Designing of Bottle Washing Machine in Virtual Environment Using the Enhanced Mechatronics System Design Methodology

Mr. Rizwanul Neyon, Purdue University Calumet (College of Technology)

Rizwanul Neyon, M.Sc, has completed his masters from Purdue University Calumet majoring in Mechatronics Engineering Technology. In his MS Directed project he worked in a Pick & Place machine where he has integrated a Programmable Logic Controller (PLC) & Human Machine Interface (HMI). He was awarded a graduate assistantship from Purdue University Calumet in 2012. As a graduate assistant in engineering Technology department of Purdue University Calumet, from August 2012 to May 2014, he assisted professors in several researches & conduction of labs & classes. In the summer of 2013 and 2014 he also worked as an intern in A Packaging Systems, La Porte, IN, where he was introduced with the primary packaging technologies such as bottle filling & bottle capping machines. As a research assistant he was also involved in designing a scaled down closed loop geothermal heat pump & simulate that model in LabVIEW software. He achieved his bachelor degree in Electrical & electronic Engineering from Chittagong University of Engineering & Technology. Previously he designed & assembled a 3 Wooden Blades Horizontal Axis Wind Turbine.

Nirjhar Das Sharma, Purdue University Calumet

My name is Nirjhar Das Sharma. I was born on November 20, 1990 in Chittagong, Bangladesh. I pursued my passion for engineering from my early childhood while I was going through High school education. I completed a four year B.Sc. course in Electrical and Electronic Engineering (2008-2013) from Chittagong University of Engineering & Technology, Bangladesh. The last two years of the Bachelor study introduced me to some real-life learning along with a lot of important experiences. I personally believe that the Industrial training at TICI (Training Institute for Chemical Industries), Narshingdi was the most valuable tour where I experienced about the Industrial Production Technology, sensing and control systems, manufacturing, packaging and Programmable logic controllers(PLC). This training made my decision easier to become a Graduate student of Mechatronics Engineering Technology at Purdue University Calumet, USA (from August, 2013 till present). Now I am learning Electrical controls, PLC (allen bradley), HMI programming and Robot (Motoman) programming as the integral part of my research. Besides, I have been working as an Instructor for an undergraduate level course ‘Electricity and Electronics fundamentals’ from January, 2014 at Purdue University Calumet. Throughout the journey that I made so far as a Graduate student, I have also experienced to work as a Teaching Assistant, designing PLC trainers and working with several mechatronics projects. At present, I am also working as an Engineering Intern at A Packaging System, La porte, IN (from May, 2014) experiencing different technologies like liquid filling machine, Bottle capping machine in a primary packaging environment. I strongly believe that my experience and education would create excellent opportunities for me and would flourish my knowledge in the future.

Mr. Priom Chakraborty, Purdue university Calumet

Priom Chakraborty, B.S, currently working as a Teaching assistant of Purdue University calumet .He is now doing his Masters focusing in Mechatronics Engineering Technology. He also worked as lab assistant in AWAKE (Assisting Workforce by Advancing Knowledge for Employment) program in Purdue University Calumet. His recent work is designing of Bottle Washing Machine in Virtual Environment Using the New Mechatronics System Design Technology. He has done his B.S. In American international University of Bangladesh(AIUB) his interests are in the area of programmable logic controlled devices, FPGA system design by Verilog programming, Application of process control in industrial works, Robot programming. Email: priomchk@gmail.com Linked In: bd.linkedin.com/in/priomchk/

Prof. Akram Hossain, Purdue University Calumet (College of Technology)

