OPTIMIZATION OF FORAGE HARVESTING BY AUTOMATIC SPEED CONTROL AND ADDITIVE APPLICATION

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ABSTRACT

Efficient use of machines is especially important in forage harvesting due to short harvesting period and expensive machinery. To achieve the best efficiency, a harvesting machine, such as a loader wagon, should be used with optimal loading. Whereas overloading the machine can cause blockages in the cut-and-feed unit, underloading consumes more time and reduces the quality of the resulting silage. In addition, the quality can be improved by optimizing the dosage of the additive. Since the quality has an important effect on the product of a dairy and beef farm, poor quality can cause significant financial loss for the farmer.

In this research, two ISO 11783 electronic control units were implemented for automating the harvesting process. The first estimates the forage mass flow in the cut-and-feed unit of the wagon with a Kalman filter based on tractor speed, swath size, mass of the load, and moisture content of the forage. Furthermore, the control unit utilizes fuzzy logic for controlling the speed of the tractor according to the mass flow estimation, the capacity of the machine, and the swath size. As a result, the mass flow in the cut-and-feed unit is always optimal regardless of the swath size and thus no blockages will be formed. The second control unit applies additive on forage according to the mass flow estimation so that the ratio of additive and forage is precisely what is desired. In the field tests, the performance of the system proved to be in line with the specification.

Keywords: ISO 11783, automation

INTRODUCTION

Forage harvesting is an important part of the work on a beef and dairy farm. Properly harvested forage lays the basis for good quality silage which in turn is a requirement for reaching the best milk productivity (Tella, 2007). Furthermore, due to short harvesting period and expensive machinery, efficient use of the machines is especially important and can bring significant savings for the farm. This paper presents the implementation of two ISO 11783 electronic control units (ECU) for optimizing the forage harvesting process, which will not only improve the silage quality but also the efficiency of the process.

The first of the ECUs, loader wagon ECU, optimizes the use of loader wagon in forage collecting. Providing the cut-and-feed unit of the wagon with a sufficient forage flow is important as it affects the quality of the resulting chop; not enough forage on the cut-and-feed unit will allow a greater number of straws to pass the knives without being cut. Shorter chop will improve the preservation properties of the resulting silage and allow more compact and heavier loads, thus increasing the work efficiency (Suokannas & Nysand, 2006) (Suokannas, 2006). In contrast to insufficient forage flow, too much forage on the cut-and-feed unit will overload the machine and cause blockages. Clearing a blockage will take several minutes and it can be an unpleasant task, especially if additive has been sprayed on the forage. To maintain a proper level of forage flow, the operator has to monitor several factors, such as the size of the swath, and control the speed of the machine accordingly. To ease the work, the loader wagon ECU estimates the forage mass flow and commands the speed based on the estimation and the capacity of the machine.

The second ECU, additive applicator ECU, optimizes the application of forage additive. A proper ratio between additive and forage will improve the preservation of silage. The additive is sprayed when forage enters the cut-and-feed unit, thus the dosing of the additive depends on the forage mass flow. For the operator it is difficult to estimate the forage flow and maintain a proper additive flow accordingly; additive is often sprayed either too much or too little. To make the dosing more accurate, the additive applicator ECU regulates the additive flow based on the forage mass flow estimation provided by the loader wagon ECU.

METHODS

ISO 11783

The ISO 11783 standard specifies the communication network between the tractor and implements as illustrated in Figure 1. The network consists of a tractor bus, an implement bus, and various ECUs connected to either one of the buses. ECUs implement control functions and communicate with each other allowing the distribution of information. A tractor bus handles the communications between the ECUs within the tractor; for instance, engine, transmission, and hitch ECUs. An implement bus connects implement electronic control units (IECU). All IECUs share a common user interface module, a universal terminal (UT), located in the tractor cabin. The two buses are connected via a tractor electronic control unit (TECU), which among other functions relies the information between the

