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A new design of embedded monitoring system for maintenance and performance monitoring of a cane harvester tractor

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Abstract

In modern sugarcane farms, sugarcane chopper harvesters are becoming widely used. A modern sugarcane chopper harvester is essentially a mechatronic system composed of a tractor and some implements with several electro-hydraulic control systems. Those control systems are controlled by electronic controller units (ECUs). It may fail during harvesting operation due to lack of maintenance, operator's awareness, skill, and field contour. This paper presents a new design of an embedded monitoring system for maintenance and production performance monitoring of a sugarcane chopper harvester in a real-time manner. A prototype of the embedded monitoring system was developed which partially realized the designed system. The experimental result showed that the main computer could communicate with other ECUs using a controller area network (CAN) bus. The dataset from four channels retrieved from the CAN bus represents the real values originating from the temperature sensor simulators. Apart from being sent to the CAN bus, the data are also recorded on a secure digital (SD) Card and sent to the internet of things (IoT) server. In the update time interval testing, the 100 ms interval does not give any error.

Keywords: embedded system; cane harvester; electro-hydraulic; control system; tractor maintenance; CAN bus.

I. Introduction

Agricultural machinery is transforming from an integrated mechanical system into an integrated mechatronic system where electronics and computers are intensively used. Such a mechatronic system enables precision farming where precise sensing and controlling of crucial variables become significantly decisive. Robotic technologies are started being used to improve sugarcane production. A computer vision was used for analyzing the quality of sugarcane billets. Billet images were captured by CCD and stereovision cameras, and image processing was carried out to classify sugarcane billet damage [1]. A critical review of sugarcane harvester technology was conducted to reduce losses during harvesting process. Potentials of improvement in some mechanical elements were identified, including base-cutter and sugarcane feeder mechanism [2]. An extractor platform was fabricated, and the effect of the fan speed, the sugarcane feeding rate, and sugarcane billet length on the impurity rate and sugarcane losses was investigated. The following conclusions were obtained: feeding rate has no significant effect on impurity rate but has a substantial impact on sugarcane losses; fan speed and sugarcane billet length have a considerable influence on impurity rate and cane losses [3].

An electrical and hydraulic control system for a double-row sugarcane chopper harvester was designed using a programmable logic controller (PLC) to reduce failure rate and improve harvesting efficiency. Several rotational speed sensors were used to monitor the engine, walking speed, cutter motors, etc. A pressure sensor and a DC voltage sensor were used to monitor the pump outlet and power supply. The monitoring system was mainly composed of a PLC, I/O modules, a touch screen, and various sensors. Data exchange between PLC and the touch screen was carried out through a serial

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communication in which the touch screen could display the critical parameters in real-time [4].

A precision agriculture concept was implemented in a sugarcane farm through a yield monitoring system. The monitoring system consists of a mass flow sensor, a global positioning system (GPS) receiver, and a data acquisition system. The mass flow sensor was load cells installed at the outlet port of the elevator. Field testing results showed that the yield monitoring system is accurate with a mean error of 4.3 % where the maximum error is less than 6.4 % [5]. A control area network (CAN) bus analyzer (CANcase XL log, Vector, Stuttgart, Germany) was utilized to get CAN message from a tractor diagnostic port. One channel was connected to the tractor bus channel and the other channel to the implement bus channel. The CAN hardware was connected to a laptop via a USB port, and the data were stored in an ASCII file in real-time during field operation. The ASCII file record contained both proprietary CAN bus messages and SAE-registered CAN bus messages. It was filtered to get liquid fuel economy (LFE) messages which had fuel use rate in hexadecimal format. The analysis results revealed the potential to estimate the field efficiency (FE) of the tractor based on tractor fuel consumption [6].

Information communication technology (ICT) was applied for the traceability of sugarcane harvesting operations in small farms. The cutting head position sensor, odometry sensor, speed sensors, and GPS were installed on the sugarcane harvester tractor. Various phases of work could be traced, and the machines' operating conditions could be better understood. Data were collected every 6 seconds and were stored in a data acquisition system. The data were saved in a memory card, and at the end of the experiment, data were sent every day via GSM to the cooperative [7]. The activity of the harvesting machine was traced each day based on variables which were divided into five categories, i.e., administrative information (seven variables), temporal information (twenty three variables), spatial and production information (ten variables), technical information (six variables), and spatial information (GIS) [7].

A sugarcane harvester may fail during harvesting operations due to lack of maintenance, operator's awareness, skill, and field contour. This paper presents a new design of an embedded monitoring system for maintenance and production performance monitoring of a sugarcane chopper harvester in a real-time manner. In the context of maintenance, the embedded system records several vital variables that significantly affect the harvester's health status. On the other hand, a yield monitoring system can monitor production performance that can discriminate products and impurities. The embedded monitoring system is integrated with the other instruments in the harvester through the control area network (CAN) bus.

This paper is organized as follows. Section II describes an overview of the sugarcane chopper harvester. Section III presents the proposed embedded monitoring system. Results and discussion are reported in Section IV. Finally, a conclusion is drawn in Section V.

