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Design of a Transparent Hydraulic/Pneumatic Excavator Arm for Teaching and Outreach Activities

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Abstract

The purpose of this work is to design and build a miniature excavator arm which can be used as a technological tool for educational purposes. Many of the miniature excavator arms used in education today operate using electronic systems and are made of steel, 3-D printed parts and other opaque materials. This unique design could either be controlled by using hydraulics or pneumatics and is made of Lexan, a transparent material, allowing students to observe all of the systems components as the excavator is being operated. The design features a portable, table top, arm that can be cut out from a piece of 3/8” Lexan and a piece of 1/4” aluminum. The hydraulic arm only requires a few tools to assemble and a standard 120VAC/15A electrical outlet to operate. Joysticks are used to manually operate the movement of the excavator arm. These joysticks actuate mechanical valves that transfer the chosen fluid (tap water or air) to actuators, which extend and retract, controlling the motion of the arms. The arm mimics a full-sized excavator and can educate the operator on modern hydraulic and pneumatic technologies and how they are being used in industry. This technological tool will be used in fluid power and data acquisition courses to enhance and support the learning experience at universities and introduce students in high school and undergraduate programs to engineering and fluid power technology using an interesting hands-on demonstrator. Furthermore, the tool provides a great environment for data analytics and real-time decision making. The portability of the kit allows it to be used in workshops, recruiting events, state and county fairs, social gatherings, and conferences. Such a tool will help draw attention to STEM fields and university engineering programs.

Introduction

There are a limited number of technological tools that support hands-on learning for students in education. Research has been done to discover why these demonstrators are not being used in education. A typical response to this question, from multiple schools that were asked, was, “We want to use technology, but we are challenged by the lack of technical tools [1]”. Hands-on learning devices have been used for a long time and have proved themselves to be useful gadgets for teaching difficult-to-grasp concepts. The United States Military Academy uses a variety of different tools within their engineering curriculum to teach the relationship between the stresses that occur in materials when forces are applied to them. It is reported, semesters after using these hands-on demonstrators, that students had a stronger recollection of fundamental concepts that were taught from the demonstrators, than in semesters past [2]. Technological tools range from software, which provides students with a virtual tool helping students to observe and visualize multiple concepts taught in lecture, to physical tools that can be used to provide students with an interactive device that students can observe and learn from. Having students design and build physical technological tools as a form of a school project or summer internship also exposes them to real-life engineering applications [3]. This work presents the use of a physical technological tool, which can be used in education to help reinforce and expand high-school and undergraduate engineering education.

Background

Hands-on technological tools have been used in education for many years. In 2009, a micro-excavator arm was designed at Purdue University to teach mathematics and physics and to interest young students in STEM fields for students ranging from kindergarten to twelfth grade. A survey was given to the participants who used this tool to evaluate the benefits of hands-on learning tools in education. The top three average responses scored on the questionnaire were 1) I would recommend activities like this to be used at my school 2) I enjoyed doing this activity very much and 3) I think this is an important activity [4]. With such a positive feedback from such a tool, Purdue University has continued this project and have made multiple versions of this tool ranging from an excavator arm utilizing mechanical valves, created in 2009, to a miniature excavator arm built almost entirely of 3-D printed components and utilizes electronic servo motors to transfer fluid power to the arm to develop a more controllable system [4] [5]. Many of such technological tools used in education are made from opaque materials ranging from plastic, 3D printed parts, and steel components. While these tools are still very usefully in teaching concepts, work is currently being done to expand the possibilities of using transparent materials, such as Lexan, to improve on and expand the possibilities available for physical technological tools.

Excavator Arm Design

To enhance courses involving technical applications of machinery, a hydraulic/pneumatic miniature excavator arm was developed as a technological tool to teach difficult-to-grasp concepts in a lecture/laboratory environment. The hydraulic system used to control the motion of the arm consists of an electric water pump, four mechanical valves, flow control valves, hydraulic cylinders, and a large reservoir. This system utilizes an electric water pump that can run on a standard electrical outlet and uses water for the systems hydraulic fluid, making the arm a very versatile tool. This mechanical excavator arm utilizes a layered Lexan design, enabling the system to be transparent. The use of a transparent designs in technological tools permit spectators to observe mechanical components from multiple angles during operation, seen in Figure 1.

Figure 1. Layered Lexan Design

This arm was designed to be cut from a 4’ x 4’ sheet of ⅜” Lexan using hand tools or water jet technology. Once the arm was cut out, bushings and bearings were then pressed into each arm using an arbor press. The layers of Lexan were then bolted together through the bottom “rib” and each arm was pinned together using quick-release pins, allowing the arm to be taken apart easily and stored inside the bin for portability purposes. Due to the geometry of excavator buckets, a unique 3D printed bucket was also created, which features 4 bucket teeth to visually mimic typical excavating buckets used on industry equipment and keep small objects from rolling out of the bucket. For structural strength the arm was mounted to an aluminum base that rotates in two flange bearings. The fluid reservoir for the system is used to mount the base of the excavator arm and its control system to keep the system compact. To mount the arm and control system to the reservoir, a ½’’ Lexan top was cut and hinged on the reservoir, making the reservoir accessible to fill and to use as a storage container when the arm is dismantled, seen in Figure 2.