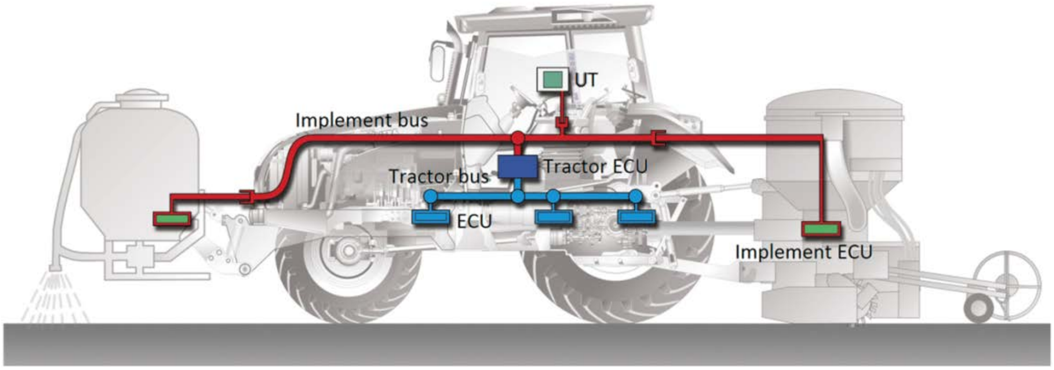

Figure 1. An ISO 11783 network consists of an implement bus, a tractor bus, and various ECUs. (Valtra, 2011)

buses. The standard defines three classes for TECUs based on the available features. Class 1 TECUs provide the implement bus only with the basic tractor internal measurements, for instance speed, power take-off (PTO), and hitch information. In addition to these, class 2 TECUs provide more advanced measurements, and class 3 TECUs are prepared to take commands from the implement bus; IECUs are allowed to command the tractor's rear-hitch, PTO, auxiliary valve control, as well as speed and steering. (ISO, 2002) The ISO 11783 communication protocol is based on the CAN 2.0B 29 bit protocol (Bosch, 1991).

Tool chain

In order to simplify the development process of an ISO 11783 ECU, various tool chains have been introduced. The tool chain utilized in this paper consists of Matlab Simulink with C code generation, PoolEdit with associated parsers, and Visual Studio with a Windows CE embedded target. The tool chain's Simulink framework provides ready-to-use function blocks for handling ISO 11783 communications, thus the whole program logic can be designed in Simulink without considering the details of the ISO 11783 standard. Furthermore, PoolEdit allows easy development of UT user interfaces. The tool chain was developed by Oksanen et al. (Oksanen, Kunnas, & Visala, 2011)

FORAGE HARVESTING

Forage collecting

The tractor, the loader wagon, the additive applicator, and the additional devices are shown in Figure 2. The tractor was equipped with a research implementation of an ISO 11783 class 3 TECU. Three pressure sensors were installed in the hydraulic suspension of the wagon in order to derive the total mass of the load. A 2D laser scanner was mounted in the front of the tractor to provide the system with a measurement of the swath's cross-sectional area. A near-infrared (NIR) sensor was fixed on the front wall of the wagon to measure the moisture percentage of the collected forage.

Figure 2. The tractor–loader wagon combination with additional devices: pressure sensor, NIR, laser scanner, additive applicator, and additive applicator ECU.

A block diagram of the loader wagon ECU software is presented in Figure 3. The forage mass flow estimation is implemented with a Kalman filter, which provides a method for estimating and filtering systems where the measurements are uncertain or the variable of interest is not directly measurable (Bar-Shalom, Li, & Kirubarajan, 2001). Here, the Kalman filter model has three states: total mass of the collected forage x_1, forage mass flow x_2, and density of the collected forage x_3. During every increment of time, the total mass increases according to the flow, whereas the flow and density are independent of the other states. The state transition model is interpreted as

$$f(x) = \begin{bmatrix} x_1 + x_2 \\ x_2 \\ x_3 \end{bmatrix}, \tag{1}$$

where x_2 has been scaled with the increment of time.

The filter has three measurement inputs: total mass of the collected forage z_1, volume flow of forage in the cut-and-feed-unit z_2, and density of forage z_3. The volume flow is a product of the swath's cross-sectional area and the speed of the tractor. Since the laser scanner is measuring the swath in the front of the tractor and the point of interest is the swath in the front of the cut-and-feed unit, the cross-sectional area measurement has to be delayed. The delay time can be calculated from the speed of the tractor and the distance between the laser scanner and the cut-and-feed unit. The density is derived from the moisture measurement. The volume flow measurement is related to the division of mass flow state and

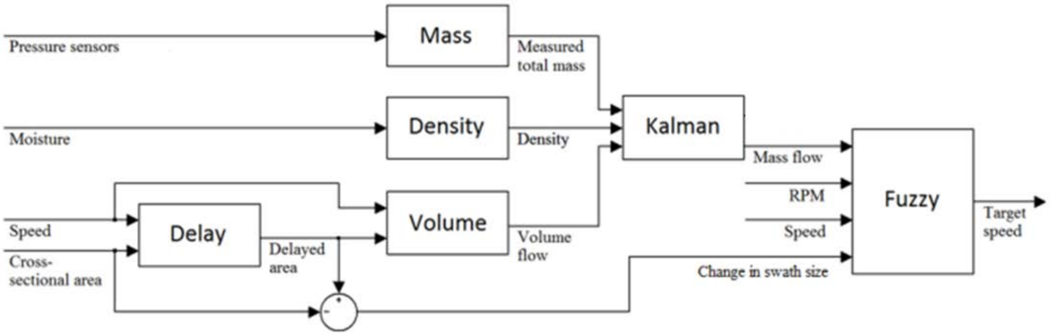

Figure 3. The main parts of the control logic are a Kalman filter and a fuzzy controller.

