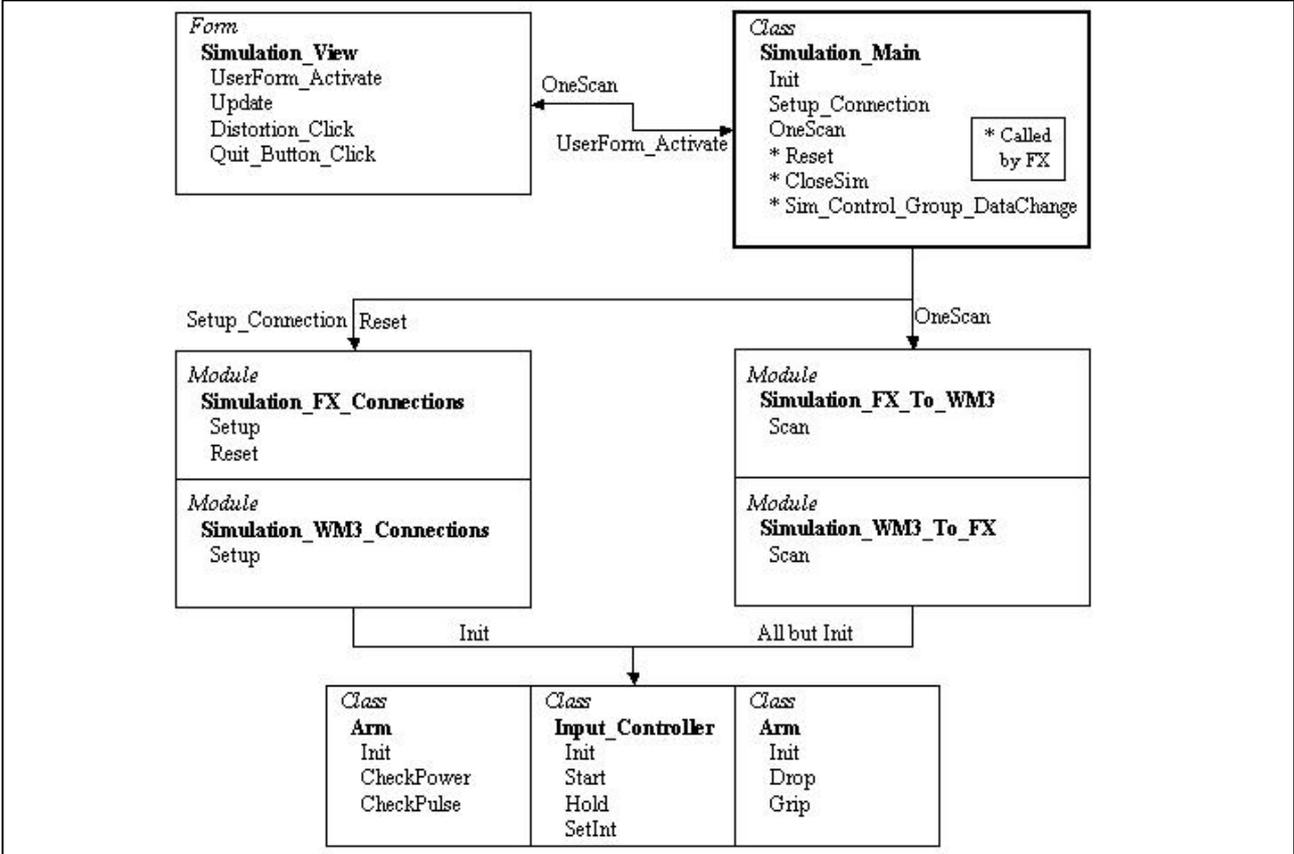


Figure 4.2 Form, class and module dependency in the simulator

In our model we use one class for the simulation core and three classes represent different “real” components in the machine. Of course a machine normally contains more than three components but for now three is sufficient. To be able to simulate a more realistic machine more objects need to be designed. The design of each such object totally depends on how the object is supposed to work and how accurate the model would be. However, it is really easy to add a new class, i.e. a new component to the model. Of course they have to be connected to the model but we don’t have to do any modifications in the simulation core, which is one of the goals of the thesis.

A closer look at the components object reveals that they have two types of methods in common, initialisations methods and runtime methods. The initialisations methods are responsible for connecting, registering and settings of a specific component. These methods are executed in the beginning of each simulation and may also be called when a simulation is reset. The runtime methods are used during a simulation and their task is to read or write signals between FX and WM3D. They are normally called once each scan during the simulation. We will discuss these classes in more detail in 4.2.2.

#### 4.2.2 Simulation\_Main class

The simulator core consists of one class Simulation\_Main and four modules. The class itself controls and runs the simulation. The modules contain all information about all used signals between FX and WM3D. The reason we use four modules is that then we don't need to change anything in the class when we are creating a new simulation model. Everything that belongs to the model itself is controlled from the four modules.

The main program in this model is actually very small and simple. Most of the simulators functionality lies in the Sim object that is an instance of class Simulatin\_Main . When we start the VB-program, a form is activated and this form creates the Sim object. It also throws an event that executes the UserForm\_Activate() method.

```
Private Sub UserForm_Activate()  
    Sim.Init_Sim  
    Sim.Setup_Connections  
    Sim.Sim_Control.Write (8)  
End Sub
```

The Sim object must first be initiated, i.e. create all object used by the simulator such as the OPC-server object, WM3D-application object and connect main control signals. Next all signals used by the model must be attended. This means that every signal defined in the Simulation\_FX\_Connections and Simulation\_WM3\_Connections modules are created, initiated and registered. Finally, signal is sent to the PLC which to run one scan.

Besides this, the form is drawn on the screen. The form is monitoring all signals connected between FX and WM3. During each cycle every signal is updated and this is a very helpful tool when we want to study the simulators behaviour.

The buttons to control the model are created in FX but they are also connected to the Sim object through the OPC-Server. The buttons, Start, Stop and Reset controls the PLC and the program that lies inside. Each one of these buttons is throwing an event when they are pushed causing VB to start, stop or restart the simulation.

As mentioned above Sim is the core of the simulator and therefore we will take a closer look at is Sim\_Init method. There are five main tasks for Sim\_Init to do. First, import and create an object, App, that corresponds to the WM3D model. WM3D must be running and the active document is the simulation model, which is reset.

```

Public Sub Init()
  Set App = GetObject( "WM3D.Application")
  Set Doc = App.ActiveDocument
  Doc.Reset
  App.Activate
  ...

```

After that an object, OPC\_Server, as discussed in chapter 3.2. is created that will handle the OPC-server

```

...
Set OPC_Server = New OPCServer
OPC_Server.Connect ("fxControl.OPCServer.1")
Set OPC_Groups = OPC_Server.OPCGroups
...

```

Third, a number of signals are registered in the OPC-server that will handle the start and stop of the simulation. For this reason a group, Sim\_Control\_Group, is added to the OPC\_groups object. It is also a good idea to set some properties for the group. Most important are the IsActive and IsSubscribed properties as mentioned in 3.2. A third property, UpdateRate, is also set. This controls the rate at which an event from the group may be fired. This rate should match the general frame rate for the simulator.

Next we create an OPCItems to hold the individual signals within the group. Since we only have five signals we could manage with one group, but I have chosen to create two groups. One contains the PLC control buttons, i.e. start, stop and restart signals, and the other one contains simulator signals. After this is done we are ready to register the items or signals to the OPC-server. So by adding them to the Main\_Group\_Items object, we create a VB-object at the same time.. The only requirement is the name of the corresponding signal in FX-control.

```

...
Set Sim_Control_Group = OPC_Groups.Add("Sim_Control_Group")
Sim_Control_Group.UpdateRate = 250
Sim_Control_Group.IsActive = True
Sim_Control_Group.IsSubscribed = True
Set Sim_Control_Items = Sim_Control_Group.OPCItems
Set Sim_Control = Sim_Control_Items.AddItem("#Command", Sim_Control_Group.ClientHandle)
Set PLC_Ready = Sim_Control_Items.AddItem("PLC_Ready", Main_Group.ClientHandle)
Set Main_Group_Items = Sim_Control_Group.OPCItems
Set Main_Control_Start = Main_Group_Items.AddItem("Main_Control.SwitchOutput[0]", Main_Group.ClientHandle)
Set Main_Control_Stop = Main_Group_Items.AddItem("Main_Control.SwitchOutput[1]", Main_Group.ClientHandle)
Set Main_Control_Reset = Main_Group_Items.AddItem("Main_Control.SwitchOutput[2]", Main_Group.ClientHandle)
PLC_Ready.Read (2)
  While Not (PLC_Ready.Value = 1)
    PLC_Ready.Read (2)
  Wend
End Sub

```

The most important signal for the simulator is the #Command signal in the PLC which allows us to control the simulator by starting, stopping and do a single scan in the controller. The object corresponding to #Command is named Sim\_Control in VB. There is an other signal in this group, PLC\_Ready that is used in the beginning to check if the controller is up and running.

As soon as all five signals are registered, the event driven method Sim\_Control\_Group\_DataChange is called when anyone of those signals changes its value. So, to start the simulation we just have to push the start button in FX.

```
Public Sub Sim_Control_Group_DataChange
    If Main_Control_Start Then
        Call OneScan
    End If
    If Main_Control_Restart Then
        Call Reset
    End If
End Sub
```

Now we have reached the core in the simulator, the One\_Scan method. If we compare the code with figure 4.1 we recognise that the four boxes in the middle row corresponds to the five lines in the method. The remaining two lines are updating the VB-form, so every signal can be monitored. This is done every time signals are parsed from FX or WM3D.

```
Public Sub OneScan()
    Simulation_Fx_To_WM3.Scan Me
    Call Simulation_Veiw.Update
    Frame = Frame + 1
    Doc.RunTo (Frame)
    Simulation_WM3_To_FX.Scan Me
    Call Simulation_Veiw.Update
    Sim_Control.Write (8)
End Sub
```

OneScan begins with passing all signals from the controller to WM3D. Then one frame is executed in WM3D. During that time period the VB script is halted and will resume first when WM3D is done. Next signals are transferred to the controller and finally one scan are executed in the PLC. Now VB is idle and waits for something to happen. And as soon the PLC has done one scan the #Command will be set to 0 and the Sim\_Control\_Group\_DataChange method is activated and another cycle is started.

### 4.2.3 Component classes

There are two things a user of the simulator has to do in VB to be able to run a simulation. One of them is creating component classes and the other is connecting them to the simulator.

When we want to design a new class corresponding to a real component there are several things to look at. First of all we want the object to act as a real one but on the other hand it must be reasonably easy to use. Depending of the type of simulation there is a trade-off between accuracy and speed. If we want better performance of the object it usually takes more time to calculate the simulated parameters of the component and vice versa.

However in our model we already has a program, WM3D, taking care of the mechanical simulation. What we have to do is extracting information from the model in WM3D and translate it to useful signals in FX-control. Some properties are easy to gain; others take some calculations to obtain. Fortunately, the API to WM3D gives us several ways to extract information, which isn't supported by the internal script language in WM3D. Exploring all possibilities using script and API together would probably give us quite good objects, but that is not one of the main goals of this thesis. Therefore only three components are modelled and in a "quick and dirty" fashion way. The most important has been to show that a controller can control WM3D during runtime.

There are three classes, each one representing one type of component in the simulation model. These are Sensor, Arm and InputController. They all have one method, *init*, in common. This method is called during Set-up and is responsible for connecting a VB variable to WM3D. During the simulation each component has its own methods depending on its functionality. Next we will discuss each component in brief.

