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

Function Requirements List and Performance Specifications

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Introduction

Caterpillar Inc. is currently using an in-cylinder position sensor in their machines to determine linkage position. This in-cylinder linkage sensor requires a long hole to be drilled into the linkage cylinder, adding substantial costs to the overall system. Moreover, the sensor has failed several times shortly after being placed into the field [1]. Consequently, the sensor'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.

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.

System Block Diagram

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. The implement position system may contain many elements, depending on the sensor design. The implement position can be determined by taking measurements the same way they have been taken in the past, using the linkage, or by taking measurements from vehicle to the implement directly. There are two types of sensing system categories. These categories include a linkage sensing system seen in Fig. 1

similar to Caterpillar's existing system and a direct implement position sensing system as seen in Fig. 2.

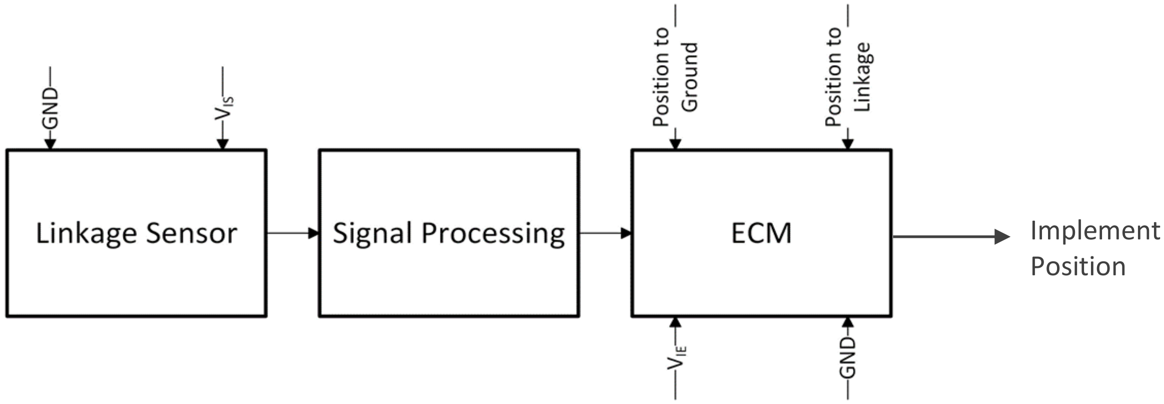

Fig. 1: General Block Diagram of Linkage Position Sensing System

For the linkage sensing system, as seen in Fig. 1, there are two voltage inputs that power the system. These inputs are the input voltages V_{IS} (the voltage to drive the sensor) and V_{IE} (the voltage that will drive the electronic controller module (ECM)). The position to ground signal indicates the position of the machine relative to the ground. The position to linkage signal indicates the position of the linkage relative to the machine, this signal could also be a constant. Both of these signals come from sensors already implemented on Caterpillar machines and are beyond the scope of this project [2]. These signals may or may not be used with our final sensor design. Further information on these signals will become available as needed. The current linkage sensor's output *Vout* is a pulse width modulated (PWM) signal. If the new sensor design does not output a PWM, then another component will be added to manipulate the signal to a PWM signal. The final output of the system, the location of the implement, is determined within the ECM. The relationship between the duty cycle of *Vout* and the location of the implement will be determined by the team but programmed into the actual ECM by Caterpillar employees.

