DEPARTMENT OF BIORESOURCE ENGINEERING
DESIGN 3

Design of Integrated Data Management Solution for Hay Yield Monitoring

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Yield monitoring systems are an efficient way of increasing management in fields and therefore increasing profit. Current hay yield systems focus mainly on flows of materials as they enter the bailer leaving a whole in the market for a system that can measure yield after the material is bailed. Our client Groupe Anderson would like to take advantage of this by developing a yield monitoring system that measures the yield of large round bales and can be attached to their trailers and grabbers. This system will measure the moisture and mass of the bales, log the values and transmit them to an outside server. Our team focused on the electronic components of the system including hardware and software selection as well as coding of the system. After consultation with the client and review of the possible options, Danfoss software and hardware were implemented as the electronic components of the system.

Contents

1.0 Introduction

Precision agriculture and horticulture systems are becoming increasingly important as the world's population increases and viable agriculture land decreases. As a population, we are continuously trying to push our fields to produce higher yields while trying to reduce overall costs that are typically associated with higher yielding crops. Yield monitoring systems allow us to better understand how our various inputs affect the growth, quality and yield of the crop. This understanding is essential to extract the yields that we are striving for from our diminishing land.

Current yield monitoring systems generally focus on crops such as corn, soybeans and wheat as they are the main cash crops grown in North America. There is significantly less investment into yield monitoring systems for forage crop systems. This represents a gap in the market where there is room to move in and conduct creative product development. This is therefore a gap in the market where there is room for product development.

Yields for cash crops are normally measured by determining feed rate through the combine. This methodology cannot be used for forage crops because they have a different harvest pattern (Adamchuk, 2018). Forage is cut, left to dry, balled and then moved to storage. Measurements but be taken right before storage to determine accurate yield measurements. The yield of a bale is determined by the moisture of the hay, the density of the bale and the mass of the bale. The density of the bale is determined by a setting on the bailer and therefore if mass and moisture are measured an accurate yield map can be created.

Our client is a company named Groupe Anderson. They have requested the construction of a yield monitoring system that will be installed on their RBM series of trailers. Some possible options of trailers include the Stackpro 5400 or the Bale Grabber 6000. These trailers include loading arms that pick up both wrapped and unwrapped round or square bales as it is driven through the field. This system will include a moisture sensor, a load sensing mechanism, a GPS and a data storage system. The possibility of implementing a telematics system in the future must also be considered. The moisture sensing system was developed by a separate design team. The trailers are already equipped with hydraulic pressure sensors. The change in pressure readings will be used to calculate load. Additionally, the tractors used to pull the trailers are already equipped with GPS units whose data will be read and interpreted by our system.

Our design team has focused on the development of the electronics system that will control the moisture sensing system, process and interpret the data received from the various sensing systems and store the data. A telematics system that will be used to transmit the data will also be discussed and recommendations will be made so that the system can be implemented later.

The finished system will allow Anderson's clients to create yield maps that allow them to better manage their inputs in their fields and therefore increase their profit margins.

1.1 Vision Statement

To service the agricultural industry by providing an efficient method of sensing hay moisture to monitor yield and increase harvest efficiency.

1.2 Initial Needs Statement

The client needs a moisture sensing system that can quickly and accurately measure the moisture content of round bales. This system must be modular and easy to implement on a variety of Groupe Anderson trailers and grabbers. The system must measure and store the mass of the round bale, the moisture content of the round bale and the GPS location of the bale. This information must then be transmitted to an off-site server via the telematics unit. The system must function in a variety of conditions and must be reliable. The final system must provide accurate data that is capable of being used to create a yield map.

2.0 Customer Needs Assessment

A list of customer needs was established through communications with the client. An initial list was established during two meetings held in September and October 2018. These meetings were attending by Groupe Anderson Staff as well as all members of the mechanical and electronics teams and the project mentor Maxime Leduc. Thorough minutes were taken at each meeting and points were further clarified through emails later in the month. The initial meeting introduced the team to the project and involved discussions of confidentiality and the timeline of the project. A proper list of constraints was set during the second meeting. A copy of these meeting notes can be found in *Appendix A1* and *A2*. From these meetings the following list of customer needs was established:

- Integrates with existing electronics
- Uses as many components already on tractor as possible
- Functional
- Works with round bales
- Moisture range of 40-70%
- Precise measurements <5% error
- No interference with existing electronics
- Cost under 2500$
- Compatible with many trailers
- Functional with various trailer
- Cannot interfere with movements
- Accurate
- Durable
- Withstand applied forces
- Strong mount
- Reliable electronics system
- Quebec climate and weather resistant
- One push button system
- User friendly
- Easy maintenance
- Safe

2.1 Weighting of Customer Needs

The constraints and criteria that were obtained from the client were grouped into 4 categories; functionality, compatibility, durability and user-friendliness. The categories were placed in a pairwise chart and given weights by using the analytical hierarchy process. These weights were determined based on the importance given to each category by the client. Categories with higher weights include the most constraints and were deemed to be essential by the client. The pairwise chart can be seen in *Table 1* below.

Table 1: Pairwise Chart

	Functionality	Compatibility	Durability	User-friendliness	Total	Weighting
Functionality	1.00	1.00	2.00	3.00	7.00	0.35
Compatibility	1.00	1.00	2.00	3.00	7.00	0.35
Durability	0.50	0.50	1.00	2.00	4.00	0.20
User-friendliness	0.33	0.33	0.50	1.00	2.17	0.10

The different categories as well as their weights can be seen in *Table 2*

Table 2: Categories and Weights

- Functionality (0.35)
    - Works with round bales
    - *Moisture range of 40-70%*
    - Accurate
    - Precise (<5% error)
    - **Cost under $2500****
        - **Use existing components**
- Compatibility (0.35)
    - Function with multiple trailers
    - **Cannot interfere with moving parts****
    - **Cannot interfere with existing electronics****
        - **Integrate with existing system**
- Durability (0.20)
    - Withstand applied forces
    - Strong mount
    - Reliable electronic system
    - Weather and climate-resistant
- User-friendliness (0.10)
    - *One push button system*
    - Ease of maintenance
    - Safe

It is important to note that these weights were established for the overall project. While user-friendliness is only given a weight of 0.1 it is extremely important for the electronics team to design a system that can be used by clients that have very little technological experience. For this reason, while functionality and compatibility are essential, we will spend a large amount of our time focusing on improving the user-friendliness of the system.

3.0 Revised Needs Statement and Target Specifications

Using our list of client needs and constraints we can revise our customer needs statement. Our client needs a moisture sensing and yield mapping system that is compatible with a variety of Groupe Anderson machinery. This system must be functional, reliable, durable, user friendly and above all safe. The system will measure the mass of the bale, the moisture of the bale and record the GPS position of where the bale was collected. This information must be logged and have the possibility of being transmitted via telematics unit. The system must function in a variety of weather and climate conditions.

The system will be developed using information learned in section 4.1. The extensive literature will detail the theory behind the system. A collection of relevant patents can be found in section 4.3 and relevant standards can be found in section 4.4. The constraints that limit our design can be found in section 4.5. Finally, section 4.2 outlines our benchmarking process. This includes finding similar systems already on the market and comparing them to our system. This will ensure that we can produce a system that holds up to existing market standards.

4.0 External Search

4.1 Literature Review

4.1.1 Hay Yield Factors

There are many factors that affect hay yields including cutting, tedding and conditioning. For the focus of this paper we will focus on the effect of bailing and storage on crop yields. Bailing losses can be extremely significant ranging from 5 to 25% (Alberta Agriculture and Forestry, 2018). A large majority of these losses come from the pick up. When the pick up on a round baler is poorly adjusted it can lead to losses of up to 12 %. Generally pickup loses are between 1 and 3%. Additionally, using a baler with an expanding chamber can lead to losses of 2-4% while using a baler with a fixed chamber leads to losses of 3-8% (Alberta Agriculture and Forestry, 2018). Generally, alfalfa losses are higher when using a round baler than a square baler and can be up to

18%. Even though the round bale market is more popular in the province of Quebec the losses associated with round balers are higher than those associated with square balers (Alberta Agriculture and Forestry, 2018). A study in Manitoba found that round baler has pickup losses of 0.5 to 11 % and chamber losses of 5 to 17% whereas rectangular balers have pickup losses of 0.5 to 5% and chamber losses of 2 to 5% (Alberta Agriculture and Forestry, 2018). Yield losses lead to increased work hours and lost profits for harvesters. Minimizing yield losses by understanding and controlling baling and storage conditions such as moisture content, bale density and growing environment can lead to significant increases in profit.

4.1.1.1 Moisture Content of Round Bales

The moisture content of the crop entering the baler has a significant impact on the yield of the crop. Moisture content is the single most important factor in determining leaf loss (Alberta Agriculture and Forestry, 2018). Bailing at a lower moisture content than the recommended value causes higher leaf loses leading to higher pickup and chamber losses. This led to lower yields and lower quality forage (Alberta Agriculture and Forestry, 2018).

The ideal baling moisture for round bales is between 15 and 18% (Alberta Agriculture and Forestry, 2018). It can be very difficult to achieve a consistent moisture content due to variation in landscape and other field conditions however aiming for this range will help to minimize bale chamber losses and spoilage as well as output bales that are of high quality (Alberta Agriculture and Forestry, 2018).

Moisture content for microbial inactivation should be between 10-12% however the energy required to lower forage crops to this moisture content is expensive and therefore crops are usually baled and stored at 15-20%. Crops that will be stored at a lower temperature (for example during the winter in colder climates) can be harvested at a higher moisture content as the cold temperature will minimize microbial growth. Moisture content also has a significant effect on losses during storage due to respiration. Bales that are stored at 20% moisture will lose 5% of dry matter due to respiration whereas bales stored at 35-40% moisture content will lose 15-20% of dry matter to respiration (Macdonald & Clark, 1987). These losses are significant and can lead to decreased profit depending on storage time (Macdonald & Clark, 1987).

4.1.1.2 Density of Bales

The density of the bale produced by the baler has an impact on the yield of the crop. In general, the density of round bales varies between 80 and 200 kg/m^3 (Kayad & al., 2015). The density of the bale is determined by factors such as the species of crop, the density of the windrows and the settings of the baler. For the sake of this report we will assume a uniform crop of alfalfa.

According to a simulation of different round bale systems done in Virginia, the density of the windrow that the forage is stored in will have a significant impact on the density of the bale (Cundiff, 1996). When windrows with a higher density are used the bale produced had a lower density. This increases total wrap-eject time, decreases baler productivity and cost per bale increases. This study found that bales made from windrows that had densities ranging from 2.2 to 3.6 kg/m lead to maximized baler capacity (Cundiff, 1996).

A study performed in Saudi Arabia focused on the effect of driving speed and baler pressure on the density of square bales. This study found that the main factor affecting round bale density is in fact the setting of the baler. They studied baler pressures ranging from 5000 to 7000 kPa and found that as baler pressure increases so does the density of the bale (Kayad & al., 2015). However, pressure over a certain point would simply have no effect on the hay bale. Initially forage crops resist deformation at small pressures, at medium pressures density increases as pressure increases but after a certain point forage crops start to be had as incompressible solids (Afzalinia, 2005). By using pressures in the intermediate zones, farmers are able to estimate density from baler pressure and tailor the density of the outputted bales to their own needs.

4.1.1.3 Environment

An increase in favourable environmental conditions (such as temperature, sunlight, soil fertility and water amount) will lead to an increase in yield (Mueller, n.d.). However, the system must stay in balance. Increases in temperature leads to faster plant maturation which in turn leads to lower nutrient content. Longer daylight hours counter the effect of increased temperature which leads to a higher quality product. Too little water leads to a stunted plant that has higher digestibility but a lower yield (Mueller, n.d.). Too much water leads to a lower concentration of nutrients in the plant and a lower yield. Soil fertility, specifically in nutrients such as nitrogen, potassium and phosphorus, is essential for proper plant growth. A lack of these nutrients will lead to a plant's growth being stunted. However, an excess of these nutrients has no positive effect on the plant and is detrimental to the waterways surrounding the field (Mueller, n.d.).

Environmental factors such as solar irradiance and relative humidity will have a large effect on the time that it takes to reach the ideal moisture content (Macdonald & Clark, 1987). The higher the solar irradiance the shorter time it will take to reach a safe level of moisture for baling and storage. Between July and September this can be a difference of 2 days. Additionally, relative humidity of the air will have a significant effect on drying times. Increasing the relative humidity from 20 to 70 % leads to a doubled drying time (Macdonald & Clark, 1987). Both conditions can lead to problematically long drying times in wet regions. These long drying times can lead to harvest at higher moisture contents. Storage of forage harvested at higher moisture contents than 20% can lead to increased microbial growth. This will spoil the hay, becoming a human or animal health hazard due to increased mold growth. Additionally, it can lead to increased temperatures in the bales due to microbial activity which is a potential fire hazard (Macdonald & Clark, 1987). These bales must be discarded and therefore decrease the total yield of the crop.

