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Integration of ZigBee based GPS receiver to CAN network for precision farming applications

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Abstract
Precision farming applications are often data centric and aim collecting data from a set of sensor modules to be delivered to the central computer. For this aim, the ISO 11783 protocol which uses the Controller Area Network (CAN) as a data link protocol to perform the data communication are used to standardize and provide the serial data communication as wired between the various sensor modules and the central computer a plug/play approach. Many different types of sensors may use to collect temporal and spatial variability in precision farming applications. Especially GPS receivers are the most important sensor in a precision farming application. And also, different data bus protocols can be used for collected data transmission to the central computer. In this context, wireless sensor protocols, especially ZigBee, is gaining popularity for managing precision farming through real-time monitoring of agricultural variability. Various parameters in the precision farming can be monitored and controlled using ZigBee communication integrated with the CAN bus. In this paper, integration of the wired CAN Bus and ZigBee communication was designed, developed and implemented. In this system, the data regarding the geographical coordinate is extracted from the GPS receiver with the help of the ZigBee communication and send it to a central computer with the help of wired CAN Bus. This method has been implemented in order to adapt the ZigBee messages to the CAN Bus and reduce wire using. Finally, the data flow within designed system between CAN and ZigBee data frames was described. In this study, multiple CAN frames usage and handshaking mechanism are explained for sending sensor data longer than 64 bits. This system's advantage is not only reduce cabling cost and increase the communication speed but also provide dynamic, flexible and applicable communication in precision farming applications.

Keywords GPS receiver · ISO 11783 · CAN · ZigBee

1 Introduction

Electronic, communication, and information technologies are widely used in the agriculture sector as well as in all sectors. Agriculture sector plays major role directly or indirectly in improving economy of developing countries. Sustainable and competitive agricultural production can be made by using electronic, communication and information technology together. In practice, the application field of the sustainable agriculture is the precision farming technology. The information or knowledge is one of the most importing factors for the precision farming technology. To be made in agricultural production process based on information, use of different technological tools is required to determination of the information, analysis, implementation and distribution of the users. Because agricultural production is performed on large agricultural fields, spatial and temporal factors have the great impact on agricultural management decisions. Therefore, spatial and temporal information that can make decision, planning and implementation on all production fields must be collected [1].

Data for some variables can be obtained by means of remote sensing techniques (such as satellite images and aerial photos). For others, however, direct field measurements are essential and this has motivated a great deal of research on sensors, devices, and equipment. Although in some cases field data acquisition is made with stationary equipment (such as weather stations) and with portable devices that are operated manually (such as those for different types of crop scouting), most of the time these sensors and related equipment are embedded in agricultural machines. Data acquisition occurs, then, as machines cross the fields to accomplish operations such as soil preparation, planting, fertilizer application, and

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harvesting [2]. Today, autonomous and connected sensors are able to selectively sample and measure many physical properties such as temperature, humidity, force, pressure, flow, position, and light intensity without impacting on the properties being measured. Also, various kinds of sensors can be integrated into the sensor network, therefore, the conditions of the crops and the soil, including temperature, humidity, illumination, crop disease, pests and etc. can be monitored remotely and in real time. With the determination of soil conditions and plant development, these technologies can lower the production cost by fine tuning seeding, fertilizer, chemical and water use, and potentially increasing production and lowering costs [3]. Sensor networks are used for collecting, storing and sending the sensed data. They can also be defined as a system comprised of a set of sensor modules and a communication system that allows real time data collection and sharing.

Wired and wireless sensor networks continue to evolve toward higher-capacity, multi-service systems. Wireless sensor networks (WSN) can be deployed in various environments, where wired networks are impossible or impractical to deploy [4]. Wired platform networks use the high capacity of fiber-optic-rich physical networks and the general-purpose capability of IP-based protocols to support a triple play of voice, video, and data services. In the wireless domain, albeit with a lag, there is a similar trend towards increased capacity and towards providing a range of services over a common IP-centric network infrastructure. These trends point to an apparent future convergence on a platform network architecture for both wired and wireless sensor networks [5].

WSN is entering a new phase. Recent advances offer vast opportunities for research and development. This is the consequence of the decreasing costs of ownership, the engineering of increasingly smaller sensing devices and the achievements in radio frequency technology and digital circuits. Currently, they are very promising in several fields such as environmental monitoring, irrigation, livestock, greenhouse, cold chain control or traceability. The systems are usually composed of a few sinks and large quantity of small sensors nodes [6]. The main features of WSN are: scalability with respect to the number of nodes in the network, self-organization, self-healing, energy efficiency, a sufficient degree of connectivity among nodes, low-complexity, low cost and size of nodes [7]. The throughput performance of WSNs is affected by the mobility of the users [8]. The wireless data connections have high bit error rates, low bandwidth and long delays. The bandwidth of wireless local area networks is limited as compared to that of wired local area networks which provide a large bandwidth. This limitation is due to the error prone physical medium (air) [9].

The sensor network architectures today are not only wired but wireless too, depending on the type of circumstances like need of mobility or rough terrains. As the technology of agricultural attachments has expanded to include electrical control communication via a message based topology, such as J1939 for a tractor and ISO 11783 for an attachment, now a large amount of information is able to be transferred on a twisted pair of wires, that is, the CAN bus [10]. Though the wired CAN sensor networks have provided the high speed and secure connectivity but due to the drawbacks like extensive cabling and immobility etc., the WSN gained momentum. WSN can be used to provide users in a limited geographical area with high bandwidth, high speed and high quality supported by the CAN sensor networks. For this reasons, given the advances in agricultural wireless sensor technology, agricultural sensors have to be adapted to existing CAN systems. In this context, the adoption of wireless sensor networks with existing CAN system will provide an important contribution to the automation of the agricultural machinery. This paper describes the implementation and evaluation of communication between CAN protocol and ZigBee protocol for GPS data transfer from the GPS receiver to the central computer. This system is proposed to adapt ZigBee wireless network to CAN communication for precision farming application.

