Using Series Elastic Actuator as a Tool to Motivate Students Engineering Learning in STEM Education

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Abstract: Engineering education is a difficult concept for student learning because the student must apply scientific disciplines and connect abstract conceptual for a design solution to solve a problem. The exciting concept in Mechatronic engineering education is concerned with the basic laws concerning physical nature. Students will learn about machine design and controls, but it is hard to understand. This paper aims to design and develop a Series Elastic Actuator (SEA) as a mechanical tool to motivate student learning in concepts of mass-spring-damping and closed-loop control systems based on the revised 5E model in STEM education. The students' activities involve hands-on learning mass-spring-damping and the control systems of SEA. This learning approach helps students to have more interactive learning in a classroom. Moreover, it makes students systemically think and understand the relationship between theory and real-world application.

Keywords: Mass-spring-damping, closed-loop control system, revised 5E model

1. Introduction

Nowadays, teaching methods in engineering are most challenging for the teacher. Because traditional teaching methods, such as the chalk-and-talk method, are not the achievement of outcomes and objectives in study. Most students cannot describe the relationship between scientific knowledge and the physical world; thus, it makes them pay less attention and interaction. This problem is one such barrier to study engineering.

One of the research was teaching high school students the basic concept of control systems based on science, technology, engineering, and mathematics (STEM) (Abramovitch, 2019). STEM is a learning framework to help improve teaching for engineering students. The key to success is to design a proper framework for teaching based on the STEM curriculum (Fan, Yu, & Lin, 2020). Thus, getting started with designing a learning approach for the curriculum is an essential process. 5E is one of the methods that widespread use for engaging students in learning. This method has been developed in many studies. For instance, the revised 5E model was used to encourage high school students' computational thinking via a robot kit (Taengkasem et al., 2020).

Usually, studying mass-spring-damping and the control systems involves advanced mathematics, which explains physical plants. Nevertheless, most students cannot make imaginary the relationship between mathematics and the physical system. Thus, the authors focused on design the mass-spring-damping and closed-loop control as a tool for student learning in STEM education. We designed Series Elastic Actuator (SEA), which used concept of passive transmission elasticity to safe actuation mechanisms, based on Pratt, and Williamson (1995). Then the revised 5E model which is created by Taengkasem et al. (2020), used to drive the learning activity for the student of the engineering course.

2. Literature Review

In the last decade, many researchers tried to improve teaching in engineering courses. For example, a low-cost lab kit of a mass-spring-damping system with an analog filter was designed. This experimental kit is used in dynamic and control system courses. Students can do self-study and hand-on at home, which gives them more time to study. Moreover, it can reduce staffs' costs and room space. (Durfee, Li, & Waletzko, 2004). In recent years, mobile learning (m-learning) have more influence in teaching in engineering education. M-learning can be in the curriculum of primary, applied, and training in science and technologies (Herrera et al., 2015). For example, m-learning is used to teach technical vocational and Engineering Education (Jaschke, 2014). In addition, a mobile application had been sued for learning the topic of closed-loop control, a mass-spring-damper system, and animation of a plant displayed as users selected control parameters (Aristizabal, Almario, & Lopez, 2014).

However, teaching concepts of dynamic and control systems with real plants are still important because students need to link knowledge with the real applications used in industry. Therefore, learning material or experiment kit is an essential physical tool for engineering students.

3. Methodology

3.1 Learning Tool Design

In this work, the series elastic actuator (SEA) is used as a learning tool. It was designed to learn the topic of mass-spring-damping and the control systems. For machine mechanism, as shown in Figure 1, is composed of 7 main parts.

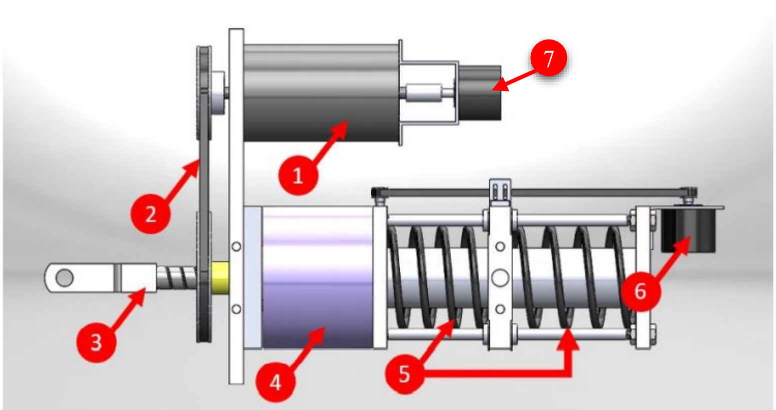

Figure 1. SEA design components.