4.1.2 Vehicle Communication Networks

4.1.2.1 Controller Area Network (CAN)

With agriculture and highway vehicles starting to increase the number of electronic components and systems on board, a greater amount of wire was needed to keep up with the increased number of serial communicating devices. The introduction of the vehicle bus allowed

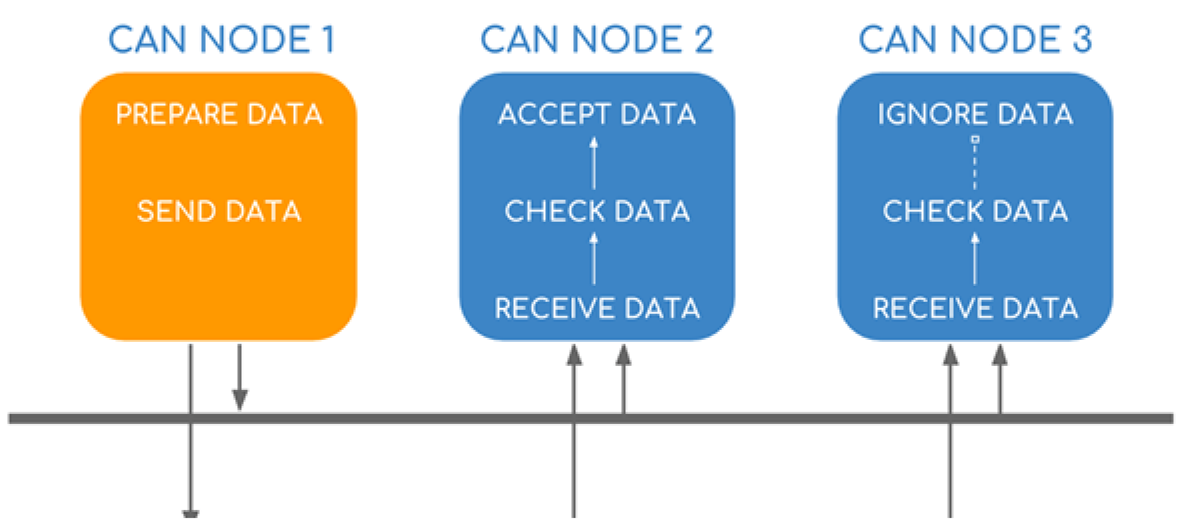


Figure 1: CAN Node and BUS configuration

for intercommunication and interconnection between onboard devices to be possible. Controller Area Network (CAN) is a protocol that was developed in 1986, allowing these Electronic Control Units (ECU) to communicate with one another (United States Patent No. 13/840,290, 2013) along the bus. CAN is a “multi-master, message broadcast system” (Corrigan, 2016) that was implemented as a simplified serial communication system that significantly reduced the amount of wiring need. Prior to its introduction, point-to-point wiring would had been done to allow for communication between devices. A typical agriculture machine such as a tractor would have two or three CANBUS, each with several ECU’s are responsible for controlling vital vehicle components such as: hydraulics & engine. The “bus” portion in the name CANBUS, refers to internal communication lines that connects the components. In order to prevent data messages from being cancelled out, it is crucial that each ECU on the CANBUS has a unique node, or identifier field. There are two main types of CAN specifications; CAN 2.0A & CAN 2.0B, each with several protocols built upon its foundation. Each message has four fields: “Data Frame, Remote Frame, Error Frame and Overload Frame” (Cook & Freudenberg, 2008). The first frame, data frame, is responsible for the holding the identification ID of the message being broadcast to other nodes on the bus. This is the frame that differentiates CAN 2.0A from CAN 2.0B as the identifier bits (Data Frame) in CAN 2.0A only has 11-bits while CAN 2.0B utilizes both the 11-bit as well as an 18-bit. This extended frame allows for more unique messages to be broadcast in large scale applications.

4.1.2.2 J1939 Protocol for Controller Area Network Devices

The J1939 is both a physical and communicational protocol that was adopted by the International Organization of Standardization (ISO) for use in heavy duty (i.e agriculture, mining) machinery. Based on the CAN 2.0B extended identifier field (29-bits instead of 11-bits found in CAN 2.0A), this protocol was standardized to “promote component interchangeability and to allow implements from one manufacturer to function with vehicles made by another company” (Sudduth, 1999). Standardization of communication protocols is extremely beneficial for the consumer, as it allows them to operate John Deere tractor with a Case IH planting unit.

The J1939 protocol messages are designed be either peer-to-peer or broadcast. “This means that the data is transmitted on the network without a specific destination” (J1939 Introduction, 2018) and allows ECU’s on the CANBUS to access the data without sending a request message.

Having both options available to manufacturer programmers allows for options while writing CAN messages. Additionally, comparative to other high-level protocols, “J1939 provides a far better data bandwidth” (A Brief Introduction to the SAE J1939 Protocol, n.d) with significantly less “clutter” or congestion of messages. This primarily stems from the organization of the Data Field (or frame) within the CAN message.

The SPN values are actual data values from sensors. Combined with an actual index

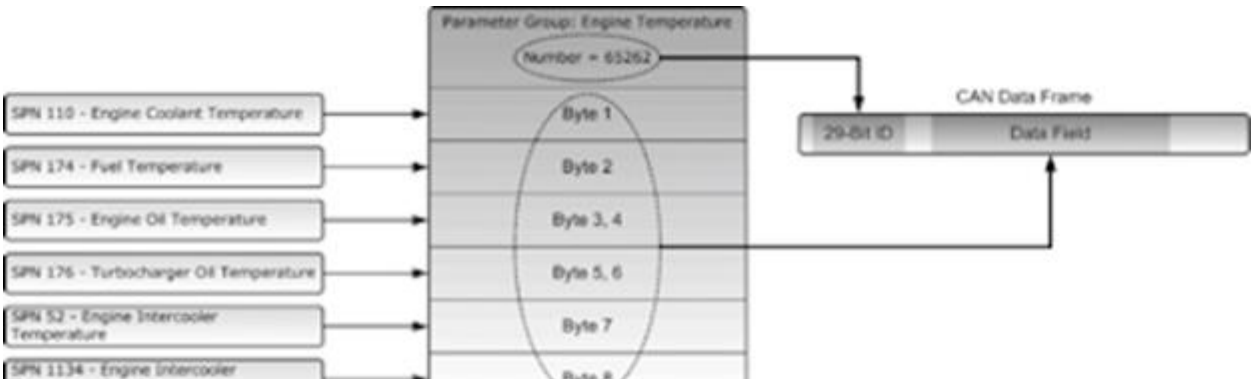


Figure 2: J1939 parameter group and data frame

number called a PGN which “identifies a message’s function and associated data” (A Brief Introduction to the SAE J1939 Protocol, n.d). These PGN’s are defined by J1939 and listed in the documentation for manufacturers to use as a reference when creating new machinery. Consequently, standardization of PGN’s allows for intercommunication between various manufacturers products as well as quick diagnostics for 3rd party repair and maintenance.

4.1.2.3 NMEA 2000

GPS is an integral portion to precision agriculture and data management solutions. It allows you to cross reference data to a location on the field and generate useful yield or nutrient solution maps for farmers. Heavily used in the marine industry for fishing boats and charters, NMEA 2000 is a protocol designed for use in a multi-talking environment, similar to that of J1939. NMEA 2000 is a CAN protocol, that adopts the exact same “requirements for the physical layer, job setting up and data communication on the network” (Cassidy, 1999) with only a slight difference in the its innate ability to self configure its location on the CAN network. Additionally, J1939 and NMEA 2000 can coexist on the same network bus, and even though transfer different types of data and commands (Cassidy, 1999), the messages have the same 8-byte PGN formatting that can be decoded as seen with j1939 messages.

4.1.2.4 Telematics

With precision farming becoming increasingly more important in practices today, we begin to see less and less human interaction with tractor and implement and more automation. For this to even be possible, there needs be an influx of communication devices recording as well as relaying mission critical information from machine to machine, and machine to human. As stated by Rich Mattern from North Dakota State University: “Telematics is a technology that captures data from farm equipment operating in a field and transfers the data to the Internet in real time” (Mattern, 2010). In contrast, older methods of logging data during operation and then retrieving it afterward, to then analyze. It is now “possible for agricultural consultants [or farmers] to troubleshoot problems remotely and offer guidance to resolve technical issues without interrupting fieldwork or making trips to the field” (Mattern, 2010). Not only does it give the farmer live mission critical data, but it also can act as a communication device between machinery. This opens the possibility to reduce the number of operators present during harvest season by the introduction of autonomous tractors.

There are currently two major methods to transfer the data from machine to the farmer: Wireless or cellular. Wireless connection can either be done real-time via radio communication or log data in the on-board computer and periodically send data to the home computer. The benefit of wireless communication is the use of radio transmission removes costs of subscriptions that are found in cellular communication but is limited by range of transmission and line-of-sight. In comparison, cellular has a subscription cost with it, comparable to a typical phone bill but has a range limitation based on service availability only and not hindered by line-of-sight.

4.1.3 Programming Languages

4.1.3.1 Plus+1 Guide®

The Danfoss Plus One system is based around two primary software's; the plus one guide and the service tool (Danfoss, 2018). The plus one guide allows the user to program hardware through a graphical programming approach. The system includes drag and drop logical components as well as software blocks. It works specifically with Danfoss hardware and is made to be run on their controllers. The system also includes the service tool which allows the user to create applications that can be used for diagnostics, maintenance and tuning (Danfoss, 2018).

4.1.3.2 LabVIEW®

LabVIEW is a software developed by National Instruments that offers a graphical interface. This software is used for systems engineering applications that require testing, measuring and controlling to be done with rapid access to hardware as well as fast data evaluation (National Instruments, 2018). The graphical interface allows the user to visualize all steps in the programming process such as data measurement and logging. It can integrate measurement hardware from any vendor and is a proven software that has been on the market for 20 year (National Instruments, 2018).

4.2 Benchmarking

4.2.1 Clemson Directed Prescriptions System

This yield monitoring system was developed by Clemensen University. It consists of an ultrasonic sensor that measures the height of a hay windrow after it has been raked and relates this height to a mass of hay per unit windrow length (Kirk, 2017). This information as well as the ground speed of the baler, the rake width and the final weight of the bale are used to determine the yield in pound per acre. Because this system does not require specific parameters from the bailer is can be implemented for a variety of bale types. After 3 years of research the system generally has an error under 10% (Kirk, 2017).

The yield mapping system can be paired with soil sampling to create soil prescription maps which allow a producer to better monitor their fields and apply fertilizer in a more economic fashion. This is where the real profitability of the system lies (Kirk, 2017).

Our system will be less complicated and require less inputs while still being able to output a yield map. Because it is a one button contained system it will take all measurements needed at one time and will not require further information to be inputted which will be saved time and minimize the possibility of human error. However, the yield maps created by our system will have lower resolution as less points will be taken. The data can be extrapolated but it will still be less precise. However, this is acceptable as it is what the client requested.

4.2.2 John Deere Bale Mobile

The John Deere Bale Mobile is a yield monitoring system run through an app that is connected to (and requires) the John Deere 1 Series Large Square Baler with moisture and mass sensors (JohnDeere, 2018). The bailer takes moisture and mass measurements for each bale as well as a GPS point. The operator is also capable of adding comments about individual bales. Information about each individual bale is then available to the operator via the app (JohnDeere, 2018). This system allows the producer to make decisions about storing bales with similar moisture contents together and produces yield maps (JohnDeere, 2018).

This system is very similar to the system that we would like to implement. However, our client does not make bailers and therefore the mass and moisture must be taken on a different piece of machinery (ie the grabber). This means that the measurements have to be taken in a different way, for example mass is taken from the pressure sensors in the hydraulics. Rather than with a built in mass sensor.

In terms of user interface this would be a gold standard to shoot for. Our screen currently displays moisture measurements and could display mass measurements, but it cannot display yield maps. Data must be downloaded from the system to construct the yield maps on a separate software. Further software purchasing, and extensive coding would have to be done to be able to display yield maps. This is something that could be looked into in the future by a professional however for the moment our client is happy with the system simply displaying moisture and logging all other measurements.

4.3 Applicable Patents

4.3.1 Yield Monitor for Forage Crops (US7096653B2)

In this patent a force measuring device is placed near the hay intake area. The force measuring device sends a signal to the computer which is closely related to the mass flow rate (Shinners, 2000). Using this information and the forage processing machinery groundspeed, and forage processing machinery intake parameters a yield measurement can be determined. The user can also set a target groundspeed to be used when harvesting (Shinners, 2000). Yield values are displayed to the operator in the cab of the machinery (Shinners, 2000).

This patent is similar to our system in that it is a yield monitoring system however the it is set up on the forage processing machinery while ours is set up on the grabbers of a tractor or trailer. Additionally, the measurements are taken on material flows rather than a packaged material. This leads to fundamental differences in programming because the data is obtained in different ways. Therefore, we should not have issues with patent infringement.

4.3.2 Yield monitor for windrow-collected materials (US10188025B2)

The system includes two sensors (such as ultrasonic sensors) that measure the height and other geometrical features of the windrow thus giving a measure of cross-sectional area (Kirk, 2016). An addition sensor or alternatively a GPS can be used to determine the length of the windrow. This gives the total volume of the windrow (Kirk, 2016). When used in conjunction with a bailer a yield map can be developed.

This system is designed to be implemented and used with a bailer where as our system is designed to be implemented on grabber forks. The system mentioned in the patent requires flows of material moving into the bailer and does not take moisture values. For these reasons our system is fundamentally different and will require completely different coding and will not infringe on the patent.

4.4 Applicable Standards

4.4.1 SAE J 1939-2-2019

This standard specifies how SAE J1939 should be applied in agricultural machinery. It outlines the requirements for the systems and which ECUs (electrical control units) can function on the protocol (SAE, 2019). This communication protocol is currently the standard for communication between ECUs in the agricultural and forestry industry. It also specifies the formatting of messages so that they are compatible on this system (SAE, 2019). This standard is important as it denotes the communication protocol we must use.

