May, 2005

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Matthew J. Darr, *Ohio State University*
Lingying Zhao, *Ohio State University*
M. R. Ehsani, *Ohio State University*
J. K. Ward, *United States Department of Agriculture*
T. S. Stombaugh, *University of Kentucky*

This is not a peer-reviewed article.
Livestock Environment VII,
Proceedings of the Seventh International Symposium, 18-20 May 2005 (Beijing, China)
Publication Date 18 May 2005, ASAE Publication Number 701P0205.
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EVALUATION OF CONTROLLER AREA NETWORK DATA COLLECTION SYSTEM IN CONFINED ANIMAL FEEDING OPERATIONS

M. J. Darr[1], L. Zhao[1], M. R. Ehsani[1], J. K. Ward[2], and T. S. Stombaugh[3]

ABSTRACT

Livestock and poultry industries play an important role in the food supply and economy of US agriculturalists. Current and historical trends show that the number of animals housed in individual facilities continues to grow on a yearly basis. While design improvements have enabled structures to physically house the growing number of livestock, a new problem exists in maintaining a safe indoor environment due to the increases in animal waste production. The Environmental Protection Agency is also beginning to enforce regulations to limit the daily emission rate of specific gases and odors associated with animal production.

Research is needed to identify enhanced methodologies to monitor indoor environment and air quality of animal production facilities. This project developed and evaluated a novel method of environment monitoring for single and multi-building production facilities. Controller Area Network (CAN Bus) nodes were developed and evaluated in their ability to transmit sensor data over the long transmission distances common to livestock facilities. As expected, the effective transmission distance was directly correlated to the data bus rate. It was found that bus rates of 50 kbits/sec or less can accurately deliver CAN messages up to 600 meters on a continuous basis. As data bus rates reach 250 kbits/sec, the maximum transmission distance is reduced to under 300 meters.

KEYWORDS. Controller Area Network, Air Quality Monitoring, Microcontrollers, Distributed Sensing Networks

INTRODUCTION

Research in animal environment monitoring is vital to Ohio's agricultural production due to the number of animals housed in confinement facilities. While the goal of agricultural animal production facilities is to be economically viable, environmentally-friendly, socially accountable, and safe, one of the challenges of live animal production is management and handling of animal waste. One specific area of concern for producers is the air quality within and emission from animal facilities. As the Environmental Protection Agency (EPA) continues to become stronger enforcers of emission regulations Ohio producers will need to invest time and resources into remediation and monitoring equipment.

Table 1. Ohio animal production statistics

Number of Animals in Ohio CAFOs	
Poultry	30.7 million
Swine	1.42 million
Beef	1.24 million
Dairy	0.48 million

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[1] The Ohio State University Department of Food, Agricultural, and Biological Engineering. 590 Woody Hayes Drive, Columbus, OH 43210 Contact Author: Matthew Darr, Phone: (614)292-1406, darr.27@osu.edu

[2] Soil Dynamics Research Unit, USDA-ARS-MSR-NSDL 411 S. Donahue Dr., Auburn, AL 36832

[3] University of Kentucky Department of Biosystems and Agricultural Engineering 128 CE Barnhart Building, University of Kentucky, Lexington, KY 40546

Understanding the indoor environment and air quality is a crucial factor in maintaining healthy and productive livestock as well as ensuring the health of employees within the agriculture sector (Arogo et al., 2003). The EPA has issued fact sheets concerning the negative impact of air quality and air emissions from large animal production facilities and has stated that continued research must be performed to accurately quantify their effects (EPA, 2001). Health organizations, such as the National Institute of Occupational Safety and Health, have also mandated standard levels of exposure for various pollutants which can lead to potentially harmful conditions.