#### Sensor component

A sensor can be one many different types, optic, heat, pressure etc. Depending of the model, different sensors will be implemented. The sensor modulated in our model is a contact sensor, which gives a *true* value when something is in contact with the sensor, otherwise *false*. There are 34 sensor objects that together act as 28 sensors in the model. The idea behind each sensor is when two objects are in contact with each other a signal should be set to *true*. Now, how do we detect this? If we look at WM3D one way would be to calculate the distance between specific points in each object. When the distance is smaller than a certain value the objects are in contact with each other. If the objects are symmetrical it would, in general, be fairly easy to make the detection. But if they were not, we would have to a bit more complex algorithm, which would take some CPU-time to execute and thereby slowing the simulation down and also increase the time to build the model.

Instead of doing all this by ourselves, we use a method for body objects in the API for WM3D. This method, *IsInterfering*, reveals if two specific objects are in contact. In WM3D the sensor consists of one single body. The size and position of the body depends on the specific model. Unfortunately, this method has two bodies as input parameters and therefore we must test every pair of bodies that are of interest. If any pair is true the sensor should be set to *true* otherwise *false*. But this method is much easier to use than calculate the distance.

The sensor object has three methods, `init` and `CheckPower` and `CheckPulse`. The difference between the last two ones is that `CheckPulse` only is set to true during the first executed frame when the two objects are in contact. `CheckPower` remains true during the whole time while the objects are in contact. The `init` method is used during connection and contains the sensor body and the trigger body. During the simulation `CheckPower` and `CheckPulse` are called every time signals are parsed from WM3D to FX.

## **Input\_Controller component**

The `Input_Controller` component is a simple object. It passes an integer value to an input object in WM3D that could be used in many ways. In our model an input controls the speed of a motor. The motor has three levels 0-2 that mean stop, half and full speed. To set the value a method, `setInt` is implemented and the value from is parsed to the input object. Besides this method `Input_Controller` has three more, `init`, `start` and `hold`. `start` and `hold` actually sets the value 1 and 0. `init` is used during setup and it has one parameter, a WM3D input object.

## **Arm component**

Finally, the `Arm` component, which basically is the same as an `Input_Controller`, but it only, has two levels. So it is fair to say that it is more like a binary controller, and that properly would be a better name. But it uses reversed logic which means that set is zero instead of one and vice versa. Besides `init` it has two other methods, named `Grip` (zero) and `Drop` (one), which makes it easier to use the component because one does not have to bother about the reversed logic.

### **4.2.4 Simulation modules**

Besides the main class we have four modules that are strongly connected and works together with the main class. Two of them, `Simulation_FX_Connections` and `Simulation_WM3_Connections` handle the initialisations of the signals and they are called once in each simulation. The other two, `Simulation_Fx_To_WM3` and `Simulation_WM3_To_Fx` are called once each scan during runtime and transfer the signals between the programs.

They all have in common that the builder of the simulation model must edit these modules. For each signal or group of signals, depending on design, in the simulation model the builder must program the four modules according to their use.

The “Connections” modules contain two methods, `connection` and `reset`. `Set-up` is called when `Sim.Setup_Connection` is called in the beginning of the simulator execution. `Connection` is responsible for connecting a signal between FX and WM3D. This means, create an object corresponding to a signal in the OPC-server and register it. And of course create an object corresponding to a component in WM3D and initiate it.

If we start looking at `Simulation_FX_Connections`, the builder must declare the object and connect it to a signal in the OPC-server. This is done in the same way as we introduced the `PLC_Ready` signal earlier. All signals are declared as `Public` and there is a naming convention, which states that every object related to the OPC-server should begin with “FX\_”. If it is a signal all the following letters are written in upper case, otherwise they are written in lower cases, but the first letter in each word is still in upper case. If it were an input to the OPC-server the letters `IN_` will be added to the object name and of course the name of an output object would be `FX_OUT_`. When `Set-up` is called the signal is registered in the `OPC_Server` and ready to be used. In the code it would look something like this

```
Public FX_Test_Group As OPCGroup
Public FX_Test_Items As OPCItems
Public FX_IN_TEST SIGNAL As OPCItem

Sub Setup (Sim As Simulation_Main)
    Set FX_Test_Group = Sim.OPC_Groups.Add("Test_Group_Name")
    Set FX_Test_Items = FX_Test_Group.OPCItems
    Set FX_IN_TEST SIGNAL = FX_Test_Items.AddItem("OPC_SIGNAL_NAME",
                                                FX_Test_Group.ClientHandle, , , )
End Sub
```

It is important to notice that the `OPC_SIGNAL_NAME` must be written exactly i.e. case sensitive as in the controller. Otherwise it will not be found in the server. The other method, `reset`, is much simpler because the only task it has is to reset the value to the initial values of the component.

The other module, `Simulation_WM3_Connections`, is a bit more complicated. Of course we have to declare the object but we also might have to declare some extra variables to support, depending how the component is designed. One example is when we use the sensor component. Besides the sensor object we need a variable to store the result of an OR function between a group of sensor. The reason behind this is the implementation of the sensor. As discussed in the previous section the `CheckPower` function works between two bodies. If we want a sensor to react upon more bodies we must test each pair. An other way to deal with this could be done with an alternative implementation of the `Sensor` component. Instead of one trigger body we could have entered several bodies, but the work of the computer would remain the same. Let’s see how the sensor placed at the end of the conveyor is modulated. First, a look at `Simulation_WM3_Connection`

```
Public WM3_OUT_CONVEYOR_END(5) As New Sensor

Sub Setup(Sim As Simulation_Main)
    ...
    WM3_OUT_CONVEYOR_END(0).Init Sim, "body[239]", "body[233]"
    WM3_OUT_CONVEYOR_END(1).Init Sim, "body[239]", "body[234]"
    WM3_OUT_CONVEYOR_END(2).Init Sim, "body[239]", "body[235]"
    WM3_OUT_CONVEYOR_END(3).Init Sim, "body[239]", "body[236]"
    WM3_OUT_CONVEYOR_END(4).Init Sim, "body[239]", "body[237]"
    ...
End Sub
```

Here each container (body[233]-[237]) acting as a sensor and will react upon contact with body[239] with is the real sensor. But we want the sensor the give us a signal when any of the containers are in contact with the sensor. So, by using the OR function we can retrieve a single value that we can parse along to the controller. This is how it is implemented in Simulation\_WM3\_To\_FX

```
Public conveyor_end As Boolean
```

```
Sub Scan(Sim As Simulation_Main)
```

```
    conveyor_end = False
```

```
    For I = 0 To 4
```

```
        conveyor_end = conveyor_end Or WM3_OUT_CONVEYOR_END(I).CheckPower()
```

```
    Next
```

```
    FX_IN_SW_CONTAINER_READY(0).Write (conveyor_end)
```

```
    ...
```

We can see that the same naming conventions apply, except that FX\_ is substituted against WM3\_. One other major difference is that the object (in this case Sensor) has methods, which is called instead of the set statement. Once again it depend on how the component is designed. In this case we start by calling the init method, which basically connects the object to an object in WM3D.

The last two modules are called during runtime. One of them contains the code that transfers the signal value from FX to WM3. The other module is taking care of the signals in the opposite direction, from WM3D to FX. They both contain a method named Scan, which is called once in each simulation cycle.

#### **4.2.5 Arrangement in FrameworX and Working Model**

In this section we will take a closer look at some special arrangement that must be done in FX and WM3D in order to make the simulator to work. First of all we must make sure of that both programs have the same simulation speed i.e. the frame rate in WM3D and the scan rate in FX. This could and should be done from the Sim Objects sim\_init method. However, for some unknown reason this hasn't been implemented in the simulator and instead it has been done manually. It should be quite easy to implement and in a full working simulator this must be done.

If we look at it in the “quick and dirty” way we begin with setting the scan rate variable. It should be set to a value no less than 50 ms even if the PLC is capable of handling scan rates down to 10 ms. Instead the limit is based on WM3D capacity and therefore 50 ms are recommended as a minimum value. In the model have chosen 250 ms to avoid a slow simulation.

Scan rate in FX corresponds to frame rate in WM3D but instead of assigning the time interval between each scan we assign the number of calculated frames per second. A scan rate of 50 ms corresponds to a frame rate of 20 frames per second. Even if it quite easy to calculate this value it should be done during the execution of sim\_init to avoid any miss configuration.

Besides actually building the model in WM3D we can do some settings to improve the simulator speed. One way is to remove unnecessary calculations among some graphical objects. For example, we can turn off collision detection for those objects that can never be in contact with each other. There are several other possibilities to improve the simulation but then one really has to know how WM3D works in detail to take advantage of those methods.

In FX, or more precisely in the controller, there is one signal in the program that belongs to the simulator. The signal, PLC\_Ready, was described in section 4.2.1 and its main purpose is to tell VB that the controller is up and running and ready to start. There will be a closer look at this in chapter 5 when the ladder code is examined in more detail.



## 5 Test Model

### 5.1 Description of the model

In the previous chapters we have focused on the simulator, but we also need something to simulate. For that reason a simple test model, the machine, has been designed, fig 5.1. The main purpose is to show how the signals from FX can control the machine in WM3D and of course the other way around. In brief the machine consists of two wheels, one conveyor and a number of grip arm stations symmetric placed around the wheels edge. This could very well be a part taken from a filling machine form the packaging industry. There is one small wheel with 3 arms and a larger wheel with 10 arms.

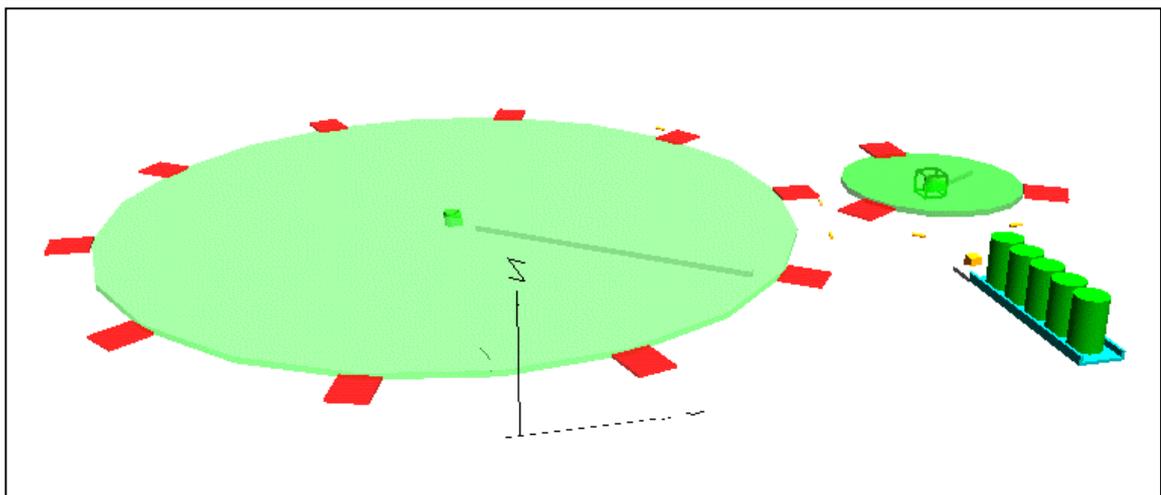


Figure 5.1 A simple graphical overview over the test model.

A package is first transported on the conveyor, and then picked up by a grip arm on the small wheel. After three-quarter of a turn it is released to the larger wheel, which controls the package for almost one turn before the grip arm drops the package and it disappears. The conveyor and the small wheel act as a synchronisation module to the large wheel, which will fill and close the package.

If we look at one package and describe what the machine is supposed to do, we have the following. A package arrives at the beginning of the conveyor and is transported along the line until it reaches the end of the conveyor. Here we need some kind of sensor (1) telling the controller that a package is ready for the small wheel. The wheels are running at continually speed so we need a second sensor (2) to tell when the grip arms are in position to pick up the package. When the controller receives the signal, it responds with a signal to the grip arm to grab the package. Actually it is the grip arm that sends a signal when it has reached the sensor and this is how the controller knows which grip arm should grab the package. The package then moves along the small wheel until it reaches the transfer point to the large wheel. Here the controller receives another signal (3), which means that the package is in position to be released to the large wheel. In the same way the large wheel has a sensor (4) at each grip arm. The controller then responds with one signal to the grip arm at each wheel, so the transfer of the package could be complete. Now the package will move almost

one turn at the large wheel before the grip arm receives a signal (5) to release the package and it will disappear.