4.4.2 ISO 11783

This standard specifies a serial data network for the control and communication of agricultural machinery and sensors (SAE J 1939). Its purpose is to standardize the communication between all possible ECUs implemented in the agriculture and forestry industry (ISO, 2017). This standard also lists the current database of ISO 11783-1 address assignment, identity assignments, and parameter definitions. All of which follow SAE J 1939 protocol (ISO, 2017). This standard denotes the protocol we will use as well as provides us with a database of useful information.

4.4.3 ISO 3767-2:2016

ISO 3767-2 standardizes the symbols used for warning symbols and displays on agricultural machinery (ISO, 2016). This standard is standard is important as we will be using a display as a part of our system and it will need to use properly symbols to conform with agricultural industry standards (ISO, 2016).

4.5 Applicable Constraints

4.5.1 Budget

The client has set a target budget for this project at 2500$. This is one of the main constraints that we are working with and it had a large effect on the selection of elements present in both electronic and mechanical systems. This constraint is important as the client must be able to market the system at a reasonable price while still making a profit. A cost estimation was done in order to estimate the total cost to the client if parts were bought in large quantities. Additionally, costs for milling and machining were estimated using the ASABE International Quarter-Scale Tractor Student Design Competition Handbook (ASABE, 2018). This allowed us to give the client a proper estimation of the cost for the project.

4.5.2 Operating conditions

The system must be operable during the hay season in Quebec. This always means operating in temperatures ranging from -10 to 40 °C as well as being stored outside (-40 to 40 °C). Additionally, all components must be environmentally sealed (ie sealed against dust, water and snow). This means that all components must be high quality which increases the cost of the system.

4.5.3 Programming ability

The extent of the electronics teams programming knowledge will seriously limit the scope of the project. For this reason, the team has chosen a language that they are already familiar with. An additional advantage of this language is that is comes as part of a system that includes hardware and that is already being used on Anderson machinery. Using this language, we are confident that we can output a high quality, easy to use product.

4.5.4 Products available

Machinery systems communicate using protocols. Some common protocols include J1939, NMEA 2000 and NMEA 0839. These protocols are already programmed into the hardware available and we must therefore select components that communicate using the same or very similar protocols. Communication between devices using certain different protocols is impossible. Additionally, we must choose hardware that is high quality and that can be programed using a language that we are comfortable in. These constraints limit the products available to us which limit the design of the system.

5. Concept Generation

5.1 Problem Clarification

The problem that needs to be rectified is that Groupe Anderson does not currently have an accurate way to measure hay moisture and estimate hay yield. This is since current systems generally have inaccurate moisture sensors. This is because most moisture monitoring systems are designed to work on flows rather than already packaged materials such as hay bales. Additionally, the system needs to be integrated with existing machinery and this can be extremely difficult. The existing machinery can be very complicated, and it is there difficult to integrate a new system without creating issues. The electronics systems that are used in the yield monitoring system are complex and need to be dirt and waterproof. For this reason, the electronics are very expensive, and this makes keeping the cost of the system at a reasonable level a real challenge. Finally finding a telemetry system that works well in the hilly terrain of Quebec is difficult. This also increases the complexity and the price of the system.

5.2 Concept Generation

5.2.1 LabVIEW & Cellular Telemetry

There are various software & hardware available on the market to use in a project such as this. One option would be to use a program developed by National Instruments™, called LabVIEW. LabVIEW is a system design platform that utilizes a graphical programming approach to help the programmer better visualize all aspects of the project (Instruments, National, n.d.). Not only does LabVIEW allow us to easily envision the flow of data through the application, but the ease and customizability of user interfaces in this program is rather unique. With this software choice, an additional CANBUS interface device would be needed such as the Stratom X-CAN Adapter for myRIO (Instruments, National, n.d.) that costs $169.00 (USD). The my-RIO 1900 model would need to be purchased and costs around $1100.00 (USD) (Instruments, National, n.d.) per unit, this could have the possibility of pushing this design over the price criteria described by the client.

Additionally, the system would need to have a telemetry system on board to both log and transmit data from the machine, to a nearby laptop or home desktop. This device would ideally transmit the relevant information about the crop to a nearby laptop, or over a longer distance to a home-based computer. In this design alternative, cellular transmission would be used. Cellular communication methods tend to require a "lower amount of work on the user end" (Chelsea, 2016) as you are typically joining an existing one, such as Rogers or Bell. Additionally, with cellular networks you have no line of sight issues that can typically be found with radio transmitters in regions that are hilly or have objects obscuring line of sight. A major downside to consider with cellular usage is the cost accompanied with it, as you must "pay a carrier to continue to use their cellular network … [which] may not be worthwhile for continuous monitoring" (Chelsea, 2016).

5.2.2 LabVIEW & Radio Telemetry

As we discussed the possibility of using LabVIEW with cellular telemetry in the previously explored design, we are now going to investigate it being paired with Radio telemetry. Without re-describing what was previously stated about LabVIEW, we will investigate radio telemetry systems. As seen in the image on the left, radio systems require the use of two transceivers (for applications of sending & receiving data) or a transceiver and receiver. Depending on the range of application required, these can be quite an expensive initial investment. Additionally, a major concern in some areas of implementation is the line-of-sight restriction on communication distances. This plays a major factor in the total distances that radios can transmit and render it unusable in some applications. One of our most important criteria for this design, is overall cost. Fortunately, without the need for a carrier or service provider, "two-way radios off a significantly lower total cost of ownership when compared directly to smartphones" (Business-Critical Communications: Benefits of Selecting Two-Way Radios over Cellular Phones, 2014) making radio an ideal candidate based on this factor alone.

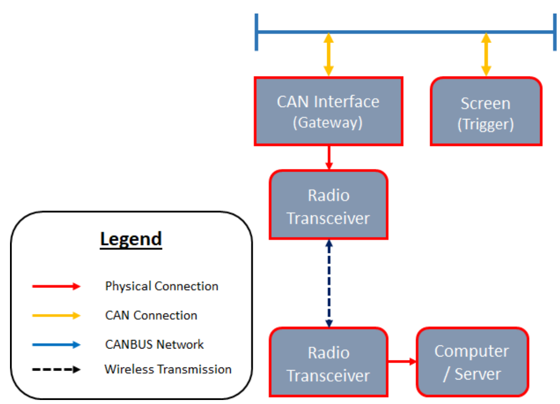


Figure 3: Radio telemetry option

Taking all the discussed pros and cons into consideration, radios are a fantastic telemetry option for those doing continuous data transmission or logging. Unfortunately, the unknown location of operation for this trailer could potentially leave the system without reliable connection to transmit data. Additionally, with setting up radio telemetry units, you need to configure your own personal network. This can be both complex and time consuming as you must spend many hours on troubleshooting.

5.2.3 Danfoss Plus+1 Guide® & Cellular Telemetry

The other program that was considered viable in this application design was Plus+1 Guide. Like LabVIEW, it takes advantage of a graphical user development program. Allowing the developer to easily visualize what he or she is creating. Major difference between the two is the fact that you can run any LabVIEW project on any computer that supports windows or Linux. Plus+1 Guide is proprietary, and therefore can only be run off Danfoss microcontrollers and devices. Danfoss additionally offers a proprietary cellular telemetry device (WS403) that is configurable with their programming environment. The simplistic integration with the already existing Danfoss products on the machinery has a major perk, though the cost accompanied is quite substantial (see economic evaluation).

5.3 Initial Screening for Feasibility and Effectiveness

Upon initial inspection all options are viable possibilities. Both programming languages are currently in use industry or academia for several applications and both forms of telemetry function can be implemented and function well. However, certain systems have major downfalls that will be discussed in section 6.1.

6. Concept Selection

6.1 Secondary Screening for Feasibility and Effectiveness

In section 5.3 it was determined that all the initial options proposed were viable options. However, each system has its advantages and disadvantages. Firstly, though LabVIEW is a top-end data acquisition software with easy user interface design, the overall cost accompanied with the implementation of this is too high. One of the main constraints of the system is an overall cost of under 2500$, using LabVIEW would make this goal extremely difficult to attain.

Secondly, with the telemetry unit, we see that cellular transmission has significant benefits to its range capability as well as service availability. However, it was also noted in a research study that “failure rates of consumer mobile devices supporting target applications was recently measured by VDC Research at 18-20%, substantially higher than the 4-8% of rugged to-way radios" (Business-Critical Communications: Benefits of Selecting Two-Way Radios over Cellular Phones, 2014). This is an issue as proper data transmission is essential. Despite its lower failure rate radio telemetry requires a direct line of sight between the receiver and the transmitter. Since the system will be operating in unfamiliar terrain this line of sight cannot always be guaranteed. Additionally, the system is being designed with the goal of implementing it in Quebec where hilly terrain is common. This makes a direct line of sight more unlikely. In either case a reliable data logging system will have to be developed to compensate for failures in the telematics systems. An added disadvantage to radio telemetry is that the user must configure the network themselves which can be complicated and time consuming.

Finally, Plus +1 Guide is a fantastic software that offers an easy graphical interface design. However, as previously stated it is a proprietary software that can only be run off Danfoss hardware. Therefore, all controllers for the system must be bought from Danfoss. This is a substantial cost. One advantage to using Plus 1+ Guide is that Groupe Anderson currently uses Danfoss hardware and software and there is already a microcontroller implemented on the trailer that they would like us to design the system for. They have indicated to us that we can use this microcontroller as a part of the system and this will decrease the cost of the hardware needed to be purchased.

6.2 Concept Screening

We presented our client with the three options that we had selected and received a lot of constructive feedback. The client was very keen to use Plus 1+ Guide as the software for the project. They are already familiar with Danfoss and they trust the quality of their products. Additionally, they already have an MC-24 on the trailer on which they would like us to implement the yield monitoring system. They stated that we could use this controller as a part of the system and this will significantly decrease the cost of the system.

When presented with the two telemetry options they preferred to use radio telemetry. They had previously implemented cellular telemetry on another piece of agricultural machinery and had had issue with it due to a malfunctioning sim card. Despite this, we presented the option of Danfoss's proprietary cellular telemetry unit. They were slightly more comfortable with this version of cellular telemetry as Danfoss provides effective customer support that could help if there was an issue.

Eventually they decided to wait to implement a telemetry unit as they are currently negotiating with their suppliers. They indicated to us that it no longer fell under the scope of our project. However, they plan on going with our recommendation of Danfoss's proprietary cellular telemetry unit (see selection process in section 6.3).

6.3 Scoring and Selection

Climate and weather resistance were each given a weight of 1 because all products on the market for a agricultural use fit these criteria. Additionally, these criteria must do more with material selection for the mechanical team than the electronics team. Ease of operation and multiplatform integration were both given weights of 2 as they are important to our design. The system must

function at the touch of a button and much be implementable on multiple models of Anderson Trailers. These criteria will be important for design selection. Finally, cost and provision of viable data were both given weights of 3 because they are essential constraints. The system must provide viable data for it to be worth it for the client to invest in and produce. Lastly the cost limit must be respected so that the client can market the system at a reasonable price and still make a profit. Precision (GPS accuracy) is less important when being implemented in a yield monitoring

Table 3: Pugh Matrix

Criteria			**LabVIEW and Radio Telemetry**		**LabVIEW and Cellular Telemetry**		**Danfoss and Telemetry Unit**	
	Baseline	Weight	Rating	Weighted	Rating	Weighted	Rating	Weighted
Weather Resistant	0	1	0	0	0	0	0	0
Climate Resistant	0	1	0	0	0	0	0	0
Ease of Operation	0	2	0	0	0	0	1	2
Multi-platform Integration	0	2	1	2	1	2	1	2
Cost	0	3	-1	-3	-1	-3	1	3
Viable Data	0	3	1	3	1	3	1	3
Score				2		2		10

application like this, as the location you pick up the bale is not exactly where the hay was cut and taken from. Therefore, cost of implementation should be valued slightly higher than that of the accuracy. In the case of our design, the use of a marine GPS Antenna would greatly reduce the cost of implementation, which was one of our critical portions of our design criteria. If these two constraints are not respected than the client will not be interested in the system.

After the use of the Pugh matrix (as seen in *Table 3*) we can see that Danfoss with telemetry is the best option and will therefore be the implemented solution.

7. Final Design

7.1 How does it work?

7.1.1 Program

As described in the previous chapter, we have chosen to develop this application in Plus+1 Guide environment. This software not only offers faster processing times comparative to LabVIEW, but also offers very easy integration into CANBUS networks with no additional interface required as you would with LabVIEW. Functionality of the program is described below. We are tasked with taking measurements of bale weight, moisture content and providing a georeferenced for these pieces of information. On the trailer, are adding a MC024 microcontroller from Danfoss, which will be the main workhorse for signal processing in this application. The sensor chosen for the application (Agreto moisture probe) sends an average mV readout from a signal conditioning box. As the signal comes into the MC024, it was noticed that the stability was not ideal and significant spiking caused issues with the final averaged value. To compensate, a exponential filter function block removed large spikes in data (figure on smoothing block *Appendix D3*). At the same time, we will be taking in values from a pre-existing pressure sensor that is located on the loading arm. Using the function block already existing in Plus+1 Guide, we run signal in from the MBS1250 pressure sensors located on the arms. Additional use of exponential filters will need to be used to clean the unwanted data spikes, as well as calibration process described later in this report.