II. Materials and methods

A. Overview of sugarcane harvester elements

1) Mechanical systems

Nowadays, mechanical sugarcane harvesters are used in some modern sugarcane farms due to their advantages. At present, there exist two types of sugarcane harvesters, i.e., whole stalk harvester and chopper harvester. The entire stalk harvester involves cutting sugarcane as the exclusive right to its base, removing the top, and placing the stalk into heap rows. A grabber-arm loads them into a trailer to be delivered to a sugar mill. The chopper harvester performs a different method to the whole stalk harvester in that the entire cane is topped, cut, and deposited into the feeder. The cane is cut into billets measuring around 20 cm in length by a chopper. Impurities are removed by a primary extractor, and the billets are traveled up by a conveyor which delivers them into a trailer through a secondary extractor.

A typical sugarcane chopper harvester system is shown in Figure 1. It is essentially a tractor that is equipped with unique apparatuses. The apparatuses

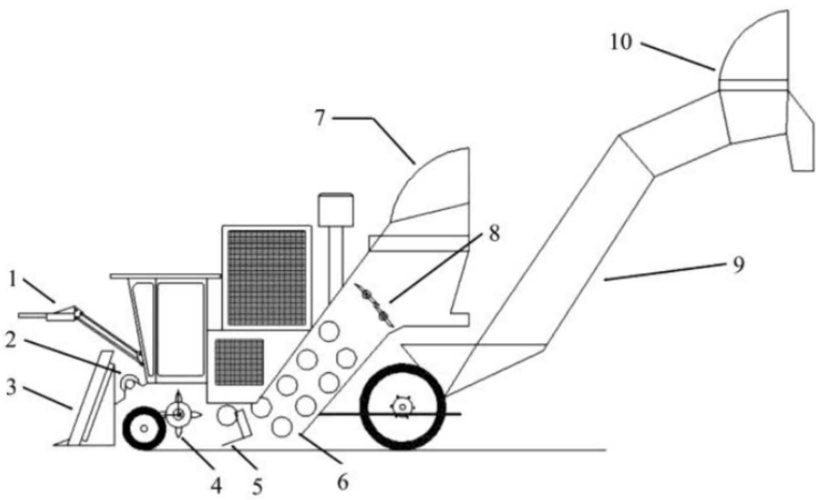


Figure 1. A typical chopper harvester system [8]

may be classified into ten subsystems, i.e. (1) top-cutter; (2) knockdown roller; (3) crop divider; (4) finned roller; (5) base-cutter; (6) feeding rollers; (7) primary extractor; (8) chopper; (9) elevator; and (10) secondary extractor [8]. The top-cutter is used to sever cane tops and then spread them onto the ground. The crop divider gathers the topped cane plants and arranges them in a proper orientation. The knockdown roller pushes the cane top forward when the tractor is moving forward. The base-cutter cuts the base of stalks close to the ground. The feeding mechanisms capture the ends of the stalks and convey the entire stalks rearward into the chopper in which the stalks are cut into billets. The primary extractor is used to separate leafy trash materials from the chopped billets. The elevator lifts the billets and sends them into a trailer. Once again, trash materials are discarded by the secondary extractor at the top of the elevator.

2) Electro-hydraulic control systems

Several electro-hydraulic control systems are used as actuators to control the movement of the cane harvester apparatuses. Figure 2 illustrates a diagram of an electro-hydraulic control system composed of a hydraulic pump, two electronic controlled manifold blocks, a hydraulic motor, a hydraulic cylinder, and a reservoir. The pump sucks in the hydraulic oil and sends it to the control manifold blocks. The control blocks are electronically controlled by the controller to send the oil back to the reservoir or send the oil to the motor and the cylinder. The cylinder piston is moved forward or backward depending on the control signal from the controller. When controlling the hydraulic motor, the corresponding control block may rotate the engine in a clockwise direction or counterclockwise direction. The power may be fixed or managed by the manifold block. A relief valve is equipped to regulate oil pressure while an accumulator is used to damp severe pressure changes.

The hydraulic motor can be used to rotate the base-cutter, the chopper, and the other appropriate mechanical subsystems of the cane harvester. A pressure sensor and a rotational speed sensor may be placed to monitor the oil pressure and speed. These sensors' signals can be used by the controller for maintenance purposes. Usually, today's modern cane chopper harvesters are equipped with three rotational speed sensors (for the base-cutter, the chopper, and the primary extractor) and two pressure sensors (for the base-cutter and the chopper). The hydraulic cylinder can control the steering mechanism, the base-cutter height, and the other appropriate mechanical sub-systems of the cane harvester. Position sensors are usually placed to measure the steering angle, the base-cutter height, and the elevator slewing angle.