## 5.2 The monitor

To watch the simulation there is a simple monitoring tool. It was the last thing implemented in the simulator and in a “quick and dirty” way. However it fulfills its purpose even if it could be improved a lot. As we can see in fig. 5.2 there is a window placed besides the FX.view so we can see all signal changes but still be able to control the simulator. The monitor is written in VB and is updated each time signals are transferred in any direction.

A minor error in the monitor is that there is a mix of Booleans and integers but they really mean the same, *false* means zero and *true* means one. As mentioned earlier, signals labelled OUT\_ are signals from FX and signals labelled IN\_ are signals to FX or as it says in the monitor from WM3. SW means the small wheel and LW the large wheel. There are three arms on the small wheel implying that there are three columns after the signals name and ten arms around the large wheel.

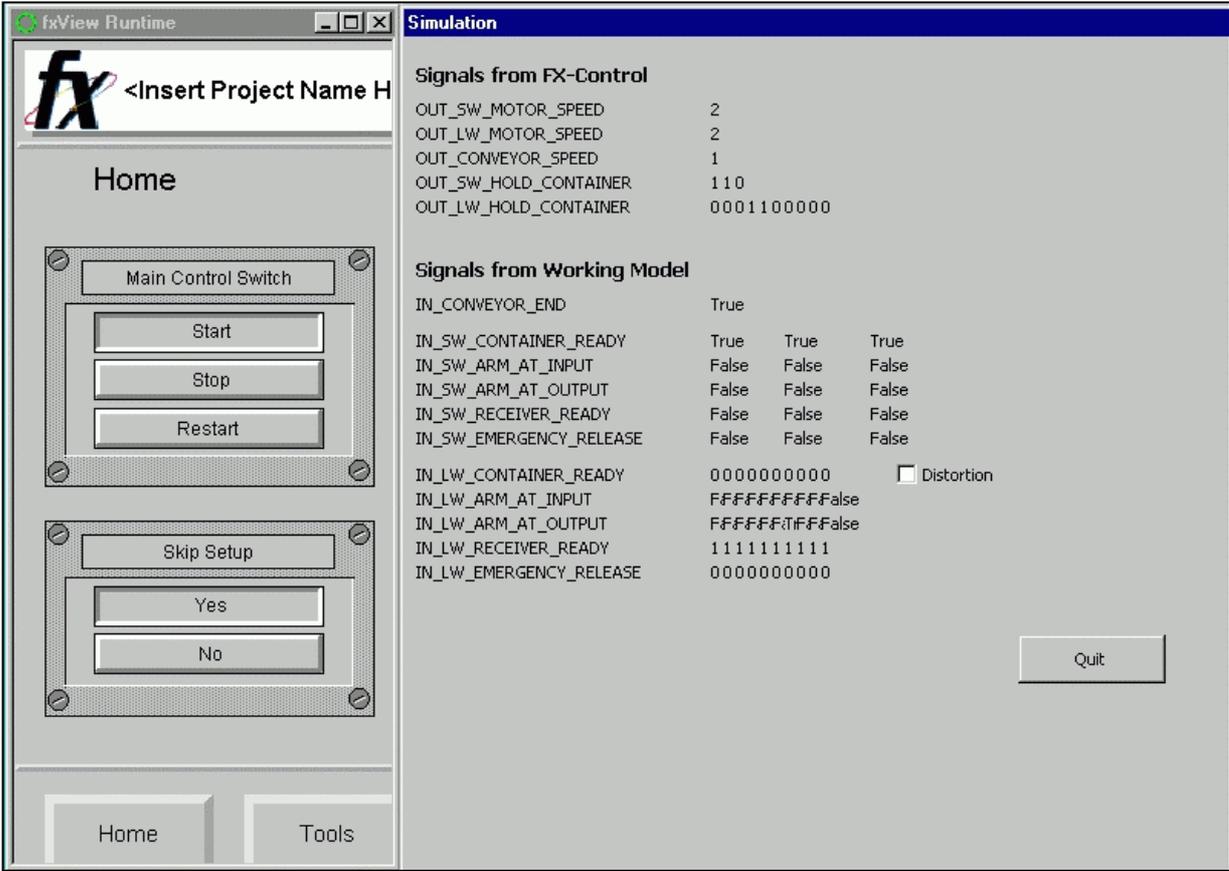


Fig 5.3 FX-view and the monitor, side by side

Besides monitoring all signals we can also put in some failure in the simulation. When active we are overriding the IN\_LW\_CONTAINER\_READY signal and the transfer between the wheels never occurs. Instead we will be able to see that the IN\_SW\_EMERGENCY\_RELEASE signal works as it should.

### 5.3 The controller

The control program in the simulation is quite simple and its main purpose is to show that it is possible to control a model in WM3. All development of the controller program is done in FX. The program is built in ladder and SFC and the full program can be found in Appendix A11. To be able to understand the simulation better a brief explanation of how it works comes next.

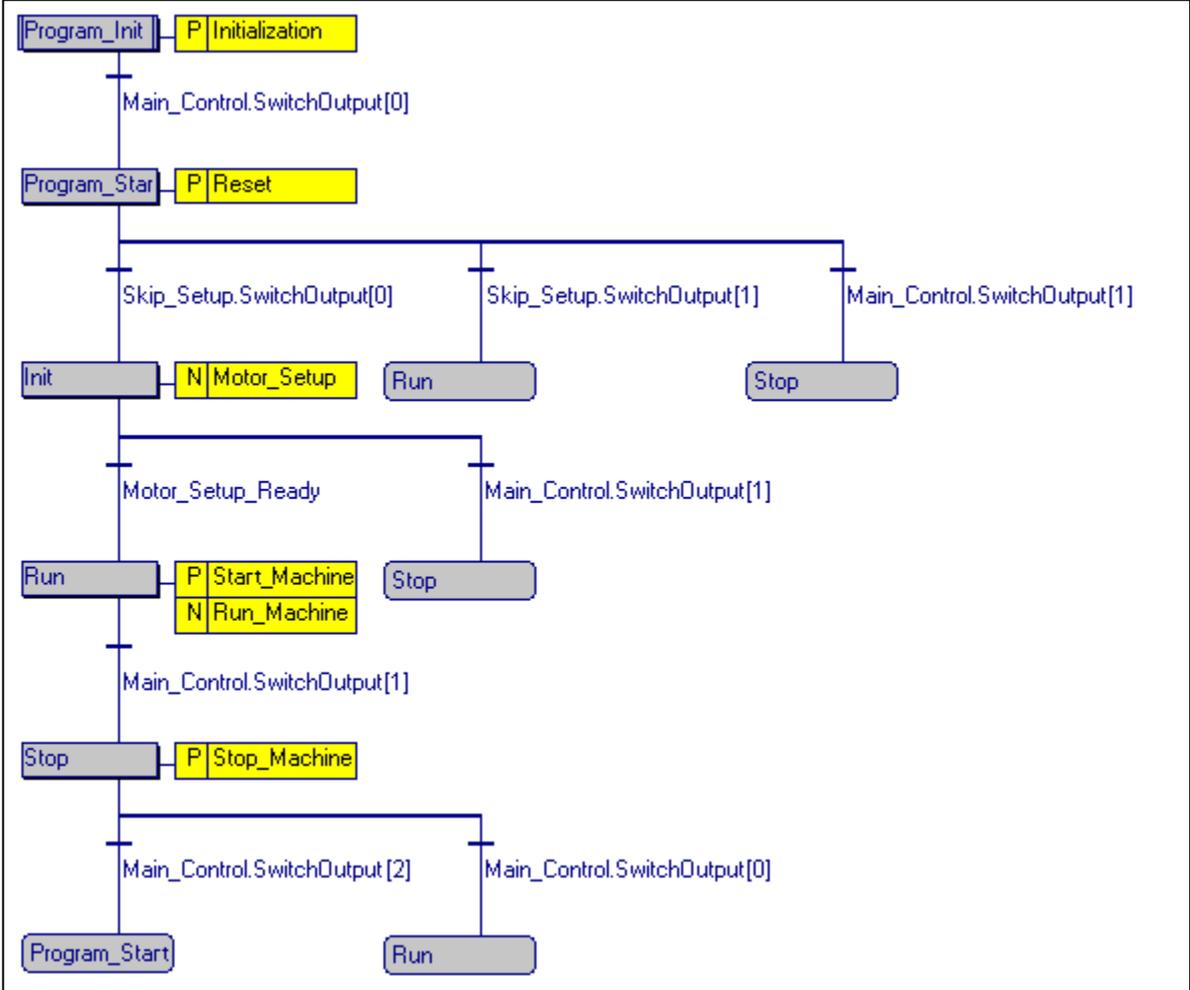


Fig 5.4 The controller described in SFC

First we have the SFC, which shows the different states that the machine can be in. There are 5 different states in the chart and almost all transitions are controlled from the main menu in FX-View. When the controller is started we start in the state named “Program\_Init” where the initialisation takes place.

Before we explain the flow further a few words about how the SFC chart works are in order. The dark grey boxes are the different states in the flow. Each state has a name and those boxes with rounded corners with the same name as a state mean that the flow will jump to that state. The remaining light-grey boxes have a link to a yellow box, which contain the name of those actions or subroutines that are executed when we are in a certain state. Before each name there is a letter ‘N’ or ‘P’. The label P means that the subroutine is executed only at the first scan after it enters a state. This is useful for initialisations of variables. The ‘N’ label means that the subroutines are executed

every scan until it leaves the state. Each subroutine is written in ladder and these are found in Appendix. Between states there is a condition to fulfil before a transition is made. In this flow a transition takes place when the variables value is true or if it is an integer greater than zero.

In the chart we can see that there are three variables, which control the transitions in the chart. Main\_Control, is an object in FX-View that controls the simulation status. The user of the simulator can start, stop and reset the simulator from FX-view. This corresponds to three Boolean attributes to Main\_Control where SwitchOutput[0] is the start button and SwitchOutput[1] is the stop button and finally SwitchOutput[2] is the reset button. A second object in FX-View, Skip set-up is controlling weather we should skip the initialisation sequence, Motor\_Setup, when running the test model. The actual reason for this control is that it takes several seconds to go through this sequence and to save some time during every test this was an easy way to do a short cut. Finally there is a transition condition, Motor\_Setup\_ready, which isn't controlled from FX-View. Instead this signals becomes true when Motor\_Setup is done.

Now, lets get back to the flow. As mentioned before there are five states in the machine, and all of them have at least one subroutine linked to them. To simplify it even further, we say that the Initialisation, Motor\_Setup, Start\_Machine and Stop\_Machine subroutines are so easy that they don't need any further explanation. The only thing they do is to change some variables value and this can be seen in the ladder code in Appendix A11. Instead we will concentrate on the Run\_Machine subroutine.

In section 5.1 the model was described and there we saw that the machine consists of 13 grippers placed around the wheels. When we run the machine each arm has its own piece of ladder code and they all run independently of each other. Each piece is encapsulated into an object and the Run\_Machine therefore consists of 13 objects of the same type. Instead of printing the ladder code here, lets look at the functionality through an equivalent state-diagram, shown in fig 5.5.