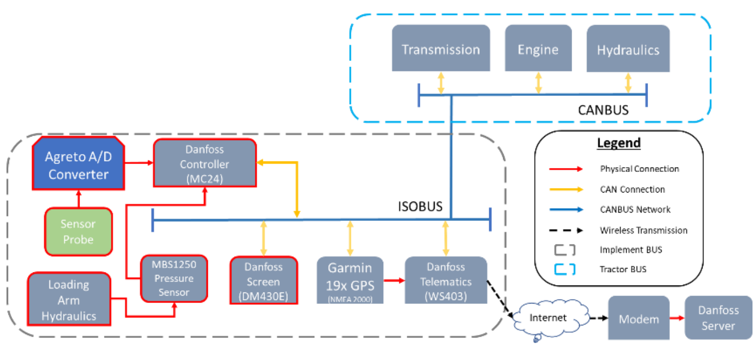


Figure 4: Final implemented design

In *Figure 4*, we can see the overall layout of the system. The object highlighted in red are controllers or sensors that we will be implementing in to the existing trailer system. Most of the items in the above diagram will be communicating amongst one another via CANBUS, therefore limiting the amount of direct line wiring needed.

We will take the filtered data from the moisture reading and weight from the pressure sensor and send it to the screen via CANBUS / ISOBUS. From here the data is picked up by the DM430E screen. As seen in *Figure 5*, the DM430E is a non-touch screen display that has capability to connect to the CANBUS and function as a microcontroller. The user will not only have access to relevant data such as moisture content and weight of the bale but with the use of the four buttons, also the ability to start and stop the log file and transmit data when finished.

Figure 5: DM430E display

7.1.2 Motor Control

Implementing an MC024 into our design brought the total cost of the system down significantly, though left issues controlling the motor. The motor required 10A when under full load, which caused issues as the MC024 could only output 3A peak. To get around this issue, we implemented a Cytron MD10C 10A motor control board to bump up the control amperage (Robotshop, 2019) . This board controls the motor using a 5V (0V = reverse, 5V = forward) control logic for directionality, while PWM (0-100%) for speed of actuation (Robotshop, 2019). We have the control signal currently set to run off a one touch interaction from the screen, where it will actuate the motor for a pre-described amount of time before flipping direction and sending the actuator back to its retracted position (*Appendix D1 and D2*). For the 5V control logic to function properly, a relay supplied by the 5V sensor power supply on the MC024. It was tripped by the directionality pin and in turn sent 5V. This is purely because on the MC024 you can not alter the output voltage on the control pins. Other models of Danfoss's microcontroller family have this ability, but in our application, we are taking advantage of an already existing controller.

Figure 6: Cytron MD10C motor control board

7.1.3 Load Measurement & Calibration

Load can be determined using pressure in the hydraulic lines of the loading arm. There is an existing pressure sensor on the hydraulics of the arm. The system will be automated to read the pressure in the line when the arm is at a specific position in its arc (Sheffield, 1998). This will ensure that there are no differences in the angles of the forces acting on the arms. This pressure reading will be converted to load using a predetermined calibration factor. This calibration factor will be determined during the testing phase by using round bales of different masses (Sheffield, 1998). The pressure in the line at the given point will be taken for each bale and this will be used to construct a calibration curve. Other bales will then be used to validate the calibration curve.

With the sale of the final product, this task will fall to the owner or operator of the implement. He/she would need to calibrate this function once per year or depending on the usage of the implement. This calibration is important due system component wear on the hydraulics and mechanical components in the system, as well as the variation in the pressures in different platforms this product is offered in. The calibration process as described above is configurable through the user interface in the DM430E screen, where the user will have to input a known weight of the bale he/she is currently planning to measure. For this calibration to be accurate over a larger range of bale weights, the operator would need to record both weights and pressures of the measured bales.

These bale inputs would be inputs into a 6-point function block (programmable function on Danfoss seen on right) that generates a calibration curve based on the parameter values described. Like curve generation in excel, for every x input you retrieve a y output. In this calibration case, the weights and pressures retrieved from the 6 bales measured will be put into the parameter inputs going into this function. Y axis is the weight, while X axis (input signal) is the pressure read out from the sensor. This if the input pressure signal from the arms reads a value that falls between one of these calibrated pressures, it linear interpolates it based on the nearest points and outputs a weight value corresponding to the pressure input.

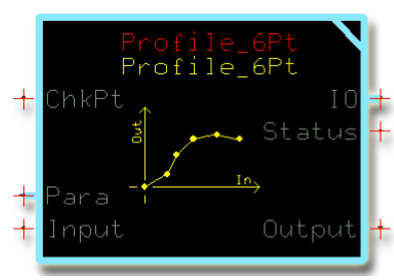


Figure 7: 6-point profile block (Plus+1 Guide)

Though this is the best solution that requires the least amount of time investment on the client's parts, there are some large issues that should be known. Linear interpolation in this system is not the best possible solution unless you have a large data scale. If the input value is larger than the value the largest value you have calibrated for, the function block takes the last point in the function curve. As an example, if a value of 600 PSI is read from the sensor, but the last point in the function block is 400 PSI, the output be that of which corresponds to the 400 PSI leading to some large error and mismeasurements.

7.1.4 Telemetry Device

Figure 8: WS403 telematics device

Additional to the MC024 and DM430E, is the cellular telemetry unit from Danfoss. The WS403 (*Figure 8*) has the capability to log data if need be, but as the screen is already tasked with this responsibility, the sole purpose of this unit is for cellular transmission of the data being logged. It also has direct access to the CANBUS and is completely configurable within the Plus+1 Guide program. Once the operator has finished the field, he / she will press one of the buttons responsible for data transmission. This log file will be sent via Global System for Mobile devices (GSM) to either the Danfoss server (or Anderson if configured) or to a cell phone / email. From here, the data will be retrieved, and with the use ARCGIS we can use the geospatial data to generate yield data maps for the farmer or manager.

7.1.5 Connectors

For this system, connection points and proper wiring is vital. In prior experiences working with other data acquisition systems, a lack of a secure connection at the controller can generate large amounts of signal noise from vibration alone. Fortunately, with the MC024, the connectors used are Deutsch.   DTM 12 pin that are IP67 rated, allowing for full submersion in water and dust proofing. As this controller is to be mounted on the trailer where we can expect vibration to generate significant signal noise; with the use of these connectors we should be able to cut this out completely. The screen (DM430E) has connectors exactly the same as the MC024, while the telematics device (WS403) utilizes a 5-pin M12 connector as well as a standard GSM and GPS connector.

7.1.6 Electrical Wiring & CAN Message ID

As Anderson strictly uses Danfoss electronic controllers and associated products, it was convenient to implement an MC024 microcontroller into our design process. *Table 4* lists all the pins that are used on both the MC024 and DM430E as well as the function they have within the program.

Pin Number	Pin Configuration	Description
Inputs		
C2-P1	DIN	Pressure Plate Switch
C2-P2	VOLT	Moisture IN (mV)
C1-P10	VOLT	Pressure Transducer 1
C1-P11	VOLT	Pressure Transducer 2
Outputs		
C2-P9	DOUT	Steering Direction
C2-P10	PWMOUT	Steering Speed
Power		
C1-P1		POWER GROUND (-)
C1-P2		POWER SUPPLY (+)
C1-P8		5Vdc Regulated Sensor Power (+)
C1-P9		Sensor Power Ground (-)
Communication		
C1-P3		CAN +
C1-P4		CAN -
C1-P5		CAN Shield

Pin Number	Pin Configuration	Description
Power		
C1-P1		POWER GROUND (-)
C1-P2		POWER SUPPLY (+)
Communication		
C1-P3		CAN +
C1-P4		CAN -
C1-P5		CAN Shield

CAN messages have been created in accordance to SAE J1939 standards. While testing the system, we were unable to get a list of the messages being communicated on the trailers CANBUS, so messages have been created to be broadcast to all nodes on the bus (*Appendix F1, F2, F3*). PDU format portion of the PGN were left as 0xFF and we then created a sequential list of message ID's for the PDU specific region. A1 being the first message, and A3 being the last message we created. Prior to implementation into a finalized product, we would need a list of PGN's used by the team responsible for programming the control functions of the trailer. This would allow us to make sure that the messages we are adding do not conflict with already existing, and cause miscommunication amongst devices on the bus.

7.2 Cost

To determine the economic viability of this we have conducted a thorough economic analysis. Due to the fact that we are working with another team and that the budget is for the project as a whole, the economic analysis will contain values from the mechanical team as well. The economic analysis includes *7.2.1 Investments and Costs*, *7.2.2 Savings and Benefits* and *7.2.3 Cost-Benefit Breakdown*.

7.2.1 Investment & Costs

The initial investment of the project includes all the investments of both the mechanical and electronics team. The proposed budget for this project is $2500. The retail price of these investments is listed in *Table 5*.

Table 5: Retail Price List of System Components

Component	**Quantity**	**Unit Cost (CAD$/Unit)**	**Total Cost (CAD$)**	**Working Period (Years)**
Moisture Sensor (1)	1	643.50*	643.50*	5
Linear Actuator (2)	1	181.25	181.25	5
Steel Angle (3)	1 x 1/4 x 36”	18.97*	18.97*	15
Motor Controller	1	15.40	15.40	-
Flange steel (3)	2	0.5	1.00	15
Laser Cutting (Labour) (4)	14 inches	0.13/inch*	1.82*	-
Fasteners (3) Bolt 9/16 x 2” (3)	2	8.3*/25	0.664*	-
Lock Nut 9/16	2	11.95/25*	0.956*	-
Hex Bolt 7/16 x 2”	1	8.51/100*	0.0851*	-
Lock Nut 7/16	1	5.85/100*	0.0585*	-
Galv. pipe 1 5/8 x 2”	1	0.18	0.18*	-
Welding (4)	4in	0.06($/in)	0.24*	-
Laser Cutting (4)	14in	0.1($/in)	1.4*	-
Assembly (Labour)	2 hours	59.84/hour*	119.68*	-
Mechanical Subtotal	-	-	969.81	-
Safety Factor (5)	15 %	-	145.47	-
Mechanical Total	-	-	**1130.68**	-
Screen (6)	1	482.05	482.05	5
Controller (7)	1	760.51*	760.51*	5
Telematics Unit (8)	1	1381.34	1381.34	5
Wire & Connectors	-	-	200	5
Electronics Total	-	-	**2823.90**	-
Total			**3954.58**	

(1) Agreto Moisture Sensor
(2) Progressive Automations PA-15-1-11 High Speed Actuator
(3) Purchased from Acier Lachine
(4) Labour costs obtained from International Quarter-Scale Tractor Student Design Competition (ASABE, 2019)
(6) Danfoss DM-430 screen purchased from Berendsen Fluid Power
(7) Danfoss MC-24 controller purchased from Berendsen Fluid Power
(8) Danfoss WS-403 telematics unit purchased from Berendsen Fluid Power
* Dollar amount converted from USD as of April 8th, 2019

Using the retail cost of items gives a cost of $3954.58 which exceeds the proposed budget of $2500 significantly. However, this is not an accurate representation of what the system will cost our client. In terms of electronics the client already has an MC024 on the RBMPRO 2000 trailer and therefore the cost of the controller does not need to be included in the pricing. Additionally, the client does not wish to include the telematics unit at this time, so it can be ignored for the moment. The telematics unit also functions as a GPS when the optional GSM/GPS antennae is included, so the price of a GPS unit can be discarded from the overall price. We bought all items at retail price and assumed a dealer markup of 30%. We also assumed that the dealer would sell to our client for a lower markup of 15%. This gives us the pricing listed in *Table 6*.

Table 6: Retail vs. Client Purchase Table

Component	**Retail Price (CAD$)**	**At Cost Price (CAD$)**	**Purchasing Price (CAD$)**
Moisture Sensor	643.50	495.50	568.85
Linear Actuator	181.25	139.42	160.34
Motor Controller	15.40	15.40	15.40
Labour and Steel	-	-	179.57
Screen	482.05	371.15	426.82
Wiring and Connectors	-	-	200
Total	-	-	**1550.98**
Telematics	1384.34	1062.57	1221.95
Total with Telematics	-	-	**2772.93**
Controller	760.51	585.59	669.24
Total with Telematics and Controller	-	-	**3442.17**

Additional savings are highly likely due to the fact that the client can perform all machining and manufacturing for the mount for the sensor in house.

7.2.2 Benefits & Savings

The financial benefits of this design include reduced cost due to better field management as well as reduced working time for the user as they will not have to measure the moisture of the bales manually. A better understanding of field output, when coupled with soil samples, will lead to better field management. This will reduce the amount of inputs such as fertilizer used on the fields thus reducing the cost. Additionally, there will be a significant reduction in operator time since the user will not need to leave the tractor to take manual moisture measurements and log the measures manually. The calculations that follow and the calculations in 5.3.2 will be based on reduction of work hours and on possible savings due to better nitrogen management.

To determine the amount of time saved we must consider the amount of hay produced per season and the number of samples that must be taken. One acre of field can produce on average 4 tons of hay per year (Greene, 1993). The average varies depending on a variety of factors including location and type of hay however it is a good estimation for the purpose of this calculation. Additionally, to accurately measure yield at least 20 samples must be taken per 200 tons of hay (Putnam, 2002). Therefore 2 samples are needed for every 5 acres. As most Quebec farms harvest hay 2-3 (use 3) times per year and generally cover 280 acres (Census of Agriculture, 2014), 336 samples are required in total. Our tests have shown that it takes 3 minutes to manually perform a moisture sensor reading, including exiting and re-entering the tractor. Therefore, the design will save 14 hours of work per year. Given that Quebec's minimum wage is $12.00 the design will save $168.00 per year (Minimum Wage, 2018).

