2018 ASEE Mid-Atlantic Section Spring Conference: Washington, District of Columbia Apr 6

Virtual Prototyping for Mechatronics

Dr. Haiyan (Henry) H Zhang, Purdue University, West Lafayette (College of Engineering)

Education

Shanghai Jiao Tong University Mechanical Engineering B.S. 1983

Shanghai Jiao Tong University Mechanical Engineering (Hydraulic Control) M.S. 1986

University of Akron Mechanical Engineering (Neural Network) M.S. 1991

University of Michigan – Ann Arbor Mechanical Engineering Ph.D. 1996

Oakland University Electrical & Computer Engineering M.S. 2007

Professional Experiences

2007 – Present Assistant Professor, Department of Mechanical Engineering Technology, Purdue University, West Lafayette, Indiana

1994 - 2007 Senior Specialist, Automatic Transmission Engineering, Chrysler Technology Center, Chrysler Corporation, Michigan

1992 - 1994 Research Assistant, University of Michigan, Ann Arbor, Michigan

1990 – 1991 Research Assistant, University of Akron, Ohio

1986 – 1989 Assistant Professor, Department of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, China

1983 – 1986 Research Assistant, Shanghai Jiao Tong University, Shanghai, China

Research Interests

- Mechatronics, Precision Machine Design
- Digital Hydraulics, High Efficiency Hydraulics
- Electric Vehicle, Powertrain / Automatic Transmission Design and Control
- Time-delay System Control in Manufacturing Processes
- Multidisciplinary Correspondence Methodology Based Design

Virtual Prototyping for Mechatronics

Ryne McHugh and Haiyan H. Zhang*

School of Engineering Technology, Purdue University
West Lafayette, IN 47907
**hhzhang@purdue.edu*

Abstract

The major difference between the 20th century industrial products and the 21st century industrial products lays in that the latter are multidisciplinary mechatronic machines/devices. Global market demands and economic turbulence have driven companies to seek innovative ways to reduce costs in developing the multidisciplinary products. The primary goal of this research is to show the validity of virtual prototyping, within the realm of mechatronics, as a means to reduce costs in the development phase of product design. The modern industrial product is often a hybrid of mechanical, electrical, sensing and embedded engineerings, and this mixture forms the core of mechatronics. The high level of multidisciplinary interaction makes it strenuous for cross-engineering association in mechatronics' design. In this paper, two industrial grade softwares, i.e., Dassault Systems' SolidWorks and National Instruments' LabVIEW, are employed in the development and deployment phases of mechatronics engineering design. For physical modeling and analysis of geometric components, SolidWorks is the CAD software chosen to serve these purposes, while for control logic/laws realization and data acquisition, LabVIEW is used as the graphical programming language. The bridging link between these two programs, the so-called SoftMotion module, has been developed by National Instruments to function as the communication between them. This research aims to explore the capability of SolidWorks-SoftMotion-Labview integration for virtual prototyping of fully functional mechatronic products via developing, analyzing and virtually co-simulation. The researcher will develop and analyze a virtual prototype of an intelligent product vending device. The features of this device include user selected product acquisition, real time inventory tracking, and self-regulated product organization.

Keywords

Virtual prototype, Mechatronics, Multidisciplinary product design

Introduction

Mechatronics devices are modern machines with high levels of complexity. The complexity of mechatronics devices requires the input of multiple engineering disciplines during their design and design validation. Traditional prototyping development, with individual subsystems independently designed, requires multiple iterations of design. In the design of mechatronics devices, the whole systems are required to be modeled and analyzed concurrently in order to achieve the best performance of the products. Obviously the traditional approach does not well suit the development of mechatronics devices due to the time and cost involved with their development and testing. Can virtual prototyping of mechatronics devices provide a valid and reliable alternative to numerous iterations of physical prototypes for use in product design verification?

