The Design of a Low-Cost and Robust Linkage Position Sensor

Function Description and Complete System Block Diagram

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Introduction

Caterpillar Inc. is a recognized leader in a variety of fields, including mining equipment, engines, turbines, and locomotives. However, the Caterpillar name is most often associated with the image of its line of bright yellow heavy machinery. Throughout the years, these bright yellow tractors have come to encompass an enormous array of machines that range from the 3,200 horsepower Caterpillar 797 haul trucks used in mining operations to the Caterpillar 216 skid steer used in construction sites of all sizes around the world. It is not only the size of Caterpillar's fleet that has been changing but also their usage of electronics in their machines. In the past several years Caterpillar machine cabs have become filled with electronics. These electronics are used in a variety of ways from monitoring equipment to steering the machine. One of the areas where Caterpillar has focused their use of electronics is in sensing the position of various linkages on a machine. These linkages are what help move the machine's implement. Their position, when combined with other information, indicates to the operator the exact location of the implement. This current linkage position sensor system, however, is expensive and has a record of breaking after being installed into the machines. Therefore, this project focuses on identifying a viable replacement that is accurate, low-cost, and robust to stand up to the grueling conditions that Caterpillar machines face every day.

Project Description

Caterpillar is currently using an in-cylinder position sensor in their machines to determine the linkage position. In addition, the current linkage sensor requires a long hole to be drilled into the linkage cylinder, this solution is not cost-effective. Moreover, the sensor has failed several times shortly after being placed into the field [1]. Consequently, the senor's failings demonstrate that the sensor cannot withstand the stress that occurs with daily use of a Caterpillar machine. Caterpillar has attempted to design a solution to this problem with a small degree of success. Therefore, Caterpillar approached Bradley University to design an alternative system. This request was turned into a convergence project consisting of students from the Business, Electrical Engineering, and Mechanical Engineering departments with Caterpillar serving as the client. Caterpillar's requests and requirements will dictate the structure of the project. Caterpillar's requirements for the alternative system are that it must be precise, robust, maintain a low cost, and have an ease of implementation. The project will also fulfill the senior capstone project requirements of the Electrical Engineering degree program. The electrical engineering group members and the mechanical engineering group members will work side by side in a four phase process: a research and concept development phase, an analysis and selection phase, a physical testing phase, and a project delivery phase.

Phase one is the research and concept development phase. During this phase the engineering students will conduct research in multiple subjects. These subjects include, but are not limited to, the normal operation of a Caterpillar machine, the extremes of the conditions in which Caterpillar machines are utilized, previous attempts by Caterpillar to solve the problem and why the sensor designs were never implemented, existing sensor designs, and sensor technology. The electrical engineering group members will focus on the sensor research of existing designs, sensor technology, and previous solution attempts. This phase will also consist of several brainstorming sessions. In these meetings, the two engineering groups will combine their research together. The group will then analyze the information to generate as many design solutions as possible. The group will then select approximately ten top designs. The business group will take these top ten designs and perform feasibility studies.

Phase two is the selection and analysis phase. During this phase the ten designs will be further analyzed so that the team can select top three designs. The engineering group will be performing design simulations and feasibility studies. Once the engineering group determines the top three designs, the business group will complete a more in-depth business analysis those top three designs. At the end of this phase the team will combine their information to present the top three designs to the client, have a recommendation for a top design, and by working with the client, select a top design.

Phase three is the physical testing phase. During this phase the engineering group will perform any remaining simulations. Then the group will develop a testing method to test the top design. The group will then begin the process of purchasing the necessary parts to build the prototype. This part of the phase will be happening simultaneously with the end of phase two. At the beginning of the next semester, the engineering group will build a prototype of the top sensor design with approval from Caterpillar. The design will be tested using the method developed earlier in phase three, debugging any issues that could arise. If no prototyping is approved the team will complete more advanced testing, perform more simulation, and construct a variety of drawings.

Phase four is the final phase, the project delivery phase. This stage will require all of the information of the project to be collected together and analyzed. This stage will also include several presentations including presenting the deliverables to Caterpillar.

Project Goals

1. Research and Concept Development
    a. Identify the scope and deliverables of the project.
    b. Perform research on the functionality of the existing and alternative sensors.
    c. Brainstorm multiple designs that would yield the implement position.
    d. Test the feasibility of the designs through brief analysis.
2. Sensor Design Selection
    a. Select the top three designs that are the most accurate, low-cost, and robust based on the research.
    b. Create simulations and feasibility reports of the designs before making any purchases.
    c. Present top three designs to Caterpillar and make a selection.
3. Physical Testing
    a. Develop a testing method and purchase necessary parts.
    b. Build a physical representation of the system in lab and perform various tests.

c. Debug any issues that arise and prepare for presentation.

4. Project Delivery
   a. Present the final system to Caterpillar for future consideration
   b. Develop an application for a physical Caterpillar machine if time permits.

Block Diagrams

This project is designed as a research and development project. Therefore, many of the specific attributes of the system will be determined during the research process. However, the high level diagram of the entire sensing system can be represented through a block diagram. The system can then be subdivided into a secondary level that demonstrates the relationship between subsystems.

Overall System Diagram

The high level system diagram describes the basic input and output characteristics of the full linkage position system operates. This project contains a considerable design phase. Therefore, a specific system design cannot be represented at the current time. Also, the implement position system may contain many elements, depending on the sensor design. However, a general overall system diagram can be constructed by using the existing system as a guide. This overall system diagram will be used to design a compatible sensor design. The overall system is in Fig. 1.