EPA air emission regulations are backed by limited data sets from agricultural facilities. Further studies are required in order to fully understand the effect of various production and environmental parameters on air emissions. While analyzers and sensors are available to monitor the key types of air quality parameters (temperature, humidity, carbon dioxide, ammonia, hydrogen sulfide, and ventilation rate), installation and data collection from these sensors are sometimes difficult and time consuming. Work by Heber et. al (2001) demonstrated a system to collect continuous air quality information in swine buildings. This system employed a central data acquisition location and acquired samples through the use of sampling tubes and electrical wiring. Many of the sample acquisition lines stretched to over 125 m in length. Figure 1 shows a general description of this type of monitoring strategy.

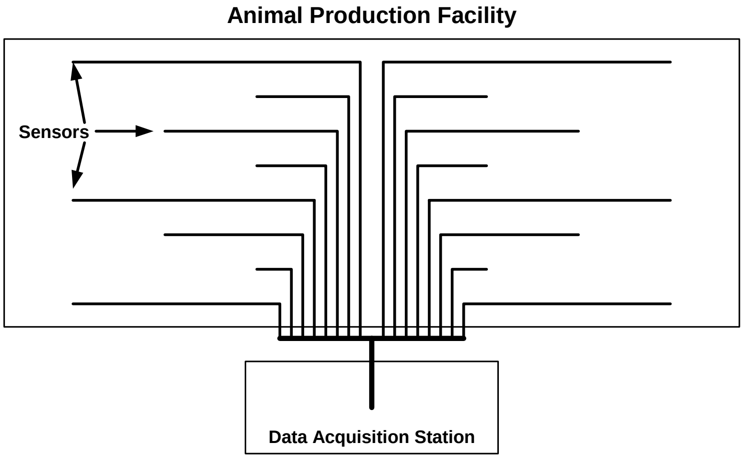

Figure 1. Traditional measurement methodology for animal production facilities.

Installation of a multi-point sampling system is time consuming and difficult (Figure 1). Extensive labor is required to correctly install the long sampling lines and sensor wiring. Furthermore, a large bank of data acquisition equipment is required to perform sampling of the multiple air environment parameters. In practice, a complete site installation can take well over six weeks to complete. The cost and complexity of this type of data collection makes it prohibitive for wide applications.

The measurement methodology depicted in Figure 1 has also been utilized by other researchers interested in air quality monitoring. Continuous monitoring of swine, dairy, and poultry was performed in 2001 using a similar methodology (Schmidt et. al, 2002). Furthermore, Whilhelm and McKinney (2001) successfully implemented a similar system for environmental monitoring within swine facilities. One conclusion made during this work was that buildings which appear structurally similar may be quite different when considering air quality. This points to a need for a cheaper and simpler system to monitor and evaluate air quality under multiple different environment and structural characteristics.

Alternative studies have focused on short-term air quality monitoring with single monitoring points (Redwine et. al, 2002, Xin et. al, 2003). These studies typically install individual sensors and data acquisition equipment at each sampling location. This adds complexity to data retrieval as each sensor must be downloaded separately and the possibility exists that the data may not be synchronous due to differences in the time stamp reference for each device. Also, the placement of these monitoring devices is often awkward as the equipment to monitor noxious gases and particulate matter is unsuited for even short-term stays within production animal facilities. While this technique does offer a reduced cost method of measurement, it has been conclusively shown that significant emission rate errors can occur due to insufficient measurement density caused by single-point monitoring (Parbst et. al, 2000).

The importance of air quality information along with the need for increased sampling density studies requires the use of sensor networking technologies, which have not before been applied to indoor environmental monitoring. Individual sensors are commercially available which provide sufficient sensitivity to the parameters of interest for indoor air quality monitoring. The limiting factor in conducting thorough studies is the lack of an inexpensive and reliable means to network multiple sensors and allow for rapid data collection.

Sensor networking has been applied in alternative disciplines when similar problems of connectivity have been apparent. A sensor network is defined as a series of intelligent sensors which not only act as signal transducers, but are also equipped with intelligent means to transfer and collect data values. Advantages of this system include simple expansion by adding more self-recognizing nodes and lower installation and setup costs.