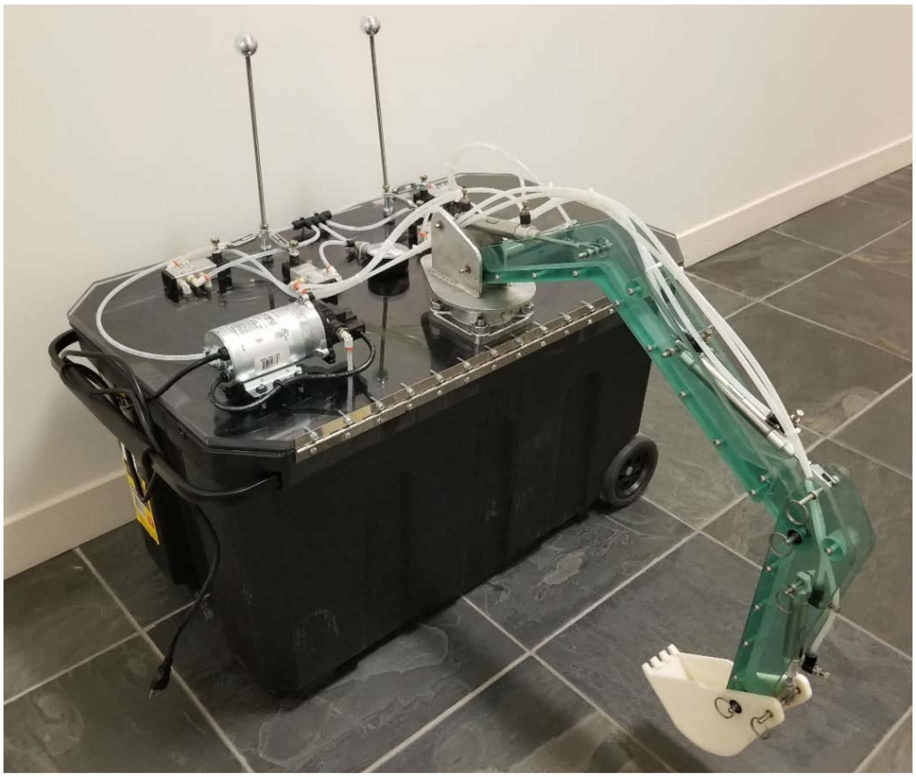

Figure 2. Front View of Excavator Arm

Control System

The controls system for the arm consists of an electrical water pump, four mechanical valves, eight flow control valves and four hydraulic cylinders. The electrical water pump is the main source of power for the system. The pump converts the electrical power to fluid power which is used to actuate the hydraulic cylinders. The fluid power is then converted to mechanical power by allowing the hydraulic cylinders to extend and retract, rotating multiple components of the arm. Figure 3 depicts a breakdown of the power transferred throughout the system.

