Virtual Prototyping of Mechatronics for 21st Century Engineering and Technology

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Abstract

Mechatronics is defined as the synergy of mechanical and electrical systems featuring their precision, electronic control with intelligence in product design and manufacturing processes. Further, these disciplines can be rendered down to the functional structure of Mechatronics, reflecting the product's six aspects: the microcontroller, power supply, mechanical body, sensing apparatus, precision mechanical actuators, and their communication. With that said, it becomes important to address why a synergistic combination is useful and necessary in engineering and industry. 21st century products demand it.

Intelligent mechatronics products are becoming more prevalent. Therefore, the students must be prepared to meet the needs to design such products in near future. They must be capable of creating products with increased functionality, reduced costs, and optimized performance thus achieving higher product value. Mechatronics and its virtual prototyping can aide the manufacturer in all these ways.

This paper will first look at virtual prototyping. Dassault System's SolidWorks in combination with National Instruments' LabVIEW and the NI SoftMotion Module provide a very effective way of virtually prototyping. The value of which lies in the reduction of cost, time, effort, and materials needed to produce physical prototypes.

Secondly, the paper will show how virtual prototyping can give a company more dexterity in the marketplace. This is achieved through another advantage of mechatronics virtual prototyping. The physical prototype is only produced after its virtual counterpart has the optimized performance, and the designer can achieve the best product with less design iterations. Thus, it takes less time to adapt and produce products that better suit the marketplace.

Risk is present in all business. Businesses must make decisions that may not result in a desired outcome. Therefore, it is important to keep risk to a minimum. It is especially important to reduce risk with respect to new products. Virtual prototyping can significantly reduce risk through a combination of all the previously mentioned advantages of mechatronics and its simulation.

Finally, this paper will present a number of useful examples of mechatronics and virtual prototyping in industry and engineering. These examples are shown through the use of virtual design tools including, but not limited to: efficiency, optimization, CAD integration, and tuning analysis.

Introduction

The 21st century has ushered in a new era of machine and methods for design. The demand for more cost effective, better, and more functional machines coupled with an unstable economy and intense global competition has put considerable pressure on engineers. They are expected to produce more complex systems at a lower cost and a faster rate. This necessitates an entirely new paradigm for design.

Traditional Design

Mechatronics is defined as the synergy of mechanical systems featured with its precision, electronic control with intelligence in the product design and manufacturing processes. Further, these disciplines can be rendered down to the functional structure of Mechatronics, reflecting the product's six aspects: the microcontroller, power supply, mechanical body, sensing apparatus, precision mechanical actuators, and their communication. These methods contrast the old paradigm of electro-mechanical design. Historically, designers of electro-mechanical systems would use a sequential method. That is, the mechanical engineers would first establish the basic design. It would then be passed on to the electrical engineers, and finally to the control and software engineers. The simple figure below illustrates this point.
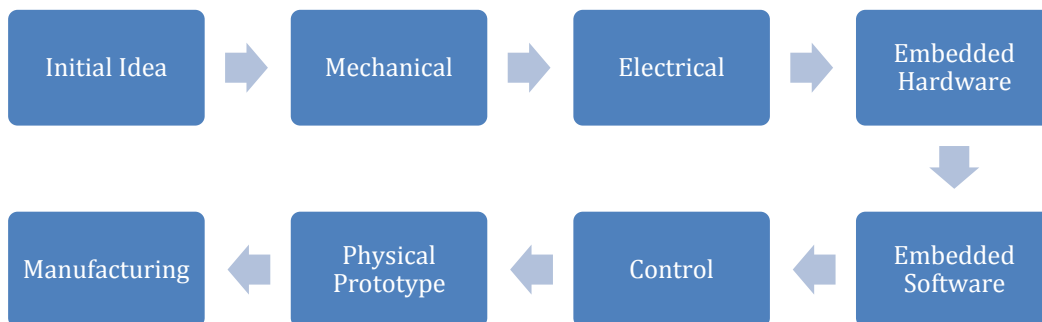

Figure 1. Traditional design method

Modern Design

The traditional approach does not promote communication or synergy, while Mechatronics design methodologies and systems do promote these values. Concurrent engineering in mechatronic design is the new paradigm. Mechanical, electrical, control,

and software engineers participate in design simultaneously. This is illustrated by the following figure, which shows the design engineering departments in parallel.
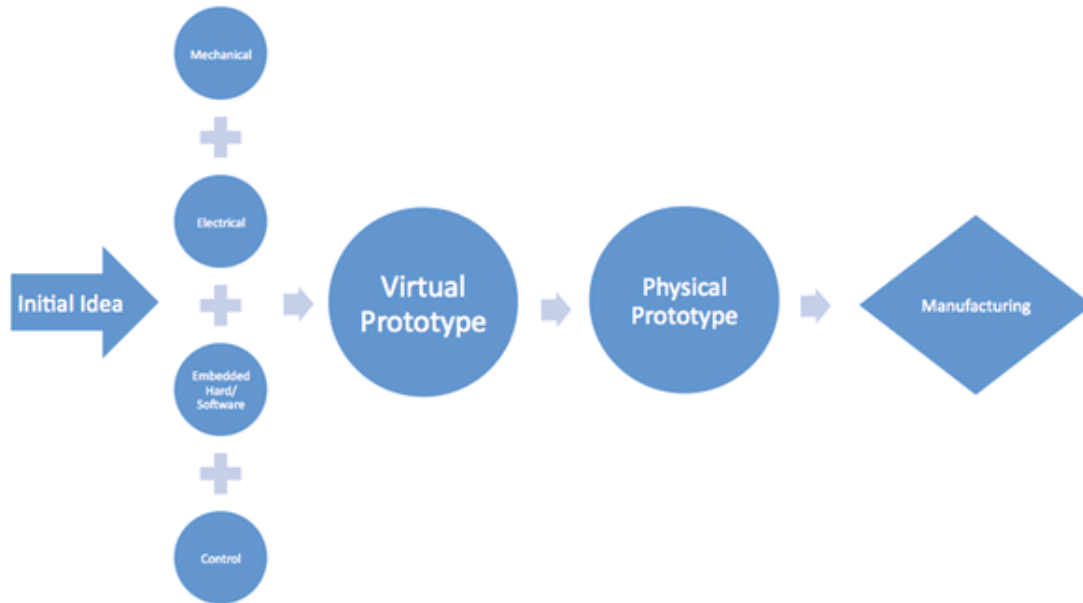

Figure 2. Modern Design Approach with Parallel Engineering Teams

Virtual Prototyping

Concurrent engineering and successful synergy was difficult when the means to effectively communicate technical data and information was underdeveloped. This is a thing of the past because virtual prototyping (VP) and the associated software can facilitate these needs. Design engineering is on the cusp of change; mechatronics and virtual prototyping are positioned to enable that change.

Prototypes are early models of equipment developed at full scale to be used for evaluating performance. Traditionally, these are physical prototypes build to identify problems in the initial design. They often lead to design changes and multiple iterations of the prototype as a means to optimize the design. To reiterate physical prototypes is extremely costly. Each new design demands more time, money, and materials to realize the next iteration.

A virtual prototype is meant to serve the same function without the need for a physical model, thus reducing cost. When engineers discover the need for a change and ways to optimize their design, they can simply alter the virtual prototype itself. This eliminates time and money consuming physical prototypes. Additionally, and perhaps more importantly, the initial design and virtual prototype can be created with simultaneous input from every engineer involved in the project. New software developments are enabling engineers to achieve optimized designs with fewer physical prototypes.

Union of LabVIEW and SolidWorks

National Instruments in combination with Dassault Systems has developed a module that allows for seamless union between NI's LabVIEW and Dassault's SolidWorks. It is known as the "SoftMotion Module." This software allows the different design engineers to work simultaneously with CAD models, embedded software, and control logic to simulate and analyze the dynamic behavior of a system.

Virtual prototyping with SolidWorks, LabVIEW and SoftMotion gives the mechanical and control engineering team a way to assess the function of the virtual Mechatronic system, in which the realistic machine operations are visualized, the cycle time throughput is simulated, the product's performance and important information about the dynamic behavior of the design are demonstrated. In the past, these properties were explored mainly through the creation and testing of a physical prototype.

21st Century Engineering

Mechatronics

As stated before, mechatronics is meant to be a synergistic combination of multiple engineering disciplines. Mechatronics devices make use of microprocessors, data acquisition sensors, and actuators, all within a mechanical structure and body. What separates mechatronics from traditional electro-mechanics is the system's intelligence, logic, and internal communication. The following picture illustrates this point.
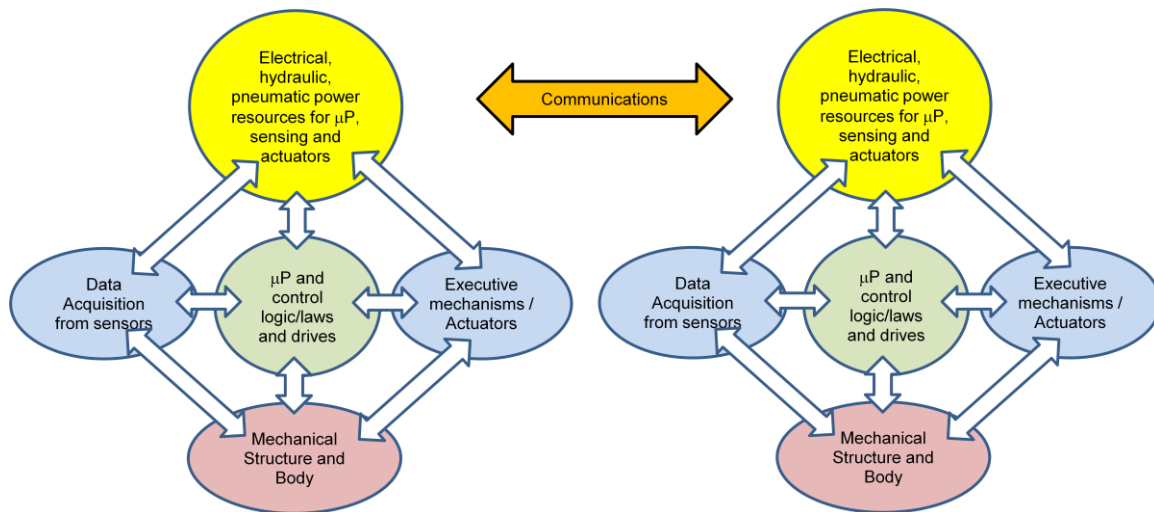

Figure 3. Synergy and Communication in Mechatronics

This is a very powerful combination of tools. If these systems are combined properly, the result is a machine that can be set to complete a task with minimal input from the user. The microprocessors and control logic allow mechatronic devices to react to inputs and make decisions based on these inputs. Therefore, nearly any process that requires mechanical actuation can be automated through the use of a synergistic

mechatronics design. However, for engineers to successfully create a synergistic system, they need to work in a synergistic manner themselves. The traditional, "over the wall" technique does not allow them to do so. Virtual prototyping of mechatronics does.

Virtual Prototyping

Virtual prototyping is the integration of computer-aided design, embedded software programming, and simulation softwares to visualize an intelligent mechatronics device in a computer environment. This environment allows design engineers to manipulate their models without the need to build a physical version. It has been commonplace in industry for decades to use CAD packages to develop solid models of mechanical designs. Programming and embedded logic have been widely used as well. The fact that these parts of the design were never developed in unison is what created a disconnect, especially in mechatronics design. Virtual prototyping with NI and Dassault software has changed that forever by bridging the gap.

Software Used

National Instruments has developed an extremely useful tool known as the NI SoftMotion Module. This tool enables the combination of a SolidWorks 3D CAD model with a LabVIEW project tree. By doing so, all motors, sensors, gear trains etc. defined within the CAD model can be connected with the LabVIEW algorithms developed to govern the model. The actuators are connected using the SoftMotion Axis tool. If using multiple axes together, the designer can create a coordinate space in which the axes will operate simultaneously. The SoftMotion Module is demonstrated in Figure 4 showing this process is presented in a very easy to understand, graphical way.
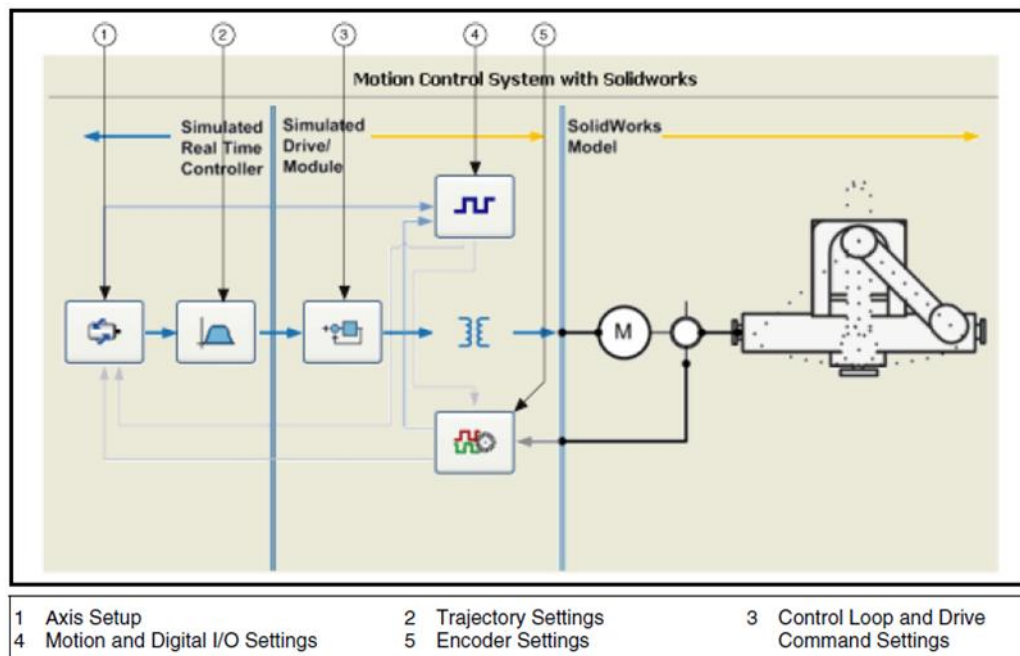

Figure 4. Graphical configuration for axes and coordinate spaces in SoftMotion Module

Once these steps have been completed, motion profiles can be created. The functions within LabVIEW NI SoftMotion Module are used to move the profiles in a variety of ways. The movements can be as simple as a single-axis, strait line movement or a complex contoured motion. If properly programmed, complex coordinated motion can be achieved. These tools allow the designer to manipulate the profiles as a means to optimize the design. Below is an example of a basic arc move in a LabVIEW function block.
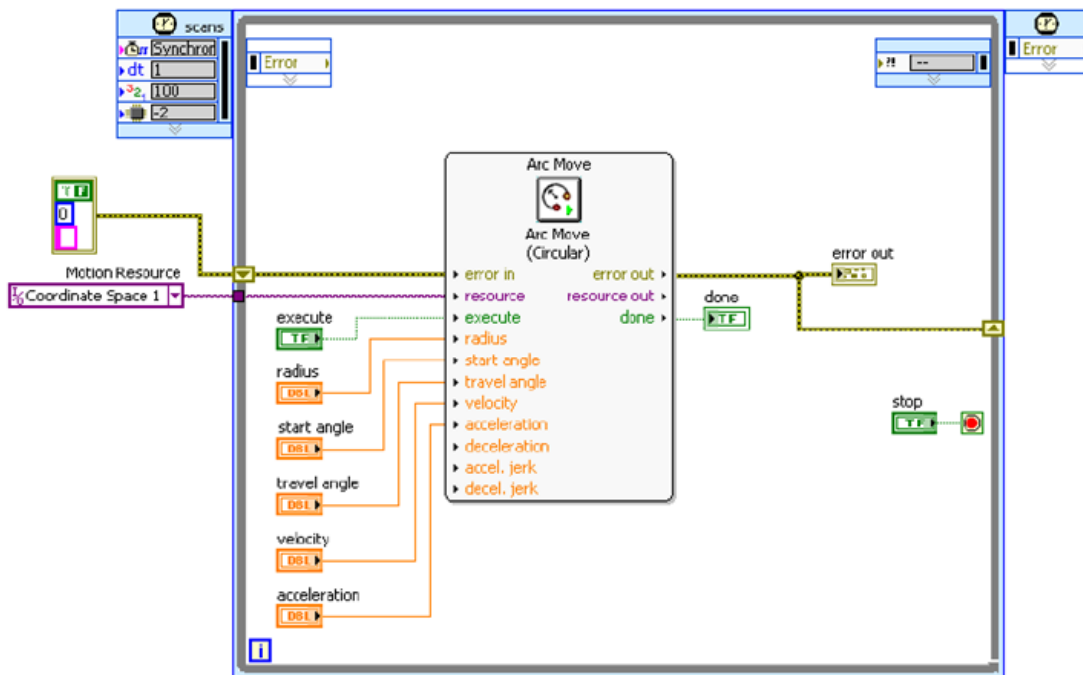

Figure 5. Motion Function Block in LabVIEW Using SoftMotion Module

If the models are properly programmed and the appropriate connections are made between the software, a 3D CAD model in SolidWorks can now be brought to life for simulation and analysis. One of the few drawbacks for this method is the inability to perform real-time visualization. SolidWorks performs intense calculations to create the simulation and must move at a pace slower than real-time. The time, however, is accurate relative to the programmed timing. The results of a simulation can serve the purpose of visualizing machine operation, cycle time estimation, accurate force and torque requirements, collision detection, validation of motion control programming, design optimization, and identification of issues on the mechanical/electrical boundary. By means of SolidWorks and LabVIEW collaboration, the mechanical dynamics, including mass and friction effects, cycle times, and individual component performance are simulated without any physical parts. These dynamic effects will be especially precise when material mass properties are accurately programmed into the SolidWorks model. Making use of these analysis results is a very powerful way to optimize a design and far less costly than doing so with a physical prototype. The benefits of virtual prototyping are numerous.

Benefits of VP for a Profitable Business

The purpose of every business is to generate profit. Engineering firms generate profit by producing products at a cost lower than they are able to sell them. Therefore, if virtual prototyping can reduce production costs, these firms can increase their profit margins. In addition, they will produce better and more efficient products that will increase sales and revenue. How do virtual prototypes reduce production costs? The most observable way is through the reduction of iterations of a physical prototype.

Physical prototypes are extremely costly. They require a large amount of input from the engineers developing it as well as materials used to actually build it. Developing a prototype in a virtual environment will save huge amounts of money by reducing not only the input time required of the engineers, but also the materials used to bring it to life. Additionally, when a physical prototype must be redesigned, much of the material used to create it will go to waste. Virtual prototyping will reduce this waste as well. Risk is also reduced through the use of virtual prototyping. Every decision a business makes runs the risk of inducing an undesired outcome. VP can make engineers more confident in their designs, thus reducing the potential for undesired outcome. Profits are increased by more than just the reduction of cost. Can virtual prototyping increase profits in other ways? The answer is yes.

Throughput is a somewhat illusive term used by businesses. With respect to design engineering, it can be thought of as the amount of information successfully transmitted from one place to another. By increasing the amount of throughput via virtual prototyping, firms can achieve more. The growing complexity of 21st century mechatronics devices demands that engineers increase their throughput. Virtual prototyping does this by allowing the various engineering departments communicate far more efficiently and work in parallel. Their ability to achieve more throughput has a threefold effect: increased functionality, optimization/customization opportunity, and marketplace dexterity.

It has been previously stated that functionality is the backbone of a 21st century mechatronics design. This means the machines themselves must be more functional. It also means that the models must be the same. When making a bid for a contract, who is more likely to win it? The company with basic CAD designs and a text based description, or the company with a fully animated, dynamic, ready to optimize and customize, virtual simulation? The choice is clear.

Being able to stay flexible and react to a changing market is also very important. Customer needs change and businesses must be able to meet those changing needs if they intend to keep their clients. The use of VP allows firms to make changes and reach final designs more quickly. This enables them to meet customer needs faster. Furthermore, given the appropriate situation, customers and suppliers could work side by side (much like the afore mentioned parallel engineering concept) to achieve a mutually beneficial design concept. Considering the current state of the economy, these are all extremely functional benefits of using virtual prototyping.

Examples and Application

There are many mechatronical systems that countless people use every day. Hybrid gas-electric vehicles and wind turbines, for example, are some of the most complex mechatronical devices and they are becoming more and more prevalent. Purdue's Mechanical Engineering Technology Department has built a physical prototype a mechatronical device. Dr. Henry Zhang and a number of his students have created a two-wheel self-balancing scooter seen below.
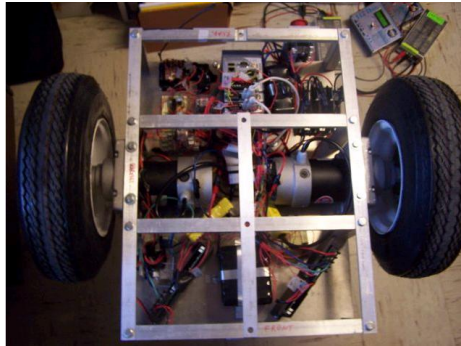
Figure 6. MET department's two-wheel self-balancing mechatronic scooter with cover plate removed

This physical prototype was developed without the use of a virtual counterpart. The final cost was greater than $5,000. This could have been significantly reduced if certain design considerations could have been made prior to the physical prototype being built. The methodology for doing so is quite simple.

Virtual prototyping has been clearly defined, the software needed, identified, and it's benefits outlined. But what are the steps within each software that should be taken to reach an optimal design? The following figure makes this clear and is followed by a simple table that can be used for analysis.
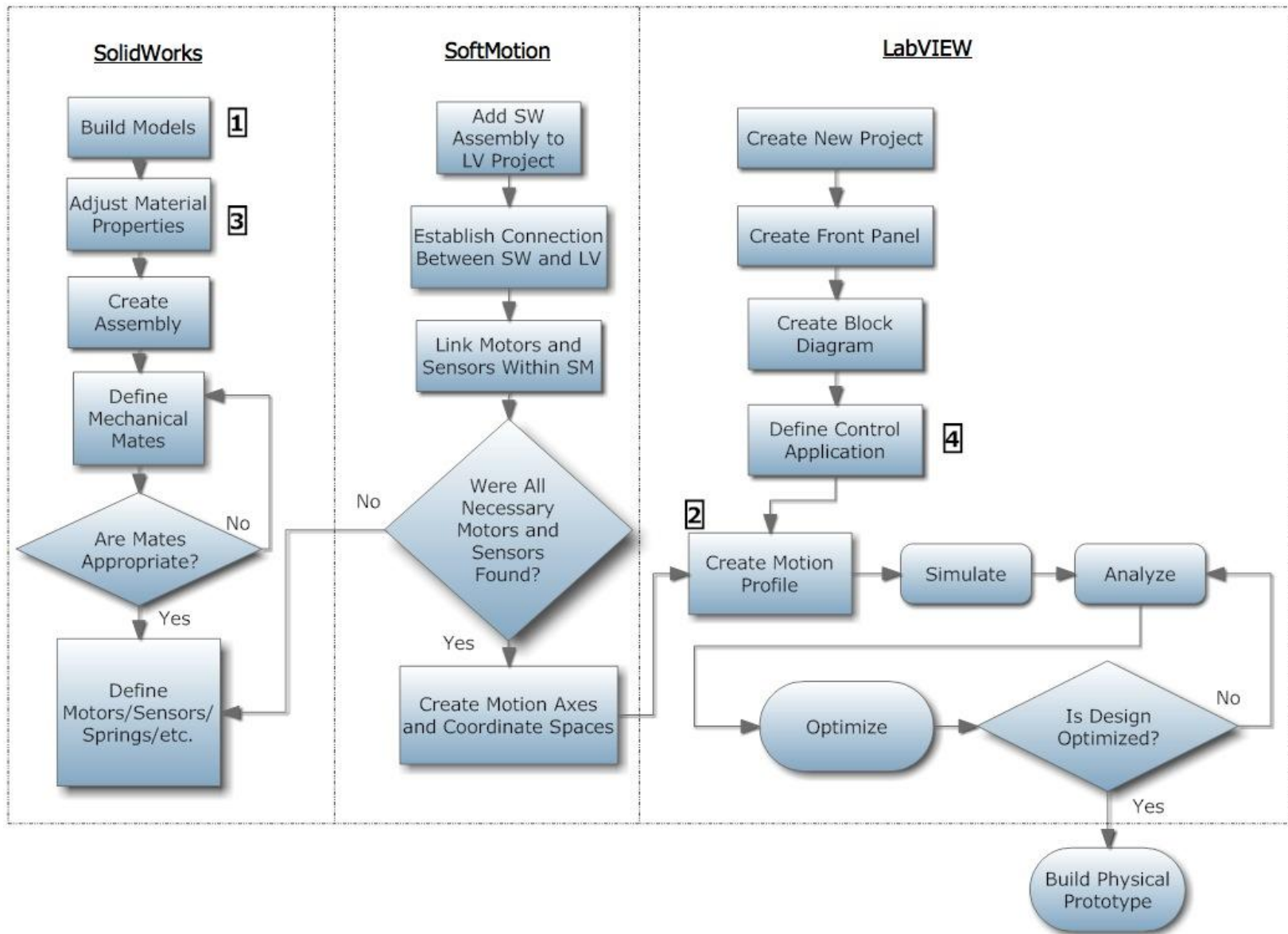
Figure 7. Virtual prototyping flowchart with SolidWorks, LabVIEW, and the SoftMotion Module

Figure 7, shown above, is a simple algorithm for use as a guide in the creation of a virtual prototype. The numbers shown in rectangles are reference points for the following table, used for the "Analyze" section of the algorithm.

Analysis	Solutions
Were there any collisions?	1 2
Is there a better material option?	3
Is there excessive friction?	1 3
Is there excessive tortional load?	1 3
Are limit switches appropriately placed?	1
Was the cycle time optimal?	1 2 4
Is the mechanical device strong enough?	1 3
Did the machine accurately perform tasks?	4

Table 1. Analysis table for optimization of a virtual prototype using Figure 7

Table 1 is meant for use with Figure 7 in the following way. The designer follows Figure 7 to produce the VP. When analyzing the VP, the questions under "Analysis" in Table 1 should be asked. If the answer to the question is "no," the designer should refer back to Figure 7 and the appropriate step that is associated with the number in the "Solutions" column. Certainly there are more questions that could be asked and further analysis that could be done, but the scope of this paper is does not allow for every one to be detailed.

Conclusion

Mechatronics devices will dominate the 21st century. The requirement for engineers to continue to increase functionality will drive the industry and virtual prototyping will become a more and more valuable tool as a means to that end. Fortunately, National Instruments and Dassault Systems have joined forces to make virtual prototyping a reality. As companies are required to be more efficient, virtual prototyping will become more popular. The design process will never be the same, and it would appear this process is moving in the right direction.

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