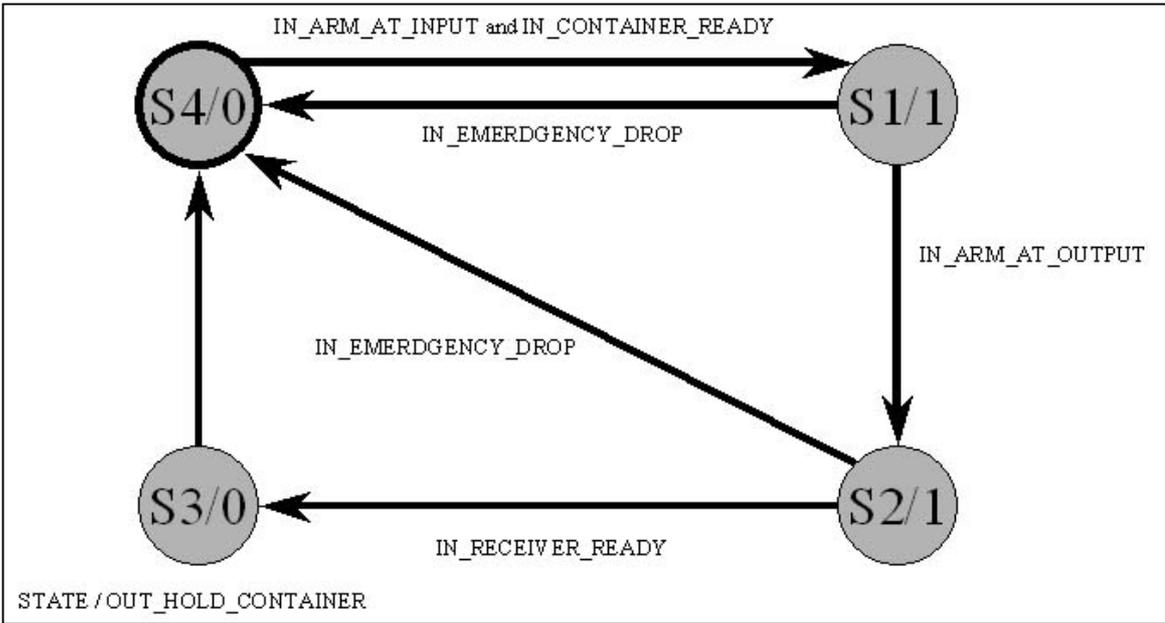


Fig 5.5 An equivalent state-diagram over the grip arm

There are 4 states in the diagram and it starts in S4. There are two requirements to meet to move to S1. First there needs to be a container in position to be picked up. Second, the arm needs to be at the right place. If both these criteria's are met, the container is picked up, i.e. the output signal to the arm is set on and the arm should grab the container. Next, we wait for a signal that we are in position to deliver the container and that takes us to state S2. Finally we wait for a signal from the receiver, which takes us to S3 and then directly back to S4. If something goes wrong there is an emergency drop signal that will take us back to S4 and the container is dropped immediately.

Since the container is transferred between the small and the large wheel these must be synchronised. They must have the same lead-time and the grip arms must be in correct position for at transfer to occur. For that matter there is a subroutine, Motor\_Setup, which will set the wheel in right position. This is done by running each motor at a lower speed until they reach a sensor. When both wheels signal that they are in right position both motors will continue in full speed.

## 6 Conclusions

### 6.1 Result

There are three major results to point out from this thesis. First and of course the most important is that the idea behind the simulator structure works. It was possible to connect these two programs with help of a third tool and let the simulator work in accurate time. The real drawback was that it is far from real-time simulation.

Second point is that if both programs would have used the same communication system i.e. OPC we would have had a much simpler and better core. Instead of a lot of connection modules we could connect the signals directly to each other and the core should only contain the timing mechanism and the monitor. But this is something the industry can work on by pushing the software manufacturers to supply them with better tools. Originally WM3 wasn't designed to handle external signals during simulation and therefore there was no need for the manufacturer to integrate any common communication interface like OPC, but now there is a reason.

Third point is about designing the model and core code as efficient as possible. Even if we will get faster computers they cannot make up for everything. We need to think carefully how the logic should be structured in the simulator and how the code can be optimised, independently of where it is located, i.e. in the core or in Working Model. If the script language in WM3 would have been a bit more powerful we could have smoother calculations and the core wouldn't have to do anything else besides controlling the flow.

Then we may ask ourselves, if WM3 is the best program for this purpose?

### 6.2 Possible improvements

Besides changing the hardware, which can improve the simulation speed, there are a few things to do to the simulator in general.

First, all signals are hard coded into the four VB modules, which takes some time and is inconvenient. It should at least be reduced to one module. Instead each object should have some more method that takes care of all initialisation and connection in a more automatic way.

The core should be replaced by stand-alone program, perhaps written in Java or C++. This should provide a faster transmission between FX and WM3. One problem here is that there is no API for C++ or Java available but since there is a VB-API it shouldn't be any problem to generate one for C++.

We could also improve the simulation of failure by adding a property to each signal. This property could contain the fail rate of the signal. The rate could determine how often a signal change would be lost or randomly changed.

There are some overall simulation properties like frame rate and scan rate that should be controlled from the simulation main instead of changing them separately inside FX and WM3.

A great improvement would be a connection tool where we could map signals from FX to WM3 and vice versa. There is some kind of support for this through the VB-API between OPC and VB but between the VB and WM3 it must be implemented from scratch. To achieve this in a simple way all logic that is performed in VB to support WM3 should be moved to WM3. The drawback here is that WM3 script language is limited, as mentioned in 2.2.2, but newer versions might provide better functions and a deeper insight into what can be done with the script may overcome this.

### **6.3 Future developments**

When we have a stable and functional simulation core there are several possible expanding tools to consider. Below there is a list with several different tools with a brief explanation. They are not ordered in any particular way.

*Graphical construction tool* – This would make the simulator much more user friendly and easier to build the model and understand the simulation.

*Libraries with objects* – Each new object constructed in the simulator should be added in the library structure in order to build up a powerful toolbox.

*Report generator* – If we want to run longer simulations we must have a tool that can summarize the simulation.

Finally, a quick look in the systems performance monitor, at the particular computer we used, reveals that it is WM3 that consumes around 75% of the CPU capacity during a simulation. So in order to have a good simulator WM3 must be improved quite a bit. One way could be to use two computers and separate WM3 from the rest. But this is a hardware issue and as mention before changing the hardware can increase the simulation speed enormous.

# A Appendix

## A1 Nomenclature

<b>API</b>	Application Programming Interface
<b>CAD</b>	Computer Aided Design
<b>CPU</b>	Central Processing Unit
<b>DCOM</b>	Distributed Component Object Model
<b>FX</b>	FX-Control
<b>GUI</b>	Graphical User Interface
<b>HMI</b>	Human Machine Interface
<b>I/O</b>	Input Output
<b>IEEE</b>	Institution of Electrical and Electronic Engineers
<b>OLE</b>	Object Linking and Embedding
<b>OPC</b>	OLE for Process Control
<b>PLC</b>	Programmable Logic Controller
<b>SFC</b>	Sequential Flow Chart
<b>VB</b>	Visual Basic
<b>WM3</b>	Working Model 3D

## A2 Form Simulation\_View

This form contains the monitor and is also the starting application in Visual Basic. When the form is activated the simulation core is started. Each time here is a transport of value the Update method is called. Beside the quit button, which ends the application there is a distortion button that removes a signal to simulate a failure.

```
Public Sim As New Simulation_Main
```

```
Private Main_Control As Boolean
```

```
Private Sub Distortion_Click() // Toggles distortions
```

```
    Sim.Interference = Distortion.Value
```

```
End Sub
```

```
Private Sub Quit_Button_Click() // Ends application
```

```
    Sim.CloseSim
```

```
    Set Sim = Nothing
```

```
End Sub
```

```
Private Sub UserForm_Activate() // Executed on activation
```

```
    Sim.Init
```

```
    Sim.Setup_Connections
```

```
    Sim.Sim_Control.Write (8)
```

```
End Sub
```

```
Public Sub Update() // Updates monitor values
```

```
    // The sensor at the conveyors end
```

```
    IN_CONVEYOR_END.Caption = conveyor_end
```

```
    // The out signal the griparm
```

```
    FX_OUT_SW_HOLD_CONTAINER_0.Caption = FX_OUT_SW_HOLD_CONTAINER(0).Value
```

```
    FX_OUT_SW_HOLD_CONTAINER_1.Caption = FX_OUT_SW_HOLD_CONTAINER(1).Value
```

```
    FX_OUT_SW_HOLD_CONTAINER_2.Caption = FX_OUT_SW_HOLD_CONTAINER(2).Value
```

```
    // The sensor which signals if there is a package ready on the conveyor
```

```
    FX_IN_SW_CONTAINER_READY_0.Caption = FX_IN_SW_CONTAINER_READY(0).Value
```

```
    FX_IN_SW_CONTAINER_READY_1.Caption = FX_IN_SW_CONTAINER_READY(1).Value
```

```
    FX_IN_SW_CONTAINER_READY_2.Caption = FX_IN_SW_CONTAINER_READY(2).Value
```

```
    // The sensor which signals if the arm is in position to grab a package at the small wheel
```

```
    FX_IN_SW_ARM_AT_INPUT_0.Caption = FX_IN_SW_ARM_AT_INPUT(0).Value
```

```
    FX_IN_SW_ARM_AT_INPUT_1.Caption = FX_IN_SW_ARM_AT_INPUT(1).Value
```

```
    FX_IN_SW_ARM_AT_INPUT_2.Caption = FX_IN_SW_ARM_AT_INPUT(2).Value
```

```

// The sensor which signals if the package is in position to be released to the large wheel
FX_IN_SW_ARM_AT_OUTPUT_0.Caption = FX_IN_SW_ARM_AT_OUTPUT(0).Value
FX_IN_SW_ARM_AT_OUTPUT_1.Caption = FX_IN_SW_ARM_AT_OUTPUT(1).Value
FX_IN_SW_ARM_AT_OUTPUT_2.Caption = FX_IN_SW_ARM_AT_OUTPUT(2).Value

// The sensor which signals if there is an arm on the large wheel in position to receive a package
FX_IN_SW_RECEIVER_READY_0.Caption = FX_IN_SW_RECEIVER_READY(0).Value
FX_IN_SW_RECEIVER_READY_1.Caption = FX_IN_SW_RECEIVER_READY(1).Value
FX_IN_SW_RECEIVER_READY_2.Caption = FX_IN_SW_RECEIVER_READY(2).Value

// The sensor which signals if the package isn't released in a normal way
FX_IN_SW_EMERGENCY_RELEASE_0.Caption = FX_IN_SW_EMERGENCY_RELEASE(0).Value
FX_IN_SW_EMERGENCY_RELEASE_1.Caption = FX_IN_SW_EMERGENCY_RELEASE(1).Value
FX_IN_SW_EMERGENCY_RELEASE_2.Caption = FX_IN_SW_EMERGENCY_RELEASE(2).Value

// Motor and conveyor speed controls
FX_OUT_SW_MOTOR_SPEED_.Caption = CStr(FX_OUT_SW_MOTOR_SPEED.Value)
FX_OUT_LW_MOTOR_SPEED_.Caption = CStr(FX_OUT_LW_MOTOR_SPEED.Value)
FX_OUT_CONVEYOR_SPEED_.Caption = CStr(FX_OUT_CONVEYOR_SPEED.Value)

// The out signal the griparm
FX_OUT_LW_HOLD_CONTAINER_0.Caption = FX_OUT_LW_HOLD_CONTAINER(0).Value
FX_OUT_LW_HOLD_CONTAINER_1.Caption = FX_OUT_LW_HOLD_CONTAINER(1).Value
FX_OUT_LW_HOLD_CONTAINER_2.Caption = FX_OUT_LW_HOLD_CONTAINER(2).Value
FX_OUT_LW_HOLD_CONTAINER_3.Caption = FX_OUT_LW_HOLD_CONTAINER(3).Value
FX_OUT_LW_HOLD_CONTAINER_4.Caption = FX_OUT_LW_HOLD_CONTAINER(4).Value
FX_OUT_LW_HOLD_CONTAINER_5.Caption = FX_OUT_LW_HOLD_CONTAINER(5).Value
FX_OUT_LW_HOLD_CONTAINER_6.Caption = FX_OUT_LW_HOLD_CONTAINER(6).Value
FX_OUT_LW_HOLD_CONTAINER_7.Caption = FX_OUT_LW_HOLD_CONTAINER(7).Value
FX_OUT_LW_HOLD_CONTAINER_8.Caption = FX_OUT_LW_HOLD_CONTAINER(8).Value
FX_OUT_LW_HOLD_CONTAINER_9.Caption = FX_OUT_LW_HOLD_CONTAINER(9).Value

// The sensor which signals if there is an arm on the small wheel in position to deliver a package
FX_IN_LW_RECEIVER_READY_0.Caption = FX_IN_LW_RECEIVER_READY(0).Value
FX_IN_LW_RECEIVER_READY_1.Caption = FX_IN_LW_RECEIVER_READY(1).Value
FX_IN_LW_RECEIVER_READY_2.Caption = FX_IN_LW_RECEIVER_READY(2).Value
FX_IN_LW_RECEIVER_READY_3.Caption = FX_IN_LW_RECEIVER_READY(3).Value
FX_IN_LW_RECEIVER_READY_4.Caption = FX_IN_LW_RECEIVER_READY(4).Value
FX_IN_LW_RECEIVER_READY_5.Caption = FX_IN_LW_RECEIVER_READY(5).Value
FX_IN_LW_RECEIVER_READY_6.Caption = FX_IN_LW_RECEIVER_READY(6).Value
FX_IN_LW_RECEIVER_READY_7.Caption = FX_IN_LW_RECEIVER_READY(7).Value
FX_IN_LW_RECEIVER_READY_8.Caption = FX_IN_LW_RECEIVER_READY(8).Value
FX_IN_LW_RECEIVER_READY_9.Caption = FX_IN_LW_RECEIVER_READY(9).Value