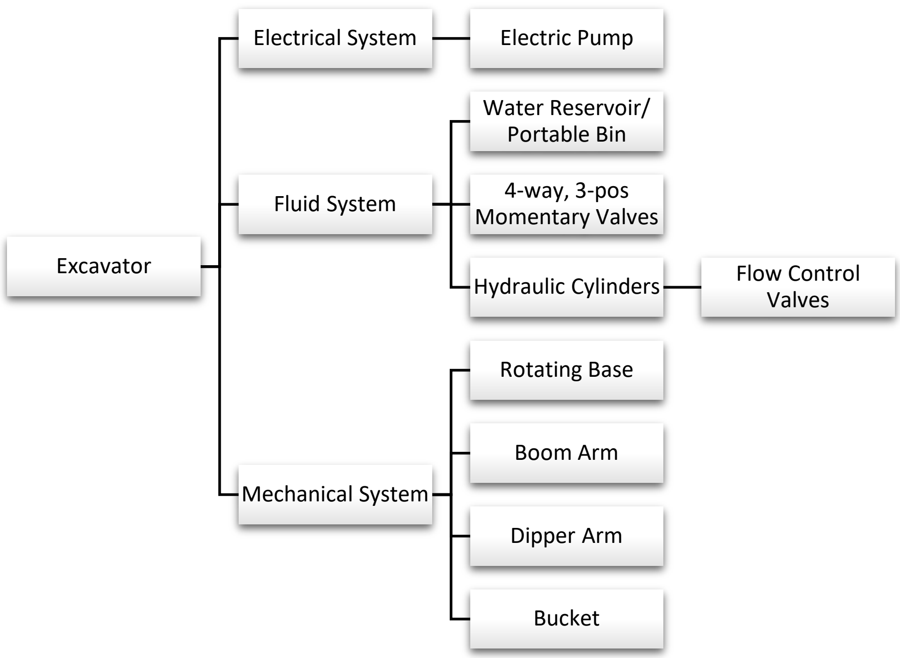

Figure 3. Excavator System Hierarchy

The manual controls for operating the arm are simple to use and the electrical water pump and four mechanical valves are mounted to the Lexan top. The valves are controlled using two joystick controllers. Each joystick controller actuates two valves, one in the x direction and the other in the y direction. This allows the joystick to move to any position in the x and y plane, actuating either a single or both valves. This joystick control allows multiple components of the excavator to be actuated at the same time, mimicking industry excavator controls. To regulate the speed at which the arm rotates, adjustable flow control valves are attached to the hydraulic cylinders to adjust the speed at which the hydraulic cylinders fill, speeding up or slowing the excavator arm. A top view of the control system can be seen in Figure 4.

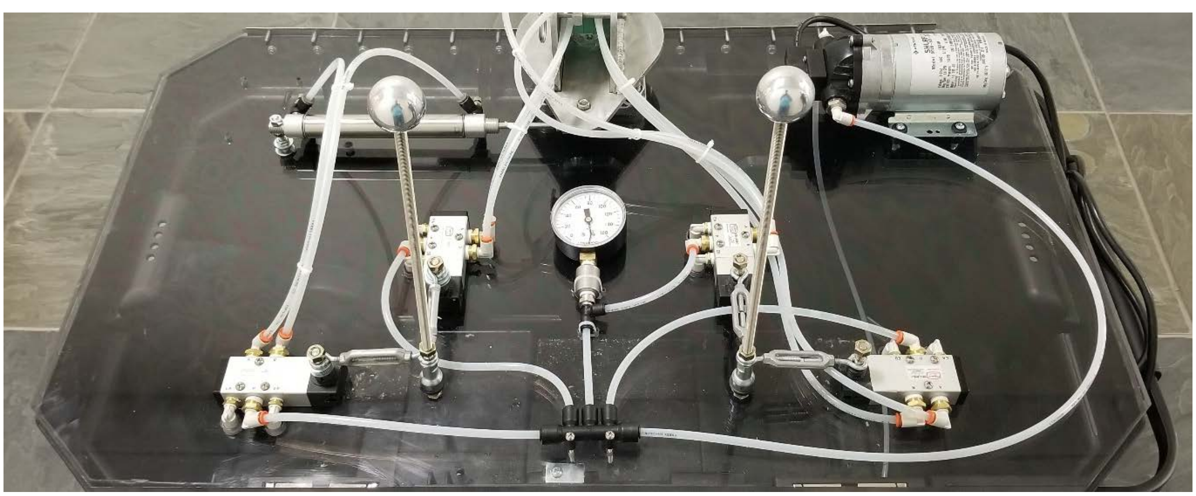

Figure 4. Top View of Control System

Fluid Power Circuit

This miniature excavator arm utilizes multiple actuators which run simultaneously. Figure 5 depicts the implementation of the hydraulic circuit of a single actuator on the arm. The system runs a meter-out system that is implemented in the form of variable orifices. A meter-out circuit allows fluid to enter the actuator at a controlled rate making the movement of the actuator smoother and steadier. Flow control valves were placed on both the inlet and outlet valves to obtain complete control of the pressure change across each actuator. These control valves allow fluid to flow in one direction and restrict flow in the opposite direction. The control valves utilize a variable needle valve that controls the flow through the valve. The needle valve allows for an efficient and high-quality operation of the hydraulic actuators. With this control design, the base can rotate along its designated trajectory with accurate positioning [6].