Savings per Acre: $0.24
Annual Hours Saved: 16.8
Annual Savings: $201.60
5 Year Savings: $1008.00

Additional Savings can be calculated due to the reduced amount of nitrogen fertilizer spread on the fields. A study at Clemensen university found that a similar yield monitoring system would result in an additional $14.5 per acre when compared to a fixed application rate of 60 lb per acre (Kirk, 2017). Their system takes continuous yield measurements as it collects hay where as our system only takes yield measurements at the bale and extrapolates from there. For this reason, our system has less resolution and will therefore result in less profit per acre. We will assume that it results in half the profit ($7.25). We will again assume 280 acres harvested 3 times per year (Census of Agriculture, 2014). This will lead to the following savings.

Savings per Acre: $7.25
Annual Savings: $6090.00
5 Year Savings: $30,450.00

The total savings for the project can be calculated through the addition of these two benefits.

Savings per Acre: $7.49
Annual Savings: $6291.60
5 Year Savings: $31,458.00

7.2.3 Cost-Benefit Breakdown

The economic viability of the design and the cost benefit characteristics were evaluated using the net present value, payback period, discounted payback period and rate of return. These were calculated using the following equations (1, 2, 3). The cost of capital will vary over time however a conservative value of 9% is used. A five-year period is also assumed. The yearly savings of $6291.60 and a consumer cost of $3954.58 were used in the calculations.

$$NPV = \frac{B_0 - C_0}{(i+1)^0} + \frac{B_1 - C_1}{(i+1)^1} + \ldots + \frac{B_n - C_n}{(i+1)^n} \quad (1)$$

$$PP = \frac{Total\ Cost}{Annual\ Savings} \quad (2)$$

$$DPP = Years\ to\ Capital\ Recovery + \frac{Unrecovered\ Cost}{N+1\ Year\ Cash\ Flow} \quad (3)$$

Rate of Return (IRR) = 158 %
Net Present Value (NPV) = $20,517
Payback Period (PP) = 0.63 years
Discounted Payback= N/A

The rate of return is over 100% because the profit in the first year is higher than the cost of the system. The discounted payback period is not applicable because the initial cost is paid back in the first year.

7.3 Design Drawings, Parts List and Bill of Materials

The wiring diagram seen in *Figure 9* represents the electrical components that will be implemented. The diagram, created in Solidworks Electrical, specifically shows the correct pin locations that each of the components will connect to. This allows the individual responsible for assembly of the electrical components to easily locate and find the correct

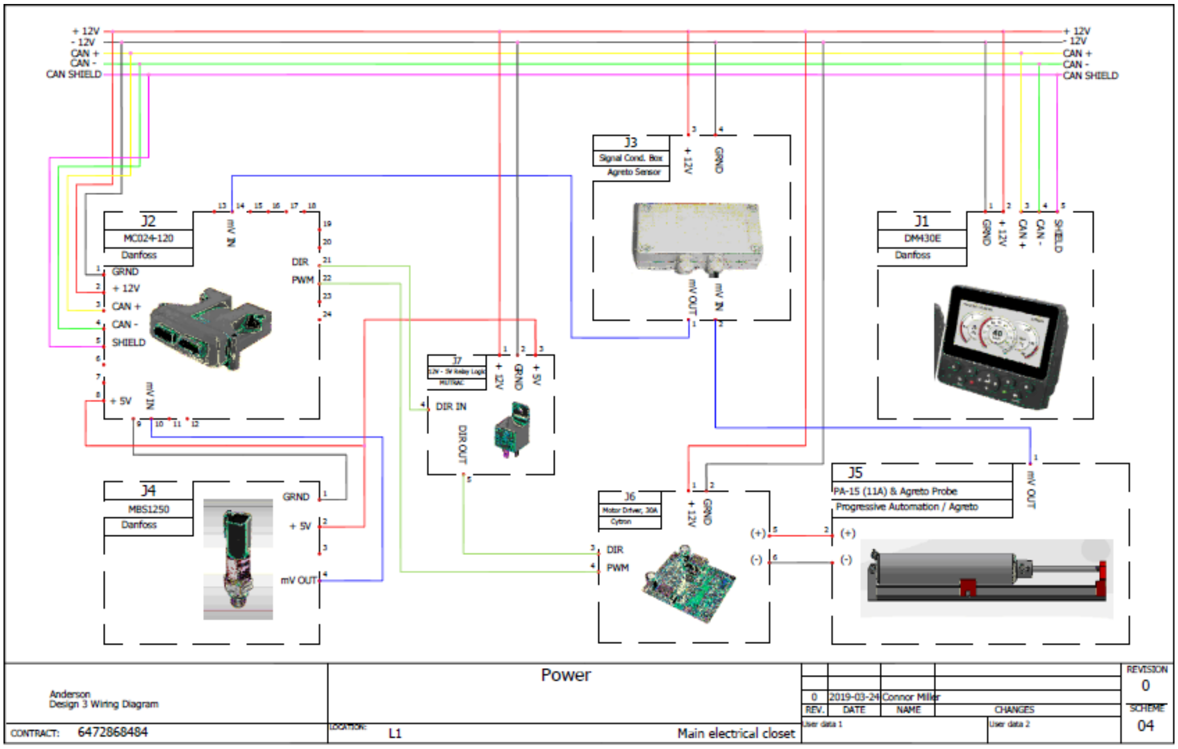


Figure 9: Solidworks Electrical Schematic, Implemented Design

positions to connect wires to. Additionally, a key component of the MC024 is the different key types use on each of the two connectors. This prevents the connectors from being placed into the incorrect position, potentially causing damage to the controller or failure of application. It is important to note that the final product wiring diagram would be significantly more complex, as the MC024 would be connected to more items on the implement. This diagram acts to merge the two together and give an idea what physical connections are necessary for seamless introduction.

A list of components involved in the system can be seen in *Table 7*. Each components quantity reflects the amount needed to complete the build of the harnesses and connectors. An additional safety factor has been included, varying depending on the type of component you are looking at, to allow for some mistakes.

Table 7: System Component List

Components	Product Description	Quantity	Supplier
MC024	Microcontroller	1	GA Danfoss Supplier
DM-430E	Screen	1	GA Danfoss Supplier
WS-403	Telematics Solution	1	GA Danfoss Supplier
CANbus wire	J1939 Physical Layer	20 ft	Mouser Electronics
16 gage wire	-	20 ft	Mouser Electronics
20 gage wire	-	20 ft	Mouser Electronics
20 gage sockets	-	30	Mouser Electronics
20 gage pins	-	30	Mouser Electronics
16 gage sockets	-	30	Mouser Electronics
16 gage pins	-	30	Mouser Electronics
DTM06-12SA	12 Pin, Keyway A	2	Mouser Electronics
DTM06-12SB	12 Pin, Keyway B	1	Mouser Electronics
DT06-3S	3 position, Socket	8	Mouser Electronics
DT04-3P-P007	CAN Splitter	4	Mouser Electronics
DT06-3S-PE01	CAN Resistor, 120Ω	2	Mouser Electronics
Motor control board	-	1	Mouser Electronics
Signal Modification Box	-	1	Agreto
Linear actuator	9 in/sec	1	Progressive Automations
Relay	-	1	Mouser Electronics
Agreto Moisture Sensor	Probe	1	Agreto
MBS 1250	Pressure Sensors	1	GA Danfoss Supplier

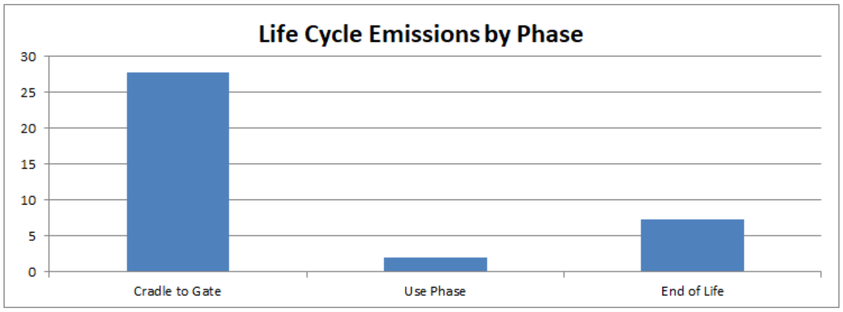
7.4 Health, Safety and Environment.

7.4.1 Environmental & Social

There are several critical environmental factors to consider while implementing this design. Firstly, we must always remember that if and when items break, we are potentially leaving behind plastic or metal scraps in a forage crop. Eventually the crop will be cut and baled to be fed to livestock. If these pieces of metal or plastic find their way into the feed and the animal is to consume this, it could cause issues with digestion and lead ultimately to death of the animal. To combat this worst-case scenario, the use of proper shielding to prevent wires from becoming entangled in mechanical components as well as high strength electrical connectors to limit breakage. Secondly, we must keep in mind that this system is an application towards precision agriculture. The yield map that we are piecing together with the geospatial data collected will allow farmers to see areas of high value and reduce the amount of fertilizer needed to be applied in that location. In turn, less amount of fertilizer that is applied can limit the amount of runoff to nearby drainage streams and ponds. This will have a positive effect on the environment.

A cursory LCA was performed (Chooses LinkCycle, n.d.) and included the production of the raw components of the system, the electricity needed to run the system and the disposal or recycling of the components. This LCA concluded that the system would produce 37.19 kg CO_2 in a 5-year period of use (Chooses LinkCycle, n.d.). However, this is an over-estimation of the CO_2 produced as the LCA assumes that the system will be running 120 days a year for 8 hours a day. The system would most likely only be used 20 days a year for hay harvest on a single farm. As seen on *Figure 10* most of the CO_2 emission occur during the production phase. The detailed LCA can be seen in *appendix A3*. This is a low environmental impact compared to the system's potential to reduce fertilizer use and if therefore worth the impact.

Figure 10: Life Cycle Emissions Plot in CO_2 eq



When we look at the social perspective of this design, we look at the relevancy of this system to the producer. Justification of implementation is key. To do this we prove to the producer that the value of this geospatial data and ultimately the implementation of precision agriculture practices is worth the investment. There are several benefits to this system. The producers yield could increase as he / she would be able to identify locations within the field and determine why they are producing less than others. Additionally, they would drastically decrease their overall inputs to the production as fertilizer applications could become spot specific. This would increase the total profit from the field and therefore justify the use and cost of the system.

7.4.2 Risk Factor Matrix

There were multiple criteria to meet when going through the many alternative designs. Of which, multiple platform integration capability as well as ease of operation were two of the more critical components. We know operators will have direct contact with the system, and we want to ensure that the user experience is not only seamless, but more importantly, safe. Below is a risk factor matrix that we have carried out with risks ranging from mechanical injuries to software failures. Each risk is given a specified weight (importance) ranging from one to three, one being least likely and dangerous while three being the most likely and most dangerous. Additionally, it is discussed that the potential root causes to these issues and potential mitigation strategies for the operators to consider.

Table 8: Risk Factor Matrix

Risk Factor	Risk Rank	Risk Contributor	Mitigation Process
Entanglement in PTO	3	-Setup and testing require close proximity to moving parts	-PTO Shield -Avoid use of loose clothing
Short Circuit	1	-Broken wires -Open leads -Loose connections	-Use of properly rated wiring harness -industry standard wires
CAN communication interference	2	-Corruptions of existing messages and programs	-Properly identify already used CAN ID messages
Interference with tractor controls	2	-Mis-implementation of electrical components	-Professional installation
Proximity to pinch points	2	-Setup and testing require proximity to pinch points	-Proper use of OSHA stickers
Proximity to high pressure lines	2	-Setup and testing require proximity to high pressure lines	-Proper use of OSHA stickers
Program failure and loss of data	1	-improper logging procedure -improper transmission procedure	-Vigorous testing of the telemetry and data logging system
Impalement/Laceration on Probe	2	Sharp edges, long acicular probe	Fillet sharp edges, probe sheathed when not in use
Complexity in Hazardous Zone	3	More time spent in hazardous zone, increased probability of bodily harm	Add standardized operator safety labels
Overloading of electric motor	1	Overheating, incorrect installation, duty cycle	Fuses, select appropriate motor size
Incorrect reading	2	Inconsistency in bale qualities	Implement appropriate probe length, provide calibration procedure manual
Shearing, bending of probe	2	Large shearing and axial forces applied	Select appropriate materials, design with appropriate dimensions

As you can see above in *Table 8*, the most dangerous of the listed risks is entanglement in the power-take-off (PTO) and increased complexity in an already hazardous zone. This isn't unique to our application, as almost all agriculture implements using PTO's should be held at high regard for safety around this area. Additionally, adding anything to areas that already include moving parts, hydraulics and sharp objects increases the potential for danger. Laceration or impalement on the probe is a substantial danger as it is operating in this complex zone. However, this risk is mitigated using shielding. The most concerning section regarding software implementation would be CAN message interference or interference of tractor controls, which could potentially be related. In this case where we are implementing software onto an already existing CANBUS, we must take great care in selection of our unique CAN message ID. If we do not, we could potentially cause vital information to tractor performance and functionality to become corrupted or, in the worst-case scenario, completely shut down a vehicle controller. Of course, mitigation of this can be simple during the test phase with the use of a generic CANBUS monitoring software, to help identify existing messages and create your own unique version.