```

```
// The sensor which signals if there is a package ready on the small wheel
FX_IN_LW_CONTAINER_READY_0.Caption = FX_IN_LW_CONTAINER_READY(0).Value
FX_IN_LW_CONTAINER_READY_1.Caption = FX_IN_LW_CONTAINER_READY(1).Value
FX_IN_LW_CONTAINER_READY_2.Caption = FX_IN_LW_CONTAINER_READY(2).Value
FX_IN_LW_CONTAINER_READY_3.Caption = FX_IN_LW_CONTAINER_READY(3).Value
FX_IN_LW_CONTAINER_READY_4.Caption = FX_IN_LW_CONTAINER_READY(4).Value
FX_IN_LW_CONTAINER_READY_5.Caption = FX_IN_LW_CONTAINER_READY(5).Value
FX_IN_LW_CONTAINER_READY_6.Caption = FX_IN_LW_CONTAINER_READY(6).Value
FX_IN_LW_CONTAINER_READY_7.Caption = FX_IN_LW_CONTAINER_READY(7).Value
FX_IN_LW_CONTAINER_READY_8.Caption = FX_IN_LW_CONTAINER_READY(8).Value
FX_IN_LW_CONTAINER_READY_9.Caption = FX_IN_LW_CONTAINER_READY(9).Value
```

```
// The sensor which signals if the arm is in position to grab a package at the large wheel
FX_IN_LW_ARM_AT_INPUT_0.Caption = FX_IN_LW_ARM_AT_INPUT(0).Value
FX_IN_LW_ARM_AT_INPUT_1.Caption = FX_IN_LW_ARM_AT_INPUT(1).Value
FX_IN_LW_ARM_AT_INPUT_2.Caption = FX_IN_LW_ARM_AT_INPUT(2).Value
FX_IN_LW_ARM_AT_INPUT_3.Caption = FX_IN_LW_ARM_AT_INPUT(3).Value
FX_IN_LW_ARM_AT_INPUT_4.Caption = FX_IN_LW_ARM_AT_INPUT(4).Value
FX_IN_LW_ARM_AT_INPUT_5.Caption = FX_IN_LW_ARM_AT_INPUT(5).Value
FX_IN_LW_ARM_AT_INPUT_6.Caption = FX_IN_LW_ARM_AT_INPUT(6).Value
FX_IN_LW_ARM_AT_INPUT_7.Caption = FX_IN_LW_ARM_AT_INPUT(7).Value
FX_IN_LW_ARM_AT_INPUT_8.Caption = FX_IN_LW_ARM_AT_INPUT(8).Value
FX_IN_LW_ARM_AT_INPUT_9.Caption = FX_IN_LW_ARM_AT_INPUT(9).Value
```

```
// The sensor which signals if the package is in position to be released
FX_IN_LW_ARM_AT_OUTPUT_0.Caption = FX_IN_LW_ARM_AT_OUTPUT(0).Value
FX_IN_LW_ARM_AT_OUTPUT_1.Caption = FX_IN_LW_ARM_AT_OUTPUT(1).Value
FX_IN_LW_ARM_AT_OUTPUT_2.Caption = FX_IN_LW_ARM_AT_OUTPUT(2).Value
FX_IN_LW_ARM_AT_OUTPUT_3.Caption = FX_IN_LW_ARM_AT_OUTPUT(3).Value
FX_IN_LW_ARM_AT_OUTPUT_4.Caption = FX_IN_LW_ARM_AT_OUTPUT(4).Value
FX_IN_LW_ARM_AT_OUTPUT_5.Caption = FX_IN_LW_ARM_AT_OUTPUT(5).Value
FX_IN_LW_ARM_AT_OUTPUT_6.Caption = FX_IN_LW_ARM_AT_OUTPUT(6).Value
FX_IN_LW_ARM_AT_OUTPUT_7.Caption = FX_IN_LW_ARM_AT_OUTPUT(7).Value
FX_IN_LW_ARM_AT_OUTPUT_8.Caption = FX_IN_LW_ARM_AT_OUTPUT(8).Value
FX_IN_LW_ARM_AT_OUTPUT_9.Caption = FX_IN_LW_ARM_AT_OUTPUT(9).Value
```

**End Sub**

### **A3 Class Simulation\_Main**

This object contains the simulator core. When the object is created the Init method should be called to initialise the simulator.

```
Public App As Wm3d.Application  
Public Doc As Wm3d.Document  
Public CollectionOfBodies As Bodies  
Public CollectionOfInputs As Inputs  
Public Frame As Integer
```

```
Public OPC_Server As OPCServer  
Public OPC_Groups As OPCGroups
```

```
Public WithEvents Sim_Control_Group As OPCGroup  
Public Sim_Control_Items As OPCItems  
Public Sim_Control As OPCItem  
Public Main_Control_Start As OPCItem  
Public Main_Control_Stop As OPCItem  
Public Main_Control_Restart As OPCItem  
Public PLC_Ready As OPCItem
```

```
Public Sub Setup_Connections() // Handles initial signals connections  
    Simulation_WM3_Connections.Setup Me  
    Simulation_FX_Connections.Setup Me  
    Simulation_FX_Connections.Reset Me  
End Sub
```

```
Public Sub Reset() // Resets the simulation  
    Simulation_FX_Connections.Reset Me  
    Frame = 0  
    Doc.GoTo (0)  
    Doc.RunTo (1)  
    Doc.EraseHistory  
End Sub
```

```
Public Sub OneScan() // Performs one simulation cycle  
    Simulation_Fx_To_WM3.Scan Me  
    Call Simulation_Veiw.Update  
    Frame = Frame + 1  
    Doc.RunTo (Frame)  
    Simulation_WM3_To_FX.Scan Me  
    Call Simulation_Veiw.Update  
    Sim_Control.Write (8)  
End Sub
```

```

Public Sub Init() // Initialise the simulation core
    Set App = GetObject( "WM3D.Application")
    Set Doc = App.ActiveDocument
    Doc.Reset
    App.Activate
    Set CollectionOfBodies = Doc.Bodies
    Set CollectionOfInputs = Doc.Inputs

    Set OPC_Server = New OPCServer
    OPC_Server.Connect ("fxControl.OPCServer.1")
    Set OPC_Groups = OPC_Server.OPCGroups

    Set Sim_Control_Group = OPC_Groups.Add("Sim_Control_Group")
    Sim_Control_Group.UpdateRate = 250
    Sim_Control_Group.IsActive = True
    Sim_Control_Group.IsSubscribed = True
    Set Sim_Control_Items = Sim_Control_Group.OPCItems
    Set Sim_Control = Sim_Control_Items.AddItem("#Command", Sim_Control_Group.ClientHandle)
    Set PLC_Ready = Sim_Control_Items.AddItem("PLC_Ready", Sim_Control_Group.ClientHandle)
    Set Main_Group_Items = Sim_Control_Group.OPCItems
    Set Main_Control_Start = Main_Group_Items.AddItem("Main_Control.SwitchOutput[0]",
                                                    Sim_Control_Group.ClientHandle)
    Set Main_Control_Stop = Main_Group_Items.AddItem("Main_Control.SwitchOutput[1]",
                                                    Sim_Control_Group.ClientHandle)
    Set Main_Control_Restart = Main_Group_Items.AddItem("Main_Control.SwitchOutput[2]",
                                                    Sim_Control_Group.ClientHandle)

    PLC_Ready.Read (2)
    While Not (PLC_Ready.Value = 1)
        PLC_Ready.Read (2)
    Wend
End Sub

Public Sub Sim_Control_Group_DataChange(ByVal TransactionID As Long, ByVal NumItems As Long,
    ClientHandles() As Long, ItemValues() As Variant, Qualities() As Long, TimeStamps() As Date)
    // An event, which is triggered from fx when one scan is done
    If Main_Control_Start Then
        Call OneScan
    End If
    If Main_Control_Restart Then
        Call Reset
    End If
End Sub

Public Sub CloseSim() // Close down connections
    OPC_Server.Disconnect
End Sub

```

## A4 Class Input\_Controller

A simple discrete controller with two predefined values but also has a method to set any discrete value

```
Private WmObjectInput As Wm3d.Input
```

```
Public Sub Init(Sim As Simulation_Main, InputObjectName As String) // Initialise the object
```

```
    Set CollectionOfInputs = Sim.CollectionOfInputs
```

```
    Set WmObjectInput = CollectionOfInputs.Item(InputObjectName)
```

```
    WmObjectInput.InputValue = 0
```

```
End Sub
```

```
Public Sub Start() // Sets the controller to one
```

```
    WmObjectInput.InputValue = 1
```

```
End Sub
```

```
Public Sub Hold() // reset the value to zero
```

```
    WmObjectInput.InputValue = 0
```

```
End Sub
```

```
Public Sub SetInt(x) // Sets any discrete value
```

```
    WmObjectInput.InputValue = x
```

```
End Sub
```

## A5 Class Arm

A simpler two level switch that uses reversed logic.

```
Private WmObjectInput As Wm3d.Input  
Public IsActive As Boolean
```

```
Public Sub Init(Sim As Simulation_Main, WmObjectName As String) // Initialise the object  
    Set WmObjectInput = Sim.CollectionOfInputs.Item(WmObjectName)  
    WmObjectInput.InputValue = 1  
    IsActive = False  
End Sub
```

```
Public Sub Drop() // Turn the switch off  
    WmObjectInput.InputValue = 1  
    IsActive = False  
End Sub
```

```
Public Sub Grip()// Turn the switch on  
    WmObjectInput.InputValue = 0  
    IsActive = True  
End Sub
```