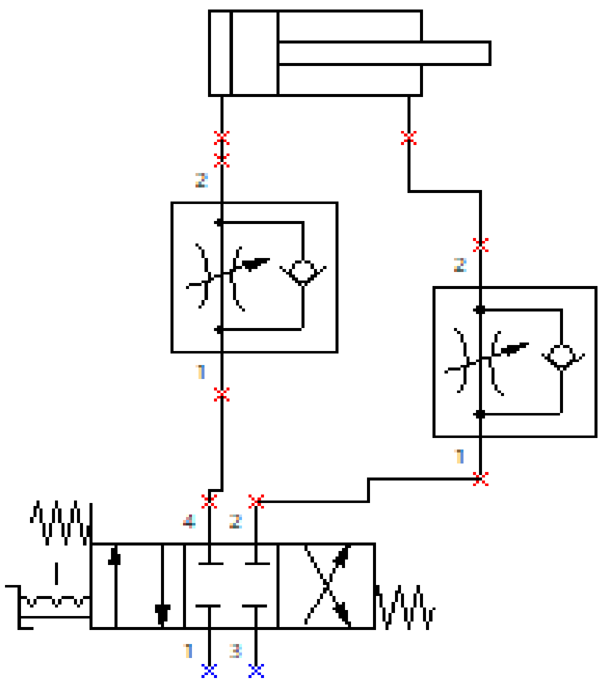

Figure 5. Individual Hydraulic Actuator Circuit

Prototype Cost

The total budget needed for construction this technological tool is about $1,318.00. Each component needed for building this tool and its price are listed in Table 1. A more detailed table could be found in the hydraulic excavator design manual [9]. This cost list is independent of the tools required to build the excavator. A detailed budget can be seen in Appendix A. Opportunity was the greatest incentive for choosing the excavator’s arms prime materials because they are relatively low cost and can be purchased in bulk. The excavator’s materials can be cut out and assembled using tools that are quite common in any workshop.

Table 1: Cost of Excavator Arm Components

Item	Cost (USD)
Tubing and Fittings	$187.00
Portable Tool Chest	$71.00
Cylinders	$112.00
Valves	$353.00
Water Pump	$125.00
Rod Clevis, Bearing, etc.	$235.00
Gauge and Manifolds	$35.00
Base Materials	$200.00
Total Cost	$1,318.00

Educational Opportunities

Currently in the engineering class environment, it is crucial for students to have an integrated 'hands on' learning experience. A few advantages for students to learn in this kind of environment are: 1) attention and perception are optimized, 2) increased retention rates, and 3) students will be more likely to get involved and gain interest in such projects [7]. The focus of this project challenges students to actively participate in the learning process to understand the different mechanics of the system. Research and analysis on this system can be done in multiple groups such as statics, fluid power application, stress analysis of Lexan based equipment, transfer of electrical, fluid, and mechanical energy. This mechanical arm was not designed for lifting heavy loads, but rather to offer a greater perception of how a system operates with the use transparent Lexan. One of the main purposes for this design is to allow students to cover a wide range of topics in building and designing processes. The 3-D printed bucket offers students an introduction into CAD design and 3-D printing. In addition, the base of the excavator was constructed of aluminum not only for heightened strength but also to instruct the use of welding. The miniature excavator arm is simplistic in design and the layered Lexan design allows for quick assembly. The Excavator also provides great research opportunities in the fields of data analytics and decision-making. For example, the arm can be tuned to automatically complete specific tasks via machine learning algorithms. The arm can then be disassembled and placed inside the portable tool bin for transport. This allows for a teacher to haul the demonstrator to different events such as, classes, conferences, and recruiting events.

Workshops

Engineering workshops that offer visual demonstration tools are a great way for students to participate in hands-on learning experiments. They are also an effective tool for teachers to instruct students how to operate tools and their uses. An ideal workshop environment for this technological tool consists of students who have little to no prior knowledge of hydraulics. Engineering is also about communication and the sharing of ideas. It is important for students who participate in workshops to participate in team building projects such as this miniature excavator arm. Team projects are great for team-building and building off each-other's strengths, where students are encouraged to communicate with each other in order to complete a task [8]. After teams have built their excavators they can then have group discussions about 1) why engineers design and build these types of tools, 2) how the design can be changed, and 3) if the design is changed, how might the system operate differently. A short demonstration would be given to the students over the following topics 1) understanding hydraulics and hydraulic circuits, 2) the importance of implementing a meter out system, and 3) discussing different areas where hydraulics could be further applied. A survey would accompany these workshops to evaluate the benefits of technological tools in education. This survey would be given to the participants of the workshops and would include questions pertaining to the workshop experience and technological tools in education assessed on a Likert scale. Some of the questions asked in this survey will include:

1. Did you feel like this technological tool aided in the concepts taught in this workshop?
2. Would you like to have more technological tools and workshops in your curriculum?
3. Would you like to see this tool used in to teach more concepts in your curriculum?
4. Was it helpful learning with a team while learning these concepts?

The data from these surveys will then be analyzed to advance this technological tool and its workshops and provide unique publishing opportunities.

Conclusion

This miniature excavator arm is a demonstration tool that allows students to get a more enriched learning experience in the classroom. Building this excavator costs a total of $1,318.00 and could be built in a day. The Lexan design allows for complete perception of the system and grants the ability to disassemble with ease. The portable tool bin is great for transportation and storage of the excavator arm. This tool is convenient for taking to classes, demonstrations, and workshops, because it utilizes a standard 120VAC/15A electrical outlet to operate. The mechanical demonstrator can be used for classes with applications in statics, dynamics, and fluid power. The excavator arm can be built by other institutes by downloading the design manual [9]. This is a great demonstrational tool to further introduce applications of statics and fluid power.

Acknowledgements

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