7.5 Design validation

7.5.1 Testing Procedure & Setup

Prototype testing and data acquisition was carried out on two different bale sizes. While visiting our client, testing was carried out on a large round bale (4'x5') while testing conducted at the Technical Service Building was done on a small square bale (14"x18"x35"). These tests were conducted in partnership with the mechanical team, where we studied both the moisture readout from the sensor as well as the load being applied on the actuator. This portion of the load cell was more important to the mechanical team's design, but results can be used to draw conclusions for inaccurate measurements. In order to retrieve applied load data from the bale on the actuator, a strain gage was positioned at the rear attachment section of the actuator. A small slot was milled out of a piece of flat steel where the actuator attached to, to allow it to have a sliding fit. Once the actuator was forced into the bale, it was driven back into its slot and in turn putting force onto the strain gage. This data was recorded on a laptop using an Arduino.

Figure 11: Square Bale Test Bench Setup

7.5.1.1 Square Bale Setup & Procedure

Square bale testing setup can be seen in *Figure 11* and is described below:

1. The probe and bracket were fastened tightly into a vise, horizontal to the table it and the square bale were on. Electronics kept at a safe distance away and stored in the bench testing box as a means to prevent entanglement and damage to lose wires

2. The bale was placed so the layers of material ran parallel to the actuation direction. We divided the bale into 4 banded sections that we marked with paint to allow for consistent location of penetration. Each banded region had a variating level of water poured onto it. Original site having no water, to the furthest (last data points) having the most.

3. For additional rigidity to the system, the bale was clamped to the table using a ratchet strap.

Procedure:

1. The sample location was probed using the Delmhorst probe 4 times, in a circular pattern around the specified location. This was done to avoid the probe going into the same sample paths and providing inaccurate measurements. This data was put into an excel spread sheet.

2. The actuator was then triggered 4 times, in 4 separate locations in the banded region and values were recorded. The bale was shifted for each new sample to ensure consistent pressure was on the sensor throughout the stroke. Moisture and load data were recorded into the excel document.

3. This procedure was completed for the other 3 remaining locations on the broadside of the bale.

7.5.1.2 Round Bale Setup & Procedure

Round bale testing setup can be seen in *Figure 12* and was slightly varied as the mounting mechanism was now on a round bale grabber attached to a tractor. For this setup all the electronics were setup in the cab, where they could be actuated and controlled by the operator. The bale was split up into 4 main sections, and each of the sections was tested twice. Load data was not acquired in this test as the implementation zone was already quite busy and electronics were too fragile.

Figure 12: Round Testing & Data Acquisition

Setup:

1. The probe bracket was attached to the top portion of the grabbing mechanism, where the quick attach was mounted, using steel clamps. The bracket was mounted so it laid parallel to the ground.
2. All electrical connections ran back into the cab of the tractor, and wires were fastened to the structural members of the loading arm in a way that prevented them from being pinched or broken.
3. During sampling, the loader was placed so that the flat plate of the grabbing mechanism is flush to the flat end of the round bale.

Procedure:

1. In order to get to the correct sampling location, the tractor had to be maneuvered to the correct position.
2. At each location, 4 samples were taken for both the automated sensor as well as the manual probe.
3. All data was recorded in an excel document. Each quadrant had eight points total.

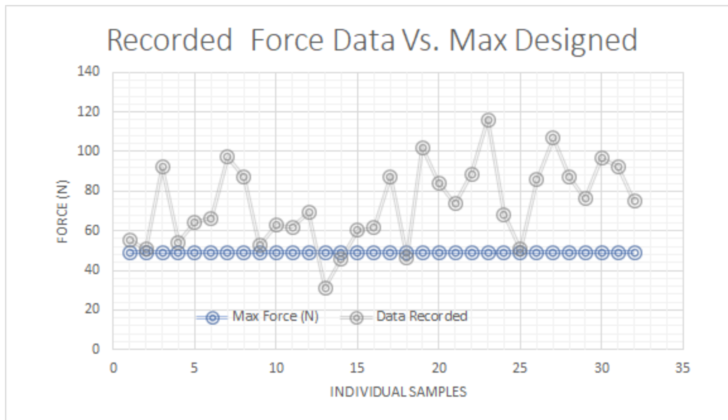
7.5.2 Results

In *appendix B*, tables *B1* and *B2* show recorded sensor data from both the load cell as well as the moisture content recorded at each sample. Though the data shown can be seen to show some similarities between the two sensor measurements and follows a similar trend as you move to wetter region of the bale, a larger data sample size would be needed to provide better correlation between the handheld Delmhorst model and the Agreto actuation model. This data helped validate the sampling cycle to which the sensor is physically taking the measurement, and determine processes and components accounting for larger amounts of errors.

7.5.3 Discussion

Through the first round of testing on this prototype, we were able to identify critical design flaws that led to inconsistent measurements. Majority of these flaws stem from the issue that the actuator strength is not compatible with the required strength to puncture the bale consistently. Even in the case of actuating in a parallel direction to the bale flakes (less compacted direction), it encountered forces of actuation well over double limitations of the actuator as seen in *Figure 13*.

Figure 13: Force Recorded on Actuator (provided by mechanical team)



As stated previously, the actuator was chosen on the allotted time available to conduct the measurement before the bale was placed on the trailer. As a consequence, the actuator was fast, yet lacked the strength to consistently puncture the bale to the same depths repeatedly. With the program being running a time-based average filter to sample over a desired region, this time within the bale varied between each sample. Even though the live read out values looked okay, the averaged value (which was needed) either failed and didn't update or held an incorrect value that was way off.

It was also noted that on retraction of the probe from the bale in wetter regions, condensation remained on the contacts of the probe. The live read out (displayed on the DM430E during testing) would remain high, but slowly return to a normalized air readout (~3%) over a period of time. It was noted that in a practical field application, this would be mitigated by the vehicle in motion and air moving over the tip in order to dry it out. It was also thought of using an o-ring or small gasket that acted as a squeegee to clean the contacts of the probe as it was retracted, though this would probably not be necessary.

8.0 Conclusions & Future Considerations

In conclusion, the goal of our project was to create the telematics and data acquisition portion of a yield monitoring system for large unwrapped round bales for our client Groupe Anderson. This system will be implemented on the grabber portion of the RBM 2000 trailer however they would like it to be modular so that it is easily implementable on other trailers that they have available. The system needed to log GPS data as well as mass and moisture for each bale. This data also needed to be transmitted to an off-site server using a telematics unit. We selected a system using both Danfoss hardware and software as the client is already comfortable with these systems and a Danfoss micro-controller is already implemented on the trailer. This system includes a screen which additionally logs and displays the moisture values to the operator in the cab as a backup feature to a situation where the telematics solution is not present. The current system does not include a telematics unit, but it has been recommended to the client. The system fulfills all the original requirements and respects the constraints set by the client.

Testing was performed to confirm the validity of the system however; more testing will need to be completed to further develop the product. As discussed in section 7.5.3, the actuator lacked necessary strength to reach a consistent measurement depth. With the averaging filter and memory function in the code being a time-based function, these inconsistencies would lead to open air readings (much lower than bale levels) having large impacts on the averaging result. It is important to note that the data logging feature in the app worked perfectly and delivered a .csv file easily opened and viewed in excel.

Several recommendations are put forth to improve the next iteration of design. Firstly, implementation of a stronger actuator would be beneficial to consistency of the program. It would also be helpful to have an internal limit feedback, that could offer additional safety to ensure the program functions properly every time. Secondly, bale measurement using the pressure sensors on the loading arm will need to be calibrated correctly. It was not possible to go through this feature while visiting the client as we were not only limited on time, but the trailer they chose to implement this feature on was not in stock. A testing and calibration procedure have been recommended and described in section 7.1.3. Finally, further data needs to be taken to provide a stronger validation against the Delmhorst manual probe. We are recommending that the additional testing on the moisture sensors as well as the calibration process for the weight measurement be completed by another design team or a student over the summer.

All in all, the system produced meets the requirements set by the client and is capable of measuring and logging hay moisture on large unwrapped round bales. It is capable of being mounted on multiple grabbing implements and takes accurate moisture readings. The system is therefore a success.

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10.0 Appendices

Appendix A: Supporting Documents

Appendix A1: September 14th, 2018 Meeting

1. Is it acceptable to break into two seperate groups? One completing the mechanical design and building of the sensor, while the other two work on the software and telemetry
2. Where does the client envision this unit being mounted and how do they see it being operated
    a. Baler and fork / Grabber combination?
    b. Mounting the moisture unit on the grabbing unit on the trailers themselves
        i. Instead of piercing bales with conductive sensors, can possibly use microwaves to dictate moisture content
        ii. Convenient for wrapped bale measurements as well
        iii. Would still need gps on tractor with baler and tractor with the trailer
    c. Forage unit?
    d. Is it for Square bale? Or Round bale?
    e. How much did you want to spend on the system
    f. Operating conditions (Summer or Fall temperature variance)
3. Another design group is currently working on a bale fork with a conductive probe to measure the moisture content of a bale,
    a. Using conductivity or capacitance is cheaper, but requires piercing the bail itself to take a measurement
4. What kind of timeline is desired?
    a. Prototype by next spring?
5. What kind of resources are available
    a. Cad drawings, sheet metal parts, etc
6. Is there a particular software system the client would prefer to use
    a. We would rather use danfoss if possible, and labview if need be.
7. How to differentiate from the product made by Harvest Tec. (Price, Stage of hay harvest implemented)
8. What land is accessible for testing of the sensor?

Appendix A2: October 18th, 2018 Meeting

1. Which trailer/grabber unit is most appropriate?
2. The microwave sensor will only work on square bales
    a. Does the client want to pursue this for square bales?
    b. Otherwise capacitive or conductive will need do be used
    c. Capacitive will be difficult because of steel parts

Appendix A3: LCA Analysis Tables

2. CONDUCT LIFE CYCLE INVENTORY

Cradle to Gate Inventory

Material	Quantity (in kg)	Emission Factor (e.g. kg CO2e per kg)	Total Cradle-to-Gate Emissions	Incoming Transport (in km)	Transport Emissions (per kg*km)	Total Emissions
Mild Steel	4.227	5	21.135			21.135
PLA plastic	0.06	4	0.24			0.24
ABS plastic	0.628	3.86	0.386			0.386
Aluminium	0.45	8.14	3.663			3.663
Copper	0.45	3.85	2.4178			2.4178
Glass	0.1	0.7	0.315			**27.8418**
			28.1568			

Use Phase Inventory

Assumptions (i.e. Operating 6 hours per day, for 5 years)	Electricity usage (in kWh)	Emission Factor (e.g. kg CO2e per kWh	Total Emissions
Operating May to November, 8 hours a day 5 days a week, for 5 years	103.8	0.02	2.076
			2.076

End of Life Inventory

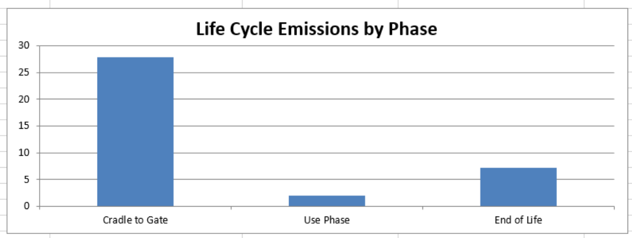
(R) = Recycled

Material	Quantity (in kg)	Emission Factor (e.g. kg CO2e per kg)	Total End-of-Life Emissions	Outgoing Transport (in km)	Transport Emissions (per kg*km)	Total Emissions
Mild Steel ®	4.227	0.88	3.71976			3.71976
PLA plastic (R)	0.06	3.1	0.186			0.186
Glass (R)	0.1	0.385	0.0385			0.0385
Aluminium ®	0.45	2.01	0.9045			0.9045
ABS Plastic	0.628	3.86	2.42408			2.42408
Copper (R)	0.45	2.77	1.2465			
			8.51934			**7.27284**

3. ANALYZE RESULTS

Totals

	Emissions from each phase
Cradle to Gate	27.8418
Use Phase	2.076
End of Life	7.27284
TOTAL	37.19064



Appendix B: Relevant Tables

Appendix B1: Square Bale Testing Data

Position	L1	L2	L3	L4	MP1	MP2	MP3	MP4	MD1	MD2	MD3	MD4
A	5.66	6.57	5.37	3.2	10	13	10	14	9	8.6	8.7	8.4
B	5.16	6.76	6.42	4.68	13	19	11	10	22.4	14.3	15.3	16.3
C	9.4	9.93	6.32	6.16	10	19	11	12	16.4	15.6	17.5	17.9
D	5.53	8.86	7.05	6.26	22	22	9	37	24	30.1	15.6	17.4
Water added to bale + averaging cycle modified on MP												
A	8.9	7.51	5.16	7.77	24	31	10	21	10.3	12.4	11	15.6
B	4.74	9.05	8.74	9.85	48	30	32	29	Above 30 reads 100			
C	10.41	11.82	1.09	9.43	17	22	26	12	27.1	24	22.8	21.2
D	8.57	6.95	8.88	7.63	28	11	39	30	22.3	15.3	24.8	28.1

Appendix B2: Round Bale Testing Data

Sample order	MDAv	Placement	MP1	MP2	MP3	MP4	Average
	(%)		(%)	(%)	(%)	(%)	(%)
1	16	C1	11	15	14	16	14
2	24	B2	30	33	32	32	31.75
3	20	B1	25	27	18	23	23.25
4	22	C2	28	60	28	26	35.5
5	23	A1	26	26	24	23	24.75
6	21	D1	33	35	24	16	27
7	25	D2	30	32	30	33	31.25
8	27	A2	36	22	27	32	29.25

Appendix C: Hardware Data Sheets

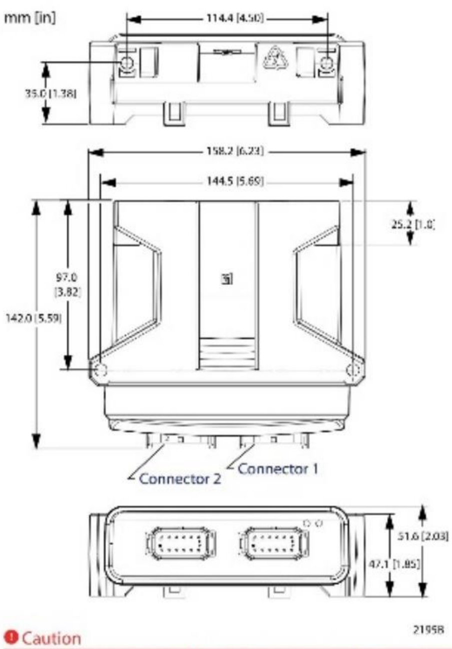
Appendix C1: MC024-120 Data Sheet

Danfoss

Data Sheet **PLUS+1® Controllers MC024-120 and MC024-122**

Dimensions and Pin Assignments

MC024-120 and MC024-122 Mounting Dimensions



Caution

PCB damage may occur. All device power supply + pins must be connected to battery +.