1.1 ZigBee protocol

The ZigBee is a reliable, low power, low cost and efficient technology for the creation of information networks; a specification of high level communication protocol based on the LR-WPAN IEEE 802.15.4 standard extending that definition by developing the higher layers of the standard. ZigBee has maximum 250 kbps data transfer rate. ZigBee Network Node Manager may be a number of sub-node, a node can manage up to 254 sub-node [11]. The communication delay and activated from hibernation is very short delay, typically 15 ms latency to 30 milliseconds. ZigBee provides the data integrity checks and authentication functions, the use of a common encryption algorithm AES2128, while the flexibility to determine their security attributes [12]. ZigBee supports three topologies, namely, star, mesh and cluster-tree [13]. The basic type of network topology is the star topology. A star topology consists of a central PAN co-ordinator surrounded by the other nodes of the network, often referred to as end devices [14]. ZigBee's frequency bands is 2.4 GHZ, Europe (868MHZ) and the United States (915MHZ) are free to apply band [15]. The transmission range for indoor ZigBee is given as 30 m and for outdoor with little clutter the range can be 75 m [16].

ZigBee system structure consists of three different types of devices such as ZigBee coordinator, Router and End device (Fig. 1). Every ZigBee network must consist of at least one coordinator which acts as a root and bridge of the network. The coordinator is responsible for handling and storing the information while performing receiving and transmitting data operations. ZigBee routers act as intermediary devices that permit data to pass to and fro through them to other devices. End devices have limited functionality to communicate with

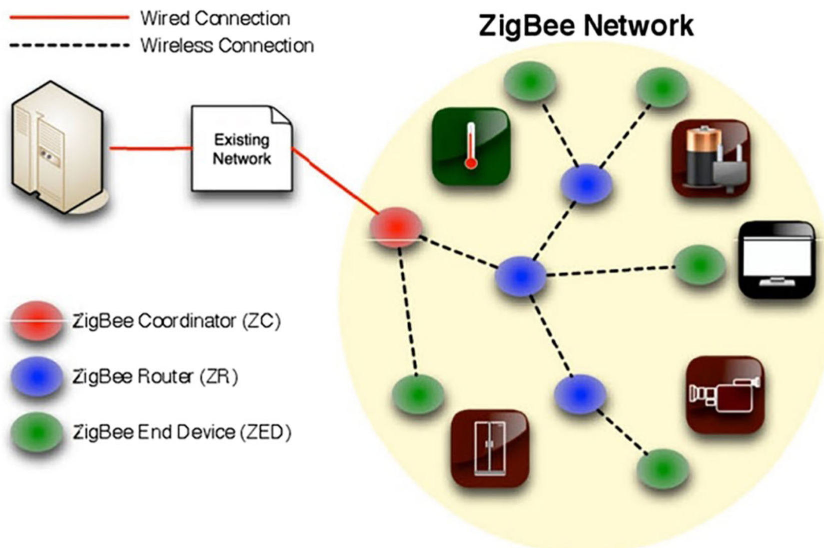


Fig. 1 ZigBee network

the parent nodes. The number of routers, coordinators and end devices depends on the type of network such as star, tree and mesh networks.

Data transmitting models for ZigBee network are divided into three types. They are transmitting from coordinator to sensor module, transmitting from sensor module to coordinator, and transmitting between coordinators. The IEEE 802.15.4 standard has the ability to use two different communication modes which are the beacon enabled mode and the non-beacon enabled mode. Beacon serves as activating the device through the special message that is allowed by the particular ZigBee network topology. In this study, we used data transmitting from sensor module to coordinator in non-beacon mode. In the non-beacon enabled mode, a sensor module can send data at any time based on unslotted CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance). In the unslotted CSMA/CA, each time a sensor module wishes to transmit data frames, it waits for a random period. If the channel is found to be idle (done by CA mechanism), following the random back-off, the sensor module transmits its data. If the channel is found to be busy following the random back-off, the sensor module waits for another random period before trying to access the channel again.

There are four basic message frame structure for ZigBee network message traffic: the beacon sent by coordinator, the data frame for all data transfers, an Acknowledgement (ACK) frame for confirming receipts of data, and the Medium Access Control (MAC) command frame that is used for MAC layer management entity. Each protocol layer in ZigBee network adds to the structure of the frame by placing specific headers and footers. In our proposed network model, we explained data frame structure for sending message from sensor module to coordinator in Fig. 2.

The size of the data frame is a maximum of 127 bytes and this value may be reduced depending on the state of some of the variable fields. The most important area within the data frame structure is the addressing area. Each ZigBee network has a 16 bit number that is used as a network identifier. It is called the PAN ID (Personal Area Network Identifier). The coordinator assigns the PAN ID when it creates the network. All sensor modules in a ZigBee network are assigned a single PAN ID. There are two different ZigBee addresses assigned to each ZigBee module. The 64-bit address is a unique device address assigned during manufacturing. The 64-bit address is also called IEEE address or extended address. The 16 bit address is assigned to the device when it joins a ZigBee network. The sensor module can send unicast messages based on either 16 bit address or 64 bit address. When communicating within the same PAN, the PAN ID must be the same for both destination and source.

1.2 CAN protocol (ISO 11783)

ISO 11783 (or ISOBUS) is a J1939-based CAN protocol for communication in the agriculture industry. ISO 11783 as a whole specifies a serial data network for control and communications on forestry or agricultural tractors, mounted, semi mounted, towed or self propelled implements. Its purpose is to standardize the method and format of transfer of data between sensor, actuators, control elements, information storage and display units whether mounted or part of the tractor, or any implements [17–19]. The ISO11783 bus has been widely due to its advantages such as good real-time performance, high reliability, quick communications rate, simple structure, good interoperability, high flexibility and so on.

The CAN was defined as a serial communication bus to replace the complex wiring harness with a two-wire bus (Fig. 3). Additionally, it is a multi-master serial bus that broadcast messages to all nodes in the network system. The CAN system offers a transmission speed of up to 1 Mbit/s with

