Detection of Slurry Flow State in Slurry Wagon Hoses

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Abstract: Precision application of slurry requires knowledge about the delay time between the sending of the turn-on command and the slurry beginning to be applied on the ground. Most systems use a fixed delay time, regularly calibrated by the farmer. This paper presents the design of a sensor to detect when slurry is flowing and thus detect the delay time. Such a system is useful for studying the quality of Task Controller Section Control (TC-SC).

Keywords: Precision farming, ISOBUS, ISO 11783, Task controller, Control latency, Automatic section control, Agricultural engineering, Blockage sensor

1. INTRODUCTION

There are many aspects to precision agriculture. One is the precise control of the application of product to the field. To address this, ISO 11783-10 defines a communications paradigm for a Task Controller (TC) server to send commands to an implement to control it. One function of the TC is Section Control (SC) whereby the TC can command the implement to turn sections of the boom on and off. The purpose of SC is to minimise areas of overlap within the field as well as minimising gaps. An introduction to ISO 11783 (marketing name ISOBUS) is given in [1].

To determine how well TC SC is working, it is necessary to obtain ground-truth readings [2]. For slurry this is laborious to do manually for a large field, and therefore this paper proposes a sensor which can be fitted to the slurry wagon's hoses to detect the flow of slurry (on or off). This data can be used to determine the ground-truth slurry application area.

Fig. 1. The Zunhammer SKE 18,5 PU slurry wagon used for testing.

ISOBUS also allows GNSS data collection and the TC is important for data management in farms [3]. However, the TC is only able to log the moment when the SC signal is acknowledged by the slurry wagon, there is not a ground-truth feedback mechanism. Therefore, the TC must rely on a fixed delay time to calculate when slurry begins to flow out of the end of the hoses. Section control requires precise information about latency.

The goal of this paper is to present the design of the sensors. Similar systems are already used in commercial seeders as good-flow sensors or for blockage detection. E.g. the Flow Performance Monitor from Vogelsang or the ME-Blockage Sensor from PTx Trimble. One motivation is fault diagnostics, e.g. [4].

2. MATERIALS

2.1 Slurry wagon

A Zunhammer SKE 18,5 PU slurry wagon and John Deere 6155R tractor were used for testing. They were operated on test farms in Kirchweihdach, Dürnast, and Hirtlbach in Germany. The application was mostly carried out by partner farmers. Some trials were conducted specifically by TUM employees.

The communication between tractor and slurry tanker was via ISO 11783, the application rate and the position were controlled via the TC.

2.2 Data collection system

In order to obtain a time-synchronous recording of all measurement data, the sensor data were all first tramsmitted on the CAN bus and then all messages from the CAN bus were logged to a datafile with a Kvaser Memorator Light HS v2 (Kvaser AB, Sweden). GNSS data were also written to the CAN bus using the NMEA 2000 protocol from the receiver. Relevant data from ISOBUS are already on the same bus.

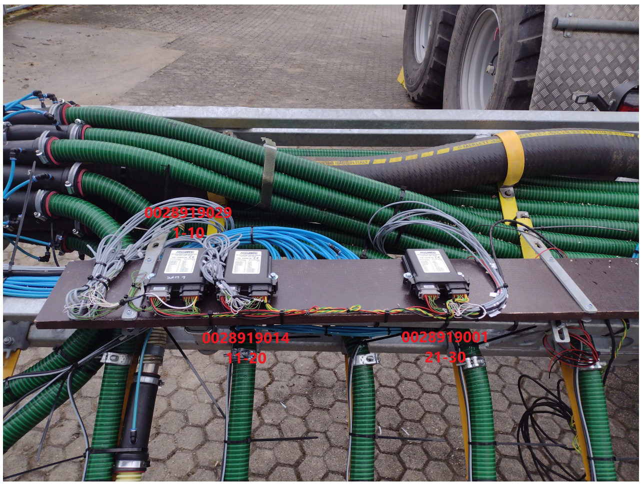

Fig. 2. Axiomatic A/D Converter mounted at the boom. The Axiomatics read the input voltages and writes them out as ISO 11783 proprietary CAN frames.

2.3 Analogue to digital converter

The analogue signals of the section valves and the sensors have been fed into an A/D converter using AX030120 (Axiomatic, Tampere, Finland) into SAE J1939 type messages. The converters were installed close to the sensor on the boom to avoid long wires to the analogue sensors, see Fig. 2.