3) Embedded systems

The embedded system in sugarcane harvester, or in general for robotic agriculture applications, acts as the brain of the vehicle or robots. In these systems, specific application programs are embedded for particular purposes, such as harvesting, seeding, plowing, fertilizing, irrigating, etc. Many of these embedded systems are based on a microcontroller, Raspberry Pi, and PLC. Xu and Cai [4] used a Siemens S7-300 PLC to construct a double-rows sugarcane harvester control system. Xu monitors the temperature, pressure, and liquid level data on the harvester vehicle. Naik *et al.* [9] used a microcontroller LPC2148 to make a robot used for seeding and can measure the depth and optimal distances between crops and their rows. Srivastava [10] used Arduino to build a plowing automation device with line lasers and potentiometers based on angle calculation devices. Jadhav and Hambarde [11] used Raspberry Pi to create an Android-based automated irrigation system. This tool monitors temperature, soil moisture, plant height, and width. Jerosheja and

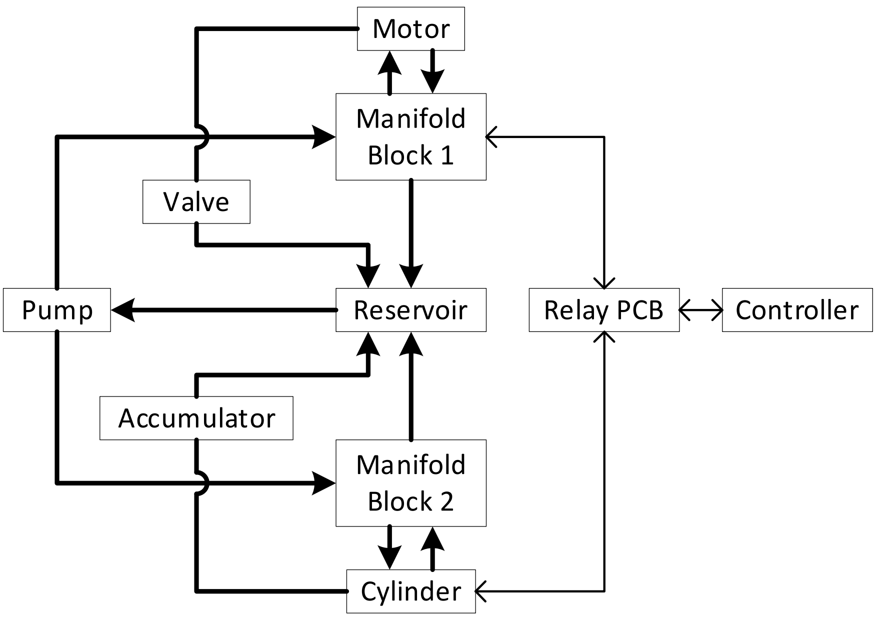


Figure 2. Diagram of electro-hydraulic sub-system

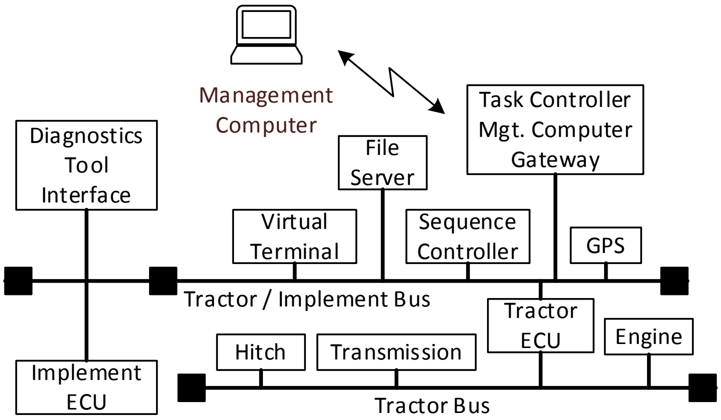


Figure 3. Illustration of in-vehicle embedded sub-systems network [18][19]

Mythili [12] proposed a solar-powered automated multi-tasking agricultural robot that uses an embedded system based on Raspberry Pi, with sensors and ultrasonic sensors spraying pesticides and weedicides. Patel *et al.* [13] used ultrasonic sensor fusion for developing real-time monitoring and navigation, including detection of the target and canopy mapping. Gupta *et al.* [14] built an IoT-based multipurpose agribot to monitor drip irrigation, fertilizing, temperature (for greenhouse farming), and crop growth by a camera. Another agribot design, using Arduino and soil moisture and temperature sensor, was also proposed by Rahul *et al.* [15]. Amandeep *et al.* [16] built a remote-controlled vehicle for monitoring temperature, humidity, soil condition, and accordingly, supplies water to the field. Kabir *et al.* [17] proposed an assistant robot and mobile app for managing an indoor farm automatically, including monitoring the concentration of CO_2 and fertilizing the plant.