Akram Hossain, Purdue University Calumet Akram Hossain is a professor in the department of Engineering Technology and Director of the Center for Packaging Machinery Industry at Purdue University
Calumet, Hammond, IN. He worked eight years in industry at various capacities. He is working with Purdue University Calumet for the past 27 years. He consults for industry on process control, packaging machinery system design, control and related disciplines. He is a senior member of IEEE and he served in IEEE/Industry Application Society for 15 years at various capacities. He served as chair of Manufacturing Systems Development Applications Department (MSDAD) of IEEE/IAS. Currently, he is serving a two-year term as the chair of the Instrumentation of ASEE (American Society of Engineering Education). He authored over 29 refereed journal and conference publications. In 2009 he as PI received NSF-CCLI grant entitled A Mechatronics Curriculum and Packaging Automation Laboratory Facility. In 2010 he as Co-PI received NSF-ATE grant entitled Meeting Workforce Needs for Mechatronics Technicians. From 2003 through 2006, he was involved with Argonne National Laboratory, Argonne, IL in developing direct computer control for hydrogen powered automotives. He is also involved in several direct computer control and wireless process control related research projects. His current interests are in the area of packaging machinery system design & control, industrial transducers, industrial process control systems, modeling and simulation of Mechatronics devices and systems in virtual environment, programmable logic controllers, programmable logic devices, renewable energy related projects, wireless controls, statistical process control, computer aided design and fabrication of printed circuit board.
DESIGNING OF A BOTTLE WASHING MACHINE IN VIRTUAL ENVIRONMENT USING THE ENHANCED MECHATRONICS SYSTEM DESIGN METHODOLOGY

Abstract:

Primary packaging signifies the part of packaging layer where the container is in immediate contact with the product. Primary packaging system involves both the product itself and also any secondary layers of packaging that might be needed. Since primary package is in immediate contact with the main product, this layer of packaging requires special attention in the area of accurate quantity of product, sanitation, labeling etc.

On the other hand, secondary packaging is the process of combining the primary packages into one single container which is used to transport the products from one place to another. Most of the time in manufacturing circumstances, secondary packaged products are not quite available for customer whereas the primary packaged one are mostly consumed by the ultimate customers. Sanitized bottles filled with drinkable liquid or solutions are very good example of one of these kinds of products.

In most of the primary packaging industries, bottle washing (rinsing) machines are one of the most widely used technologies which is developed for efficient washing, sanitizing and drying of bottles before they are ready to be filled with liquid product or solution. Currently, there are some automatic bottle washing machines available in the packaging industries. Generally these machines are designed and manufactured from practical experiences of conventional machine designer. This design and development process often requires longer time and higher cost of fabrication. The simultaneous mechatronics system design methodology can serve the better opportunity to overcome these difficulties.
Mechatronics is the synergistic integration of mechanical and electrical engineering, computer science and information technology that comprises control system, in addition to mathematical analysis which is used to design products incorporated with intelligence. The modern mechatronics system design is based on concurrent approach to design products with more synergy whereas the conventional design and development process uses a sequential approach to design and development. In enhanced mechatronics system design methodology, the first step of designing a machine starts at modeling and simulation followed by emulation of the machine. The term emulation of a system refers to the fact that the system will act as similar as a real system without the hardware. It will also enable us to test and debug a system in a virtual environment. Products that are manufactured through this process are more reliable, robust, and provide greater customer satisfaction because the machine can be tested by emulating in a software environment before building it. Enhanced mechatronics design and development process can easily be beneficial to a company to build and improve a machine by making them more reliable, cost effective, and efficient. This virtual environment allows us to incorporate and see the performance of the smart sensor in absence of actual hardware. These kinds of virtual design and development environment is helpful for modeling, simulation, and reducing overall cost of actual hardware implementation. The environment also improves utilization of machine.

**Introduction:**

Sequential engineering is a process where each steps is followed one after one. In sequential engineering, main outcome is defined and consequent steps are followed to achieve the desired outcome. Here each step has to be completed properly before starting the next step. So the process become slow and expensive. For today’s competitive market this can lead the project to failure.