- *Number 1*: It is a 24 Volt AC motor.
- *Number 2*: It is a small conveyer belt.
- *Number 3*: It is a ball screw.
- *Number 4*: It is a structure.
- *Number 5*: It is two series spring.
- *Number 6 and 7*: they are incremental encoders.

First, the motor drives the ball screw through the conveyer belt. The rotary encoder that is attached to the shaft of motor driving measure the speed of the motor. The ball screw distance can be computed using the speed of the motor and reduction gear. The movement of the ball screw has an effect on changing the distance of spring, which can measure from another increment encoder. The dumbbell 2.5 kg., as shown in Figure 2, is used as a mechanical load for testing the SEA system. The force of this load in each angle relates to the spring distance from the theory of Hooke's law. For microcontroller unit in this work is NI myRIO. It uses to read all sensors, compute data, and send pulse width modulation command to the driver to control the DC motor. LabVIEW program is used to create GUI transfer data to the microcontroller via the universal serial bus. Figure 3 shown the control programing system in this work.

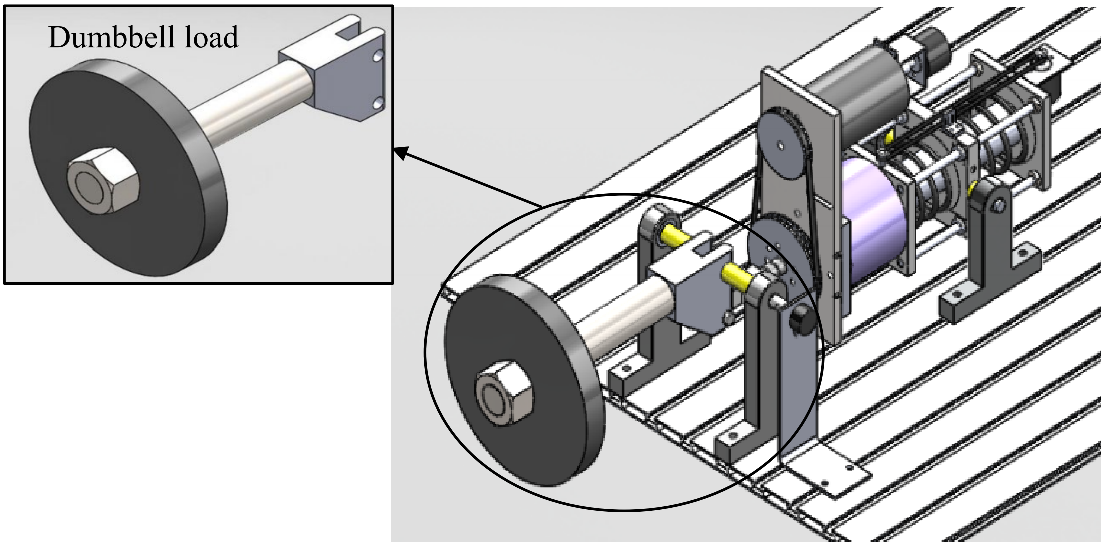

Figure 2. SEA with dumbbell load.