3. SLURRY SENSOR DESIGN

3.1 Design requirements

The most important requirement was that the sensors must not cause slurry blockages. Therefore, there should be no parts in the slurry flow which long-fibre components such as straw could get stuck to.

The sensors were 3D printed with engineering plastics. It was assumed that this is sufficient for the prototype. The durability of plastic on field operations was not an important requirement for this prototype as the devices are designed only to last for the lifetime of the project.

It was also decided to read the flow with a continuous sensor value instead of a simple on/off switch, as calibrating the switches per material and per shoe was not feasible for trials where the farm should be able to carry out its regular operations without needing to recalibrate. Analogue sensing and later post-processing was therefore chosen.

Easy assembly and installation was another requirement. The number of shoes to be mounted to the slurry wagon boom is relatively many and repair procedures in the field should be possible.

3.2 First design

In the first design, the focus was on the trouble-free flow of the slurry inside the shoe. The design was based on the idea that slurry flow pushes the flap open proportionally with the flow rate and counterforce is realized with spring. The flap is designed with a larger opening in the outlet to allow debris in the slurry to exit the shoe by pushing the arm fully open, to keep the sensor and shoe unimpeded.

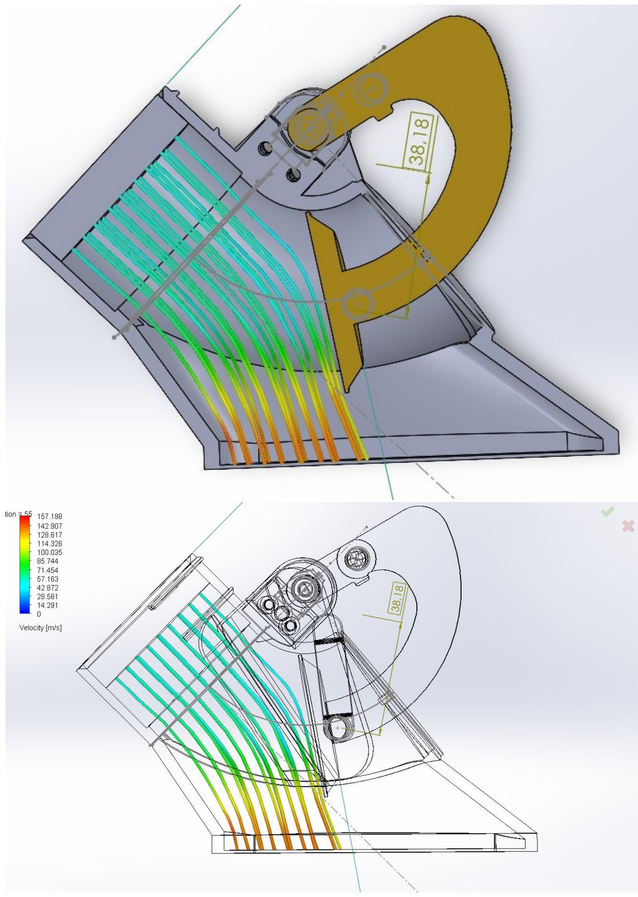

Fig. 3. First design

Flow simulations were performed to design the shape and opening of the flap arm, see Fig. 3. Careful attention was paid to ensuring that no edges were created on the flap where fibres could get caught.

The first design was manufactured for each shoe and installed on the boom of the slurry wagon. The shoes were tested with water, with special tests in the university test farm and finally delivered to the contractor, who used the machine for the whole season for data collection.

3.3 Second design

During the first measurements in the field it quickly became apparent that the springs which were attached to the sides for closing the flaps had been torn off by high grass.

This was solved in the short term by attaching deflectors to the side of the shoes. Unfortunately, the spring mechanism in this version did not last a whole season in practical contractor operation in a real farm. In addition, the built-in potentiometer that measures the opening angle of the flap was also destroyed by the aggressive slurry in almost every flap. Therefore, a new design for the shoe and the flap was constructed over the winter time.

The arm was designed so that the spring could be attached in the middle of the flap without the spring being touched when the flap was opened.