In traditional design process, the individuals trained in mechanical, electrical or other disciplines are not working synergistically. Virtual prototyping enables them to work simultaneously. This synergy can lead to better outputs in a shorter time period, while also reducing the number of design iterations, thus reducing cost and time to market with increased functionality. Traditional prototyping techniques are cumbersome and expensive. This is especially true for modern prototyping technique of mechatronic devices. This paper is meant to be a study of modern mechatronics prototyping known as virtual prototyping with a mechatronics virtual prototyping project, to explore information regarding the relevance of the research, technical terms used in the study, parameters within which the research will be conducted, as well as the processes involved in completion of the project. Identifying the traits of mechatronic devices will pave the way for virtual prototyping of said devices. These prototypes will include solid models, motion control logics, and in depth dynamic analyses.

Virtual prototyping (VP) was originally deemed as a way for the designer to foresee the product-to-be's functionality and performance in the computer-based environment. Santori[1] suggested VP to include the combination of software, mechanical, and electrical systems. Hren and Jezernik[2] incorporated the use of computers claiming VP "refers to a computer model of a product presented in virtual environment with, ideally, all information and properties included, for the analysis and evaluation." There is still some ambiguity with respect to mechatronics. The most valuable definition was found in Mathur[3], which was tailored specifically to mechatronic devices: "A virtual machine prototype is a 3D CAD model that interacts with a simulation of a machine controller to visualize and test machine movements and logical operations." The reference to the machine controller as well as the CAD system is what separates this definition from the others.

Traditional design methods are typically a sequential design approach, which typically begins with the mechanical engineers, followed by electrical and embedded software control engineers.[3] In addition, traditional design is flawed by its dependence of individual disciplinary work in numerous physical prototype iterations. This is not suitable for design of interdisciplinary products such as mechatronic devices. The design of mechatronics devices requires the input of mechanical, electrical, and embedded engineering disciplines. Modern methodology promotes concurrent, parallel engineering through VP. VP is a relatively new idea, but years before it reached the level of application it has today, its potential is recognized since 1990s. It is indisputable that VP can promote interaction among multidisciplinary engineering members during machine design process with the promise of better products and without the flaws in the traditional design approach.

VP Methodology and Design of A Mechatronic Device

The most critical part of this research was the development of useful VPs accurately representing their corresponding physical system, such as mechanical system, control/motion logic, and user interface for an intelligent mechatronics device. Dassault Systems' SolidWorks and National Instruments' LabVIEW were used in conjunction via the SoftMotion module to develop and analyze the VP of this intelligent vending system. The NI developed SoftMotion Module allows the researcher to import a SolidWorks 3D CAD model into a LabVIEW project tree, and thus develop the virtual prototype through the connection that was made. Figure 1 displays a detailed flowchart followed to create the virtual prototype.