On the other hand, Concurrent engineering is a technique of working where tasks are performed concomitantly. It is a methodical approach to the assimilated, concurrent design of outcome and their related process. In this process flaws can be detected at earlier stage due to parallel approach which saves time and money.
The enhanced mechatronics system design is based on concurrent Engineering. This process is all about building a machine in virtual environment before constructing in actual hardware. Here we can detect fault at earlier stage by creating animation and emulating it in virtual environment. If we follow the conventional process there is high chance to get faulty result and also have to spend more time and money to finish the project whereas by using concurrent engineering it is more useful to develop the project in more efficient and cost effective way. One of the very essential steps of enhanced mechatronics system design technology is to emulate the whole process by creating the animation of the machine using the Programmable Logic Controller (PLC) software tool. The main purpose of this research is to establish a procedure to emulate a machine in virtual environment before the actual fabrication. In this research we are going to emulate a bottle washing machine. We will use PLC (Programmable Logic Controller) software tools and Human Machine Interface (HMI) animation tool to achieve the desired outcome of the research. By using this process students will be familiar with the PLCs’, ladder diagram, electrical panel diagrams, HMI design even without having the real hardware.

Enhanced Mechatronics System Design Methodology:
There are 4 phases of a mechatronics system design process-
1) Modeling and Simulation
2) Emulation
3) Prototyping
4) Deployment and Life cycle

Modeling and Simulation:
Modeling of a system means collecting information about how something will behave without actually testing it in real life \(^{[1]}\). It also represents the behavior of a real system by collection of mathematical equations and logic. However in enhanced mechatronics system design methodology the term modeling refers to the creation of look-alike model in virtual environment using the AutoCAD® or SolidWorks software tool. The terms simulation refers to the imitation of the operation of a real-world process or system over time.
The first step of modeling and simulation is to recognize the need of proper design to get desirable output. Then create the mechanical model in virtual environment.
Next step will be to set the operating procedure and identify the specification of the system.

Third step will be selecting appropriate sensors and actuator for the system. It is a vital factor in mechatronic systems which are intrinsically linked to instrumentation, and its function is to provide a mechanism for collecting different information about a specific process. Selection of a sensor or actuator for a specific system depends on the modeling parameters and the variables measured, the nature of accuracy, and the sensitivity required for the measurement, cost, size, and usage.

**Emulation**

An emulator is a software program that simulates the functionality of another program or a piece of hardware [2]. Generally, the efficiency of a machine running in a complex environment depends on various factors like specifications, software programing or hardware. As a result utilizing various software tools are sometimes recommended to establish the performance of the machine before implementing it. Emulator has been an important tool to achieve this goal. To emulate a machine in software environment, the first step of the emulation process is to configure the chassis of the emulator. Then create the ladder diagram for the machine. After setting up a link in between HMI (Human Machine Interference) and emulator, animation of the machine has to be created in HMI software.

**Prototyping** [3]

In this step the non-computer part of the model is replaced with the actual hardware. Sensors and actuators provide the interface signals to connect the hardware subsystem to the model. Here the part of the system is mathematical and part of that is real. Synchronization between this two is very important. This synchronized model is called the hardware in loop simulation. Next step in prototyping is design optimization. In this step the design of the model is optimized by eliminating the unnecessary parts from the model.

**Deployment and life cycle**

Deployment of embedded software refers to the activities that make a software system available to use. In this step the layout designs (both mechanical and electrical) are translated in real
world. To translate the layout designs in real world the exact hardware is required. For that reason the exact bill of material is also very important. DMAT software tool also helps us to have an exact bill of material.