Successful sensor network integration has led to advancements in many industrial fields. Factory automation has shown improved efficiency by incorporating sensor network technologies. Robotic machine capacity can increase due to an increase in the availability of sensory data and command instructions. Costs have also fallen due to a decrease in wiring by utilizing already present sensor network wiring. Flexibility has improved as sensor networks allow for improved distribution of monitoring and control systems over conventional methods.

Sensor networking is also not a new concept as it applies to agriculture. Various mechatronic research groups have implemented sensor networks over the past several years (Stone et. al, 1999, Tian et. al, 1999, and Darr, 2004). These groups have proven that reliable sensor networks can be developed in the harshest of operating conditions.

Sensor networks will enhance environmental air quality monitoring by allowing sensing nodes to be located in precise locations, allowing as many sensors as necessary to be installed within a facility, reducing the overhead installation cost, and allowing for rapid adjustment of sensor location to adapt to changes in the measured environment.

The Controller Area Network (CAN) protocol is an ideal platform for developing an agricultural sensor network. This protocol has been used widely in agricultural machinery and has the advantage of being a multi-master based network which relies on only two wires for shared communication (Stone et. al, 1999 and Darr, 2004). Several CAN sensor nodes can be linked over the same bus network and allow for data transmission between all points. In air quality applications, this is advantageous because the desired sample can be digitized at the source and the digital value can be transmitted to the appropriate storage device. This digitization process reduces errors associated with transmitting analog signals in long distances within noisy building environments.

CAN bus nodes are easily located throughout a CAFO (Figure 2). Once each sensor node is placed in the desired location, a single connection allows for multipoint communication.

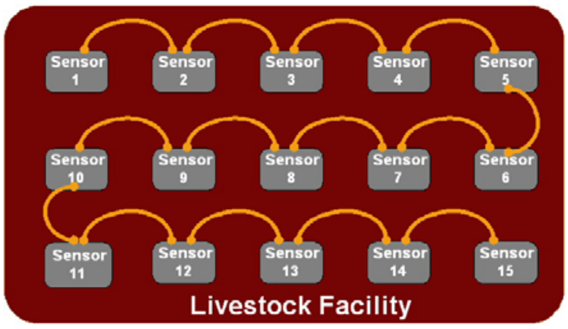

Figure 2. CAN bus installation in CAFO

Sensor networks show promise in enabling advanced methodologies for air quality monitoring, but preliminary research must be performed to identify how different technologies respond under the harsh environment of animal housing facilities. Improvements in this area will enhance the ability of researchers to quickly and accurately assess air quality emission load, enable producers to manage and control production facilities more efficiently, and will allow large corporate producers to monitor branch sites effectively.

OBJECTIVES

The general objective of this project was to evaluate the effectiveness of CAN bus communication over long bus segments. The bus lengths tested were comparable to those required for sensor networks within confined animal feeding operations. Specific objectives include:

1. Development of a CAN bus sensor network
2. Identification of critical CAN performance parameters
3. Testing of critical parameters as a function of bus length, data rate, and termination method
4. Development of a range of operating criteria for successful CAN implementation in livestock facilities.

METHODS AND MATERIALS

Development of a CAN Bus Sensor Network

A CAN bus sensor network was developed and tested during this project to evaluate its effectiveness in transmitting sensor data within large animal confinement facilities. Although few generic CAN data acquisition systems are commercially available, several standard microcontroller products contain hardware CAN controllers. The PIC18F258 from Microchip ® was chosen as the microcontroller of choice for this project based on its simple CAN implementation, low power consumption, sufficient analog to digital conversion capabilities, and researchers previous experience with the product line. The PIC18F258 was matched with an MCP2551 transceiver chip also from Microchip ® to provide the necessary level shifting for CAN bus communication.