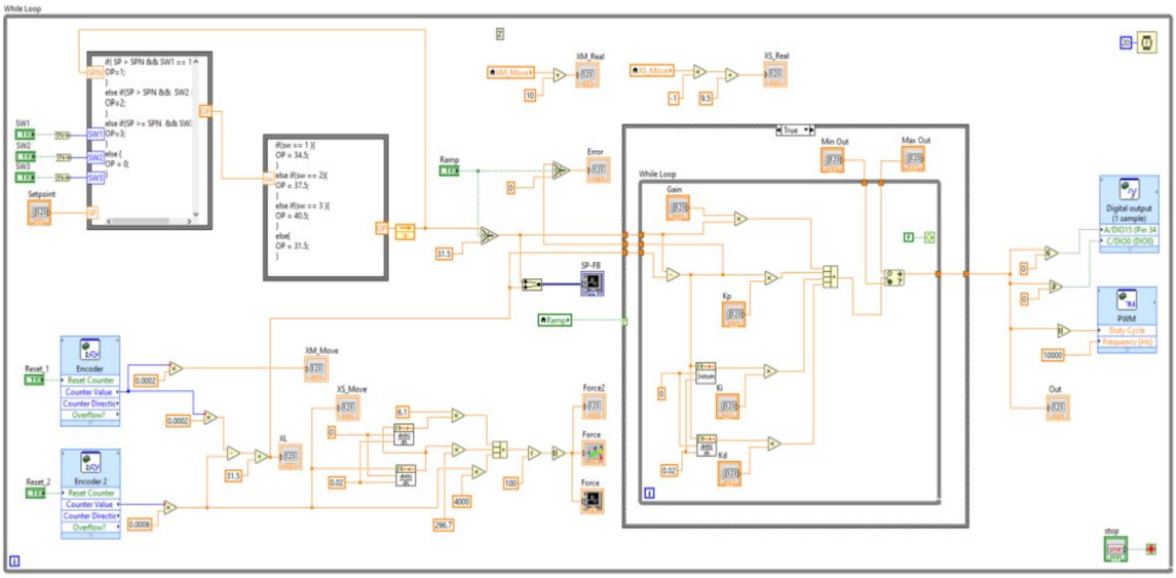

Figure 3. Control system program.

3.2 Revised 5E Model

In this work, we propose the technique to enhance students learning in the topic of dynamic and close-loop control systems in STEM education. Our proposal on pre-experimental design is a design based on a revision of the 5E model, consisting of engagement, exploration, explanation, execution, and evaluation, as in Figure 4. The learning activity with the revised 5E model is followed as:

- *Engagement phase:* In the first phase, the teacher starts with the teacher's experience using mass-spring-damping in the real world to encourage students to think and motivate. After that, the teacher asks questions that require students to discuss and allows students to talk using their skills. Finally, the teacher creates an excellent problem to engage and focus on the learning activity.
- *Exploration phase:* This phase has come after students have some motivations and ideas. The teacher gives time for students to explore their ideas. The teacher gives them some guidance and resources. However, they need to find more information or theories from other resources in order to solve problems.

- *Explanation phase:* The step of explanation phase starts with students present or explain their outcome to solve problems. After that, teacher supports their concept in formal pedagogy based on science, technology, engineering, and mathematics.
- *Execution phase:* For this step, students are required to execute all concepts using a learning tool and correct the data. Then data is analyzed in purpose to compare with the concepts.
- *Evaluation phase:* After students achieve learning activities using their knowledge, they should have more understanding of the concepts. Then students are evaluated in purpose to see each student's outcome.

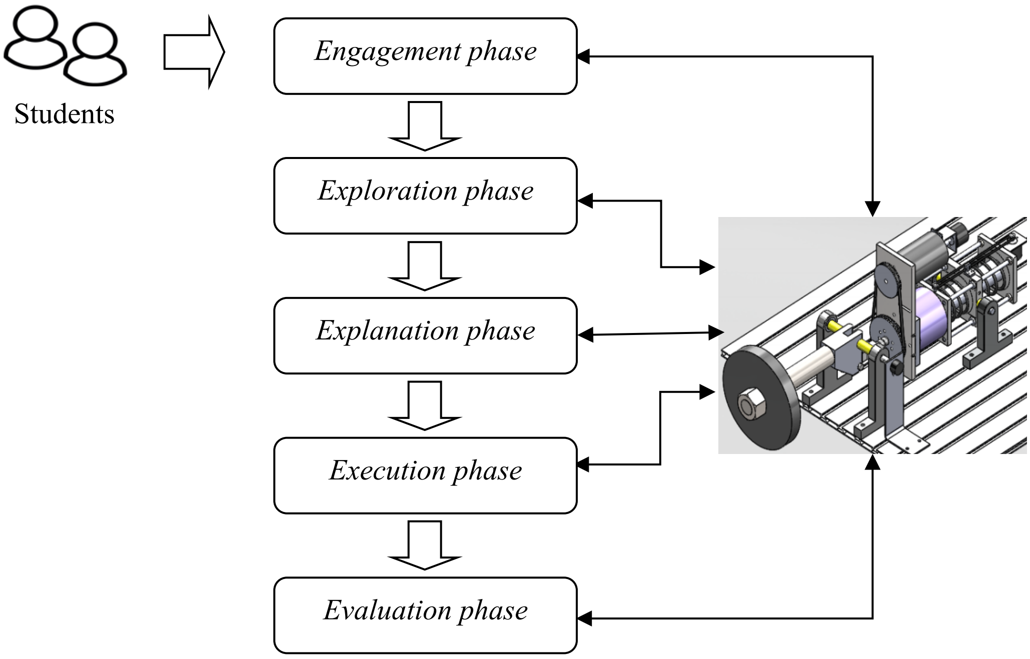

Figure 4. Diagram of revised 5E model.