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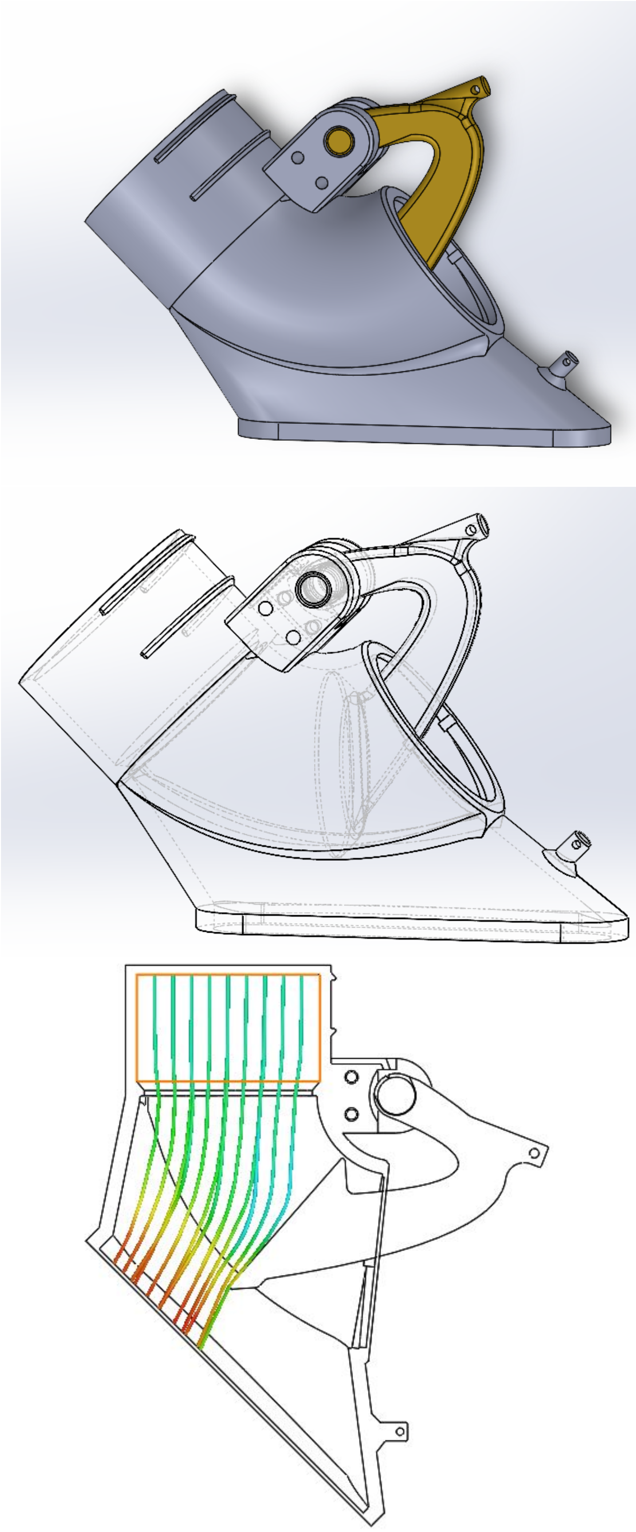

Fig. 4. Second design

To be able to measure the opening angle without contact, a Hall sensor (model TLE4905L) was inserted into the shoe to replace the potentiometer. The magnetic field was generated by a ring magnet with an external N-S magnetic field that was glued into the flap.

The Hall sensor was supplied with a constant voltage of 5V. The output voltage is between 1 and 4 volts depending on the position of the magnet. The output voltage is identical to that of the potentiometer so no changes had to be made to the analogue to digital converter.

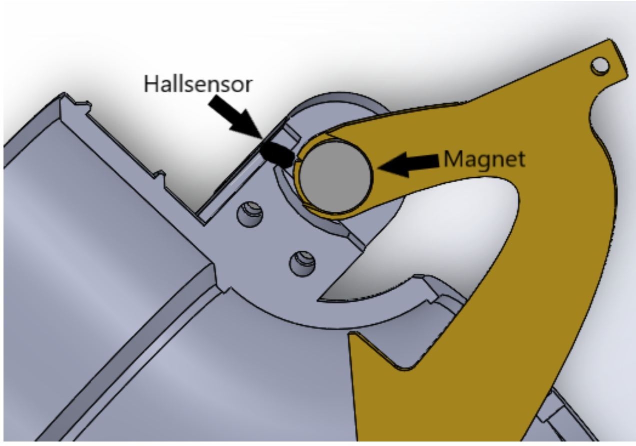

Fig. 5. A Hall sensor was inserted into the shoe to replace the potentiometer. This works well because it does not rely on friction to operate and so contact with slurry did not degrade it.