density state, and total mass measurement and density measurement are related to the corresponding states, thus the measurement model is

$$h(x) = \begin{bmatrix} x_1 \\ x_2/x_3 \\ x_3 \end{bmatrix}. \tag{2}$$

Another important component in the software is a fuzzy controller, which is often utilized in multiple variable systems where no exact equation defining the system exists (The MathWorks, Inc. 2011). Here, the fuzzy controller is used for speed control, whose purpose is to maintain a sufficient forage mass flow and prevent blockages. In order to achieve these purposes, there are four measurements that need to be taken into consideration: forage mass flow, changes in the swath size, tractor speed, and engine RPM. The mass flow should be maintained within reasonable boundaries by controlling the speed, i.e. the speed should be increased when the flow is low and vice versa. In addition, the controller should react to changes in the swath size; decreasing the speed when there is an increase in the swath size can prevent the mass flow from rising. Furthermore, the higher the speed, the stronger the decrease of the speed should be. Finally, the engine RPM is affected by the loading of the cut-and-feed unit in the loader wagon. A decrease in the RPM is a sign of overloading and might result in a blockage. Thus, if the RPM decreases, the machine should slow down in order to reduce the mass flow and lighten the load in the cut-and-feed unit. These ideas form the basis for the fuzzy controller rules.

Additive application

A commercial additive applicator was modified to be driven with the additive applicator ECU and mounted on the side of the loader wagon as shown in Figure 2. The ECU obtains the forage mass flow estimation from the loader wagon ECU and the desired ratio of additive from the UT. Based on this data, the ECU utilizes a PID controller with a feedback from a flow meter to maintain an additive flow that will result in the desired ratio. The process is illustrated in Figure 4.

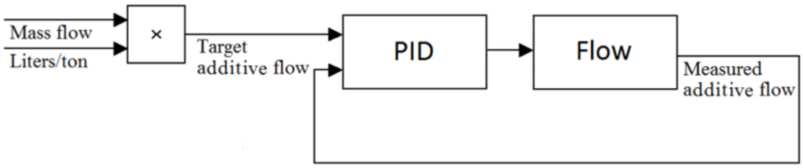

Figure 4. PID controller with a feedback measurement regulates the additive flow

RESULTS

Here is presented the behavior of the whole system during one load that was collected from two swaths. The change of swath caused a step in the total mass measurement (cyan) shown in Figure 5 at 300 seconds. The figure also shows the total mass estimation (blue) and the accumulated mass (red) based on the mass flow estimation. Whereas the reference measurement with a scale produced a value of 7320 kg for the total mass, the weighting system in the loader wagon measured a mass of 7180 kg, thus resulting in an error of 1.9%.

Figure 8 shows more of the Kalman filter measurements and estimates: volume flow measurement (green), density measurement (cyan), and density estimation (green). The mass flow estimation (blue) together with other speed controller parameters are shown in Figure 6. It can be seen, that the mass flow is maintained on the desired level regardless of the swath size (black). Another example of the speed controller behavior is seen in Figure 7, where the swath size change is more obvious; when the size gets smaller, the speed (magenta) following the speed command (green) rises, thus maintaining the mass flow at the desired level.

Figure 9 shows the behavior of the additive applicator. The additive flow (blue) was following the target (red). The consumption according to the applicator (cyan) was 27.8 liters, whereas the reference measurement implied a consumption of 23.9 liters. Thus, the error in consumption measurement was 16.3%.