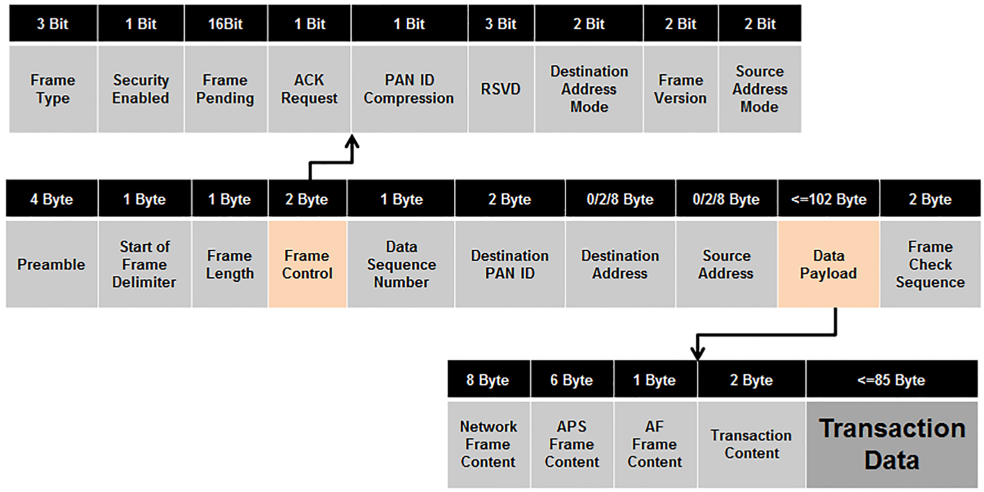


Fig. 2 ZigBee data frame

reliable and error detection method for effective transmission [20]. CAN protocol can be considered as a message-based protocol as messages are transmitted to all nodes in the network. Therefore, each node receives the messages and decides whether the message received is to be discarded or processed. Depending on the configuration of the network, a transmitted message can be destined to either one node or many nodes [20–22]. This has several important consequences such as system flexibility, message routing and filtering, multicast, together with data consistency [23].

CAN is a multi-master broadcast serial bus standard for connecting Electronic control units (ECUs). Each node is able to send and receive messages, but not simultaneously, and every node on the CAN bus will hear a transmitted message. The devices that are connected by a CAN network are typically Sensors, Actuators, and other control devices. These devices are not connected directly to the bus, but through a host processor with built in CAN controller or external CAN controller, and CAN transceiver.

CAN data is transmitted and received using formatted message frames. CAN protocol define four different types of messages (or frames). The first and most common type of frame is a Data Frame. This is used when a node transmits information to any or all other nodes in the system. Second is a Remote Frame, which is basically a Data Frame with the RTR bit set to signify it is a Remote Transmit Request. The other two frame types are for handling errors. One is called an Error Frame and one is called an Overload Frame. Error Frames are generated by nodes that detect any one of the many protocol errors defined by CAN. Overload errors are generated by nodes that require more time to process messages already received. Data Frames consist of fields that provide additional information about the message as defined by the CAN specification. Embedded in the Data Frames are Arbitration Fields, Control Fields, Data Fields, CRC Fields, a 2-bit Acknowledge Field and an End of Frame. The Arbitration Field is used to prioritize messages on the bus. Since the CAN protocol defines a logical 0 as the dominant state, the lower the number in the arbitration field, the higher priority the message has on the bus. The arbitration field consists of 12-bits (11 identifier bits and one RTR bit) or 32-bits (29 identifier bits, 1-bit to define the message as an extended data frame, an SRR bit which is unused, and an RTR bit), depending on whether Standard Frames or Extended Frames are being utilized. The current version of the CAN specification, version 2.0B, defines 29-bit identifiers and calls them

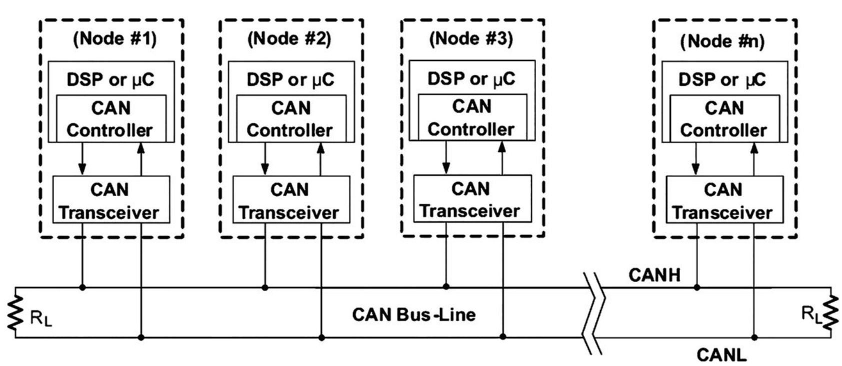


Fig. 3 CAN network

>=130 Bit						
1 Bit	32 Bit	8 Bit	0 - 64 Bit	16 Bit	2 Bit	7 Bit
SOF	Arbitration Field	Control Field	Data Field	CRC	ACK	EOF

Fig. 4 CAN data frame

Extended Frames (Fig. 4). Previous versions of the CAN specification defined 11-bit identifiers which are called Standard Frames [20].

1.3 NMEA 0183 protocol

GPS receivers send data such as latitude, longitude, speed, time, etc. by cable to other electronic devices via the RS-232 serial port. NMEA (National Marine Electronics Association) 0183 is a standard protocol, used by GPS receivers to transmit data. NMEA 0183 sentences are all American Standard Code for Information Interchange (ASCII). The maximum number of fields allowed in a single sentence is 82 characters (82 Byte) including delimiters. Values in the table include the sentence start delimiter character "$" and the termination delimiter <CR><LF > (Fig. 5).

A 2-digit 'YY' code follows, giving the instrument type (e.g. for a GPS device this should be 'GP'). A 3-digit 'XXX' code follows, giving the sentence data type (e.g. 'GGA' is a 'Global Positioning System Fix Data' sentence). A comma follows, then the contents of the sentence data, which changes depending on the data type and the current values of what is being monitored.The final part is an optional two-digit checksum - optional, but all good equipment will include this to help safe-guard the data in the sentence. The checksum is preceded by the '*' character and is calculated by taking the 8-bit exclusive-OR of all characters in the sentence, including ',' delimiters, between but not including the '$' /'!' and '*' delimiters. The string always ends with a carriage return and line feed combination (Hex 0D 0A, ASCII '\r\n').

2 Hardware of the proposed system

WSN technology brings several advantages over traditional wired agricultural monitoring and control systems, including self-organization, rapid deployment, flexibility, and inherent intelligent processing. WSN based systems will greatly offer new and more effective functions and solutions which traditionally could not be met through the conventional wired instrumentation systems. In this study, CAN-ZigBee based hybrid agricultural sensor network model was proposed for GPS based data collection and monitoring. Furthermore, the data flow was explained between the GPS receiver and the central computer located on the tractor (Fig. 6).

CAN based ZigBee sensor/coordinator module include the following basic components: sensor (GPS receiver), microcontroller, RF transceiver, CAN transceiver and battery (Fig. 7). GPS receiver is responsible for receiving navigation information. The microcontroller is responsible for management of data acquisition, handling communication protocols, scheduling and preparation of data packets for transmission once it has gathered, filtered, and synchronized the data from the coordinator or sensor module. RF transceiver is a 2.4 GHz IEEE 802.15.4 radio transceiver module intended for longer range applications. It has an external antenna connector, matching circuitry and is an ideal solution for wireless sensor networks. The CAN transceiver is a high-speed CAN transceiver, fault-tolerant device that serves as the interface between a CAN protocol controller and the physical bus. It provides differential transmit and receive capability for the CAN protocol controller and is fully compatible with the ISO-11898 standard [24].