Communication between electronic control units (ECUs) and other agriculture machinery instruments usually uses the communication protocol standard ISO 11783 [18]. This can improve management activities since it contains the following parts: (1) General standard; (2) Physical layer; (3) Data link layer; (4) Network layer; (5) Network management layer; (6) Virtual terminal; (7) Implement messages layer; (8) Drive train; (9) Tractor ECU; (10) Task controller & management; (11) Data dictionary; (12) Diagnostic services; (13) File server; and (14) Sequence control. Figure 3 illustrates an example of hardware-based connectivity between ECUs on farm machinery. There is a main bus where all ECUs and instruments are connected using hard-wire, including the tractor ECU, implements' ECUs, GPS, and task controller management computer gateway [19]. Nowadays, all producers widely accept CAN 2.0B to define the physical layer in the ISOBUS protocol. The CAN logger 5102 GPS data logger, with two CAN interface and a built-in GNSS receiver, was directly connected to a farm tractor's CAN-bus to log all ISOBUS messages [20]. An example of a CAN message received from the data logger is shown in Figure 4.

B. Embedded monitoring system design

This research aims to design an embedded monitoring system capable of conducting predictive maintenance functionalities and reporting the production performance of a sugarcane chopper harvester. Usually, the engine used as the prime-mover in the cane harvester is equipped with an ECU. The designed embedded system can communicate with the engine ECU and other controllers in the cane harvester through CAN bus using ISO 11783. Moreover, the designed embedded system communicates remotely with a farm management information system (FMIS) computer through wireless communication networks [21].

1) Monitoring system architecture

This paper presents an embedded system shown in Figure 5. For maintenance, several sensors are used to measure several variables, i.e., rotational speed, hydraulic pressure, position, fluid level, temperature, distance, voltage, and current. Rotational speed sensors are fixed at the base-cutter, the chopper, the primary extractor, and the wheels. Pressure sensors are placed at the base-cutter and the chopper. Position sensors are used to measure the steering angle and the base-cutter height. Level sensors are placed at the cooling water tank and the fuel water filter. Temperature sensors are used for temperature monitoring of the hydraulic oil and the cabin. Voltage and current sensors are placed at the battery. A set of sensors are fixed for production

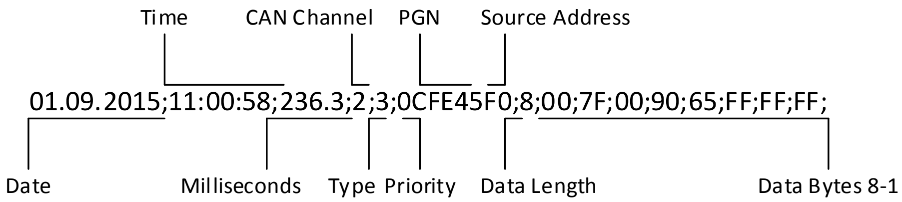


Figure 4. An example of a CAN message [20]

performance measurement; those are load cells and inclination sensors. Ultrasound sensors are used to measure the distance between the body of the cane harvester tractor and the ground surface. A global positioning system (GPS) receiver is used to measure the position of the cane harvester. A computer vision is designed for two-fold objectives: production monitoring and contour estimation of the field. Specifications of the sensors are listed in Table 1.

All the above sensor signals are read by a data logger connected to a modem that performs telecommunication with other devices remotely. A computer is used to conduct necessary tasks, including retrieving available data from the engine ECU via the CAN bus, pre-processing data from the sensors before they are sent to the FMIS, and processing necessary information from the computer vision.

2) Maintenance-oriented monitoring method

A maintenance-oriented monitoring method performs predictive maintenance functions to avoid sudden damage when the cane harvester tractor is operated. This function is defined based on the operation and maintenance records of the tractor that has been experienced so far, as well as the life cycle specification provided by the components' manufacturers. Since the embedded system is connected with a farm management information system (FMIS), the maintenance manager can always monitor the health status of the tractor in a real-time manner. The manager can anticipate spare parts before the harvest season and can predict damage so that preventive handling can be carried out.

3) Production performance-oriented monitoring method

A new production performance monitoring method is designed to measure yields and impurities. Mass flow of the cane is measured using load cells placed at two different places. One signal represents gross mass flow which includes cane and impurities and the other signal represents net mass flow in which the impurities are excluded. Load cell signals are compensated against noises due to vibration and inclination of the elevator. Billets weights before and after the cleaning processes are instantaneously recorded. The recording data will be used to analyze the effectiveness of the cleaning process and also as a yield monitoring process in a real-time manner.

Table 1.
Sensors specification

Sensor	Physical specification	Electronic signal
Rot. speed	640 – 1100 rpm	0 – 15000 Hz
Pressure	2500 – 2750 psi	4 – 20 mA
Proximity	0 – 20 mm	0 – 10 V
Level	300 – 2000 mm	4 – 20 mA
Oil temperature	40 – 80°C	9800 – 180 ohm
Base-cutter height	0 – 1000 mm	0 – 10 V
Steering cylinder	50 – 2500 mm	0 – 10 V
Load cell	0 – 100 kg	0 – 5 V
Distance	30 – 1300 mm	0 – 10 V
Inclination	-60 – 60°C	0.1 – 4.9 V

III. Results and Discussions

A. Hardware implementation

Data-logger hardware that partially realizes the proposed design was developed, as shown in Figure 6. The schematic of this data-logger is demonstrated in Figure 7. It consists of two ESP32 microcontrollers (ESP32 DevKit module) as the master controller and the slave controller. The master controller handles the functions of reading data from the sensors, CAN bus communication, recording data to the SD Card, and sending it to the internet of things (IoT) server. The slave controller was disabled in the present experimental testing, and it will be used as a watchdog to increase system stability. On the data-logger, there is a Wemos D1 mini shield functioning as an interface module to the secure digital (S.D.S.D.) Card. The data-logger uses the DS3231 RTC module as its real-time clock. The data-logger is connected to the CAN module which uses SN65HVD230 CAN bus chip from Texas Instruments.