3.3 Design Learning Activities

First, start with the engagement phase, the teacher giving the experience of using mass-spring-damping in SEA and give applications such as prosthetic knee (Rouse, Mooney, & Herr, 2014). Students discuss, ask and share their experiences. After a while, the teacher gives a concept of mass-spring-damping and control system. Next, the teacher play role of using a learning tool (SEA), then the teacher ask some problems, "how is mass-spring-damping working with unforce and force?", "how to solve the mass-spring-damping second-order differential equation?" and "how to control the system using PID controller?".

The next phase is the exploration phase. The problems have been purpose in the last step of engagement. Then the teacher gives them some resources such as a textbook and a summary of the theory. The students have to inquire into problems using more resources, such as YouTube, e-book. In this phase, the teacher acts as a coach to support students learning. Then they come out with their idea to solve all problems.

Explanation phase, students present the method to solve all questions in the engagement phase. Moreover, teacher helps to support their ideas based on STEM format, for example, in Hooke's Law, Newton's 2nd Law, torque, second-order differential equation, transfer function, and PID controller, PID feedforward controller.

For the execution phase in our work step, SEA is using as a learning tool. Students have a hands-on activity to solve that their concepts were correct or not. Learning activity in this step consists of 4 activities as following:

- *Activity 1:* Measuring spring distance in different ball screw positions when SEA has not connected to dumbbell load.
- *Activity 2:* Measuring spring distance and external force when dumbbell load has a different angle.

- *Activity 3:* The ball screw position of SEA is control using PID and PID with a feedforward controller based on a step input signal.
- *Activity 4:* The ball screw position of SEA is control using PID and PID with a feedforward controller based on a ramp input signal.

The last phase involves student evaluation. Students finish all learning activity parts. Then they need to compare the result of the experiment and the result of their thinking using theory. They have to analyze data and link it to their skill. Finally, the teacher evaluates student's understanding using presentation. This evaluation can tell that "How well they can explain learning activity based on STEM," and the teacher supports more ideas to students.

4. Results

In this study, we have constructed a learning tool with two components consisting of a hardware tool that is Series Elastic Actuator (SEA), as shown in Figure 5. In part of Software, LabVIEW was used to require test, measurement, and control with rapid access to hardware and data insights, as shown in Figure 6.

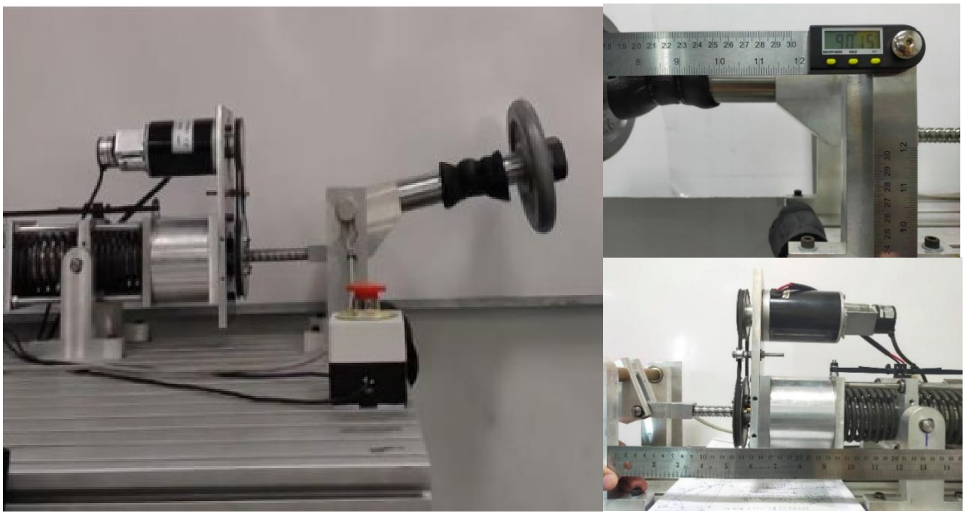

Figure 5. Using Series Elastic Actuator (SEA) of learning activity.