ZigBee network is composed of at least ZigBee coordinator, ZigBee router and ZigBee sensor module. In the star topology, there is no presence of ZigBee router. A star topology was used in proposed system. The star topology contains a coordinator positioned in the center and one sensor module. Sensor module is linked directly with the ZigBee coordinator. In this configuration, the sensor module can only interact with the coordinator. Different sensor modules can be added to the designed network. The ZigBee coordinator module is connected to CAN Bus of the tractor as wired. The primary aim of the coordinator is to establish all the network parameters for example: packet size and topology etc. It is the gateway for the outside world to communicate with the network. It maintains all the network modules.

In proposed circuit, the PIC32MX570F512L is a high performance 32-bit Microcontroller packs powerful RISC architecture with MIPS M4K core. It offers all of the advantages of the high-performance ×32 architecture with standardized features including 512 KB of addressable program memory size, 3 KB of auxiliary flash, 65,536 B of data memory size, three comparators, and 48-channel 10-bit analog-to-digital converter. It operates at a maximum frequency of 50 MHz with wide operating voltage of 2.3 to 3.6 V. It can be used to communications and networking, audio, embedded design and development, and multimedia applications. The MRF24J40MA is 2.4GHz IEEE 802.15.4 radio transceiver module. The MRF24J40MA has an integrated PCB antenna, matching

Fig. 5 NMEA 0183 message structure

1 Byte	5 Byte	Max. 71 Byte	1 Byte	2 Byte	1 Byte	1 Byte
Start Character ($)	<Address> (YYXXX)	{, <Value>}	Checksum Delimiter (*)	Checksum	Carriage Return (CR)	Line Feed (LF)

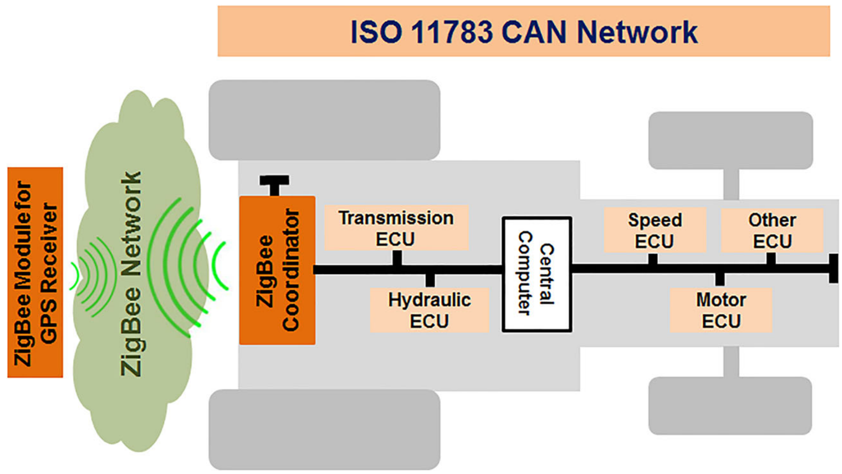


Fig. 6 Structure of the proposed system

circuitry, and supports the ZigBee protocol. The MRF24J40MA module can connect to 32-bit microcontrollers and is an ideal solution for wireless sensor networks. It can be used to wireless, security, automation, and consumer electronics applications. The RS232 serial communication protocol is used for two way communications between the GPS receiver and the CAN based ZigBee sensor modules. At the same time, NMEA 0183 row data are transferred to CAN based ZigBee sensor modules by the GPS receiver.

3 Method of the proposed system

In this study, it is developed two algorithms for sending GPS data from the GPS receiver to the central computer. The first algorithm describes the data traffic between the NMEA 0183 data and the ZigBee message. The second algorithm describes the data traffic between ZigBee message and the CAN data frame. In proposed system, GPS receiver is connected to the ZigBee sensor module via RS232 port. It sends NMEA 0183 messages every second to the microcontroller. In NMEA 0183 protocol, each sentence begins with dollar sign ($) and the next five characters determine the sentence type. The $GPRMC sentence type is the most important and useful format and includes positional and temporal data. For this reason, this sentence type was illustrated in the proposed system. All of the microcontroller software was written using the mikroC. The mikroC for PIC is a powerful, feature-rich development tool for PIC microcontrollers. Serial communication is basically the transmission or reception of data one bit at a time. Each serial port has two software buffers (queues), one for data pending transmission and one for storing received data bytes. In the first algorithm, ZigBee sensor module software has an infinite loop which continuously reads the serial port. If the read character matches a "$" character, It reads characters received via UART until the "*" delimiter sequence is detected and stores an array variable. After that, It is inserted a "$" sign at the beginning of the array and a "*" sign at the end of the array. Lastly, the array is sent to the ZigBee coordinator module (Fig. 8).

ZigBee coordinator module is the central node of the proposed system, and also the core device. Each network should