Caution

This device is not field serviceable. Opening the device housing will void the warranty.

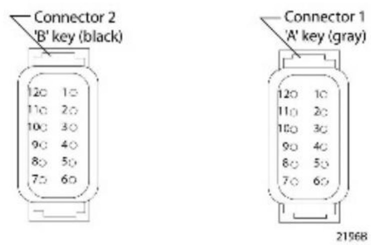
MC024-120 and MC024-122 24 Pin Connectors

Connector 2

Pin	Controller function
C2-P1	DIN/AIN/FreqIN
C2-P2	DIN/AIN/FreqIN
C2-P3	PWMOUT/DOUT/PVGOUT
C2-P4	PWMOUT/DOUT/PVGOUT
C2-P5	PWMOUT/DOUT/PVGOUT
C2-P6	PWMOUT/DOUT/PVGOUT
C2-P7	PWMOUT/DOUT/PVGOUT
C2-P8	PWMOUT/DOUT/PVGOUT
C2-P9	PWMOUT/DOUT/PVGOUT
C2-P10	PWMOUT/DOUT/PVGOUT
C2-P11	Power supply +
C2-P12	Power supply +

Connector 1

Pin	Controller function
C1-P1	Power ground -
C1-P2	Power supply +
C1-P3	CAN +
C1-P4	CAN -
C1-P5	AIN/CAN shield
C1-P6	DIN
C1-P7	DIN
C1-P8	5 Vdc sensor power +
C1-P9	Sensor power ground -
C1-P10	DIN/AIN/FreqIN
C1-P11	DIN/AIN/FreqIN
C1-P12	DIN/AIN/FreqIN



Use care when wiring mating connector. Above pinouts are for device pins.

Specifications

Product Parameters

Supply voltage	9 to 36 Vdc
Operating temperature (ambient)	-40°C to 70°C [-40°F to 158°F]
Storage temperature	-40°C to 85°C [-40°F to 185°F]
Programming temperature	-40°C to 70°C [-40°F to 158°F]
IP rating (with mating connector attached)	IP 67
EMI/RFI rating	100 V/m
Weight	0.40 kg [0.88 lb]
Vibration	IEC 60068-2-64
Shock	IEC 60068-2-27 test Ea
Maximum current, sourcing	24 A
Maximum current, sinking	8 A

Product part Numbers

MC024-120	11131280	
MC024-122	11131281	
CG150 CAN/USB Gateway	10104136	
Deutsch® mating connector bag assembly	10102023 (16 to 20 AWG)	10100945 (20 to 24 AWG)
PLUS+1 GUIDE single user license	10101000	

Danfoss product literature on line at: www.danfoss.com

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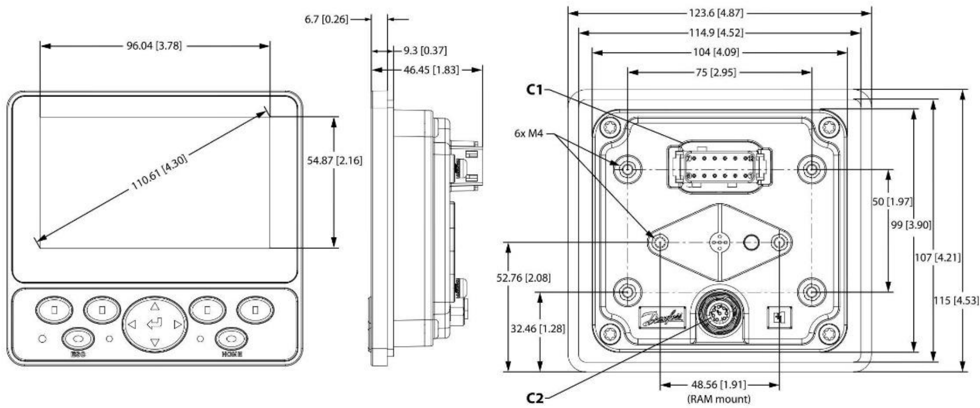
Appendix C2: DM430e Data Sheet Page 1

Dimensions in mm [in]

Front, side view, and rear view



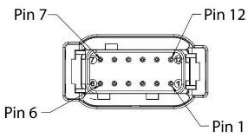
Specifications

Characteristics

Processor	ARM-based Cortex-M7
RAM	32MB
EEPROM	32kB
Flash (Program memory)	32MB
Flash (Application log)	32MB
Supply voltage	9-36 V_{DC}
Connector	DEUTSCH DTM06-12
Size	4.3"
Aspect ratio	Wide
Resolution	480x272
Brightness	>700 cd/m2
Contrast ratio	500:1
Viewing angle	+/- 70 degrees in all directions
Color depth	24-bit
Glass	Optically bonded, anti-glare coating
IP rating (with mating connector attached)	IP66 and IP67 (front and back)
Operating temperature	-30°C to +70°C [-22°F to +158°F]
Storage temperature	-40°C to +85°C [-40°F to 185°F]
Weight	328 g (0.72 lb)
Vibration	IEC 60068-2-64 (7.67g)
Shock	IEC 60068-2-27 test Ea (50g)
EMI/RFI rating (V/m)	100

Appendix C3: DM430e Data Sheet page 2

12 pin DEUTSCH connector

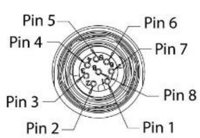


DEUTSCH DTM06-12SA 12 pin

C1 pin	DM430E-0-x-x-x	DM430E-1-x-x-x	DM430E-2-x-x-x
1	Power ground -	Power ground -	Power ground -
2	Power supply +	Power supply +	Power supply +
3	CAN 0 +	CAN 0 +	CAN 0 +
4	CAN 0 -	CAN 0 -	CAN 0 -
5	AnIn/CAN 0 Shield	AnIn/CAN 0 Shield	AnIn/CAN 0 Shield
6	DigIn/AnIn	DigIn/AnIn	DigIn/AnIn
7	DigIn/AnIn	DigIn/AnIn	DigIn/AnIn
8	DigIn/AnIn	CAN 1+	Sensor power
9	DigIn/AnIn	CAN 1-	Secondary power input*
10	Multifunction input (DigIn/AnIn/Freq/4-20 mA/Rheostat)	Multifunction input (DigIn/AnIn/Freq/4-20 mA/Rheostat)	Multifunction input (DigIn/AnIn/Freq/4-20 mA/Rheostat)
11	Multifunction input (DigIn/AnIn/Freq/4-20 mA/Rheostat)	Multifunction input (DigIn/AnIn/Freq/4-20 mA/Rheostat)	Multifunction input (DigIn/AnIn/Freq/4-20 mA/Rheostat)
12	Digital out (0.5A sinking)	Digital out (0.5A sinking)	Digital out (0.5A sinking)

* From controller (requires surge protection).

8 pin Binder connector



Binder M12-A 8 pin

C2 pin	Function
1	Device Vbus
2	Device data -
3	Device data +
4	Ground
5	Ground
6	RS232 Rx
7	RS232 Tx
8	NC

Related product part numbers

DEUTSCH 12-pin Connector Kit (DTM06-12SA)	10100944
Mounting Bracket Kit	11198661
CG150-2 CAN/USB Gateway	11153051
PLUS+1® GUIDE Professional	11179523
Cable, M12 8-Pin to USB Device	11130518
Cable, M12 8-Pin to Lead Wires	11130713

Appendix C4: WS403 Data Sheet

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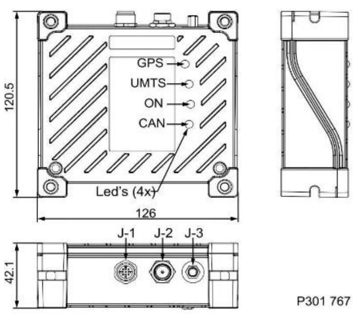
Dimensions



J-1 Power Supply/CANBus connector

Pin	Designation	Description	Color
1	Ground	Power supply	Brown
2	Vcc 6 … 32 Vdc	Power supply	White
3	Dig-IN / Terminal 15	Input (ignition)	Blue
4	CAN-High	CAN bus	Black
5	CAN-Low	CAN bus	Gray/green

J-2 GSM/UMTS antenna connector

Pin	Designation	Description
1	Signal	GSM/UMTS
2	Ground	Shield/housing

J-3 GNSS antenna connector

Pin	Designation	Description
1	Signal	GPS
2	Ground	Shield/housing

Mechanical data

Device Type	WS403
Dimensions w /h / l	126 / 120.5 / 42 mm [4.96/4.74/1.65 in]
Standard housing	Aluminum, powder-coated
Color	Charcoal
Operating Temperature	-30 °C … +75 °C [-22 °F … 167 °F]
Storage Temperature	-40 °C … +85 °C [-40 °F … 185 °F]
IP Rating	IP 65 with all connectors plugged in
Weight	Max 0.650 kg [22.9 oz]
Status LEDs (2 colors)	4 (green / red)

Electrical data

Supply Voltage	6 ... 32 V
Controller MCU	ARM Cortex M4
EMI/RFI rating	EEC EMC Directive 89/336 V/m
Power input (operating/sleep)	<150 mA /<1mA (25°C; 24 Vdc)
Memory: Program/Configuration + Logging	1 MB/32 MB

Interface / Protocols / Certifications

CAN bus Network	1 (ISO 11898-2 High Speed, 2.0A/B)
GSM/GPRS/EDGE class 10 [MHz]	850/900/1800/1900
UMTS/HSPA six band [MHz]	800/850/900/1700/1900/2100
GNSS engine	Concurrent GNSS engine for GPS, GLONASS, Galileo and BeiDou
GPS/Glonass (tracking capability/accuracy/update rate)	72 channel /up to 2.5m /1Hz
Micro-SD Card Interface	SD/SDHC card up to 32GB - Recommended Class 10 and Temperature Proof
Certifications	CE, E1, FCC

Additional features

RTC Real Time Clock with Backup Capacitor	✓
Accelleration sensor	✓ - 3 axes, ±16g, 10bit

Ordering information and part numbers

Product	Parts number
WS403[1]	11156350
Antenna GSM/GPS, screw mount[1]	11149644
M12 5pin socket/open - 5m cable[1]	11149645
Remote Solution Kit WS403	11157545
CG150-2 CAN/USB Gateway	11153051
Mounting Kit Insulating Board	11179694