## A6 Class Sensor

A simple sensor which gives a signal if two object is interfering with each other.

```
Private SensorObjectBody As Wm3d.Body
```

```
Private TriggerObjectBody As Wm3d.Body
```

```
Private CollectionOfBodies As Bodies
```

```
Private SensorMemory As Boolean
```

```
Public Sub Init(Sim As Simulation_Main, SensorObjectName As String, TriggerObjectName As String)
```

```
    // Initialise the object
```

```
    Set CollectionOfBodies = Sim.CollectionOfBodies
```

```
    Set SensorObjectBody = CollectionOfBodies.Item(SensorObjectName)
```

```
    Set TriggerObjectBody = CollectionOfBodies.Item(TriggerObjectName)
```

```
End Sub
```

```
Public Function CheckPower() // Checks if the two object are interfering
```

```
    CheckSensor = SensorObjectBody.IsInterferingWith(TriggerObjectBody, True)
```

```
    CheckPower = CheckSensor
```

```
End Function
```

```
Public Function CheckPulse() // Checks only for the first scan they interfere
```

```
    CheckSensor = SensorObjectBody.IsInterferingWith(TriggerObjectBody, True)
```

```
    TempMemory = CheckSensor
```

```
    CheckSensor = (Not SensorMemory) And CheckSensor
```

```
    SensorMemory = TempMemory
```

```
    CheckPulse = CheckSensor
```

```
End Function
```

## A7 Module Simulation\_FX\_Connection

This module connects every signal that is used between FX and the simulator core. The names in the OPC server are case sensitive.

```
Public FX_Conveyor_Group As OPCGroup
Public FX_Conveyor_Items As OPCItems
Public FX_OUT_CONVEYOR_SPEED As OPCItem
Public FX_SW_Group As OPCGroup
Public FX_SW_Items As OPCItems
Public FX_OUT_SW_MOTOR_SPEED As OPCItem
Public FX_OUT_SW_HOLD_CONTAINER(3) As OPCItem
Public FX_IN_SW_RECEIVER_READY(3) As OPCItem
Public FX_IN_SW_CONTAINER_READY(3) As OPCItem
Public FX_IN_SW_ARM_AT_OUTPUT(3) As OPCItem
Public FX_IN_SW_EMERGENCY_RELEASE(3) As OPCItem
Public FX_IN_SW_ARM_AT_INPUT(3) As OPCItem
Public FX_LW_Group As New OPCGroup
Public FX_LW_Items As OPCItems
Public FX_OUT_LW_MOTOR_SPEED As OPCItem
Public FX_OUT_LW_HOLD_CONTAINER(10) As OPCItem
Public FX_IN_LW_RECEIVER_READY(10) As OPCItem
Public FX_IN_LW_CONTAINER_READY(10) As OPCItem
Public FX_IN_LW_ARM_AT_OUTPUT(10) As OPCItem
Public FX_IN_LW_EMERGENCY_RELEASE(10) As OPCItem
Public FX_IN_LW_ARM_AT_INPUT(10) As OPCItem
```

```
Sub Reset(Sim As Simulation_Main) // Resets all signal to initial value
FX_OUT_CONVEYOR_SPEED.Write (0)
```

```
FX_OUT_SW_MOTOR_SPEED.Write (0)
For I = 0 To 2
    FX_OUT_SW_HOLD_CONTAINER(I).Write (0)
    FX_IN_SW_RECEIVER_READY(I).Write (0)
    FX_IN_SW_CONTAINER_READY(I).Write (0)
    FX_IN_SW_ARM_AT_OUTPUT(I).Write (0)
    FX_IN_SW_EMERGENCY_RELEASE(I).Write (0)
    FX_IN_SW_ARM_AT_INPUT(I).Write (0)
Next
```

```
FX_OUT_LW_MOTOR_SPEED.Write (0)
For I = 0 To 9
    FX_OUT_LW_HOLD_CONTAINER(I).Write (0)
    FX_IN_LW_RECEIVER_READY(I).Write (0)
    FX_IN_LW_CONTAINER_READY(I).Write (0)
    FX_IN_LW_ARM_AT_OUTPUT(I).Write (0)
    FX_IN_LW_EMERGENCY_RELEASE(I).Write (0)
    FX_IN_LW_ARM_AT_INPUT(I).Write (0)
```

Next

End Sub

**Sub** Setup(Sim As Simulation\_Main) // Connects all signal and sets them to initial value

With Sim

Set FX\_Conveyor\_Group = .OPC\_Groups.Add("Conveyor")

Set FX\_Conveyor\_Items = FX\_Conveyor\_Group.OPCItems

Set FX\_OUT\_CONVEYOR\_SPEED = FX\_Conveyor\_Items.AddItem("OUT\_CONVEYOR\_SPEED",  
FX\_Conveyor\_Group.ClientHandle)

Set FX\_SW\_Group = .OPC\_Groups.Add("Small\_Wheel")

Set FX\_SW\_Items = FX\_SW\_Group.OPCItems

Set FX\_OUT\_SW\_MOTOR\_SPEED = FX\_SW\_Items.AddItem("OUT\_SW\_MOTOR\_SPEED",  
FX\_SW\_Group.ClientHandle)

For I = 0 To 2

Set FX\_OUT\_SW\_HOLD\_CONTAINER(I) = FX\_SW\_Items.AddItem("SW\_ARM[" + CStr(I) +  
"].OUT\_HOLD\_CONTAINER", FX\_SW\_Group.ClientHandle)

Set FX\_IN\_SW\_RECEIVER\_READY(I) = FX\_SW\_Items.AddItem("SW\_ARM[" + CStr(I) +  
"].IN\_RECEIVER\_READY", FX\_SW\_Group.ClientHandle)

Set FX\_IN\_SW\_CONTAINER\_READY(I) = FX\_SW\_Items.AddItem("SW\_ARM[" + CStr(I) +  
"].IN\_CONTAINER\_READY", FX\_SW\_Group.ClientHandle)

Set FX\_IN\_SW\_ARM\_AT\_OUTPUT(I) = FX\_SW\_Items.AddItem("SW\_ARM[" + CStr(I) +  
"].IN\_ARM\_AT\_OUTPUT", FX\_SW\_Group.ClientHandle)

Set FX\_IN\_SW\_EMERGENCY\_RELEASE(I) = FX\_SW\_Items.AddItem("SW\_ARM[" + CStr(I) +  
"].IN\_EMERGENCY\_DROP", FX\_SW\_Group.ClientHandle)

Set FX\_IN\_SW\_ARM\_AT\_INPUT(I) = FX\_SW\_Items.AddItem("SW\_ARM[" + CStr(I) +  
"].IN\_ARM\_AT\_INPUT", FX\_SW\_Group.ClientHandle)

Next

Set FX\_LW\_Group = .OPC\_Groups.Add("Large\_Wheel")

Set FX\_LW\_Items = FX\_LW\_Group.OPCItems

Set FX\_OUT\_LW\_MOTOR\_SPEED = FX\_LW\_Items.AddItem("OUT\_LW\_MOTOR\_SPEED",  
FX\_LW\_Group.ClientHandle)

For I = 0 To 9

Set FX\_OUT\_LW\_HOLD\_CONTAINER(I) = FX\_LW\_Items.AddItem("LW\_ARM[" + CStr(I) +  
"].OUT\_HOLD\_CONTAINER", FX\_LW\_Group.ClientHandle)

Set FX\_IN\_LW\_RECEIVER\_READY(I) = FX\_LW\_Items.AddItem("LW\_ARM[" + CStr(I) +  
"].IN\_RECEIVER\_READY", FX\_LW\_Group.ClientHandle)

Set FX\_IN\_LW\_CONTAINER\_READY(I) = FX\_LW\_Items.AddItem("LW\_ARM[" + CStr(I) +  
"].IN\_CONTAINER\_READY", FX\_LW\_Group.ClientHandle)

Set FX\_IN\_LW\_ARM\_AT\_OUTPUT(I) = FX\_LW\_Items.AddItem("LW\_ARM[" + CStr(I) +  
"].IN\_ARM\_AT\_OUTPUT", FX\_LW\_Group.ClientHandle)

Set FX\_IN\_LW\_EMERGENCY\_RELEASE(I) = FX\_LW\_Items.AddItem("LW\_ARM[" + CStr(I) +  
"].IN\_EMERGENCY\_DROP", FX\_LW\_Group.ClientHandle)

Set FX\_IN\_LW\_ARM\_AT\_INPUT(I) = FX\_LW\_Items.AddItem("LW\_ARM[" + CStr(I) +  
"].IN\_ARM\_AT\_INPUT", FX\_LW\_Group.ClientHandle)

Next

End With

**End Sub**

## A8 Module Simulation\_WM3\_Connection

This module connects every signal that is used between WM3 and the simulator core. The name of the object in the WM3 model is used to connect

```
Public WM3_IN_CONVEYOR_SPEED As New Input_Controller
Public WM3_OUT_CONVEYOR_END(5) As New Sensor
Public WM3_CONVEYOR_Package_List(4) As String
Public WM3_IN_LOAD_NEW_PACKAGE_ON_CONVEYOR As New Input_Controller
```

```
Public WM3_IN_SW_MOTOR_SPEED As New Input_Controller
Public WM3_OUT_SW_ARM_AT_INPUT(3) As New Sensor
Public WM3_OUT_SW_ARM_AT_OUTPUT(3) As New Sensor
Public WM3_OUT_SW_EMERGENCY_RELEASE(3) As New Sensor
Public WM3_IN_SW_HOLD_CONTAINER(3) As New Input_Controller
```

```
Public WM3_IN_LW_MOTOR_SPEED As New Input_Controller
Public WM3_OUT_LW_ARM_AT_INPUT(10) As New Sensor
Public WM3_OUT_LW_ARM_AT_OUTPUT(10) As New Sensor
Public WM3_IN_LW_HOLD_CONTAINER(10) As New Input_Controller
```

**Sub** Setup(Sim As Simulation\_Main) // Connects all signal and sets them to initial value

```
WM3_IN_CONVEYOR_SPEED.Init Sim, "Conveyor_Motor[240]"
WM3_IN_LOAD_NEW_PACKAGE_ON_CONVEYOR.Init Sim, "input[244]"
```

```
WM3_OUT_CONVEYOR_END(0).Init Sim, "body[239]", "body[233]"
WM3_OUT_CONVEYOR_END(1).Init Sim, "body[239]", "body[234]"
WM3_OUT_CONVEYOR_END(2).Init Sim, "body[239]", "body[235]"
WM3_OUT_CONVEYOR_END(3).Init Sim, "body[239]", "body[236]"
WM3_OUT_CONVEYOR_END(4).Init Sim, "body[239]", "body[237]"
```

```
WM3_IN_SW_MOTOR_SPEED.Init Sim, "SW_Motor[45]"
```

```
WM3_OUT_SW_ARM_AT_INPUT(0).Init Sim, "body[46]", "body[10]"
WM3_OUT_SW_ARM_AT_INPUT(1).Init Sim, "body[48]", "body[10]"
WM3_OUT_SW_ARM_AT_INPUT(2).Init Sim, "body[50]", "body[10]"
```

```
WM3_OUT_SW_ARM_AT_OUTPUT(0).Init Sim, "body[59]", "body[12]"
WM3_OUT_SW_ARM_AT_OUTPUT(1).Init Sim, "body[61]", "body[12]"
WM3_OUT_SW_ARM_AT_OUTPUT(2).Init Sim, "body[63]", "body[12]"
```

```
WM3_OUT_SW_EMERGENCY_RELEASE(0).Init Sim, "body[59]", "body[274]"
WM3_OUT_SW_EMERGENCY_RELEASE(1).Init Sim, "body[61]", "body[274]"
WM3_OUT_SW_EMERGENCY_RELEASE(2).Init Sim, "body[63]", "body[274]"
```

WM3\_IN\_SW\_HOLD\_CONTAINER(0).Init Sim, "input[246]"  
WM3\_IN\_SW\_HOLD\_CONTAINER(1).Init Sim, "input[248]"  
WM3\_IN\_SW\_HOLD\_CONTAINER(2).Init Sim, "input[250]"

WM3\_IN\_LW\_MOTOR\_SPEED.Init Sim, "LW\_Motor[47]"