A custom designed circuit board was developed to house the microcontroller, transceiver, and all necessary components for their operation. A 20 MHz crystal oscillator was used to provide adequate bit timing for CAN data transfer rates of up to 250 kbits/sec. On-board voltage regulation ensured a stable and noise free power supply for each individual node. Peripheral interfaces were also incorporated to facilitate LCD screen connection for data verification and for external signal conditioning such as filtering and amplification.

A daisy-chain wiring approach was adopted for this sensor network and Belden 1583A CAT5 cable was used to connect each node. This wire has an input impedance of 100 ±15 Ω and is commonly used in data transmission applications. RJ45 connectors were used to interface the physical data wires to the node circuit board. Bus termination was accomplished using passive resistor terminators at each end of the network.

Software development was realized by using the PIC Basic Pro Compiler from Micro Engineering Labs ®. It allowed simple access to the PIC18F258 registers via a BASIC language interface as well as provided multiple software routines to assist with peripheral interfacing and serial communication. The compiled hex files were transferred to the PIC18F258s via an EPIC EEPROM programmer, also from Micro Engineering Labs. Each of the network nodes operated based on a similar program with just the CAN identifier being different between the nodes. After startup, the nodes acquired sensor data via the signal conditioning circuits and transmitted the data along the CAN network.

Sensor data from each node was stored via a custom CAN bus data logger. This device integrated a PIC18F258 with a Compact Flash storage card. The specialized PIC accepted all CAN bus messages and stored the transmitting identifier and all data bytes to the Flash card for future analysis. The serial communication link between the PIC18F258 and the Compact Flash card was operated at 19.2 kbits/sec and was the limiting factor in the amount of data that could be recorded

Identification of Performance Parameters

Experimental testing was completed to evaluate the effect of bus length and data transmission rate on the efficiency of CAN message transmission. Three commonly used data transmission rates were evaluated: 50, 100, and 250 kbits/sec. Each was evaluated over varying bus lengths from 100 to 600 meters. Two nodes were used for each test and a successful message transmission was determined by noting whether messages were successfully passed from one end of the network bus to the other. Although this digital qualification ultimately determined if the bus parameters permitted data transmission, several other data transmission measurements were recorded to quantify the amount of attenuation and distortion present in each message.

Sources of data transmission errors are based on two unique sources. First, the signal attenuation increased as the bus length increased. This can be estimated quite accurately based on datasheets provided by the wire supplier. A second type of signal distortion existed due to data transmission reflections. By properly sizing the termination resistors, this reflection was minimized. The termination resistance should balance the wire impedance, which again was provided by the wire supplier. As the termination resistance of a bus increased, so did the amplitude of the differential signal because less current is drawn through the transmission lines causing less voltage drop from one end to another. But just as the differential voltage increased, so did the reflection which acted like a superimposed data transmission signal with an induced phase lag.

During ideal conditions, the nominal CAN differential signal had an amplitude of 2 volts. When considering the electrical characteristics of the transceiver though, it would correctly recognize any dominant signal greater than 1 volt and any recessive signal below 0.5 volts. If the reflected wave had a significant amplitude, it is possible that the superimposed reflected wave would have a magnitude greater than 0.5 volts and thus could easily cause bit errors during message transmission.

Physical Layout of Testing Method

In order to evaluate the CAN bus for each of the parameters discussed above, a series of tests were conducted over varying bus lengths and data transmission rates. Two nodes were connected via a specified length of Belden 1583A wire and a Tektronix TPS2000 oscilloscope was used to analyze the data signal at different points along the bus.

At the receiving node, the following parameters were measured:

1. Differential signal voltage, V_d
2. Differential signal rise time, T_r
3. Maximum to critical transition fall time, T_a
4. Maximum to critical transition fall voltage, V_a
5. Critical to zero fall time, T_c
6. Critical to zero fall voltage, V_c = 0.5 volts based on MCP2551 specifications

At the transmitting node, the following parameters were measured:

1. Reflection imposed excess fall time, T_b
2. Reflection imposed excess fall voltage, V_b

These eight criteria are illustrated below.