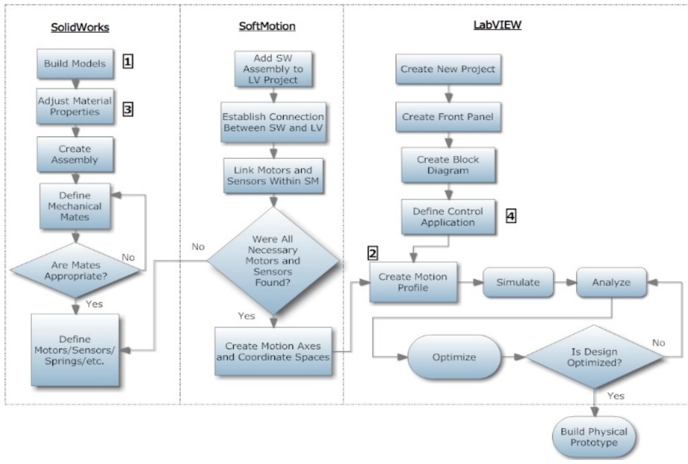


Figure 1. Virtual prototyping flowchart

1. Creation of the Solid Models with SolidWorks

In this paper, the mechatronic device is an automated vending system for single serving beverages with 16 product locations. The composition of this virtual prototype began with the construction of the 3D CAD model, including constructing (a) the framing of the vending system, (b) “Picker Assembly” for X-Y axis product acquisition, (c) “pusher assembly” for Z-axis product acquisition, (d) functional architecture, and (e) final assembly of product vending VP, respectively (as shown in Figure 2). Cost effectiveness and strength were paramount, and alloy steel was chosen for its composition. The extensive use of aluminum was chosen for these components because 6061-T6 aluminum possesses high strength properties but also low weight. This was an important consideration for the shelving because higher weight would have put higher stress on the fasteners used to mount the shelves and their content to the framing. Weight was also an important consideration for the moving product acquisition components because as it increased, the stress on the drive system did as well. This would also lead to increased power consumption and component size.

(a) (b) (c) (d) (e)

Figure 2. Vending system VP

The final step in creating a useful SolidWorks model for virtual prototyping was setting up a motion study containing motors. This required enabling the SolidWorks Motion add-in. By doing so, the motion analysis menu and motors became available within the motion study. The number of motors added was dependent on which motion study was in being analyzed. Figure 3 shows a motion study with three motors added.

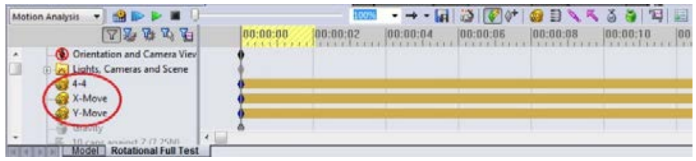


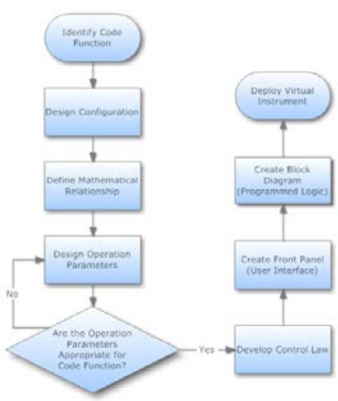
Figure 3 Motion study with motion analysis and motors enabled

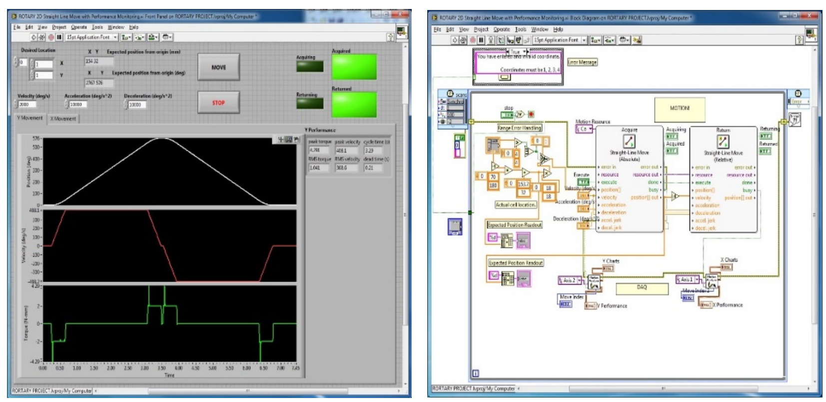
2. Creation of LabVIEW Instruments

LabVIEW was employed to define the control logic using NI LabVIEW's virtual instrument (VI). For VP of the vending system, three virtual instruments are developed for its own purpose:

- to analyze the picker system which moves in the X-Y direction,
- to test the Z movement assembly,
- to test functionality of an end-user interface.

This process was completed by developing a front panel or graphical user interface (GUI) for each VI as shown in the block diagrams (Figure 4). The X-Y Picker Test VI was developed as shown in Figure 5. The other applications, such as Z pusher test VI, can be done in the similar way. As for functionality test VI for user interface, it is presented in Figure 6.