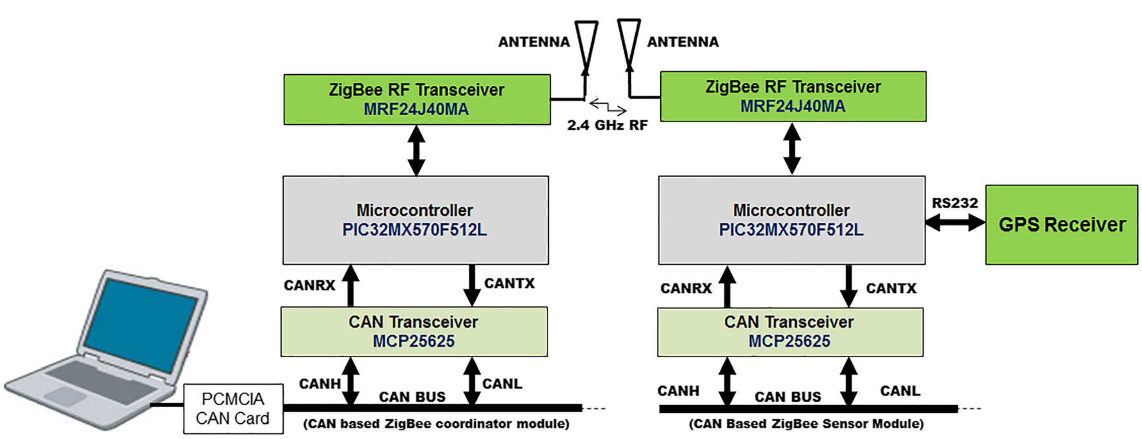


Fig. 7 Proposed CAN based ZigBee sensor/coordinator modules

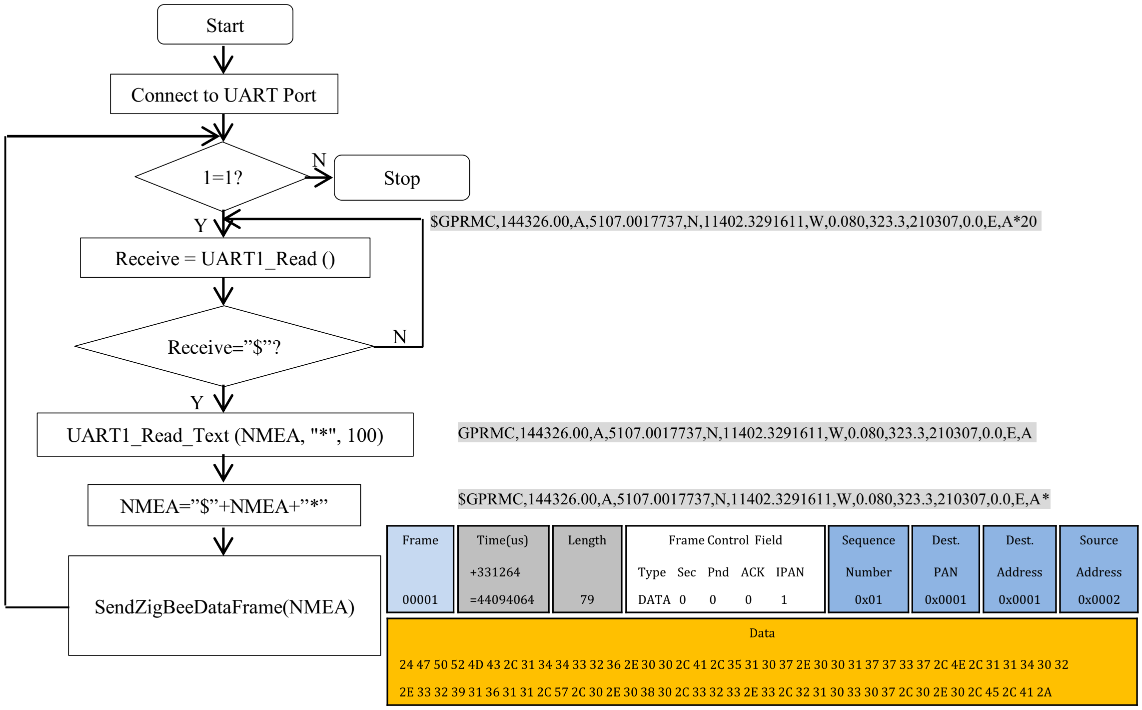


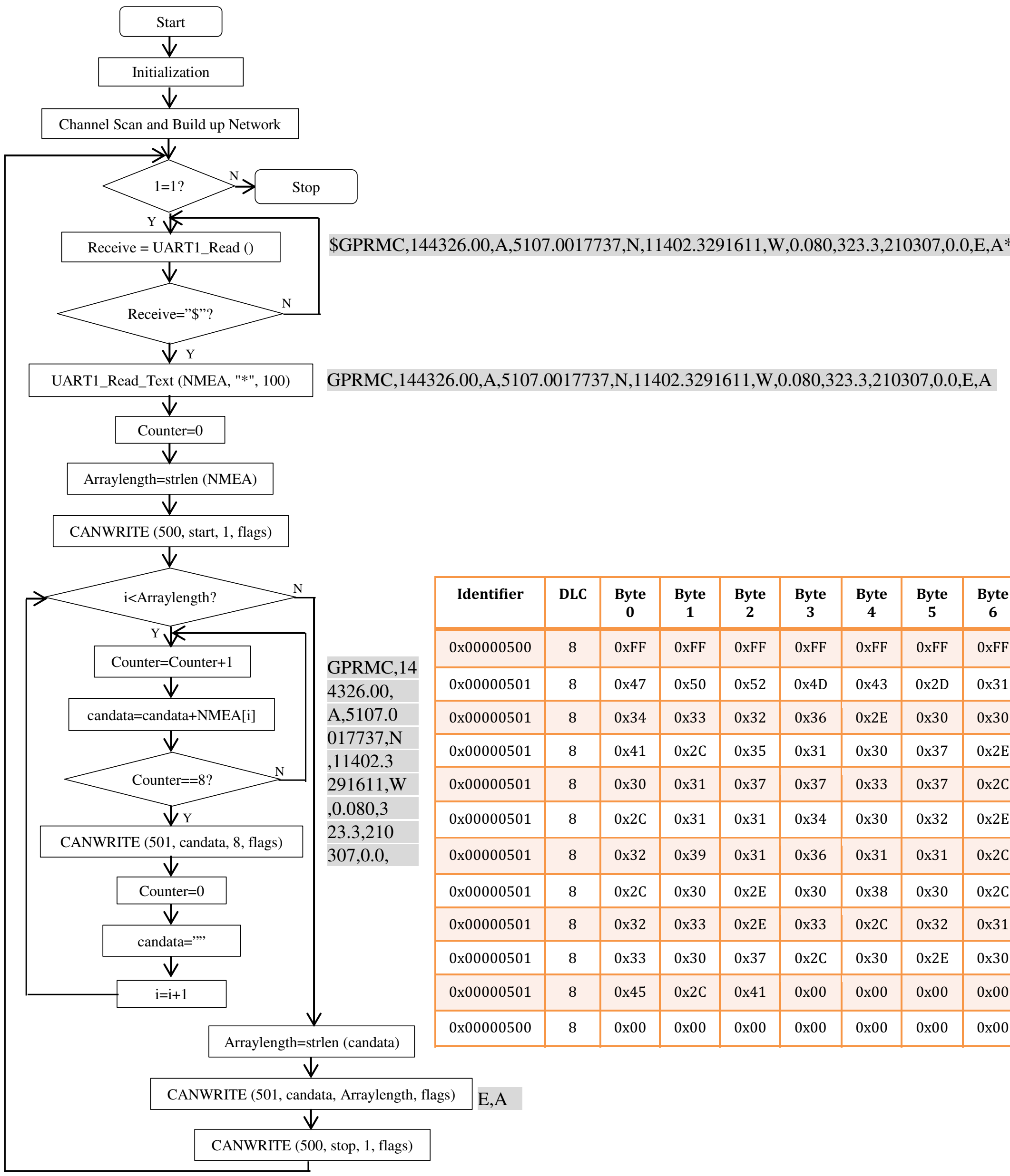
Fig. 8 Data transmission from NMEA 0183 to ZigBee

