BUILDING TWO PHYSICS ROBOTS FOR EDUCATIONAL USE IN K-12 SCHOOLS

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1. ABSTRACT

One of the most important aspects of building and growing an engineering community is to encourage more people to get excited about the field by reaching out to communities of K-12 students to get them excited about engineering. The goal of the project is to design two robots combining the disciplines of mechanical and electrical engineering, which would be inexpensive for schools to buy and a tool that teachers can use to demonstrate to student's principles of engineering, physics, and robotics. With how little time and resources educators must expand outside of their teaching expertise, the goal is to make the design intuitive and give a clear understanding of what's happening. The design requirements entail that the robots should be able to fit on a cart so that they can be transported from classroom to classroom, to make robots able to survive accidents, like falling off a table, and making them simple. The team picked out two concepts to demonstrate, first being a self-balancing, inverted pendulum robot, and second being a robot that follows a line. A self-balancing robot demonstrates physics at the forefront to students and control sensors. The line following robot will follow a line traced by the students which it will try to navigate and follow. The design will incorporate a touch screen such that the robot is interactive yet has a visual output for students to see the brain of the robot. The team's method of building the robot and prototype includes using small computers and microcontroller interfaces such as the Arduino and raspberry pi. The goal of the team is to build two robots by the end of this semester to get a feel for how the robots work and secondarily, to work on building more units for production.

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3. BACKGROUND

The Robotics Travelling Van capstone group aims to build two physics robots which will increase student interest in robotics and physics. The first robot is an inverted pendulum robot, while the other one is still under consideration. The former robot can give children an example of physics in action and show them what the robot is 'thinking', all while balancing the inverted pendulum. The latter robot is going to be a more interactive, more complex robot. The goal of this robot is to expose schoolkids to a more complicated but visually interesting robot. To make the robot more interactive, different methods for the kids to interface with the robot are being discussed. Some notable examples are voice activation or a controller, in addition to a touch screen, which both robots will have.

In addition to being physics and robotics demonstrations, these robots are educational. The touchscreens on the robots will display the values measured by the robots in real time and show a simple overview of what the robot is thinking. These touchscreens will also allow children to experiment with changing different aspects of how the robot works, either through editing variables or through pre-coded functions.

4. REQUIREMENTS

The two education physics robots will be built with requirements and constraints given to the team by Dr. Willy. He gave requirements that the robots are durable, inexpensive (under $150 per unit), functional (battery powered, interactive, and works within a confined space), educational, and kid-friendly. These general requirements were refined into a specific list of engineering requirements, which the team will then use to build the decision matrix from.

From Dr. Willys requirements, both robots must be under 14” × 10” × 5”, or the approximate size of a shoebox. The durability requirements are that the robots must continue to function after a 30” drop onto concrete. And to keep costs low, cheaper boards such as the Arduino Uno were selected over competitors like the Raspberry Pi 5 or Raspberry Pi Compute modules. The robots must run for up to 90 minutes between charge, have an interactive touchscreen displaying information about each robot, and stay within a 20” square area. To make these robots educational, the information displayed will explain, at a high level, what the robot is ‘thinking’ while running. These touchscreens will also allow schoolkids to select from multiple operating modes and change some of the code’s variables, affecting the function of the robots. Lastly, programming diagrams will be included, which can aid in the explanation of how these robots work to children.

The last requirement is that the robots be kid-friendly, which will be fulfilled as a bi-product of making the robots US CPSC compliant. This consumer product safety standard covers a large variety of toys, with some of their sections applying to the two physics robots. Section 4.7 covers hazardous edges accessible to children, both before and after "use-and-abuse testing" [1]. From Section 4.13, any folding mechanisms and hinges must be designed to eliminate the chances of children hurting themselves [1]. Notably, the inverted pendulum on the first robot will need to be specifically designed to comply with 4.13. Section 4.17 covers wheels, which both robots will have. The wheels on the robots must not "pose a laceration, puncture, or ingestion hazard" before or after use [1]. Lastly, Section 4.25 specifies that battery-operated toys must ensure that the batteries are inaccessible during use [1]

5. OBJECTIVES

The end goal of this capstone project is to create two mass producible robots for the purpose of demonstrating engineering principles. This will allow K-12 students to learn more about the STEM field early in their education and see the thought process that goes into creating devices such as these. As this will be presented to a young audience, the robots will be displayed as an interactive toy to help spark an interest.

With the clear goal of creating two robots, the project's client expressed interest in creating and demonstrating a prototype for each robot by the end of the semester. The Mechanical Engineering counterpart to this capstone project created a timeline that will allow us to satisfy this request and keep the team on schedule.