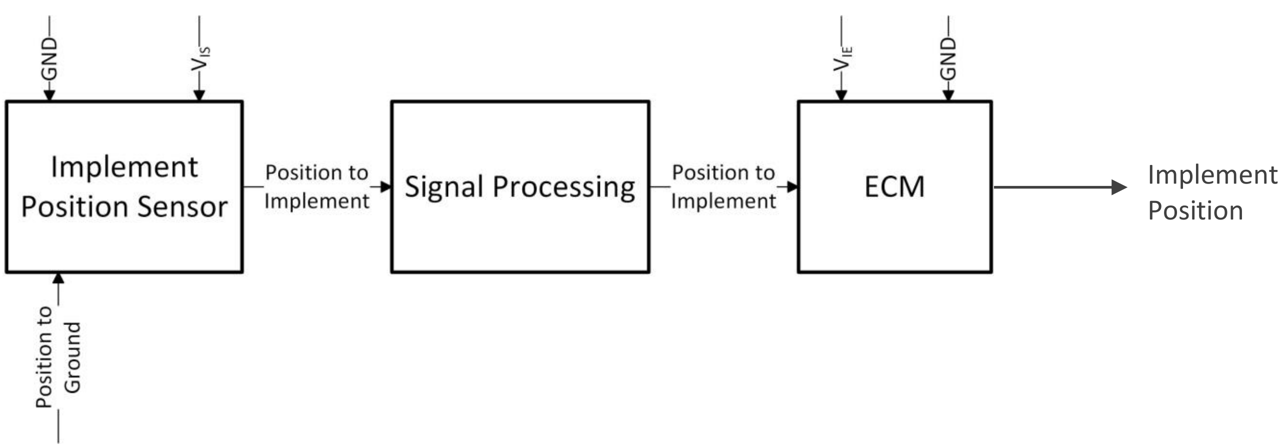

Fig. 2: General Block Diagram of Direct Implement Position Sensing System

Not many of the specifications for the direct implement sensing system change from the linkage sensing system. There are only two changes in the system. The first change removes the position to linkage signal because that step has been bypassed since the measurement is bypassing the linkage entirely. The second change is in the internal calculations of the implement location using the ECM.

Either one of these systems could be selected as the final design. During the design process, each of the designs will be evaluated based on the function requirements and system specifications.

Functional Requirements

Since this project is based around design development, many of the specific requirements are unknown. However, the requirements that are known are even more important. Using these requirements a new design will be constructed, compared, and possibly eliminated. The functional requirements can be divided into two categories:

a. Design Requirements

These requirements focus more on the physical aspects of the design. Although the requirements are not technical requirements they are still requirements that will guide the design process. These requirements may be adapted by the client if the change in requirements yield a positive trade off to the overall system.

- Cost
  - Cost, including the cost of the sensor, manufacturing, and installation costs, must be reasonable
    - Benchmark cost based on the cost, manufacturing, and installation of current sensing system
      - Less than $1,000-1,500
- Robustness
  - The sensor system must withstand vibration of 8 g minimum when on tractor
  - The sensor system must operate in an environment with high levels of dirt, smoke, and dust
  - Must be able to handle extreme weather conditions
- Reliability
  - The sensor system must have the potential for 10,000 hours.
- Accuracy
  - Linkage Position Sensor System: The sensor system must determine the location of the linkage with an accuracy of 0.1±0.003 mm Direct Implement Position Sensor System: to be determined
- Calculation

    - System must have clear steps on how to calculate the end implement position

b. System Specifications

The sensor system specifications are the technical aspects of the design. These specifications will also guide the design process by ensuring that the final design will be successfully integrated into Caterpillar's existing system.

- Output of Sensor System Design
    - PWM signal
    - Low current ~3.8 mA
    - ECM has pull up resistors to handle up to 5 V
    - Frequency range: 0.1 Hz to 12.8 Hz
    - Duty Cycle Range: 3-97 %
- Output of ECM to Sensor
    - Output Current Capacity (Engine): min: 300mA
    - Output Current Capacity (OEM): min: 80mA
    - Output Voltage: min: 4.90 VDC, nom: 5 VDC, max 5.10 VDC
    - Other Possible Voltage Outputs
        - 8V and 24V
- ECM pins
    - ECM active analog sensor input: Pin 2
    - ECM passive analog sensor input: Pin 4
    - PWM/Freq input: Pin 16
    - PWM/Freq input (precision): Pin 4
    - 300mA sinking/PWM driver output: Pin 3
    - 5 V sensor supply: Pin 200
    - 8 V sensor supply: Pin 400
- A/D in ECM
    - Sampling rate is 50 Hz, 16-bit resolution

References

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

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

[3] M. Fike, “ECU 101: Inputs,” Caterpillar Inc., Peoria, IL, Presentation, Mar. 10 2010.

[4] J. Schumacher, “ECM Outputs,” Caterpillar Inc., Peoria, IL, Presentation, Feb. 1 2010.

[5] Caterpillar Inc., “A4M1 ECM Specs. and Pinout,” Excel Document.