have a coordinator, which is responsible for the formation and maintenance of the entire network, and allows ZigBee sensor module to join the network, which is the organizer of the entire network. ZigBee coordinator module flow chart is shown in Fig. 9. After completing the system initialization, the ZigBee coordinator module constructs a new ZigBee network. Then the network enters into the state of wireless monitoring to check if any wireless signal exists. If there is one ZigBee sensor module applying to enter the network, the coordinator will assign the short address to the node. When the coordinator receives the data from the ZigBee sensor module, it collects data, creates CAN data frame, and transfers it to central computer via CAN Bus. In the second algorithm, the data sent from the ZigBee sensor module is stored to the an array variable. CAN is limited to transmit a maximum of 8 Bytes of data on a single Frame. We need to send multiple CAN data frames of up to 8 bytes each to send more than 8 bytes. For this reason, we have to split the array variable into multiple frames, and use a handshaking mechanism to tell the receiver when multiple CAN frames started and stoped. The ZigBee coordinator module is a simple module that can receive GPS position data from the ZigBe network and make it available over a CAN Bus in extended CAN 2.0B data frames. It sends NMEA 0183 data to central computer via two specific CAN message Identifiers. CAN message 0×00000500 is used to tell to the central computer CAN frame transmission started or stopped. If CAN data is 0xFFFFFFFFFFFFFFFF hex, the central computer understands transmission is started. If CAN data is $0 \times 0000000000000000$ hex, the central computer understands transmission is completed. CAN message 0×00000501 is used to send divided NMEA 0183 data.

CAN specifies variable length CAN frames with a maximum data field length dependent on the protocol device used. Generally, a CAN frame can transmit or receive data with data field ranging from 0 bit to 64 bits per frame. But, proposed system in this study can transmit or receive frames with data field length from 0 bit to infinity bits with the help of multiple CAN frame and handshaking mechanism. Also, this system is also capable of transmitting or receiving standard CAN frames. This structure is described in Fig. 9.

4 Experimental results

This work is focused on the ZigBee / CAN communication mechanism for precision farming. Precision farming applications may require the use of heterogeneous networks composed by wired and wireless communication systems. In this paper, a software gateway that incorporated both ZigBee wireless technology and CAN protocol was proposed to solve wired and interferences difficulties. Proposed software gateway converts data from ZigBee NMEA 0183 message to CAN Bus. Also can read GPS data from RS 232 and converts the packets to ZigBee message to send them to ZigBee coordinator module. The experimental setup contains a ZigBee coordinator module and sensor module. But, both modules have same hardwares. As can be seen in Fig. 10, proposed module has four hardwares. Microchip’s automotive



Identifier	DLC	Byte 0	Byte 1	Byte 2	Byte 3	Byte 4	Byte 5	Byte 6	Byte 7
0x00000500	8	0xFF	0xFF	0xFF	0xFF	0xFF	0xFF	0xFF	0xFF
0x00000501	8	0x47	0x50	0x52	0x4D	0x43	0x2D	0x31	0x34
0x00000501	8	0x34	0x33	0x32	0x36	0x2E	0x30	0x30	0x2C
0x00000501	8	0x41	0x2C	0x35	0x31	0x30	0x37	0x2E	0x30
0x00000501	8	0x30	0x31	0x37	0x37	0x33	0x37	0x2C	0x4E
0x00000501	8	0x2C	0x31	0x31	0x34	0x30	0x32	0x2E	0x33
0x00000501	8	0x32	0x39	0x31	0x36	0x31	0x31	0x2C	0x57
0x00000501	8	0x2C	0x30	0x2E	0x30	0x38	0x30	0x2C	0x33
0x00000501	8	0x32	0x33	0x2E	0x33	0x2C	0x32	0x31	0x30
0x00000501	8	0x33	0x30	0x37	0x2C	0x30	0x2E	0x30	0x2C
0x00000501	8	0x45	0x2C	0x41	0x00	0x00	0x00	0x00	0x00
0x00000500	8	0x00	0x00	0x00	0x00	0x00	0x00	0x00	0x00

Fig. 9 Data transmission from ZigBee to CAN Bus

networking board is the main hardware to execute programs and connects the other hardwares each others. MikroElektronika's RS232 2 click was used to connection between GPS receiver and ZigBee sensor module. MikroElektronika's MCP25625 was used to interface between the CAN protocol controller and the physical wires of the CAN Bus lines. MikroElektronika's Bee click was used for ZigBee communication between coordinator and sensor modules arranged in a star topology.

For central computer, data acquisition software was developed for receiving data through CAN Bus. Software was written in Microsoft C# programming language (Fig. 11). Kvaser Leaf Professional HS was used to connection between the central computer and the Automotive Networking Board. Kvaser Leaf Professional is a one channel, high performance, USB interface for High Speed CAN.

Figure 12 shows an algorithm for collecting and merging the divided CAN data frames by the help of developed software. Incoming CAN messages are placed in a queue in the driver. In most cases the hardware does message buffering as well. The messages can be read from queue by calling CANRead function. If the Message Id equals 0×00000500 and message data equals 0xFFFFFFFFFFFFFFFF hex, the next message is read. If the the next message is 0×00000501, it merges the received data in loop. If the Message Id equals 0×00000500 and message data equals $0 \times 0000000000000000$ hex, the merged message can be converted string format and viewed on the software screen. This