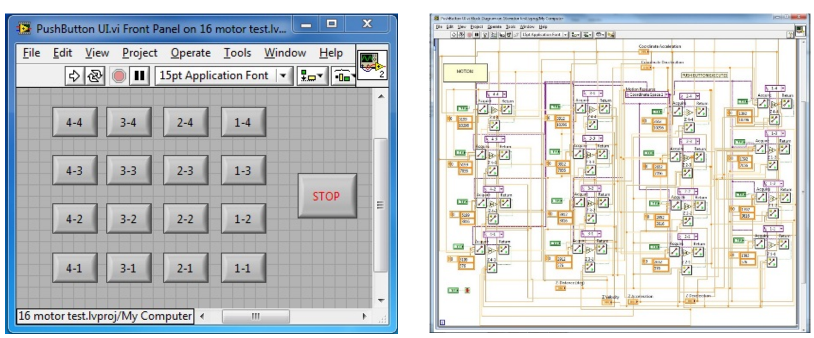




(a) X-Y picker test VI (b) X-Y picker test VI

Figure 4. Creation of control law

Figure 5. X-Y picker test VI



(a) Functionality test VI user interface (b) Functionality test VI block diagram

Figure 6. Functionality test VI for user interface

3. Creation of Connection between SolidWorks Assemblies and LabVIEW VIs

The final step in creating a virtual prototype was connecting the SolidWorks assemblies and the LabVIEW VIs used to control them. The connection of the two is established within a LabVIEW project. The previously mentioned SoftMotion Module by NI allows SolidWorks assemblies, in addition to VIs, to be imported into a LabVIEW project. The need for three separate LabVIEW VIs resulted in the creation of three separate LabVIEW projects, one for each VI.

4. X-Y Picker Test Project, Z Pusher Test Project, and Functionality Test Project

In X-Y picker test project, the SolidWorks test picker assembly, X-Y picker test VI, two SoftMotion axes, and a coordinate space are included. In Z pusher test project, the SolidWorks Z move assembly, Z test VI, and one SoftMotion axis are involved.

In functionality test project, the SolidWorks full test assembly, the functionality test VI, 18 SoftMotion axes, and one coordinate space are tested, and 18 motors were necessary for the X and Y (horizontal and vertical) picker motion, and the 16 possible locations for Z pusher motion.

5. Analyses in VP of the Vending System

Analyzing this virtual prototype was the entire purpose for creating it. It allowed the creator to complete a number of necessary tasks in the creation of a new product. These tasks included static analysis of the solid model via FEA in SolidWorks, analysis and verification of the motion and control logic in LabVIEW, and the final analysis of a functional automated model via the SoftMotion module. These analyses allowed the researcher to appropriately size components including fasteners, structural members, and motors as well as dial in the timing and location of the motion profiles. Other analyses, such as logic and motion profile analysis, location verification, timing verification, collision elimination, automated Solid Model analysis, opposing forces, cost analysis, LabVIEW-Excel Communication and User Accounts, rearrange logic etc., are also performed in VP mechatronics design.