As a power supply, the data-logger uses two MP1584 step-down power supply modules to produce 5 V and 3.3 V voltages. 5 V voltage is used by ESP32 DevKit module, while the 3.3 V voltage is used by RTC, SD Card, and CAN bus Transceiver module.

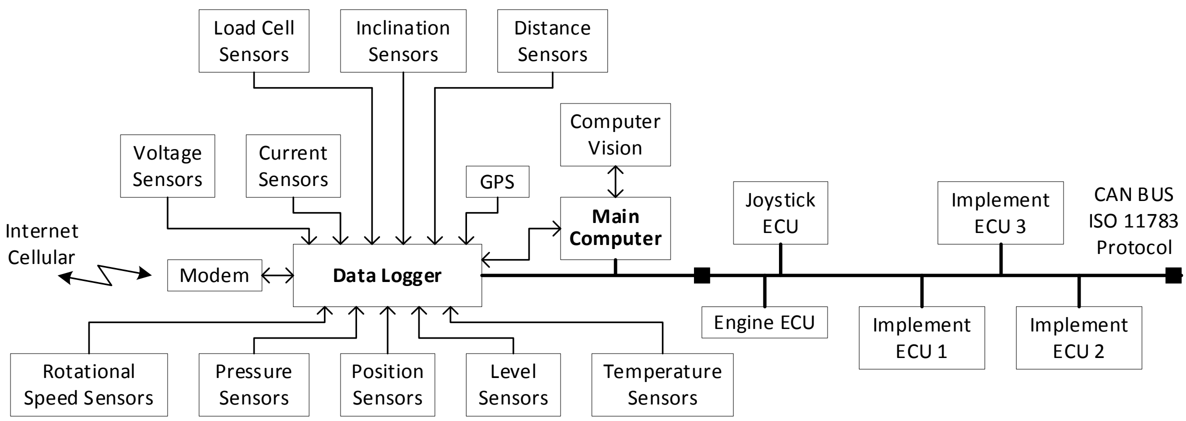


Figure 5. The proposed in-vehicle embedded monitoring system

B. Experimental results

The data-logger experimental testing procedure in this research is shown in Figure 8. The data-logger simulates the analog sensor rotation speed, pressure, proximity, level, oil temperature, base-cutter height, steering cylinder, load cell, distance, and inclination. Since one ESP32 consists of six ADC channels, two proposed data-loggers are needed for this experiment. The data-logger 1 receives input from the temperature sensors measuring the cabin's temperatures, engine oil, hydraulic oil, and oil cooler system. In contrast, data-logger 2 receives information from other sensors. These two data-loggers are connected to the same CAN bus, but each message has a unique character as the identifiers for each CAN controller. If the identifier is correct, the data-logger will send the sensor data values. CAN message is sent by a computer connected to another ESP32 module as a converter RS-232 to the CAN bus. In addition to sending data on the CAN bus, the data-logger, namely the master microcontroller, also sends data to the IoT dashboard. The IoT dashboard displays real-time measurement data and has a data