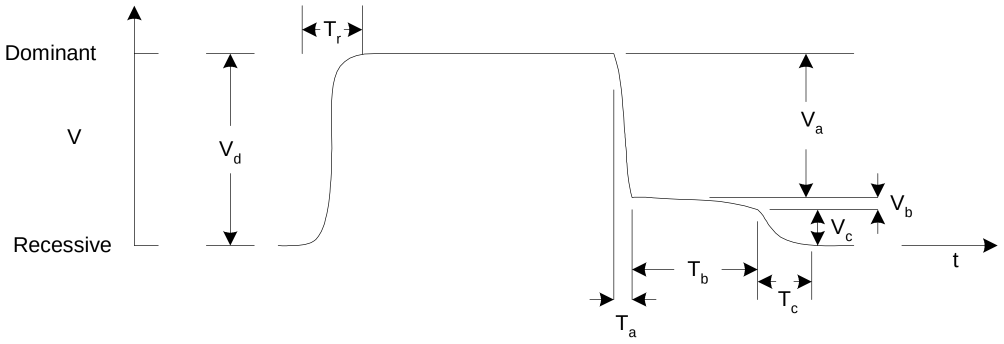

Figure 3. CAN Bus Bit Evaluation Diagram

It is clear from Figure 3 that if the imposed voltage from signal reflections is less than 0.5 volts then it will not affect the accuracy of data transmission. This is directly due to the transceiver maintaining a constant recessive differential voltage of 0.5 volts or less.

The number of successfully transmitted messages was also recorded and compared to the theoretical message transmission rate based on the data transmission frequency of 10 hertz. Message transmission success was broken into three categories: no errors, minor errors, and major errors.

RESULTS

Data Transmission Effectiveness Based on Bus Length and Baud Rate

A series of tests were conducted at 50, 100, and 250 kbits/sec and over a bus length of 100, 140, 180, 300, 450, and 600 meters. The termination resistance for all tests was set at 118 Ω as prescribed by many widely accepted CAN implementation protocols.

Table 2. Data Transmission Statistics for 50 kbits/sec Baud Rate

Bus Length (m)	Vr (Volts)	Tr (μsec)	Ta (μsec)	Va (Volts)	Tb (μsec)	Vb (Volts)	Tc (μsec)	Vc (Volts)	Success
100	1.780	0.200	0.060	1.280	0.000	0.000	0.612	0.500	Y
140	1.700	0.300	0.072	1.200	0.000	0.000	0.628	0.500	Y
180	1.600	0.400	0.096	1.100	1.800	0.300	0.850	0.500	Y
300	1.420	0.640	0.196	0.920	2.860	0.420	1.080	0.500	Y
450	1.260	1.040	0.260	0.760	4.220	0.500	1.980	0.500	Y
600	1.120	1.120	0.300	0.620	5.800	0.560	2.080	0.500	Y

Table 3. Data Transmission Statistics for 100 kbits/sec Baud Rate

Bus Length (m)	Vr (Volts)	Tr (μsec)	Ta (μsec)	Va (Volts)	Tb (μsec)	Vb (Volts)	Tc (μsec)	Vc (Volts)	Success
100	1.780	0.150	0.060	1.280	0.740	0.280	0.460	0.500	Y
140	1.700	0.252	0.076	1.200	1.050	0.300	0.496	0.500	Y
180	1.600	0.292	0.100	1.100	1.860	0.340	0.568	0.500	Y
300	1.420	0.432	0.190	0.920	2.860	0.440	0.850	0.500	Y
450	1.280	0.528	0.250	0.780	4.240	0.500	1.200	0.500	Y
600	1.020	0.752	0.230	0.520	5.240	0.520	1.410	0.500	Y