3.4 Manufacturing methods

Various materials were tested for the support structure and the shoes. The first prototypes were printed from Polylactic acid (PLA), which can be printed easily and without warping. The material for the support structure was Polyvinyl alcohol (PVA), which could be easily washed out but is very expensive to purchase. It quickly became clear that PLA did not remain dimensionally stable for long in harsh outdoor conditions and under sunlight. The support structures and the overhangs of the components were optimized for minimal required support structure. This allowed the use of washable PVA to be avoided, and both the component and the support structure were printed from the same material. This reduced material costs and significantly shortened printing time, and printers with a single extruder could also be used. Acrylonitrile Butadiene Styrene (ABS) met the stability requirements, but the complex shape of the components could not be printed without warping. Through research of various material manufacturers, we became aware of the material Acrylic Styrene Acrylonitrile (ASA). This material has the same temperature resistance as ABS, is additionally UV resistant, has less warping, and better layer adhesion, resulting in greater stability.

The positioning of the components on the printer also increases the stability of the parts. By printing the flap in a horizontal position, the stability of the arm was significantly improved. The reason for this is that the force could be absorbed by the continuously printed lines, rather than pulling apart the different layers.

3.5 Angle sensor autocalibration

Because the sensors do not always respond the same way due to the varying composition of the manure and the solid deposits in the shoe, certain methods were developed to detect the flow/no-flow status. This will be outlined in a future publication.

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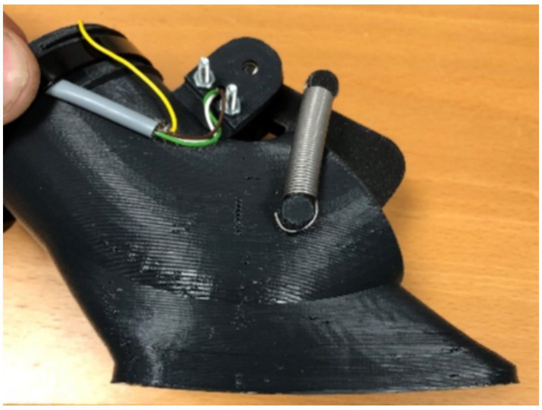

Fig. 6. A photograph showing the warping of the Acrylonitrile Butadiene Styrene (ABS) on a prototype slurry shoe.

Fig. 7. A photograph showing the 3D printed slurry shoes.

4. SIGNAL BEHAVIOUR

When turning on, there is generally an overshoot and a dip before reaching steady state. A typical turn-on event is shown in Fig. 8. This phenomena seems to be caused by air in the hose.

When the valves are closed, and the remaining slurry in the hose drains out, the flap slowly closes. A typical turn-off event is shown in Fig. 9.

A full cycle from turn-on to turn-off is shown in Fig. 10. Due to the solids content of the slurry and the rotating blade of the Exacut and the resulting short-term closure of the individual hoses, no constant flow is measured.

5. VALIDATION

To verify the signals, LEDs were mounted near the flaps, which were switched on when the section was requested via the CAN bus. This was then filmed with an action cam (Leica Insta OneR) and a handheld camera. The purpose was to allow the video and the CAN logs to be time-synchronised to validate the observable behaviour of the slurry wagon against the recorded data.