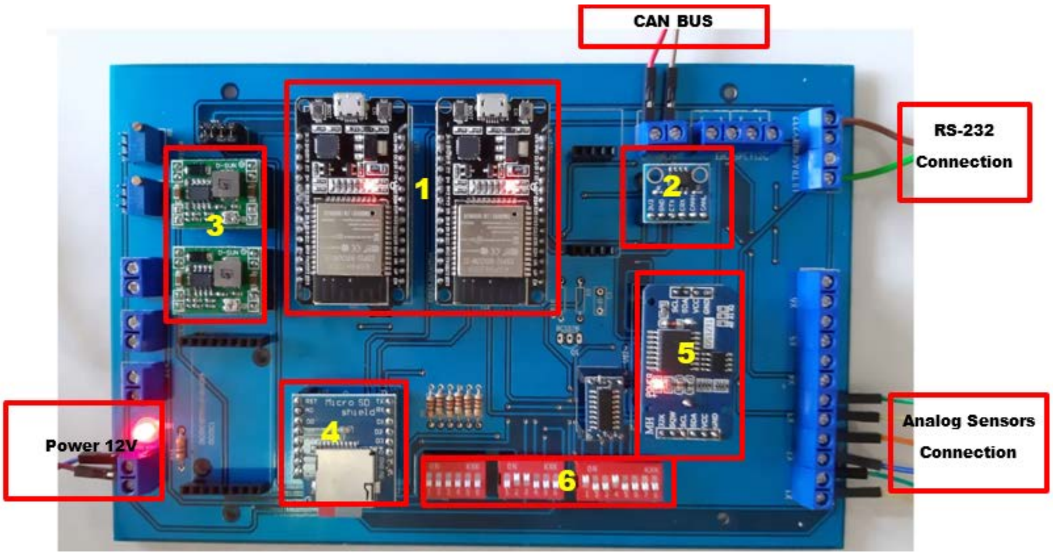


Figure 6. The data-logger proposed in this paper: (1) Microcontroller ESP32; (2) CAN bus transceiver; (3) Power supply 5 V and 3.3 V; (4) S.D.S.D. Card; (5) RTC; (6) Configuration switches

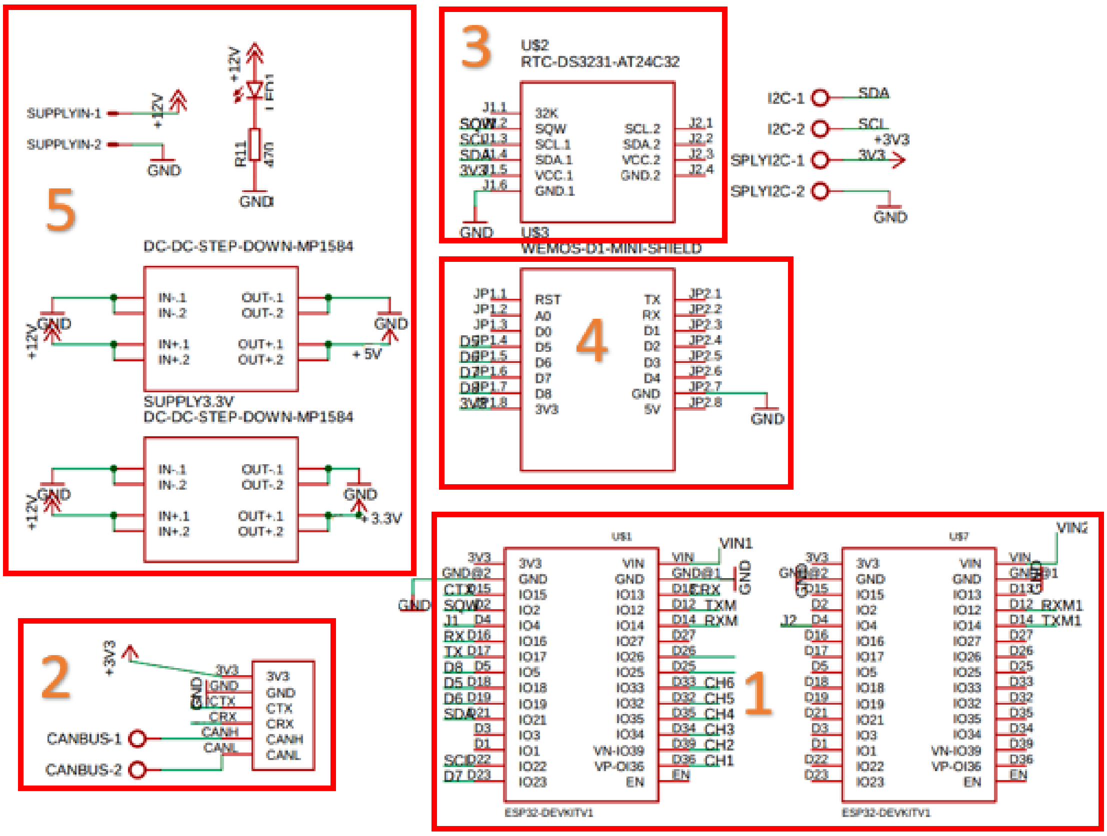


Figure 7. Data-logger schematic: (1) Two microcontrollers ESP32; (2) CAN transceiver SN65HVD230; (3) RTC DS3231; (4) SD Card interface; and (5) Power supply modules

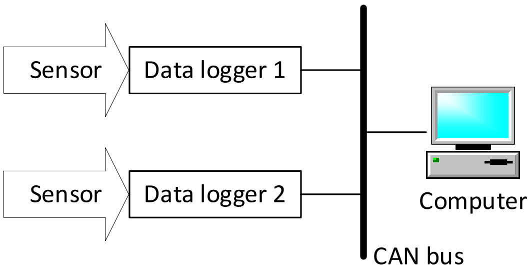


Figure 8. The data retrieval testing using two data-loggers connected to the same CAN bus

Figure 9. CAN bus frame message

exporting feature. The data-logger also records the data to S.D.S.D. Card for offline downloading purposes.