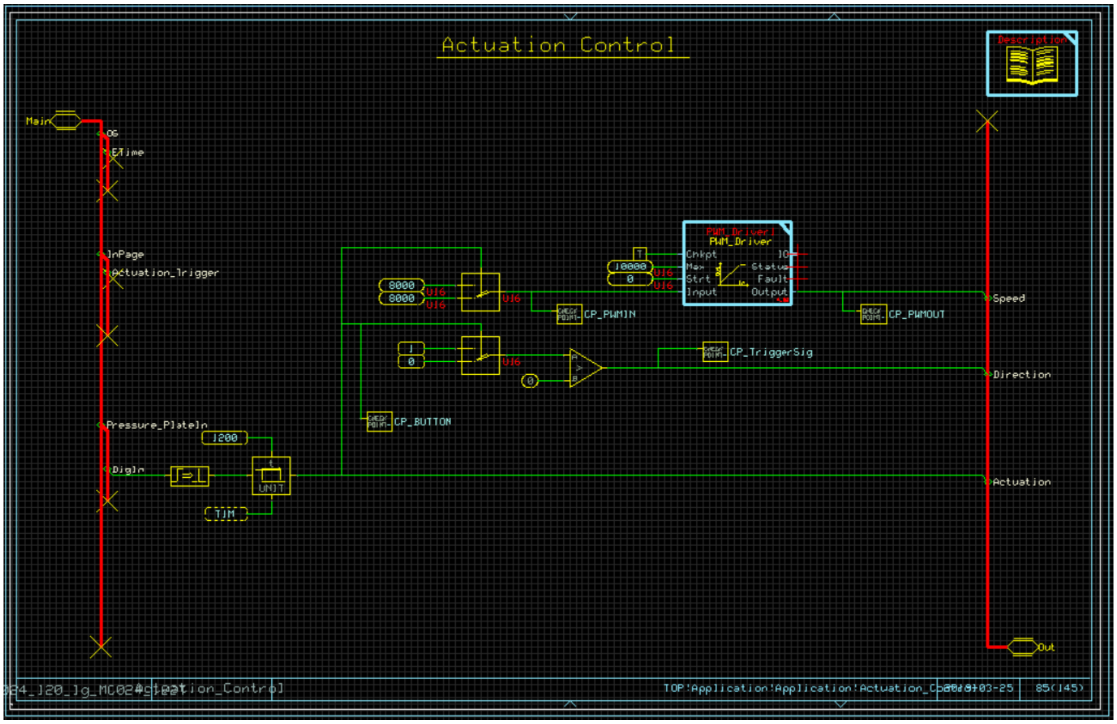
[1] parts included in the kit

Reference literature

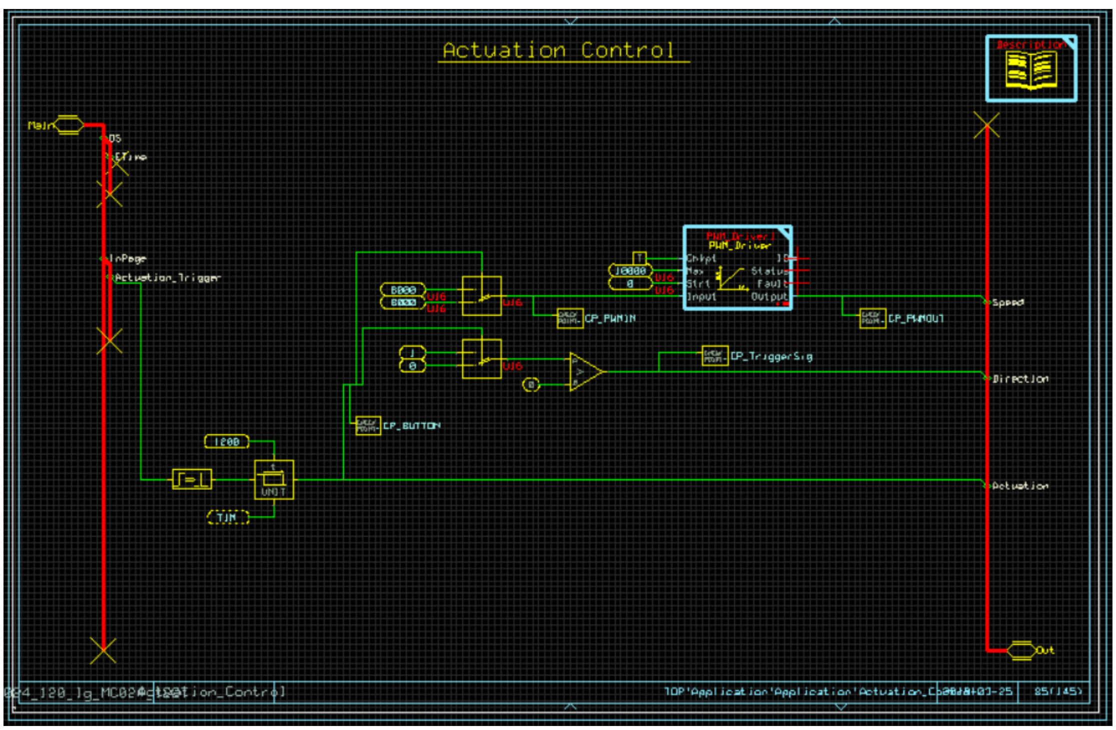
Danfoss product literature on line at www.danfoss.com	Literature number
WS403 Remote Solution Data Sheet	L1426546
WS403 Remote Solution Technical Information	L1426375
WS403 Remote Solution Installation Guides	L1419125

Appendix D: Alternative Design Diagrams

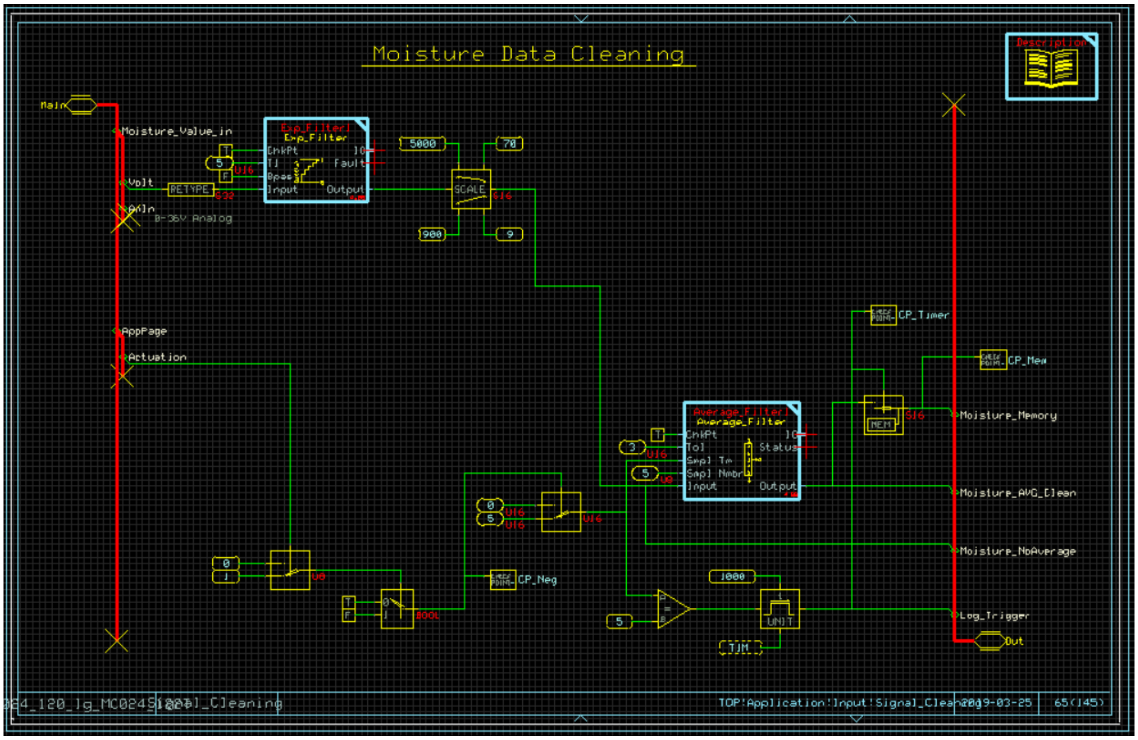
Appendix D1: Actuation Control Code (Triggered using pressure plate)



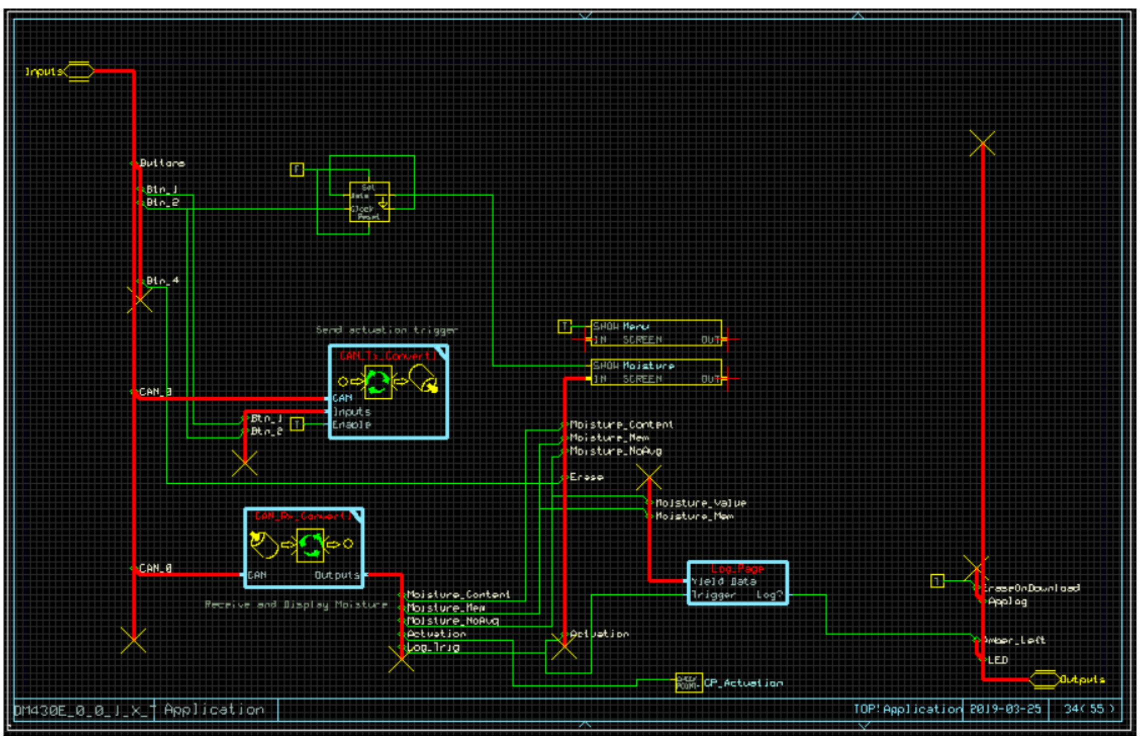
Appendix D2: Actuation Control Code (Triggered using screen button)



Appendix D3: Moisture Sensor Data Cleaning Code

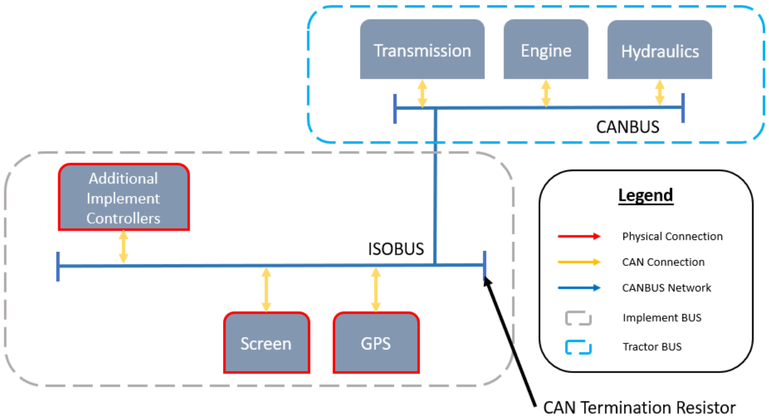


Appendix D4: DM430e Screen Code

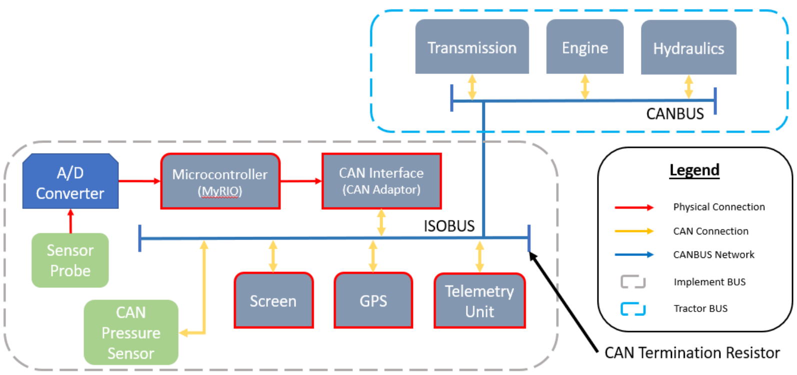


Appendix E: Code Snips

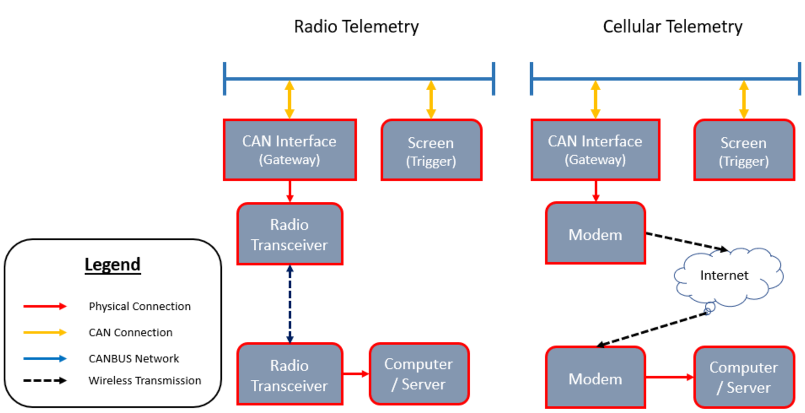
Appendix E1: CanBUS Communication System



Appendix E2: Radio Telemetry with LabVIEW



Appendix E3: Radio Telemetry Vs Cellular Telemetry



Appendix F: Can Messages

Appendix F1: CAN Pressure Messages

CAN_Pressure		
Node	0x05	**Signal Name**
Message ID	0x18FFA105	
Start Bit	**Length**	
Byte 0	16 bit	High Pressure PSI
Byte 1		
Byte 2	16 bit	Low Pressure PSI
Byte 3		
Byte 4		255
Byte 5		255
Byte 6		255
Byte 7		255

Appendix F2: CAN Moisture Messages

CAN_Moisture		
Node	0x04	**Signal Name**
Message ID	0x18FFA204	
Start Bit	**Length**	
Byte 0	16 bit	Moisture_Avg_Clean
Byte 1		
Byte 2	16 bit	Moisture_Memory
Byte 3		
Byte 4	16 bit	Moisture_NoAverage
Byte 5		
Byte 6	2 bits (1/msg)	Actuation, Log_Trigger
Byte 7		255

Appendix F3: CAN Button Messages

CAN_Button		
Node	0x23	**Signal Name**
Message ID	0x18FFA323	
Start Bit	**Length**	
Byte 0	1 bit	Acutation_Trigger
Byte 1		255
Byte 2		255
Byte 3		255
Byte 4		255
Byte 5		255
Byte 6		255
Byte 7		255