VP Results for the Vending System

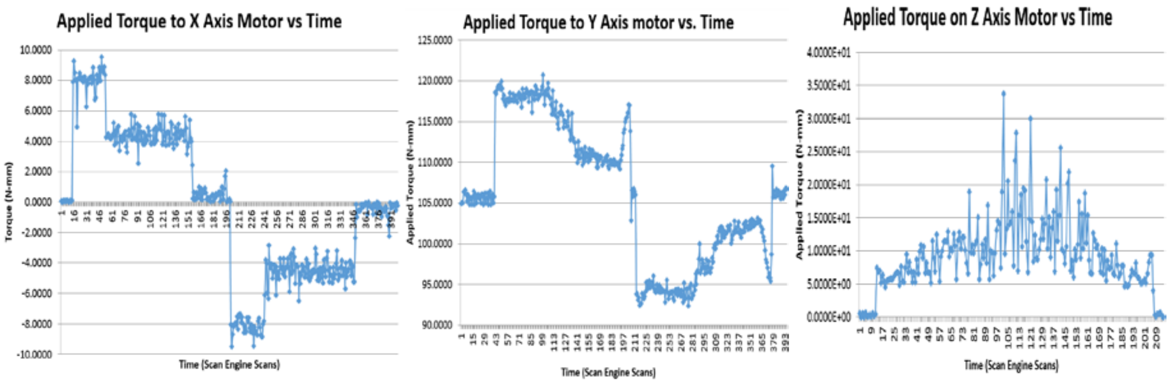
Static model FEA is executed via SolidWorks' SimulationXpress Analysis Wizard for the Z pusher frame, shelf, load bearing fasteners, and picker assembly. Z Pusher Frame, Shelf, Load Bearing Fasteners, Picker Assembly are also performed.

The LabVIEW created control logic and motion profiles were analyzed to verify their functionality, including the correct location and timing without collision.

In this section, the dynamic analyses are presented with detailed charts in three motion direction: X motor, Y motor and Z motor. (see Figure 7)

Conclusions

Virtual prototyping of mechatronic devices is a burgeoning field. CAD, FEA, control logic, and motion studies have been around for decades, but their combination through VP will become more important over time. Proving the validity of mechatronic VP was the main goal for this project and, in general, it was met. Unfortunately, there were some shortcomings in the details.



(a) X motor (b) Y motor (c) Z motor

Figure 7. X-Y-Z dynamic analyses

The ability to effectively connect SolidWorks with LabVIEW via SoftMotion, control an assembly through that connection, and monitor the results was very successful. Adjusting the displacements and velocities of various components for optimal results was made quite simple by the software. Unfortunately, the means of doing so was rather cumbersome. In the experience of this study, subassemblies, even when solved as flexible, were not able to be controlled. Also, patterns of parts could not be controlled without error. This resulted in the tedious requirement to import and mate each assembly component individually.

The analysis phase was also somewhat limited by resources. SolidWorks' FEA tool is incapable of executing its functions with the SoftMotion add-in. While it can analyze simple motion inputs, it cannot do the same with the LabVIEW controlled profiles. This limited significantly the valuable analysis of the device.

This study was also meant to focus specifically on mechatronics devices. An important trait, not obvious in the name, of mechatronics devices is their use of sensing elements. This combination of software did allow for some sensing, but not nearly the amount required for legitimate mechatronics. This was easily the biggest shortcoming of the study. It limited significantly the capability of this device and any future devices created using this method. Therefore, it is only useful for simple systems' pre-programmed motion verification.

References

1 M. Santori, "Prototype your way to success," Electronic Design, Penton, 2009, pp. 29-31.

2 G. Hren, and A. Jezernik, "A framework for collaborative product review," International Journal of Advanced Manufacturing Technology, Vol. 42, Springer-Verlag, London, 2008, pp. 822-830.

3 N. Mathur, "Mechatronics resolves design challenges," Control Engineering, Elsevier, June 2007, pp. 1-3.

4 R. P. McHugh, Virtual Prototyping of A Mechatronic Device (MS Directed Project), Purdue University, August 2011.

Ryne McHugh

Received MS in Mechanical Engineering Technology at Purdue University in 2011. Since then, he has been working for Intel Corporation in Hillsboro, OR.

Haiyan Henry Zhang

Is an Associate Professor of Engineering Technology and the founding director of Center for Technology Development at Purdue University. He received his Ph.D. from University of Michigan-Ann Arbor in 1996. With the multidisciplinary engineering background and industrial experience, his research foci are analytical mechatronic design, advanced manufacturing control, and design of traditional and hybrid electric vehicle powertrains.