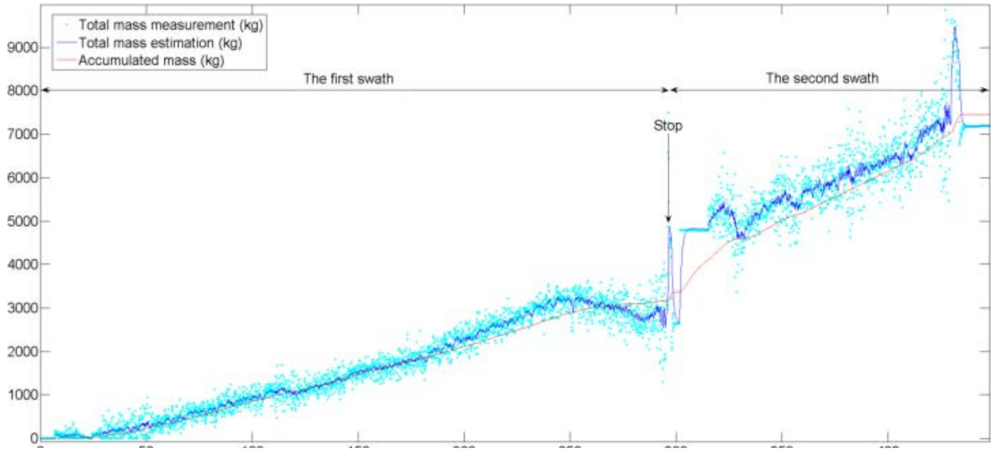

Figure 5. Measurements before and after the change of swath are not consistent but have some offset, thus causing a step in the mass measurement (cyan).

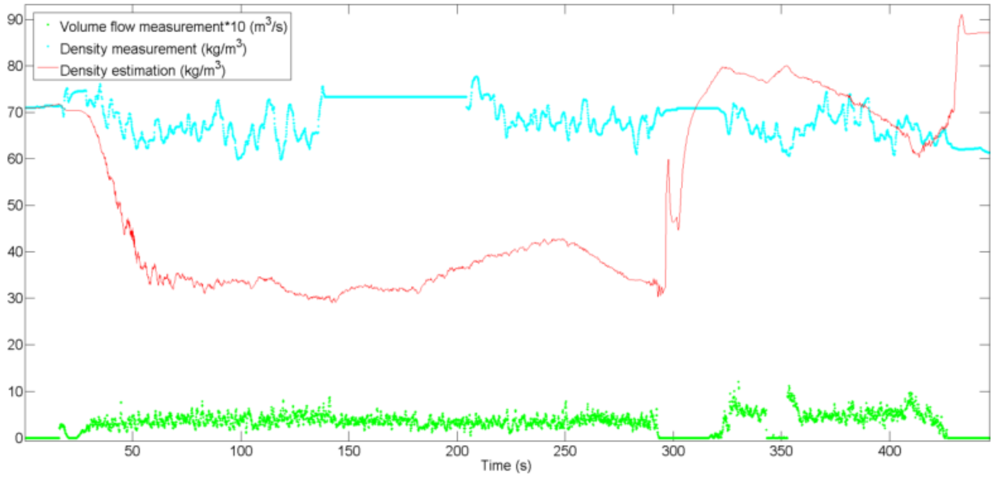

Figure 8. The behavior of volume flow measurement (green), density measurement (cyan), and density estimation (red).

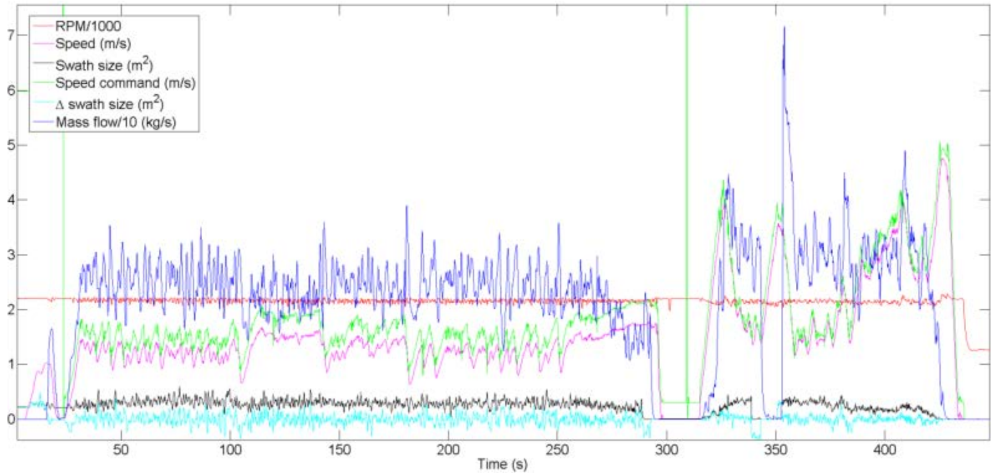

Figure 6. The speed controller was able to maintain the mass flow (blue) at the desired level.