<table>
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<tr>
<td><strong>System</strong></td>
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<td>140U-H2C3-C30</td>
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Control Circuit Power - note double click power supply and modify "family" to select the higher

<table>
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Control Circuit Protection - note double click circuit breaker to select different pole

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<td>1492-SP1C010</td>
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<td>1489-A2D250</td>
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Surge / Filter - note double click surge product to select other current, voltage or pole

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<th>Surge / Filter</th>
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<tbody>
<tr>
<td>4983 Surge and Filter Protection, Din Rail Mount, UL1449, 120V, 25 Amp, 480V/277V AC</td>
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Figure 1: Bill of Material from DMAT tool

The last step of this whole method is to optimize the life cycle.
The whole process of developing a machine through this enhanced mechatronics system design methodology can be written in flow chart as follows:

![Diagram of enhanced mechatronics system design process]

Figure 2: Enhanced mechatronics system design process [4]
Modeling of the bottle washing machine
In this project the mechanical frame is built using the AutoCAD® software. This is the very first step of building the bottle washing machine. After identifying the I/O of the machine the next step is to make electrical panel layout and wiring diagram of the electrical panel box. DMAT gives the basic structure of the electrical wiring & layout drawings. Depending on the I/O of the machine the wiring diagram of the machine has been changed. The following diagram (figure 3) shows the basic wiring diagram of the input module of the controller that has been retrieved from DMAT software tool.

![Diagram](image)

Figure 3: Digital input layout from DMAT software tool

Figure 4 shows the electrical diagram of the digital input module of the controller.
Emulation Process of bottle washing machine

The project of bottle Washing Machine Emulation will be emulated by the PLC (Programmable Logic Controller) software such as RSLogix™ 5000, Talk®View ME (Machine Edition). PLC will be emulated by RSLogix™ 5000 Emulator. The whole emulation will run in Allen Bradley Factory Talk®View ME. To emulate this bottle washing machine, ladder control logic will be developed in RSLogix™ 5000 selecting the PLC type as RSLogix™ 5000 Emulator. The communication between the Emulator and Talk®View Machine Edition is required to run the virtual animation of the desired machine. The configuration of Talk®View is also an important step for the communication with the programmable ladder logic. Allen Bradley software DMAT (Drive and Motion Accelerator Toolkit) tool will be used for the electrical control, schematic design, panel layout design and HMI design.
Steps involved in this whole procedure are

1. Creating ladder diagram of the bottle washing machine

   Ladder diagram of the bottle washing machine is written in RSLogix 5000.
   DMAT software tool gives the basic structure of ladder diagram, later it is modified in RSLogix 5000.

2. Configuration of RSLogix 5000 Emulator

   To simulate the ladder diagram of RSLogix 5000 in RSLogix 5000 emulator, RSLogix 5000 emulator has to be configured first.
a) Right Click on an empty slot in the RSLogix 5000 Emulator and click create →
Select RSLogix Emulate 5000 Emulator

b) Configure drives with RSLinx
Now Go to RSLinx Classic → Configure Drivers → Virtual Backplane

c) Go to Emulator → Right Click and Run

3. Set up a link between Factory Talk® View and RSLogix™ 5000 emulator.
   a) Go to RSLinx Enterprise in the Explorer Window.
b) Click Add → Name it → Browse and find your saved Studio 5000 file

c) Right click on 1789-A17, Backplane → Add device
d) Double click on 1756-Lx/Em, ControlLogix 55xx Emulator, expand it and choose revision 21→ OK
e) Verify it, then press ok

4. Create animation of the whole project in FactoryTalk® View

To create the animation of the bottle washing machine, firstly the whole process is divided into some subgroups. Create the animation and assign appropriate tags for those groups. The subgroups are bottles, conveyors, proximity sensors, nozzles, tank, screw conveyor and motors.

a) **Animation of the bottles**

For the animation of the bottle, first select a bottle from the library. Then right click on the bottle to select the properties to change the back style color and back color of the bottle. After that take two bottle with two different colors and make them a group. Before making the group from the animation selects color and fills animation with appropriate tag.
b) Animation of the conveyors
Select the conveyer from the library. From animation select the rotation animation with the appropriate tag to make the circle of the conveyer rotating look like.