Table 4. Data Transmission Statistics for 250 kbits/sec Baud Rate

Bus Length (m)	Vr (Volts)	Tr (μsec)	Ta (μsec)	Va (Volts)	Tb (μsec)	Vb (Volts)	Tc (μsec)	Vc (Volts)	Success
100	1.760	0.116	0.072	1.260	0.980	0.220	0.276	0.500	Y
140	1.680	0.220	0.086	1.180	1.420	0.260	0.340	0.500	Y
180	1.600	0.280	0.104	1.100	1.800	0.320	0.472	0.500	Y
300	1.460	0.460	0.172	0.960	2.980	0.460	0.680	0.500	C_1
450	1.340	0.670	0.310	0.840	3.900	0.360	1.050	0.500	C_2
600									N

All bus lengths for 50 and 100 kbits/sec allowed successful message transmission. This was based on physical indications that the messages and data values were successfully transferred between the two test nodes. For the 250 kbits/sec, successful message transmission was only attainable up to the 180 m bus length. At the 300 meter bus length an occasional message was repeated unnecessarily due to mistaken acknowledgement bit recognition (C_1). At 450 meters this same problem existed, although on a much larger scale (C_2). Above 450 meters, message transmission was unattainable.

As expected, the differential voltage signal attenuation increased as the baud rate increased. This is readily shown as the general trend for V_r declines as the bus length increases. It was found though, that none of the tested baud rates and bus lengths produced a signal amplitude below the threshold dominant level for the MCP2551 transceiver. Both the 50 and 100 kbits/sec baud rate did come close to the 1 volt threshold and in practice careful consideration would be required to ensure that increased attenuation would not develop with normal system operation.

Signal reflection was measured in significant magnitude and is denoted above by T_b and V_b. In most cases though, the magnitude of V_b was less than 0.5 volts and thus did not affect the accuracy of data transmission.

Data Transmission Effectiveness Based on Termination Resistance

A second termination resistance of 148 Ω was tested and did improve the differential voltage (V_r) as expected, but also increased the reflection of the network to a level that was no longer negligible.