Data that are produced by the data-loggers are incorporated into the CAN frame. The data are described in Figure 9, with an explanation of each piece of the structure is shown in Table 2. Figure 10 shows a data segment received by the computer through the CAN bus from the data-logger. The first five rows are CAN bus header, the first data in the segment is data-logger's data header, and the last eight rows are data packets. The data are represented in ASCII Decimal. The action of sampling data from the data-logger goes as follows. The first action of Send-and-Receive orders from the computer is to determine which mode the data-logger is currently in. The second action of Send-and-Receive is the sampling data. Table 3 shows the meaning of the CAN message in Figure 10. Eight packets of data were received. Since we are simulating only four sensors, the data containing the signal information is present in the first four data packets. The last four data packets are space and can be ignored by the computer. The previous data packet ends with the character C.R.C.R. (ASCII = 13) or a carriage return. From the CAN bus data packets, the computer can read the sensor reading values, as shown in Table 4. From Table 3 and Table 4, we conclude that the data retrieved from the CAN bus is precisely the same as the data generated by sensor simulators.

Apart from being sent on the CAN bus, the data was also sent by the main microcontroller on the

Table 2.
CAN bus frame message

Frame name	Remarks
StdId	Standard Identifier, 1 is used to identify messages from a computer, and 2 for messages from devices
ExtId	Extended Identifier, 1 is used for the first data-logger and 2 for the second data-logger
IDE	Identifier type
RTR	Determine whether the message is a standard message or an remote transmission request (RTR)
DLC	Data size, 8 data
Data	Data from data-loggers consist of 8 data of byte type

```
SEND
1 1 0 0 8 0 0 0 36 48 53 50 13
Receive
2 1 0 0 8 0 0 0 33 48 53 48 69
2 1 0 0 8 0 0 0 48 54 48 48 13
SEND
1 1 0 0 8 0 0 0 36 48 53 54 13
Receive
2 1 0 0 8 62 43 48 50 54 46 52 48
2 1 0 0 8 0 43 48 57 54 46 53 48
2 1 0 0 8 0 43 48 56 54 46 54 48
2 1 0 0 8 0 43 48 52 52 46 52 48
2 1 0 0 8 0 32 32 32 32 32 32 32
2 1 0 0 8 0 32 32 32 32 32 32 32
2 1 0 0 8 0 32 32 32 32 32 32 32
2 1 0 0 8 32 32 32 32 32 32 32 13
```

Figure 10. Example of data received from the CAN bus

data-logger to the IoT server. The IoT server was built using Thingsboard v3.1.1PE with the visualization shown in Figure 11 and Figure 12. In this dashboard, the real-time data is displayed, and the user can download or export the data to CSV (Comma Separated Value) or XLS/XLSX (Microsoft Excel) format. The data were sent to the Thingsboard based server with the MQTT protocol. In this testing, Thingsboard v3.1.1PE was installed in a private server.

As shown in the IoT dashboard (Figure 11), the sensor's data is read by the analog and digital converter (ADC) and sent to the IoT server every 5 seconds. If needed, this time interval can be shortened. By default, the server limits a maximum of 300 updates per second and no more than 3000 updates per minute. This limitation is mainly because of database writing time in the server. In the update time interval testing, the 100 ms interval does not give any error.

Table 3.
The meaning of each channel fragmented CAN message in the experiment

Channel	Character
1	43= + 48=0 50=2 54=6 46=. 52=4 48=0
2	43= + 48=0 57=9 54=6 46=. 53=5 48=0
3	43= + 48=0 56=8 54=6 46=. 54=6 48=0
4	43= + 48=0 52=4 52=4 46=. 52=4 48=0
5 – 8	32=(Space) 32=(Space) 32=(Space) 32= (Space) 32=(Space) 32=(Space) 32=(Space) 13=end of data

Table 4.
Sensor values in the experiment

Channel	Sensor	Variable	Value (°C)
1	Thermocouple Type J	Cabin temperature	26.4
2		Engine oil temperature	96.5
3		Hydraulic oil temperature	86.6
4		System cooler oil temperature	44.4