c) Animation of the proximity sensors
Select the proximity sensor from the library, and then select the color animation with appropriate tag. The sensor will turn on green when that value

d) Animation of the nozzles
For the animation of the nozzle, the pipe and water jet has to be created. The water jet has the tag named visibility with appropriate tag, so when the bottles are present in the washing station, the water jet become visible.
e) Animation of the tank

For the animation of the tank, select tank from the library, the select the fill animation along with color animation. The fill direction will be ‘down’.

f) Animation of the screw conveyor

To create the animation of the screw conveyor, the screw conveyer was build first, and then from the animation selects the horizontal position with appropriate value and tag. This is done on each bar of screw conveyer
g) Animation of bottle rotating frame

h) Animation of the bottle washing frame
Limitations of the research

This research was performed up to emulation of the bottle washing machine in virtual environment due to the limitations of budget, timeline and availability of equipment and parts for the project. Prototyping and deployment of the system is still important to present the desired outcome of the research. Due to above limitations, these two steps are not performed for this research. Without the actual implementation, it was not quite possible to analyze the percentage of cost and time that can be saved, if the enhanced mechatronics system design methodology is applied to build a new machine. Nevertheless, one of the main challenges of this research is to replicate the exact real world condition in virtual environment. Extensive knowledge and experiences are also required to use these software tools to create animations and emulation of bottle washing machine. Without these steps, it will not be that much beneficial to a company to utilize this methodology for developing cost effective machines.

Discussion of Results

The process optimization of machine design and making the perfect operational logic of a machine are very useful for packaging machine manufacturer. The products that are manufactured through this virtual intuitive process are generally high quality, robust in nature, low in cost and customer satisfied. Furthermore, it brings some benefits to the company who will use this virtual instinctive environment to build a machine before building it in real world.

This process helps to predict the time frame for the project accurately. More accurate bill of material is being made by using the DMAT software tool rather than using the individual’s technical experience. The mechanical design of the filling machine was achieved using the AutoCAD® software tools. DMAT software tool was used for panel layout, electrical wiring diagram, and ladder logic of the filling machine. Later, depending on the I/O of the machine those are modified. But as the basic structure of the electrical control panel and ladder is already made, these also plays an important role in terms of time and money saving. The enhanced mechatronics design and development process significantly reduces the development time
compared to conventional way of designing and building a machine. It also enables the producer
to have more design flexibility and more custom made specification of the product.

**Benefits to the students**

This enhanced mechatronics system design methodology can also be beneficial to the students.
Students can learn the ladder diagram, electrical panel wiring diagram and HMI design even
without having the real hardware.

RSLLogix™5000 Emulator is a programming tool that is capable of emulating RSLLogix™5000
controllers such as ControlLogix®, FlexLogix®, CompactLogix®, SoftLogix® and DriveLogix
controllers [5]. It can be used in conjunction with RSLLogix™5000 to write and test students’
application code without connecting the real hardware. In addition, student can design, test and
debug their HMI by using RSLLogix™5000 emulator as a part of the laboratory experimentation.

**Conclusion:**

The primary objective of this research is to set up procedure of building a machine using the
enhanced mechatronics system design methodology and also analyze the amount of savings in
terms of money. In this method there are four phases to build a machine. The first two stages
are modeling and emulation of the machine in virtual environment whereas the last two stages
are involved with hardware. Due to the limitation of time, money and resources the research
objectives are confined to modeling and emulation of the machine. The hardware
implementation and analyses of the savings part is kept for the future research. To emulate the
bottle washing machine an animation was created to replicate the real machine. The animation
is done using the PLC software. AutoCAD® and DMAT software tools are used for the
modeling. DMAT software tool gives the basic structure of the panel layout and wiring diagram
which saves approximately 40% of the time and less chances to have an error in wiring diagram
as well as in the machine. Despite of some limitation, it is evident that this methodology saves
both time and money as the accurate ladder diagram, wiring and layout diagram of electrical
panel, HMI (Human Machine Interface) configuration was done even before the parts are in the
hands.
References: