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Student Explorations in Animatronics to Demonstrate Digital Twins and Digital Threads

Dr. Neil Littell, Ohio University

Dr. W. Neil Littell is an Associate Professor at Ohio University within the Russ College of Engineering in the Department of Engineering Technology and Management, where he leads the Master of Science in Project Management as well as some of the Russ College's digital engineering initiatives.

Kouree Chesser, Ohio University

Lab and Student Experiences Coordinator for Mechanical Engineering, working with faculty and students to develop hands-on, interactive, and experiential learning activities, for first year students and beyond.

Brock William Klamfoth, Ohio University

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Abstract

The concept of digital twins and digital threads as a modern strategy of manufacturing execution can be an abstract concept for some students. In this paper, the authors will describe how they are using an approachable demonstration of digital twins and digital threads using both commercial and open-source animatronics to showcase how a digital twin can be developed to mirror a cyber-physical system. Additionally, the instructors will show how a digital thread can be established between the physical system and the digital environment to control the physical system in real time from the virtual environment. This paper is intended to orient the audience toward these solutions as a starting point for discussions and lab activities with their students on how they can use similar strategies to design and implement cyber-physical systems for industrial applications.

Background

Advances in technology have enabled companies to implement automation to help with a variety of tasks within their organization. The US Department of Defense released their instruction 5000.97 tilted “Digital Engineering’ [1] which articulates the importance of incorporating digital solutions into the development and sustainment of our defense assets, thereby also recognizing the importance of digital transformation to improve execution. Typically, digital engineering improvement projects are focused on improving processes, yielding a competitive advantage for the organization. Process improvements could be related to increasing manufacturing speed, reducing the reliance on manual labor, improving quality through increased automated inspections, or a myriad of other process changes which are deemed to yield value to the company.

Furthermore, implementing new products, derivative products, or new equipment into the manufacturing environment can be problematic for many companies, forcing them to implement and then work towards optimization post-implementation. This yields waste to the organization through reduced capabilities, either suboptimal processes or unforeseen challenges due to the complexity of implementing such changes in the manufacturing environment.

Companies seek continuous improvement to gain or retain their competitive advantage. However, the ability to implement improvement strategies relies on engineers analyzing the current state, proposing a change to the current state, and then iteratively restarting the process. This DMAIC (Define, Measure, Analyze, Implement, Control) framework is a commonly used continuous improvement strategy for many companies. One way that the DMAIC processes themselves could be improved is through the use of simulation, as determined by [2], [3], [4] and many others.

From a process perspective, it is widely recognized that the cost of changes increases as the lifecyle of a product progresses [5]. For example, a design change made early in the new product development process typically costs much less than a change to the product closer to the start of production or once the product is launched. The ability to accurately simulate the manufacturing processes in a highly realistic and geometrically correct way can help reduce some of the issues related to the start of production [6].

One way that companies can begin to realize efficiencies earlier is to implement strategies to enable them to execute changes virtually. If companies have a geometrically realistic representation of their environment, engineers could then use that environment to propose process changes and observe the impact of those changes virtually. This capability also offers the benefit of the engineers being able to implement several changes at once and observe the reaction of those simulations without disrupting the manufacturing environment.

The overarching goal of these initiatives is to speed the time to realize production improvements and to reduce the time required to implement new changes in the manufacturing environment. The perception is that through using digital engineering techniques such as digital twins and digital threads, a company can mitigate some of the failure opportunities if such tools were not utilized [7].

Defining Digital Engineering

The definition of Digital Engineering remains elusive because as a new label intending to describe the packaging of data, software, hardware, people, and processes means different things to different people, industries, and companies. Perhaps the simplist definition of digital engineering comes from CIMdata, who state that "Digital Engineering is simply another way to say engineering with technology" [8]. The Department of Defence (DoD) in their Instruction 5000.97, define digital engineering as "Digital engineering is a means of using and integrating digital models and the underlying data to support the development, test and evaluation, and sustainment of a system [1]. The DoD has also defined Digital Engineering as "an integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal" [9] also [10]. Giachetti [11] reports that the foundation to digital engineering is the representation of the system data in a format sharable between all stakeholders. This implies that for effective digital engineering to occur, digital threads and digital twins must exist to facilitate the enterprise processes.

Digital Threads

A digital thread refers to integrating people, processes, and data through an information technology-powered infrastructure so that each stakeholder can more easily execute their tasks. The goal of a digital thread is to allow the organization to execute more quickly in a digital environment to fail faster, that is, identify issues earlier in the product lifecycle, so mitigation steps can be executed to remediate earlier in the process. Digital threads are defined by the digital twin consortium as "a bidirectional, dependable and trustworthy interconnected information system that links multiple dimensions, including structure, behavior, space, time, and lifecycle stages" [12].

The term digital thread has been used in a Global Horizons report [13] which described the need to leverage synergies between discrete systems to create an integrated framework with a goal of reducing design lifecycle time by 25%. The report, authored in 2013, also discusses the importance of a system of systems, where cross-domain individuals are able to execute together and have the confidence that everyone is working from an authoritative source. This requirement of digital threads necessitates that a database-managed and revision-controlled environment is a prerequisite for enabling digital threads. The digital enterprise is, therefore, also required to provide a comprehensive data management strategy and solutions to provide data governance to its employees to help ensure the integrity of the authoritative source of truth.

Digital Twin

The first concept of the digital twin was in a presentation executed at the University of Michigan in 2002, related to the development of a Product Lifecycle Management (PLM) center. In this presentation, Dr. Grieves refered to the concept as a mirrored spacs model, which was then expanded through future presentation and scholarly works [14].

Digital Twins are formally defined by the Digital Twin Consortium as “an integrated data-driven virtual representation of real-world entities and processes, with synchronized interaction at a specified frequency and fidelity” [15]. The Global Horizons report [13] also discusses the concept of a digital twin, as the authoritative model governing the item. The goal is to build a digital twin that represents the physical assets thereby enabling various types of simulation with the goal of accurately being able to evaluate the life cycle of such assets virtually.

Learning Objectives

To teach the concepts of digital twins and digital threads, two faculty members at a mid-sized midwestern university proposed a project to explore and demonstrate these emerging technologies. The demonstration was required to:

1. Be approachable and appealing to a K-12 audience.
2. Be appropriate and appealing to working professionals to inspire conversations concerning how digital threads and digital twins could be implemented to yield benefits within their company.
3. Enable the physical system to be controlled in real-time in a virtual environment, providing a simple demonstration of the concept of both a digital twin and a digital thread.
4. Enable the students working on the demonstration to push their skillsets in ways that can be articulated on their resume for future job opportunities.

In response to these requirements and the desires of a few of the students, the faculty members were able to seek and receive funding for the students to build a digital twin and digital thread demonstration utilizing animatronics as the medium for the project. An animatronics demonstration was chosen because the physical product used in the demonstration, the physical system, could be designed to be appealing to the K-12 audience.

The interdisciplinary team of students on the project includes two computer science, one mechanical engineering, and one engineering technology student. This structured formation has allowed each student to contribute and build skills within their field of study and interest. The students have had and taken the opportunity to understand and learn more about new and unfamiliar concepts and skills as well.

Animatronics

Animatronics are animated puppets or characters, given personified roles, that are controlled primarily through electromechanical devices. Modern animatronic units have primarily existed in the film, amusement, and entertainment industries, but their design, components, and electronics can be further investigated and explored in an educational setting. Animatronic units can be used to demonstrate mechanical and electrical components in a way that is engaging to a younger audience. While the end goal of our project is to explore digital twins and threads, the animatronic model is the base and foundation of our physical system that provides more appeal to younger audiences. Student engagement in these creative outlets can enhance knowledge and understanding of the methods and components in animatronic designs and the knowledge translated into industry applications as they begin career development, higher education, and workforce training.

Bottango

In initial explorations of commercially available animatronics, we discovered Bottango, a company providing open-source hardware animatronic kits and free animation studio software for control of animatronic applications. The authors purchased two “Maxwell” animatronic kits from the company. These robotic kits use easy-to-understand, step-by-step instructions to walk the students through the assembly process, using low-cost components which provided an environment where the students could assemble the animatronics without fear of breaking components.

Students involved in the project have been able to use these to understand motor controls and the use of the animation studio software. The Maxwell by Bottango consumer grade kit has enabled the engineering students to explore the common components and functionality of animatronics, and how to translate this software to work with other animatronic designs. Figure 1 illustrates the software used to animate the animatronics and the physical assembly of the Maxwell animatronic.

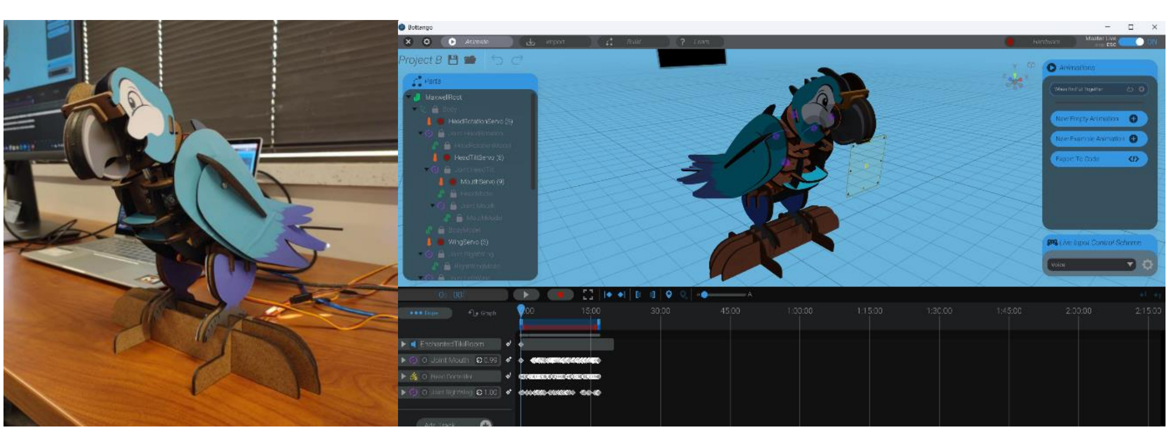

Fig 1 Physical and Virtual Maxwell

As an open-source project, the researchers have challenged the students to improve the abilities of the Maxwell birds by building a wireless capability for animatronics to connect to the computer. This capability is an exciting challenge for the engineering students so the animatronics can be operated without being physically connected to a computer for demonstration purposes. This enables demonstrations to be more polished and professional, removing many of the previously visible wires that could have been a distraction for novice observers of the animatronic.

Eva

Eva, an open-source humanoid robot provided by researchers at Columbia University [16], has provided a starting ground for building an animatronic-like application that can be used as our physical model. Eva is a much more advanced animatronic than Maxwell, providing the capabilities to offer a human-like head complete with some facial expressions.

As an open-source project, Eva can be freely downloaded from https://www.creativemachineslab.com/eva.html with design files, a bill of materials, general overview of assembly processes, and servo code provided. The Eva project has also allowed our undergraduate students a more advanced, yet still guided opportunity (through documentation, web resources such as forums, and faculty interactions) to learn more about mechanical and electronic (mechatronic) components as they create the physical animatronic. Figure 2 is a 3D model of the original Eva final build that students referenced when creating their build [17].

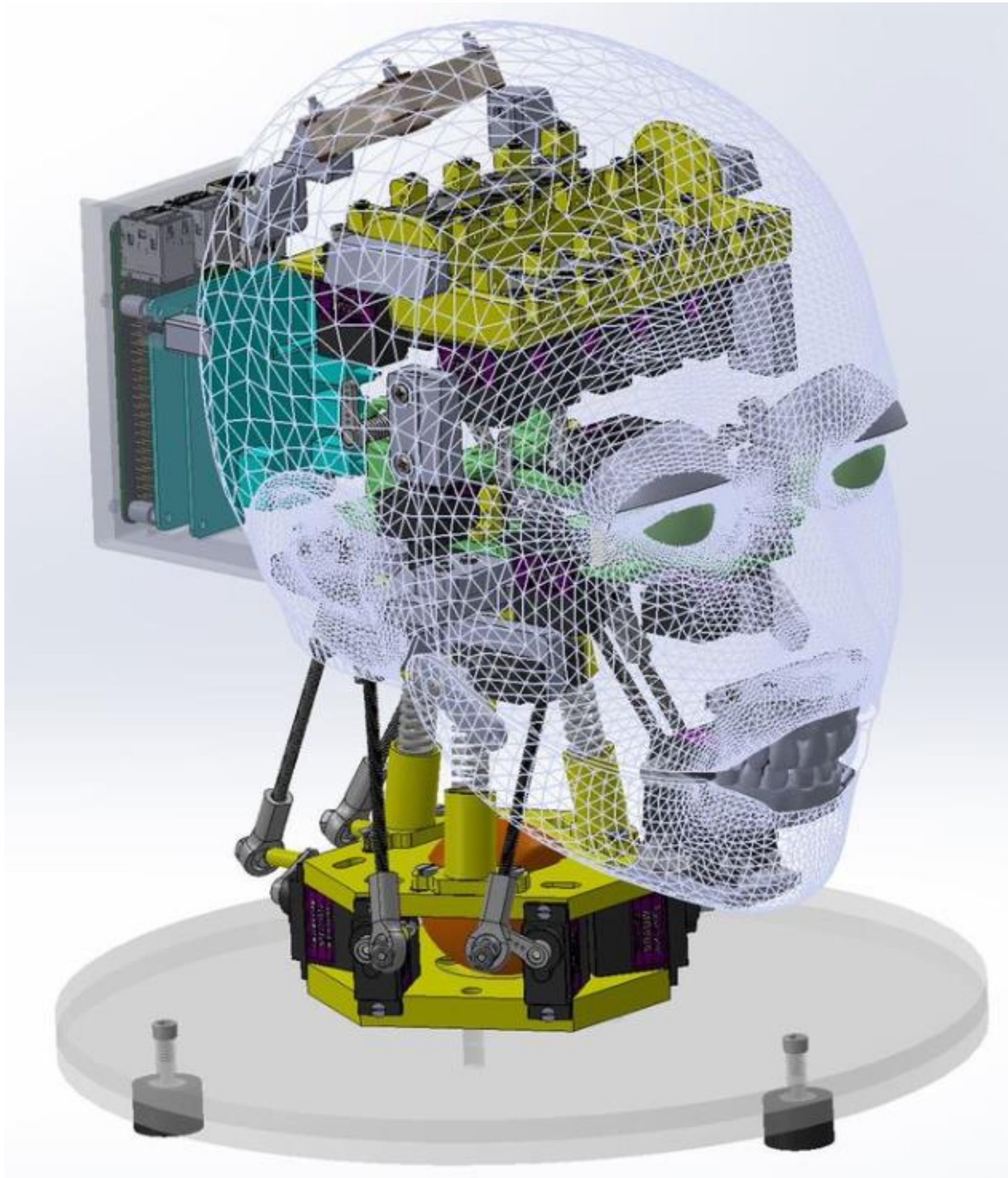

Fig 2. CAD Representation of Eva from Columbia University [17]

A primary difference noted by students is that the build process of Eva is more advanced than what they experienced with Maxwell. One student assimilated the build processes between Maxwell and Eva as “training wheels on versus off.” While intermediate guidance is provided on the build process of Eva, students are left to interpret and determine how to connect the individual materials to assemble the final product. In addition, this project provided a learning opportunity for students to integrate many of their technical skills, such as 3D printing, soldering, and programming. Opportunities to practice and improve soft skills such as problem solving, critical thinking, and adaptability as challenges have arisen.

The students have encountered challenges and learning opportunities through the programming aspect of this project as the tools originally provided on the coding platform were unfamiliar. It is also noted that the team of students responsible for programming were unfamiliar with how code integrates with the physical components such as servo motors, camera modules, and audio devices. However, they were able to work with the mechanical and engineering technology students to bridge that information gap.

Conclusion

While this is still a work in progress, the preliminary results of this effort have yielded excellent results. The students involved in the design and construction of the animatronics for this project have had several opportunities to showcase their work to faculty members, other students, and a few members of the public. Initial responses have been overwhelmingly positive, especially with our pair of animatronic birds, who are capable of talking to each other via a script.

The capability of the Bottango birds to move and react to each other is important because it accomplishes the task of illustrating both the digital thread and digital twin in real-time to the audience. This demonstration has proven to be effective at sparking conversations concerning digital twins and digital threads, and inspiring students to become more involved in engineering.

The faculty sponsor has also challenged the student build team again to extend the open-source animatronic. The anticipated expansion of this model will include new hardware and software features, such as the ability to interpret verbal communication from others and develop an audio response based on input. The students are also exploring providing Eva with the capability to follow items with its eyes.

The stretch goal for the Eva project is to implement the technology in a way that can be useful to visitors to our College of Engineering. The vision is for Eva to reside at a kiosk, where it can interact with visitors verbally, based on a custom GPT model. Eva should be able to tell visitors where the offices, facilities, or other basic questions are to showcase the technology and inspire our visitors.

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