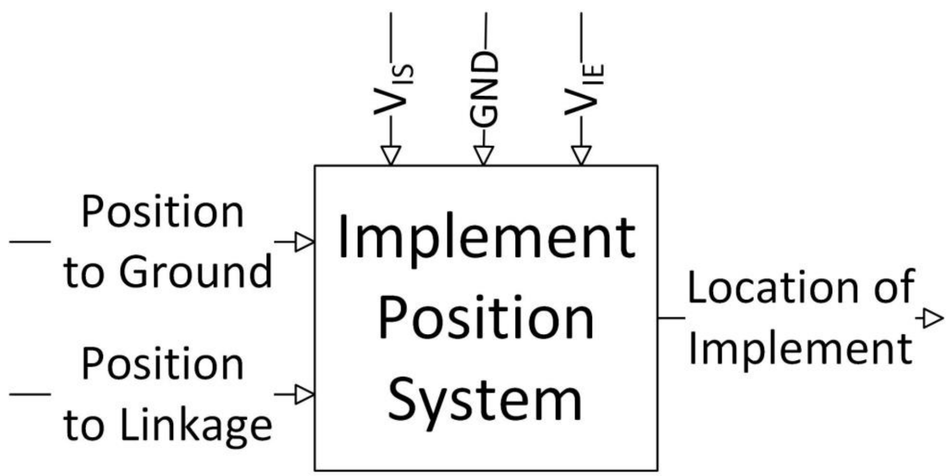

Fig. 1: Top Level Description

The inputs into the system are the input voltages V_{IS} (the voltage to drive the sensor) and V_{IE} (the voltage that will drive the ECU) that run the two main components of the linkage position system which will be described in the secondary subsystem diagram section. The position to ground and position to linkage inputs come from sensors already implemented on Caterpillar machines [2]. These signals may or may not be used with our final sensor design. The system output is a PWM signal that indicates the location of the implement in PWM format to be used in any manner that Caterpillar decides.

Secondary Subsystem Diagram

The secondary system, shown in Fig. 2, is a subdivision of the two components that make up the linkage position system. The first component is the linkage sensor itself. Although the specific design of the sensor is yet to be determined, it will always be powered by some source and will output a PWM signal, V_{out}, which will indicate the location of the linkage. This voltage level will be processed within the second component the engine control unit, or ECU, technology implemented on CAT machines [1]. The PWM signal will be combined with other sensor information to output the precise location of the implement. These other sensors give a position of the linkage relative to the machine and a position of the machine relative to the ground. The three signals are processed in the ECU and then the ECU calculates the position of the implement through a predetermined relationship.

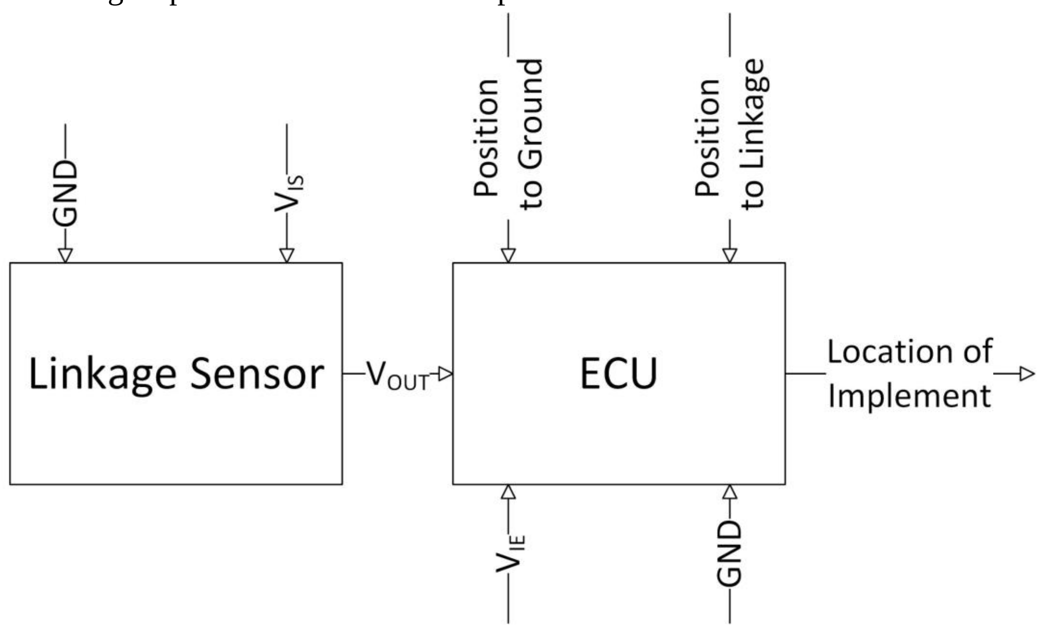

Figure 2: Secondary System Block Diagram

Conclusion

In this convergence project, the main objective is to design a robust, accurate, and cost effective alternative solution to Caterpillar's existing linkage sensor or their implement position system. This project consists of four phases. The project starts with research and brainstorming. Then a final design will be selected, a prototype will be made and then be presented to Caterpillar. If successful, this project will give Caterpillar a solution that could drop their overall cost which would increase profitability, prevent the negative PR that occurs when the sensors break quickly, and allow Caterpillar to automate their machines in the future.

References

[1] E. Morris, Private Communication, September 2013.

[2] R. Carpenter, Private Communication, September 2013