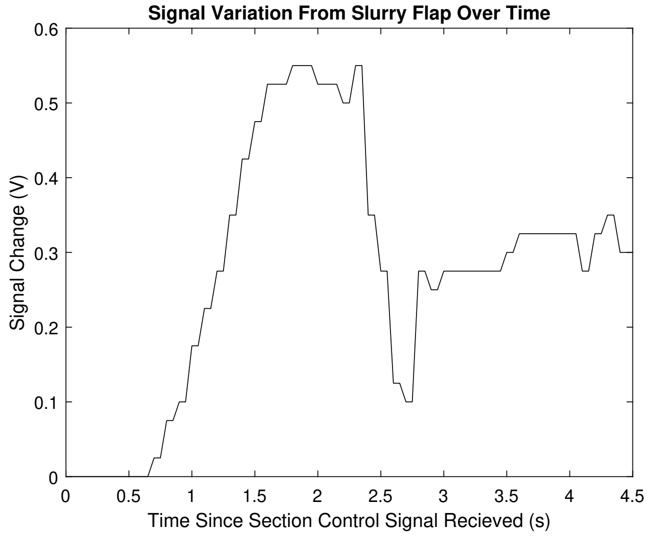

Fig. 8. A typical turn-on event. The voltage increases as the flap opens, then there is a splutter of trapped air in the hose and the signal falls before going back up to the steady-state level.

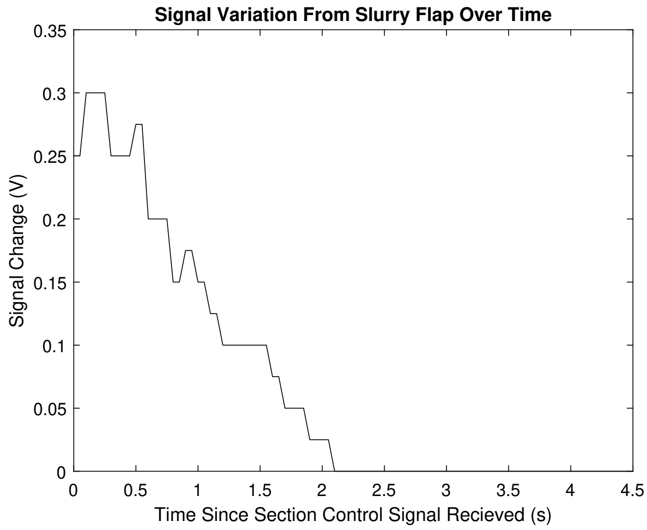

Fig. 9. A typical turn-off event. The voltage decreases as the flap closes where it remains.

6. DISCUSSION

The aggressiveness of manure should not be underestimated; many failures have been caused by the oxidation of normally waterproof connectors. Solids (long hay or straw) can block the valve, causing the sensor to remain at a constant reading. Even the application in fallow land with partly high vegetation is very problematic for components that are not tightly attached to the shoes, as these can be torn off.

7. CONCLUSION

Detecting the flow/no-flow status of slurry is possible with the presented method. The first design was fragile with external components, the position of the springs was not good and the potentiometer could not withstand the aggressive slurry. However, the second design worked much better, with a more robust design and new sensor elements.

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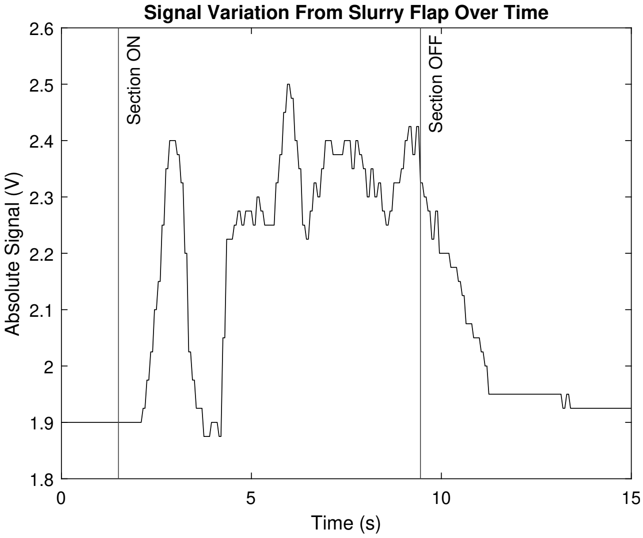

Fig. 10. A typical turn-on, remain on, then turn-off event. It can be seen that the steady state 'on' signal is noisy.

Fig. 11. A photo showing a white clip holding three LEDs on the hose. The LEDs flash when the section is turned on, aiding with time-synchronising the camera video with the data logged from the CAN bus.

While the system met the aim of detecting when slurry is flowing or not, it may be possible to design a similar system which can also detect the flow rate of the slurry. Our research used weak springs for the purpose of pulling the flap closed when no slurry was flowing. Further research could investigate whether by using stronger springs with the correct level of force, it could be possible to create a system whereby the opening level of the flap correlated to the flow rate of the slurry.

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