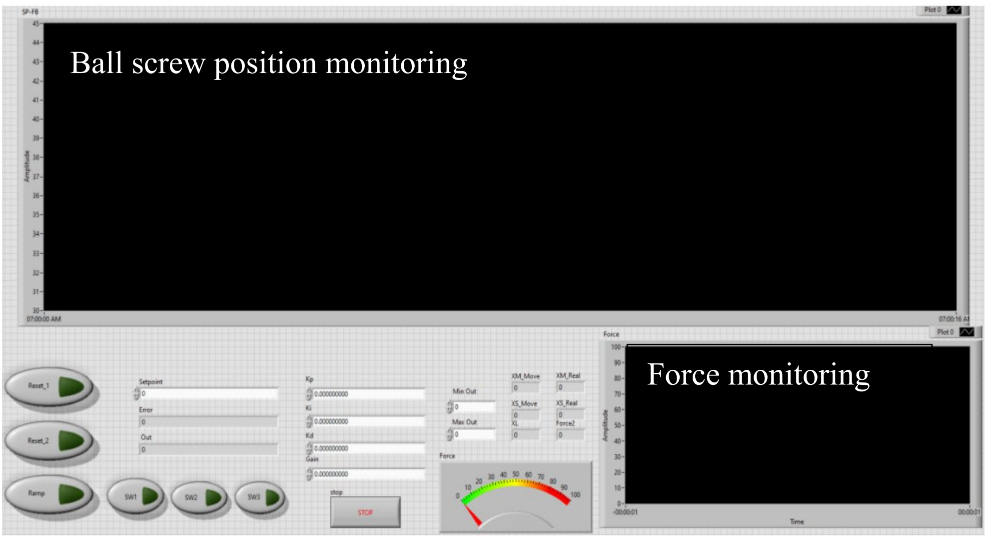

Figure 6. LabVIEW for monitoring engineering concept.

5. Conclusion

Normally, teaching in the mass-spring-damping and the control systems for student engineers is most challenging for teachers. Most students cannot understand the concept when teachers teach in traditional ways such as chalk-and-talk. Thus, the important key is to change the way to teach them. In this work proposed pre-experimental research design is based on the revised 5E method. This learning approach design expects the teacher to improve the student's skills. The design allows students more interaction in the class. In addition, students are free to solve the problems with their skills and prove their understanding of the SEA learning tool. This step allows students to link concepts with real mechanics that are used in industry. Moreover, the teacher evaluates students and supports some missing points to make sure that students deeply understand all concepts of mass-spring-damping and closed-loop control systems. Future work will focus on implementing the SEA tool into the class. Moreover, a design of appropriate examination based on bloom's taxonomy levels is needed to measure and evaluate students' performance in the topic of mass-spring-damping and closed-loop control systems.

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References

Abramovitch, D. Y. (2019). Introducing feedback control to middle and high school stem students, Part 2: Control system math. *IFAC-PapersOnLine*, *52(9)*, 177-183. https://doi.org/10.1016/j.ifacol.2019.08.191

Aristizabal, L. F., Almario, D. F., & Lopez, J. A. (2014). Development of an Android App as a learning tool of dynamic systems and automatic control. In *2014 III International Congress of Engineering Mechatronics and Automation (CIIMA), Oct. 2014* (pp. 1-5). https://doi.org/10.1109/CIIMA.2014.6983438

Durfee, W., Li, P., & Waletzko, D. (2004). Take-home lab kits for system dynamics and controls courses. In *2004 American Control Conference, Jun. 2004* (pp. 1319-1322). https://doi.org/10.23919/ACC.2004.1386757

Fan, S. C., Yu, K. C., & Lin, K. Y. (2020). A framework for implementing an engineering-focused STEM curriculum. *International Journal of Science and Mathematics Education,* 1-19. https://doi.org/10.1007/s10763-020-10129-y

Herrera, S. I., Fennema, M. C., Morales, M. I., Palavecino, R. A., Goldar, J. E., & Zuaín, S. V. (2015). Mobile technologies in engineering education. In *2015 International Conference on Interactive Collaborative Learning (ICL), Sept 2015* (pp. 1157-1164). https://doi.org/10.1109/ICL.2015.7318197

Jaschke, S. (2014). Mobile learning applications for technical vocational and engineering education: The use of competence snippets in laboratory courses and industry 4.0. In *2014 International Conference on Interactive Collaborative Learning (ICL)*, *Dec.2014* (pp. 605-608). https://doi.org/10.1109/ICL.2014.7017840

Pratt, G. A., & Williamson, M. M. (1995). Series elastic actuators. In *Proc. of the 1995 IEEE/RSJ International Conference on Intelligent Robots and Systems. Human Robot Interaction and Cooperative Robots*, *Aug 1995* (pp. 399-406). https://doi.org/10.1109/IROS.1995.525827

Rouse, E. J., Mooney, L. M., & Herr, H. M. (2014). Clutchable series-elastic actuator: Implications for prosthetic knee design. *The International Journal of Robotics Research*, *33(13)*, 1611-1625. https://doi.org/10.1177/0278364914545673

Taengkasem, K., Chookaew, S., Howimanporn, S., Hutamarn, S., & Wongwatkit, C. (2020). Using Robot-based Inquiry Learning Activities for Promoting Students' Computational Thinking and Engagement. In *Proc. of the 28th International Conference on Computers in Education*, *Nov 2020* (pp.386-393).