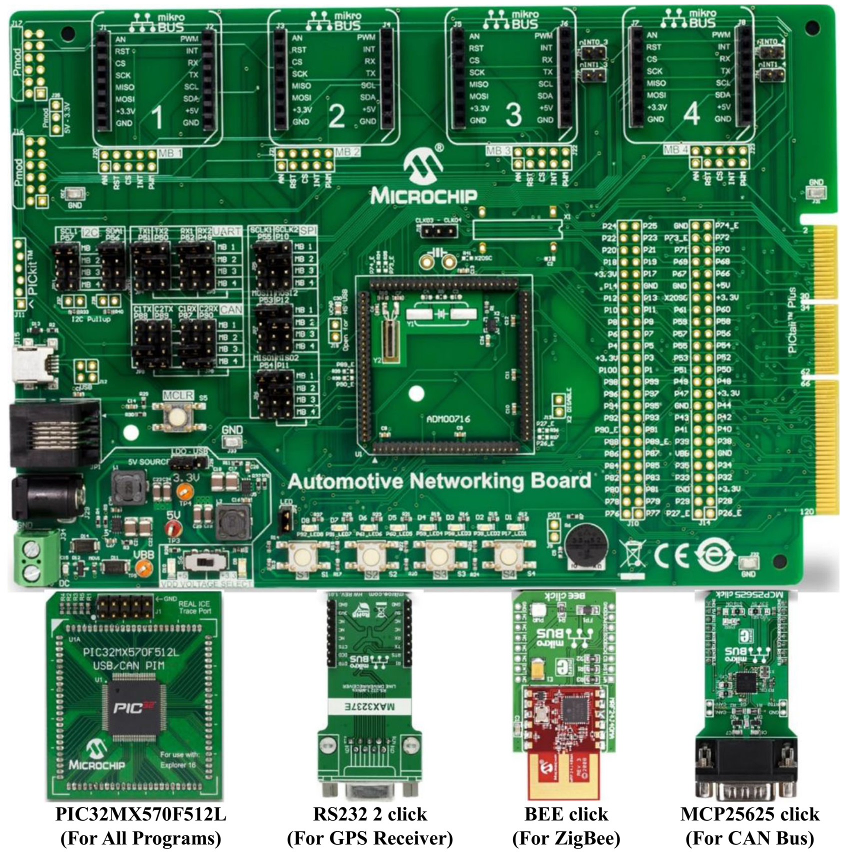


Fig. 10 Proposed hardware for ZigBee – CAN data transmission

message is NMEA 0183 format. In all other conditions, the program reads the driver's queue.

In the literature, there is no study for the integration of ZigBee based GPS receiver to CAN network for precision farming applications in agriculture science. However, there have been studies researching and adapting ZigBee wireless network and CAN bus in different sciences. However, most of the work is focused in placing a maximum 64 bit sensor data within the CAN message frame, which has a 64 bit data field length. It is not described how to load data longer than 64 bits sensor data within the CAN message. GPS receivers generally use either NMEA 0183 protocol to communicate with many other types of instruments. Data field of the NMEA 0183 message consists of the comma, delimiters and position data with variable length. Data length of most NMEA 0183 messages have larger than 64 bits, such as "RMC" and "GGA". For this reason, multiple CAN frames and handshaking mechanism should be used for data transmission from ZigBee to CAN network.