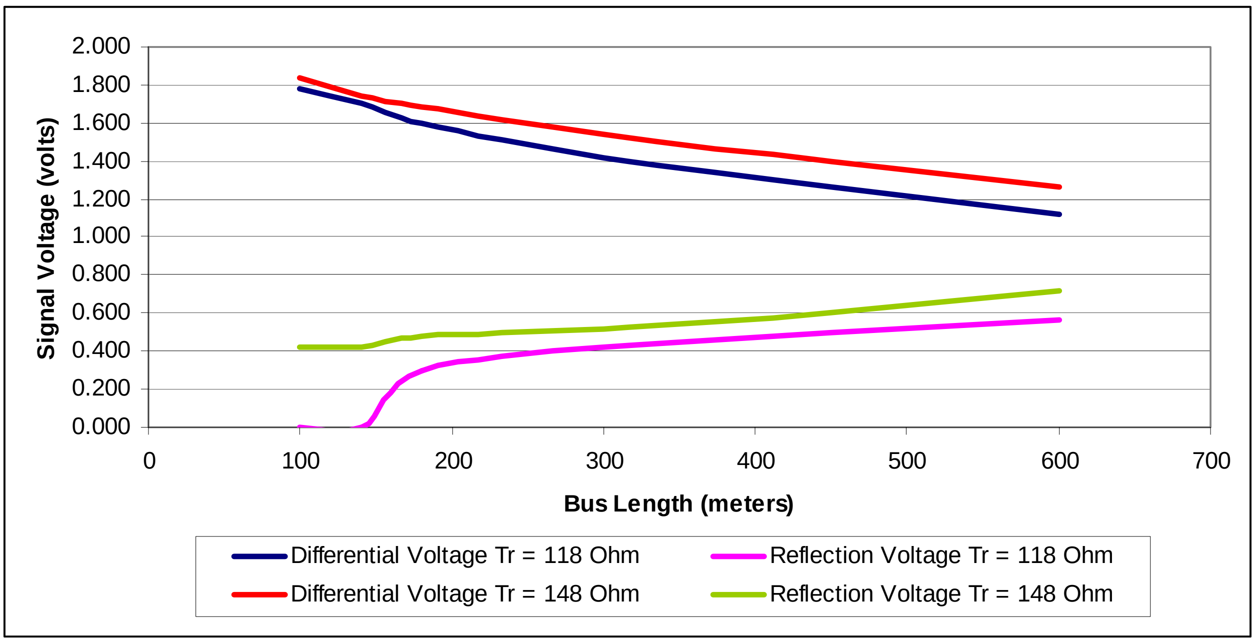

Figure 4. Effect of termination resistance on differential signal voltage and reflection voltage

Cause for Minor Data Transmission Errors

Minor data transmission errors occurred due to a lack in acknowledgment bit recognition by the transmitting node. The receiving node indicated that the message was successfully acquired without errors and should have driven the second recessive acknowledgement bit dominant as an indication to the other node that at least one listener was present. The assertion of this bit was unsuccessful due to signal attenuation and reflectance of the data signal.

Recommendations for Reliable CAN Systems

A reliable CAN system must be one that is guaranteed to operate within harsh conditions and has a factor of safety build in to overcome unforeseen problems. With this said, the authors advise that extreme care be taken when designing a CAN system to ensure signal attenuation and reflectance levels are within appropriate ranges. Always experimentally measure the actual system attenuation as different node components and wire types can influence the operational characteristics of a system.

When longer bus lengths than those described in this paper are required, it is advisable to utilize CAN repeaters to boost the signal qualities and prevent undesirable attenuation. Great care must also be taken to minimize the stub length of CAN nodes as this will add directly to rising data reflection problems.

CAN Bus Bandwidth Capacity Approximation for Air Quality Monitoring

As a traditional rule, most CAN networks should be designed to operate at 35% of the maximum bus capacity. This is done traditionally to allow for segments of increased bus traffic and to ensure that critical messages are able to quickly reach the network. The use of CAN bus systems for general data acquisition can stretch the bus load capacities since the frequency and length of each message is already known and since critical control messages are not being transmitted. Based on these parameters a bus load of 70% capacity is suitable for data collection applications. If repeaters are used to boost signals the total bus load for all linked busses must be below the designated threshold level.

Transmission Units are defined as the total number of 8 byte data messages that can be transmitted per second over a single network. A single node may send several transmission units depending on the number of sensors interfaced with that particular node. The maximum number of transmission units can be calculated if the data rate and target maximum bus load are known (Equation 1). The factor of 134 in Equation 1 is the number of bits per CAN message and is used as a unit conversion factor.

$$Transmission\,Units\left(\frac{Messages}{Second}\right)=\frac{DataRate\left(\frac{bits}{\sec}\right)*BusLoad(\%)}{134\left(\frac{bits}{message}\right)} \tag{1}$$

Table 5. Transmission Unit Capacity as a Function of Data Rate

Data Rate (kbits/sec)	Number of Transmission Units	Number of 16 bit Sensor Data Points
50	261	1044
100	522	2088
250	1305	5220

CONCLUSION

Based on this work it was found that 50 kbit/sec baud rate CAN bus data can be successfully transmitted up to 600 meters. This will allow over one thousand 16-bit sensor data points to be collected per second. This meets the need for most data collection applications within confined animal feeding operations and provides an open-ended means to expand on the data network for future applications. It was also found that adjusting the termination resistance did not improve transmission content, but rather that the most desirable results indicate accurately matching termination resistance with input impedance of the network wiring is critical.

FUTURE WORK

Work in sensor networks is currently being expanded to integrate wireless networking capabilities and remote data collection. Specifically, support is pending for research into telemetry systems that will directly link to environmental data networks and present the data in an online format for storage and access.

ACKNOWLEDGEMENTS

Salaries and research support provided by state and federal funds appropriated to The Ohio State University, Ohio Agricultural Research and Development Center.

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