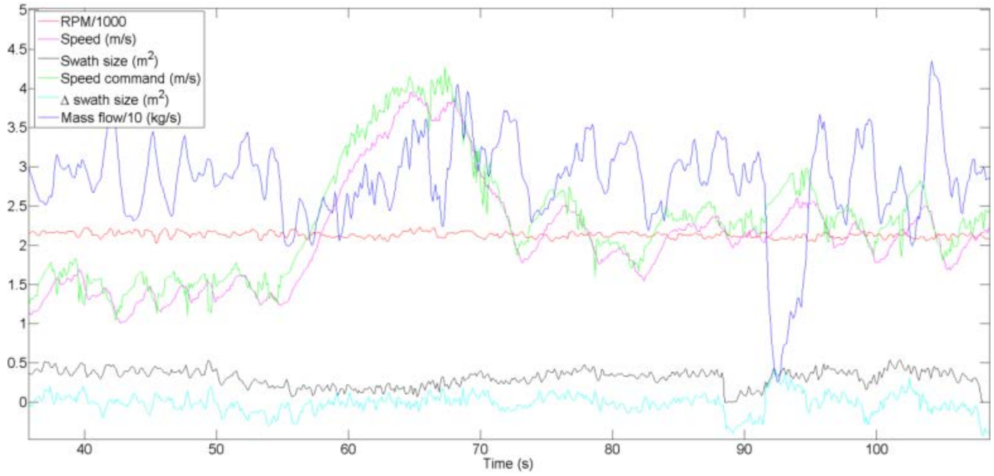

Figure 7. The speed (green) increases when the swath size (black) decreases in order to maintain the mass flow (blue) at the desired level.

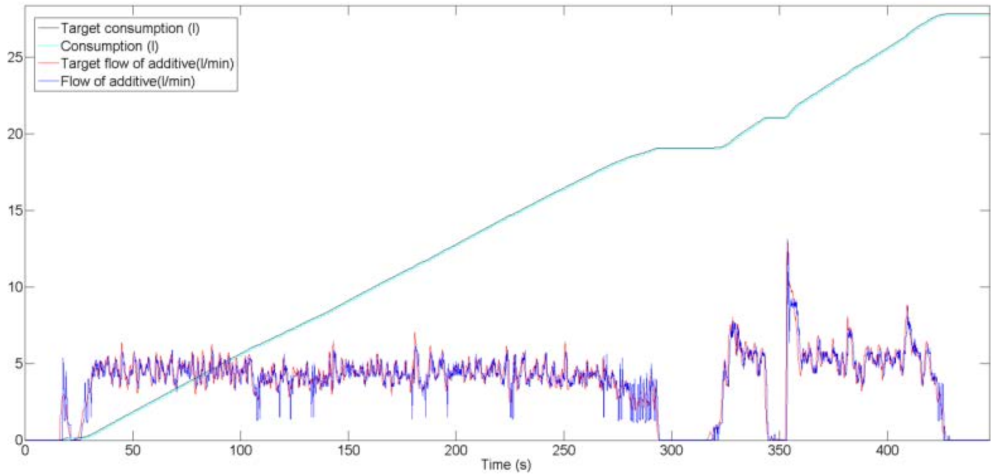

Figure 9. Behavior of the additive applicator during the test. The measured consumption (cyan) follows the target consumption (red)

DISCUSSION

The concept of optimizing forage harvesting process presented in this paper was proved to be working. The Kalman filter provided the system with good estimates for most of the time. However, some faults in the measurements caused problems for the filter; the pressure sensor based mass measurement was interfered by the movement and declination of the wagon, thus causing peaks like in Figure 5 at 300 seconds. Furthermore, attempts to derive density from the moisture were not successful. As a result, the density was estimated based on the volume flow and total mass measurements and the estimate does not follow the density measurement, as shown in Figure 8.

As the speed controller is trying to maintain a steady mass flow, its performance is dependent on the mass flow estimation. Assuming a correct estimation for the flow, the performance of the speed controller was in line with the specification; it was able to maintain the mass flow within the defined boundaries regardless of the changes in swath size.

Furthermore, the mass flow estimation is used by the additive applicator for controlling the additive flow. The applicator was able to maintain a flow according to the estimation. However, the accuracy of the ratio of forage and additive finally depends on the accuracies of the mass flow estimation and the flow meter. The flow meter was not accurate, as seen in results.

CONCLUSIONS

This paper presented the implementation of two ISO 11783 electrical control units for optimizing forage harvesting process. With further development, they could improve time efficiency, ease the operator’s work, prevent excess consumption of additive, and improve the silage quality.

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