WM3\_OUT\_LW\_ARM\_AT\_INPUT(0).Init Sim, "body[80]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(1).Init Sim, "body[82]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(2).Init Sim, "body[84]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(3).Init Sim, "body[86]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(4).Init Sim, "body[88]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(5).Init Sim, "body[90]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(6).Init Sim, "body[92]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(7).Init Sim, "body[94]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(8).Init Sim, "body[96]", "body[11]"  
WM3\_OUT\_LW\_ARM\_AT\_INPUT(9).Init Sim, "body[98]", "body[11]"

WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(0).Init Sim, "body[80]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(1).Init Sim, "body[82]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(2).Init Sim, "body[84]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(3).Init Sim, "body[86]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(4).Init Sim, "body[88]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(5).Init Sim, "body[90]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(6).Init Sim, "body[92]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(7).Init Sim, "body[94]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(8).Init Sim, "body[96]", "body[275]"  
WM3\_OUT\_LW\_ARM\_AT\_OUTPUT(9).Init Sim, "body[98]", "body[275]"

WM3\_IN\_LW\_HOLD\_CONTAINER(0).Init Sim, "input[251]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(1).Init Sim, "input[253]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(2).Init Sim, "input[255]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(3).Init Sim, "input[257]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(4).Init Sim, "input[259]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(5).Init Sim, "input[261]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(6).Init Sim, "input[263]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(7).Init Sim, "input[265]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(8).Init Sim, "input[267]"  
WM3\_IN\_LW\_HOLD\_CONTAINER(9).Init Sim, "input[269]"

Sim.CollectionOfBodies.Item("body[233]").SetConfig 0.78, -0.12, 0.142, 0, 0, 0, True  
Sim.CollectionOfBodies.Item("body[234]").SetConfig 0.78, -0.065, 0.142, 0, 0, 0, True  
Sim.CollectionOfBodies.Item("body[235]").SetConfig 0.78, -0.01, 0.142, 0, 0, 0, True  
Sim.CollectionOfBodies.Item("body[236]").SetConfig 0.78, 0.045, 0.142, 0, 0, 0, True  
Sim.CollectionOfBodies.Item("body[237]").SetConfig 0.78, 0.1, 0.142, 0, 0, 0, True

**End Sub**

## A9 Module Simulation\_FX\_To\_WM3

This module contains the code which transfers signals from FX to WM3 and is called once during every simulation cycle

*Private load\_new\_package\_on\_conveyor As Integer*

*Private load\_new\_package\_on\_conveyor\_memory As Integer*

**Sub** Scan(Sim As Simulation\_Main) // Copy values from FX to WM3

FX\_OUT\_SW\_MOTOR\_SPEED.Read (2)

WM3\_IN\_SW\_MOTOR\_SPEED.SetInt (FX\_OUT\_SW\_MOTOR\_SPEED.Value)

FX\_OUT\_LW\_MOTOR\_SPEED.Read (2)

WM3\_IN\_LW\_MOTOR\_SPEED.SetInt (FX\_OUT\_LW\_MOTOR\_SPEED.Value)

FX\_OUT\_CONVEYOR\_SPEED.Read (2)

WM3\_IN\_CONVEYOR\_SPEED.SetInt (FX\_OUT\_CONVEYOR\_SPEED.Value)

load\_new\_package\_on\_conveyor = 0

For I = 0 To 2

FX\_OUT\_SW\_HOLD\_CONTAINER(I).Read (2)

WM3\_IN\_SW\_HOLD\_CONTAINER(I).SetInt (FX\_OUT\_SW\_HOLD\_CONTAINER(I).Value)

load\_new\_package\_on\_conveyor = load\_new\_package\_on\_conveyor +

FX\_OUT\_SW\_HOLD\_CONTAINER(I).Value

Next

For I = 0 To 9

FX\_OUT\_LW\_HOLD\_CONTAINER(I).Read (2)

WM3\_IN\_LW\_HOLD\_CONTAINER(I).SetInt (FX\_OUT\_LW\_HOLD\_CONTAINER(I).Value)

Next

If Not Hold\_Conveyor Then

If load\_new\_package\_on\_conveyor\_memory <> load\_new\_package\_on\_conveyor Then

WM3\_IN\_LOAD\_NEW\_PACKAGE\_ON\_CONVEYOR.SetInt (1)

Else

WM3\_IN\_LOAD\_NEW\_PACKAGE\_ON\_CONVEYOR.SetInt (0)

End If

load\_new\_package\_on\_conveyor\_memory = load\_new\_package\_on\_conveyor

End If

**End Sub**

## A10 Module Simulation\_WM3\_To\_FX

This module contains the code which transfers signals from WM3 to FX and is called once during every simulation cycle

*Public conveyor\_end As Boolean*

**Sub** Scan(Sim As Simulation\_Main) // Copy valus from WM3 to FX

conveyor\_end = False

For I = 0 To 4

conveyor\_end = conveyor\_end Or WM3\_OUT\_CONVEYOR\_END(I).CheckPower()

Next

FX\_IN\_SW\_CONTAINER\_READY(0).Write (conveyor\_end)

FX\_IN\_SW\_CONTAINER\_READY(1).Write (conveyor\_end)

FX\_IN\_SW\_CONTAINER\_READY(2).Write (conveyor\_end)

FX\_IN\_SW\_ARM\_AT\_INPUT(0).Write (WM3\_OUT\_SW\_ARM\_AT\_INPUT(0).CheckPower())

FX\_IN\_SW\_ARM\_AT\_INPUT(1).Write (WM3\_OUT\_SW\_ARM\_AT\_INPUT(1).CheckPower())

FX\_IN\_SW\_ARM\_AT\_INPUT(2).Write (WM3\_OUT\_SW\_ARM\_AT\_INPUT(2).CheckPower())

FX\_IN\_SW\_ARM\_AT\_OUTPUT(0).Write (WM3\_OUT\_SW\_ARM\_AT\_OUTPUT(0).CheckPower())

FX\_IN\_SW\_ARM\_AT\_OUTPUT(1).Write (WM3\_OUT\_SW\_ARM\_AT\_OUTPUT(1).CheckPower())

FX\_IN\_SW\_ARM\_AT\_OUTPUT(2).Write (WM3\_OUT\_SW\_ARM\_AT\_OUTPUT(2).CheckPower())

FX\_IN\_SW\_EMERGENCY\_RELEASE(0).Write WM3\_OUT\_SW\_EMERGENCY\_RELEASE(0).CheckPower()

FX\_IN\_SW\_EMERGENCY\_RELEASE(1).Write (WM3\_OUT\_SW\_EMERGENCY\_RELEASE(1).CheckPower())

FX\_IN\_SW\_EMERGENCY\_RELEASE(2).Write (WM3\_OUT\_SW\_EMERGENCY\_RELEASE(2).CheckPower())

sw\_receiver\_ready = False

For I = 0 To 9

sw\_receiver\_ready = sw\_receiver\_ready Or WM3\_OUT\_LW\_ARM\_AT\_INPUT(I).CheckPower()

Next

FX\_IN\_SW\_RECEIVER\_READY(0).Write (sw\_receiver\_ready)

FX\_IN\_SW\_RECEIVER\_READY(1).Write (sw\_receiver\_ready)

FX\_IN\_SW\_RECEIVER\_READY(2).Write (sw\_receiver\_ready)

lw\_container\_ready = False

For J = 0 To 2

lw\_container\_ready = lw\_container\_ready Or (WM3\_OUT\_SW\_ARM\_AT\_OUTPUT(J).CheckPower() And  
FX\_OUT\_SW\_HOLD\_CONTAINER(J).Value)

Next

If Not Fail\_Container\_Ready Then

lw\_container\_ready = False

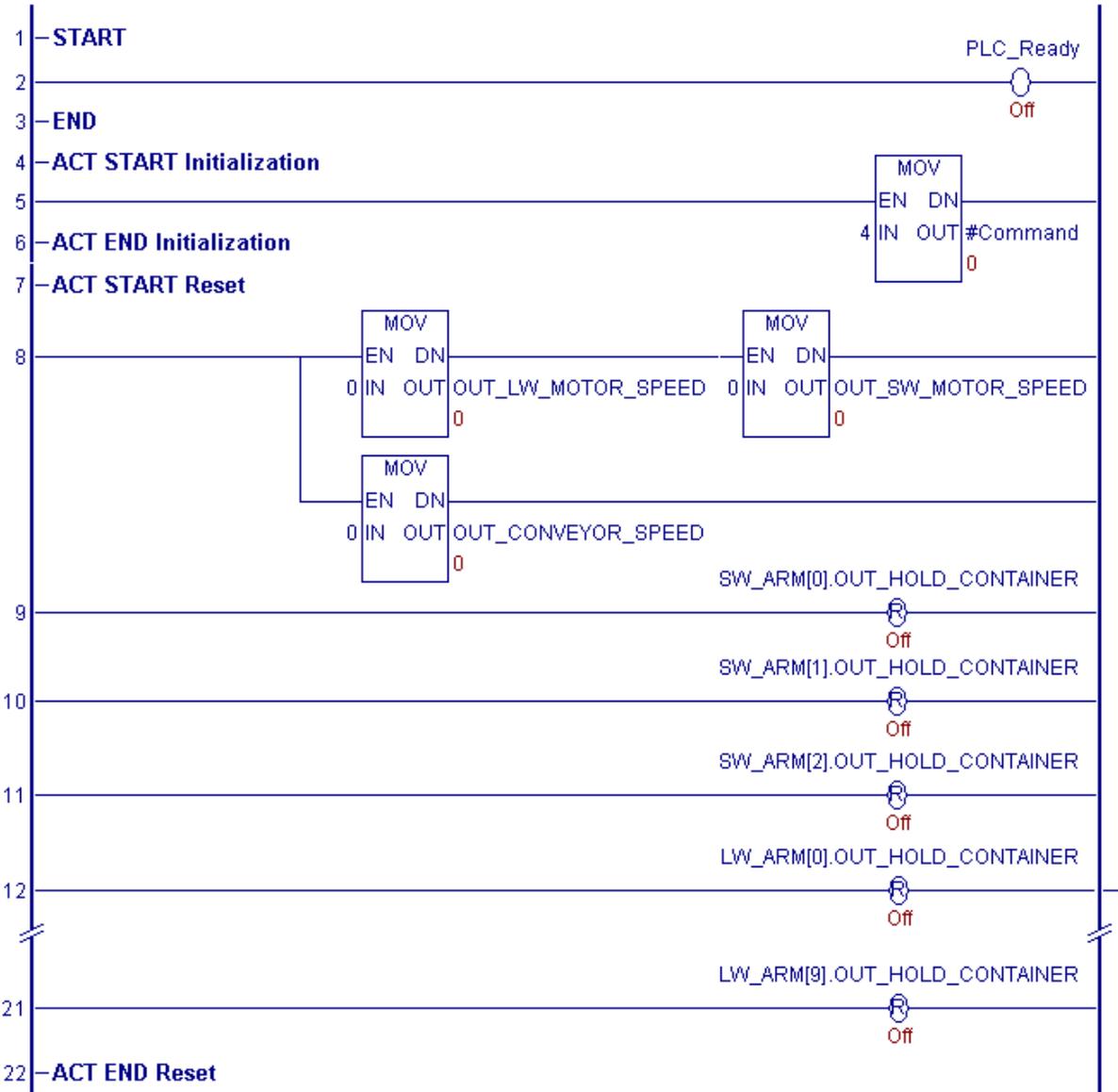
End If

```
For K = 0 To 9
  FX_IN_LW_CONTAINER_READY(K).Write (lw_container_ready)
  FX_IN_LW_ARM_AT_OUTPUT(K).Write (WM3_OUT_LW_ARM_AT_OUTPUT(K).CheckPower())
  FX_IN_LW_EMERGENCY_RELEASE(K).Write (0)
  FX_IN_LW_ARM_AT_INPUT(K).Write (WM3_OUT_LW_ARM_AT_INPUT(K).CheckPower())
  FX_IN_LW_RECEIVER_READY(K).Write (1)
Next
```