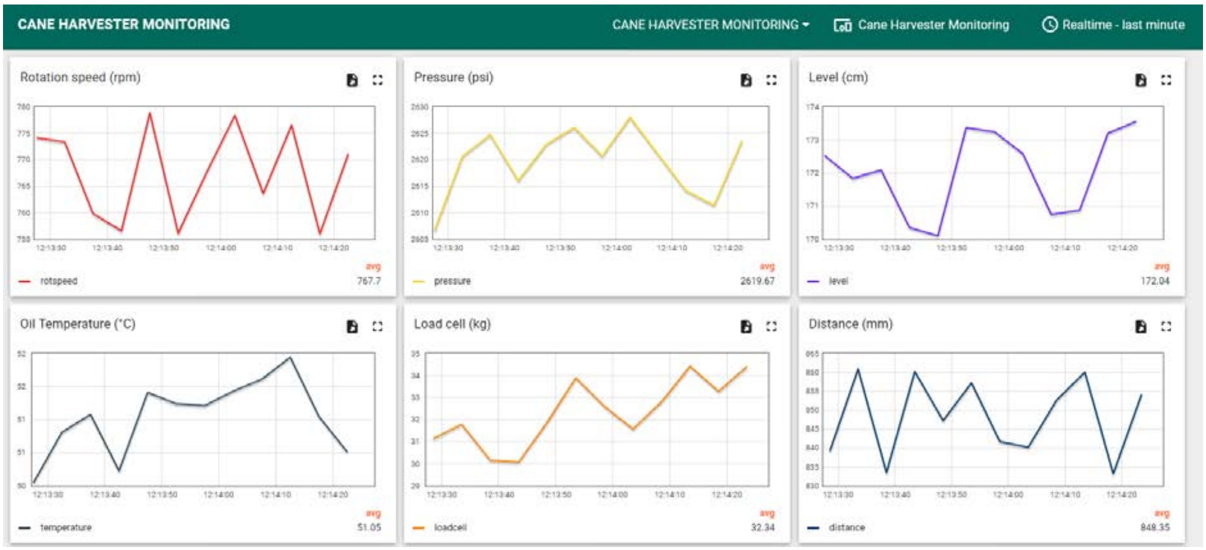
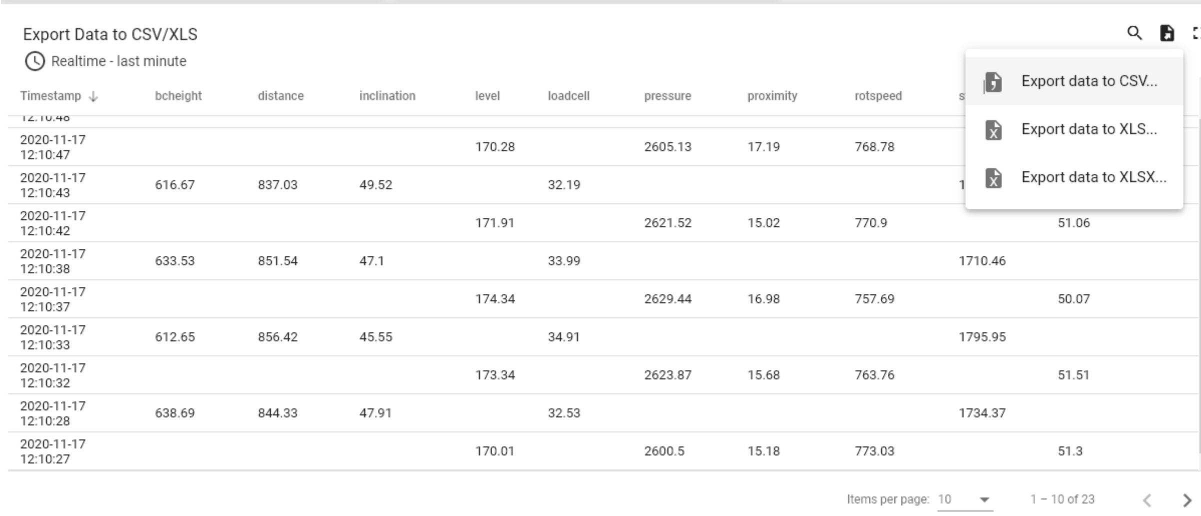


Figure 11. IoT dashboard for cane harvester monitoring system



Timestamp	bcheight	distance	inclination	level	loadcell	pressure	proximity	rotspeed	s	
2020-11-17 12:10:47				170.28		2605.13	17.19	768.78		
2020-11-17 12:10:43	616.67	837.03	49.52		32.19				1	
2020-11-17 12:10:42				171.91		2621.52	15.02	770.9		51.06
2020-11-17 12:10:38	633.53	851.54	47.1		33.99				1710.46	
2020-11-17 12:10:37				174.34		2629.44	16.98	757.69		50.07
2020-11-17 12:10:33	612.65	856.42	45.55		34.91				1795.95	
2020-11-17 12:10:32				173.34		2623.87	15.68	763.76		51.51
2020-11-17 12:10:28	638.69	844.33	47.91		32.53				1734.37	
2020-11-17 12:10:27				170.01		2600.5	15.18	773.03		51.3

Figure 12. The IoT dashboard has the feature to export data into CSV, XLS, and XLSX formats

IV. Conclusion

The designed embedded monitoring system comprises several sensors, a data logger, and the main computer. It is connected to other instruments through a CAN bus. A prototype of the embedded monitoring system was developed which partially realized the designed system. The experimental result showed that the main computer could communicate with other ECUs using the CAN bus. The dataset from four channels retrieved from the CAN bus represents the real values originating from the temperature sensor simulators. Apart from being sent to the CAN bus, the data are also recorded on the SD Card and sent to the IoT server to display real-time data on the dashboard and exported to CSV/XLS/XLSX for offline data processing purposes. In the update time interval testing, the 100 ms interval does not give any error.

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Declarations

Author contribution

All authors contributed equally as the main contributor of this paper. All authors read and approved the final paper.

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Conflict of interest

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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