1. Robot Development	Week 6 - Week 12
1.1 Mechanical Design Phase	Week 6 - Week 8
1.1.1 CAD Modeling	Deliverable: 3D CAD model of key components
1.1.2 Material Procurement	Deliverable: Purchase orders, BOM for Robots
1.2 Electrical Design Phase	Week 7 - Week 12
1.2.1 Circuit Design	Deliverable: Schematic & PCB layout
1.2.2 Programming	Deliverable: Control software with basic functionalities
1.2.3 Testing & Debugging	Verify hardware & software integration with debugging reports

Table 1: A timeline that will keep the robotics traveling van capstone project on course to being able to create two prototypes ready for demonstration by the end of the 2025 fall term.

The team will stick to the timeline to stay on track for finishing two working prototypes that are ready to display to the client at the end of the 2025 fall term.

6. STANDARDS

As per a requirement for the project, the design must follow appropriate standards for safety, the law, and be compatible with standards set by the IEEE association for the two robots. The subsequent paragraphs go into more specific detail about the appropriate safety standards and the engineering standards the robots will be using.

As per the United States Consumer Product Safety Commission, a ‘toy’ is any object designed, manufactured, or marketed as a plaything for children under the age of 14 [1] Our objective is to design an educational toy for K-12 students, our robots must comply with the rules set in place by the CSPC regarding toys. These requirements are outlined in ASTM F963 Section 4 [1]. A summary of the relevant subsections detail that:

- The product should be free from infestation (4.1)
- The product should not be flammable (4.2)
- The product should not contain excessive hazardous (toxic, corrosive, irritant, pressure generating, radioactive, etc.) substances (4.3.1)
- The product should not contain excessive heavy elements (lead, chromium, etc.) (4.3.5.2)
- The product should not contain more than 0.1% phthalates (4.3.8)

The product should not contain choking hazards (4.6.1)

The product should not have sharp edges (4.7)

If the sharp edges are required for the function of the product, there should be a warning label (4.7.2)

Metal edges that can be accessed should not have hazardous burrs (4.7.3)

Wires in the interior of the product should not break off and create points (4.10)

The list of standards for toy safety is extensive. More standards that are relevant to this project will be added as needed during this project.

There are also IEEE standards that correlate to the project. Specifically, the IEEE Standard for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments. The main goal of these standards is to create a uniform user experience when it comes to power controls. This applies to all consumer electronics, which, if the product is not only being sold to schools, is the category in which our robots lie. The standards are summarized as follows:

- Devices should have three basic power states: on, sleep, and off. There may be additional states, but they must be sub-states of the three main states [2].
- If the device has a sleep state, it must have one or more ‘wake events’ to bring it back to the on state [2].
- The power consumption for these three states is required to be:

  Pon > = Psleep and Psleep >= Poff

- Holding the power button down for four seconds will cause the product to shut down regardless of what is happening (an emergency override) [2].

As with the previous set of standards, this list of relevant IEEE standards will also continue to grow as the project continues.

7. DESIGN

The pendulum balancing robot is the first robot the team has started to work on. The purpose of this robot is to balance a rod on top of itself and be able to move on wheels to correct the rod position when it begins to tilt or fall. For this, the robot will consist of the following parts: an Arduino Board, Wheels, a Potentiometer, 9V DC Motors, Ultrasonic Sensors, and a Touchscreen Interface.

The team will program the Arduino to balance the rod by using potentiometers attached to the rod fixture measuring the angle of the rod that provides real-time readings of the rods position. The ultrasonic sensors will be used to track the robo t's position on the school table and ff the robot gets too close to the edge of the table, it will go the other direction, so it doesn't fall off. The motor will drive the wheels.

The robot is required to be an interactive experience for the students, achieved through the touch screen. The students will be able to use the touch screen to make some kind of changes to the robot. For example, the students may be able to change how quickly the rod will fall so the robot will have to adjust its speed to stand the rod upright.

8. CONCLUSION

The team plans on developing two robot designs as teaching and demonstratoin tools for K-12 students for the client, Dr, Willy. The plans for the first robot design have been thought out and are looking to be sent into the prototyping stage to get everything developed. As for the design, using Arduinos and control modules, such as potentiometers, to have the robot able to be interacted with. The design of the line following robot is still in the early stages of development and will be developed more as the semester progresses. For the design of the robots, they will always be evaluated to make sure that they meet the requirements given to the team and that the team is making good progress to reach its goals.

References

[1] "Toy Safety Business Guidance," U.S. Consumer Product Safety Commission. https://www.cpsc.gov/Business--Manufacturing/Business-Education/Toy-Safety

[2] "IEEE Standard for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments," *IEEE Std 1621-2004*, pp. 1–18, June 2005, doi: 10.1109/IEEESTD.2005.96205.