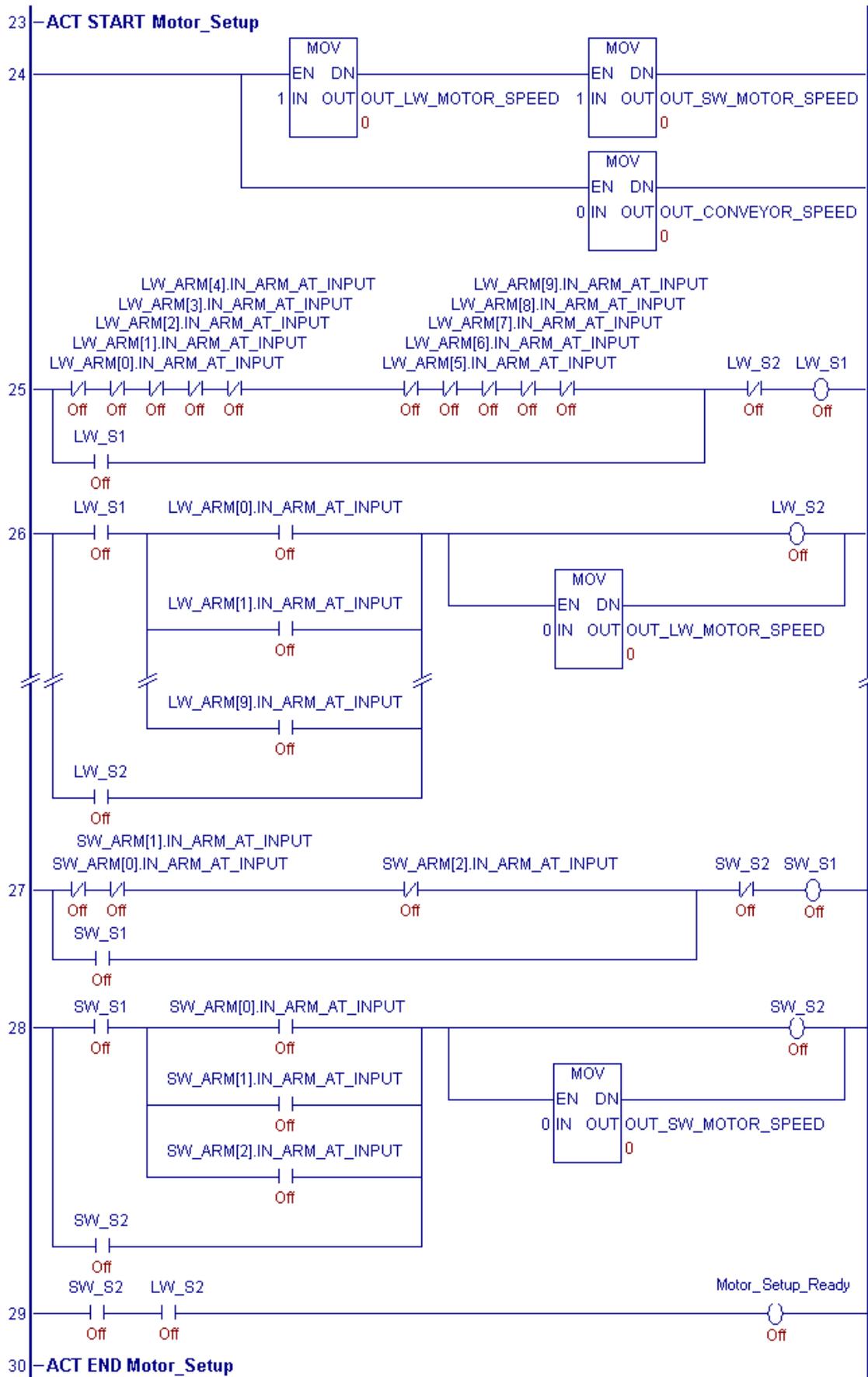
**End Sub**

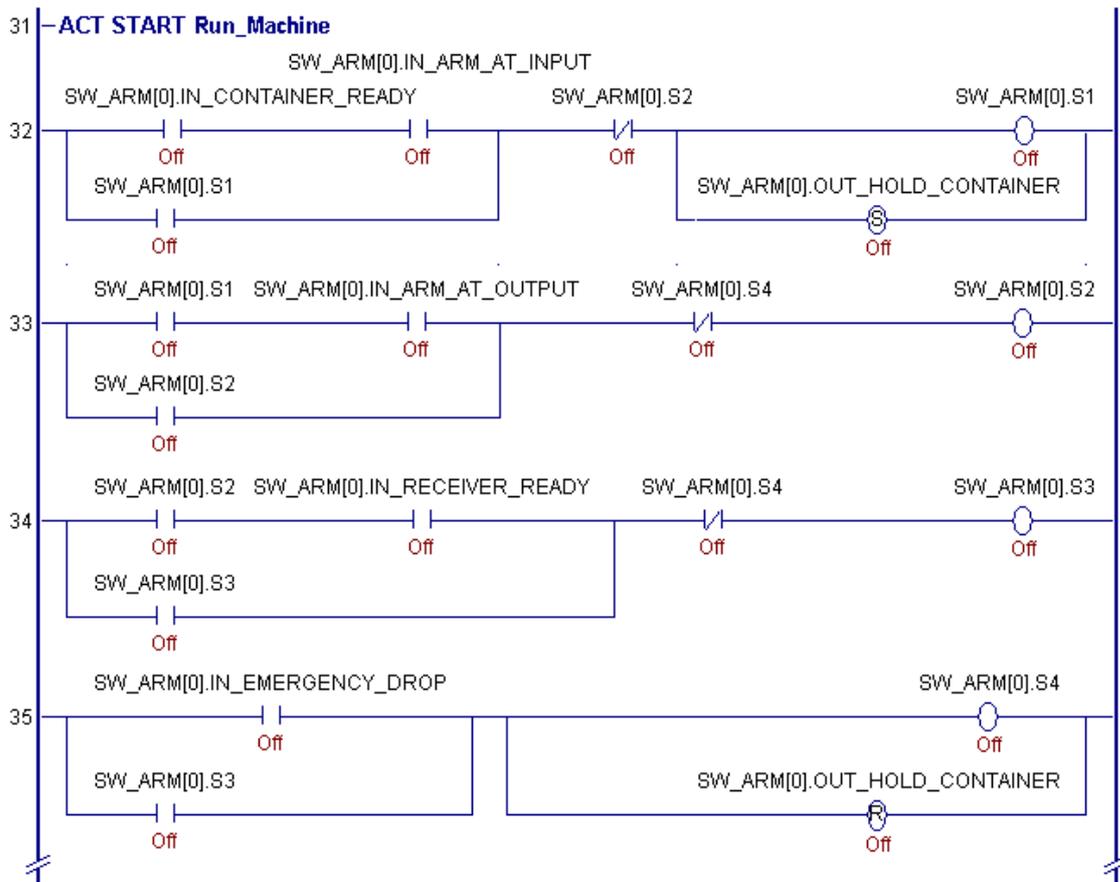
# A11 Controller, ladder code

The ladder code for the controller.

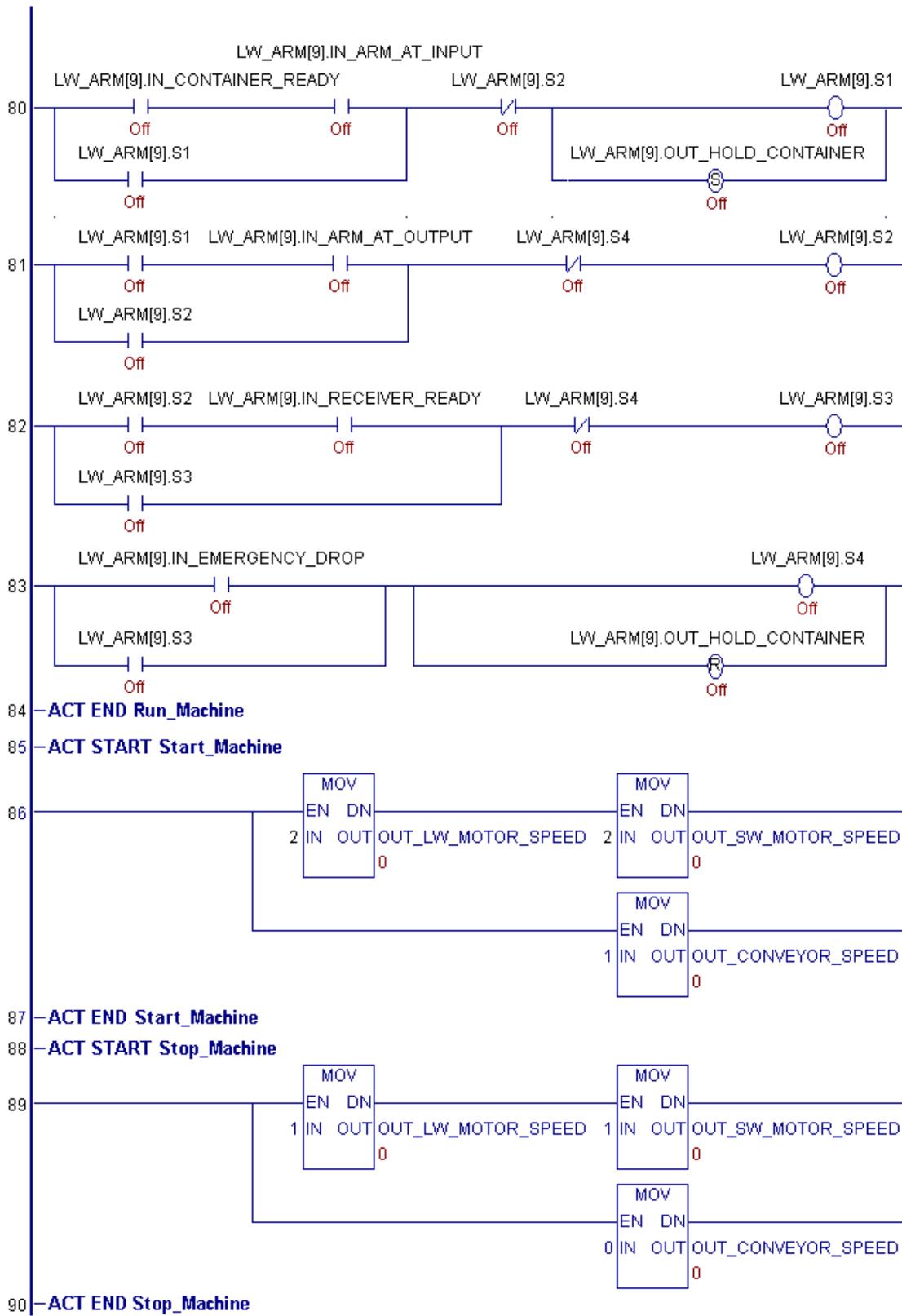


Rung 13 through 20 are identical as rung 12 except for the index.





Rung 32 through 35 is the ladder code corresponding to the grip arm discussed in chapter 5.3 and described in fig 5.5 as a state diagram. Rung 36 through 79 contains the remaining 12 grip arms.



# References

## Reports

Norén, Adam (2000), Simulating logical functions in a filling machine, master thesis at Tetra Pak R&D AB and Dept of Industrial Electrical Engineering and Automation, Lund University

## Books

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## Manuals

OPC Foundation (1999), OPC Data Access Automation Specification, version 2.02

Working Model 3D, Automation Programming Guide.

MSC/Working Model User manual version 5.0

FrameworkX Beta 3 Package, Online manual

## Internet resources

[http://www.gefanuc.com/totalcontrol/products/oas/frameworkx\\_home/frameworkx\\_home.html](http://www.gefanuc.com/totalcontrol/products/oas/frameworkx_home/frameworkx_home.html)

<http://www.opcfoundation.org>

<http://www.workingmodel.com>