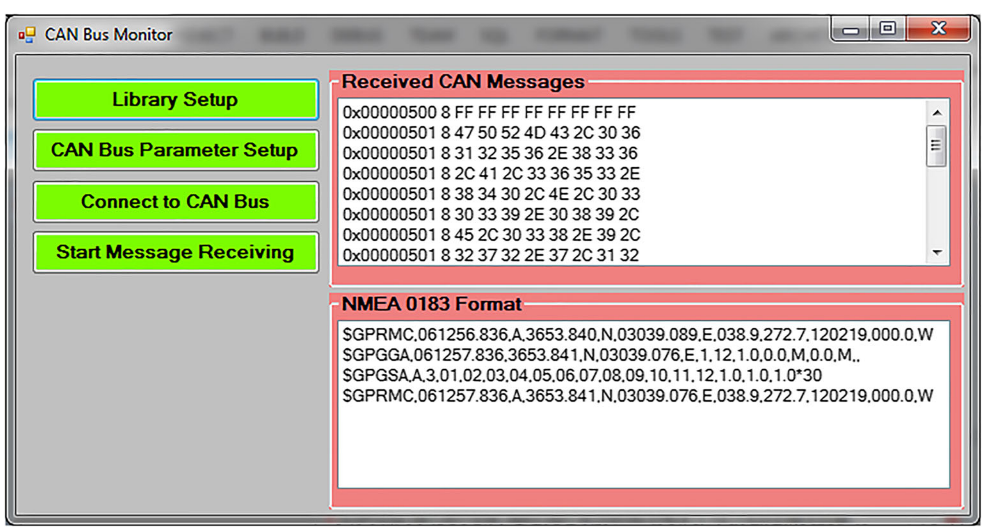


Fig. 11 Developed software for ZigBee – CAN data transmission

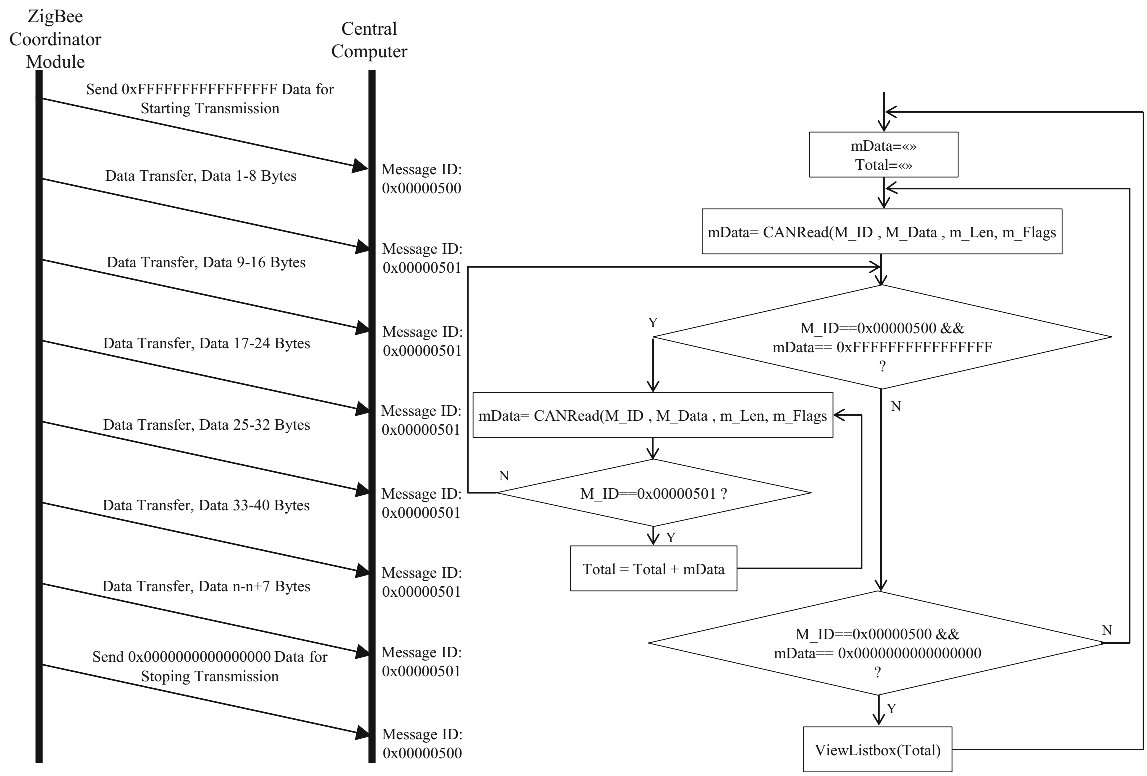


Fig. 12 Algorithm for collecting and merging the divided CAN data frames

Hongju et al. [25] designed coal mine personnel positioning system based on ZigBee and CAN for improving coal mines management and guaranteeing coal industry safety production. In system structure, CAN nodes, repeaters and wireless base stations with known locations were installed in the shaft, mine laneways intersection, and working faces according to some distances to monitor the underground personnel and key equipment. In positioning system, underground personnel have to wear helmet or belt embedded identity card which has 64-bit permanent address as its unique identification. It sends periodically radio frequency signal data to the wireless base stations. Then the collected data of identity card and key equipment,via ZigBee network to access to CAN nodes, are transmitted to personal computer for analyze identity card ID by backend database. The researchers reported that the system uploading data could provide scientific basis for rescuers taking measures and shorten the time of making decisions. As a result, data length is 64 bit and data can be sent with a single CAN Frame in proposed system. But, in our system, GPS data length is variable and more than 64 bit due to the structure of the NMEA 0183 protocol. For this reason, it was used multiple CAN Frames and handshaking mechanism.

Gomes et al. [26] developed a special purpose ZigBee-CAN gateway that allows for transparent flows of information originating in both sensors and actuators in heavy industrial applications. The researchers focused on the maximum amount of information passing by the sink gateway, through which all data from the network passes. Researchers reported that the ZigBee network accepts a maximum of 504 end devices and the network maintains a good performance until a maximum of 16 nodes transmitting one message per second. But, the researchers indicated that a maximum of half of this value would be ideal. Also, the researchers reported that the cabled islands of sensors / actuators can be part of a wireless network of devices due to requirements such as data rate and power supply. In proposed gateway, data transmission algorithm and message structure from ZigBee to CAN or from CAN to ZigBee was not explained. On the other hand, it is understood that the message to be sent per second is 64 bit and is sent with a single CAN message frame.

Li et al. [27] introduced and tested a new method of conversion to achieve the communication between CAN network and ZigBee wireless network for automotive applications. The researchers tested tire pressure and temperature in the real car using the standard CAN bus configuration and the ZigBee network with four-node star topology. The researchers reported that the results obtained the proposed system performed the established network functions successfully and works well, allowing each ZigBee node to share information not only in ZigBee network, also with each CAN node. Also, the researchers reported that the converter has certain applied value in intelligent control and user friendly design of car wireless. As in other studies, data are sent in a single CAN message frame in this study.

Kumar and Rao [28] designed a coal mine safety monitoring system based on wireless sensor network using CAN Bus along with ZigBee technology to reduce the cabling cost and increase improve the speed of communication between base station and sync nodes. The researchers developed the sensor module consisting of some MEMS based sensors that measures real-time underground parameters like temperature, humidity and gas to introduce the flow of communication between the ZigBee modules. On the other hand, the data transmission and gateway between ZigBee network and CAN Bus was not explained. However, it is understood that the data length of the CAN message frame can be sent with a single CAN message frame considering that the humidity, temperature and gas data can be a maximum of 64 bits.

Zheng et al. [29] designed a wireless monitoring system based on CAN Bus and ZigBee technology of tower crane to improves the monitoring and fault diagnosis technology of tower crane. Hardware design of the system consists of CAN data acquisition module, CAN communication module, ZigBee wireless communication modules, and LCD display module. CAN data acquisition module which consists of sensor module, A/D switching circuit, and the microcontroller can measure a variety of physical parameters of the tower crane and send to the CAN communication module for wirelessly transmit these parameters to the monitoring center by ZigBee technology. The researchers reported that this system has a certain economy and cost savings and also has a good application prospect in the long run. In proposed system, each CAN data acquisition module sends a parameter value of a single sensor to the ZigBee wireless communication module via CAN communication module. This means that the data length of the CAN message is a maximum of 64 bits and the multiple CAN frames and handshaking mechanism is not used for data transmission. On the other hand, the ZigBee and CAN message structures are not explained in this study.

In precision farming domain, different sensors are used to match the crops to different soils and weather conditions, measure the different physical and chemical properties of the soil or plant, and achieve the maximum yield. But, most sensors used in precision farming applications do not have a suitable interface for the CAN network or ZigBee network. In this context, The GPS receiver is the most important positioning sensor used in a precision farming system. Therefore, this study focused on adaptation of the GPS receiver to CAN and ZigBee network. Because, data length of the NMEA 0183 sentence is larger than the data length of a single CAN message frame. Therefore, multiple CAN frames usage and handshaking mechanism was explained in this study. However, the other sensors used in precision farming applications also can be easily adapt to CAN and ZigBee networks with this proposed system. The designed system is suitable for the demand of precision farming applications, and has a good application prospect. This system's advantage is not only reduce cabling cost and increase the data processing acceleration but also provide dynamic, flexible and applicable communication between the central computer and the other sensors/actuators in precision farming applications. In addition, the sensors used in precision farming applications can be mobile or stationary, depending on the application. In this situation, ZigBee provides an adaptable and elegant solution to connect all sensors and networks to each other in precision farming applications.

5 Conclusions

In order to allow the communication between a wired CAN Bus and wireless ZigBee, integration of ZigBee based GPS receiver to CAN network for precision farming applications was designed, implemented and proposed. This paper has successfully demonstrated data transmission from ZigBee to CAN Bus. The results show that the system is able to send GPS data via ZigBee, can send ZigBee message via CAN Bus, and can collect and merge the CAN messages with the help of central computer. It is capable of converting CAN data frames or ZigBee messages, and transmitting them to each other. It can be implement for practical precision farming applications. This study is only available for the GPS receiver. But, the proposed system is also designed to enable many different sensors to send data from ZigBee to the CAN network. In the future, one inertial measurement unit (IMU) will added to the proposed network system to improve navigation solutions for precision farming applications.

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