

Wireless Sensor Node System to Monitor Pig Activities for Behavior Classification

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Abstract—Wireless sensor nodes (WSNs) are useful to monitor animals remotely and continuously. The proposed WSN aims to monitor pig activities, and it consists of a 3-axis accelerometer, a 3-axis gyroscope, and a microcontroller with embedded BLE (Bluetooth Low Energy) radio. The WSN was designed and prototyped with a custom PCB and used to collect data from pigs in field for about 131 hours, and the collected data was processed to classify pig behaviors with machine learning models. The sampling rate of the sensors is 10 samples per second. The proposed WSN dissipates 6.29 mW, on average, and the peak power dissipation is 41.01 mW during transmission of the sensed data. The WSN is estimated to operate for about three weeks with a coin cell battery CR2477.

Index Terms—Pig monitoring, wireless sensor node (WSN), 3-axis accelerometer, 3-axis gyroscope, BLE radio.

I. INTRODUCTION

The swine industry supplied an estimated 27.8 billion pounds of meat in 2020 according to a USDA livestock report [1]. Production efficiency is achieved by frequent visits to farms or manual reviews of recorded videos to monitor adverse behaviors in pigs [2]. However, these approaches can be subjective and laborious. Animals are managed increasingly as large groups, in particular pigs, who are social animals. This group-based management is challenging as careful monitoring of individual animals is labor-intensive [3].

To assess individual animals' health and welfare objectively and continuously, animal monitoring using sensors and video cameras have been investigated in the past decade and aims to provide necessary information. Virtually all existing sensor nodes sense accelerations of pigs [4]–[11] at one or multiple locations. To monitor pigs remotely, it is necessary to wirelessly transmit the sensed data to a local computer, which uploads the data to a cloud server [9]–[11]. The major challenge for wireless data transmission is power dissipation of wireless sensor nodes (WSNs). Once WSNs are attached to pigs for sensing, it is highly desirable for the WSNs to operate for about six months, until the pigs reach market weight, so that the remote monitoring can continue without human involvement to replace WSN batteries.

Haladjian et al. presented a WSN composed of an Inertial Measurement Unit (IMU), an ARM Cortex microcontroller, and the WSN transmits the sensed acceleration data with Bluetooth Low Energy (BLE) [9]. The team collected data from a pig in outdoor for 320 seconds in total. The WSN is described briefly at a high level and power dissipation of the WSN is not mentioned. To our knowledge, it is the

first WSN for pig monitoring presented in open literature. Pandey et al. developed a WSN composed of various sensors (such that temperature and sound sensors, accelerometer, and gyroscope) and a microcontroller with embedded BLE (i.e., NRF51822 SoC) [10]. The WSN transmits sensed data to a nearby receiver by BLE, and the team collected data from two pigs in a pigpen for 75 minutes. It is expected the sensor node would operate over 3 days with a coin cell battery CR2032. We developed a WSN composed of a 3-axis accelerometer and a 3-axis gyroscope, and our WSN also transmits the sensed data to a nearby PC by BLE. Our WSN is integrated with a video camera for data analysis, and we collected data for 131 hours over two months from pigs in a pigpen. It is expected our WSN would operate for about three weeks with a coin cell battery CR2477. Unlike the above two publications, we present detailed power measurement results of our WSN, which indicates the major source of power dissipation of transmission of the sensed data. The data collected by the above three WSNs are processed to classify behaviors of pigs, and classification results for our WSN system is presented in [11].

The rest of the paper is organized as follows. Section II reviews the sensors and the microcontroller used to develop the proposed WSN. Section III presents the system overview, the proposed WSN design, and the data transmission. Section IV presents the experiment set-up and measurement results, and Section V draws conclusion.

II. PRELIMINARIES

This section presents two different types of sensors and the microcontroller with embedded BLE radio, which are used to design and prototype the proposed WSN.

A. Sensors

Two different sensors, accelerometer and gyroscope, are used for the proposed WSN to measure linear acceleration and angular speed on three dimensions. An important consideration for the selection of those sensors is low power dissipation but a sufficient data rate, while simultaneously maintaining an acceptable digital range for design are capable of measuring pigs' motion behavior on the sensor range. A sufficient data rate of ensures the speed of data transmission in the system, while having an acceptable digital range ensures the maximum data can be collected for data analysis. With this criteria in mind the following sensors were selected for the proposed

design, BMA400 for the accelerometer and BMG250 for the gyroscope.

1) *Accelerometer*: The BMA400 3-axis ultra-low-power accelerometer, was produced by Bosch. This WSN design selected this accelerometer due to its low power requirement, high accuracy, and high precision. The selected accelerometer has a maximum measurement range of $\pm 16 \times 9.81 \text{ m/s}^2$ which is more than sufficient to track pigs' acceleration [12]. Additionally, the digital resolution of a 12-bit unsigned integer gives sufficient resolution on data analysis [12]. Most importantly, the current consumption of the selected accelerometer in typical use cases is as low as $5.8 \mu\text{A}$, and the current consumption can be lowered to $3.5 \mu\text{A}$ for low-power uses cases. If a higher level of performance is needed, the current consumption of the selected accelerometer running at maximum performance does not exceed $14.5 \mu\text{A}$ [12].

2) *Gyroscope*: The BMG250 low-noise, low-power triaxial gyroscope, is the gyroscope that was selected for the proposed wireless sensor node design. This gyroscope was selected for the proposed design due to its low power requirements, high accuracy, and high precision. The selected gyroscope has a maximum measurement range of $\pm 2000^\circ/\text{s}$ or $\pm 5.55 \text{ rev/s}$, which is more than sufficient to measure the angular speed that pigs can exhibit; additionally, the digital resolution of a 16-bit unsigned integer gives a sufficient resolution for data analysis [13]. Most importantly, the current consumption of the selected gyroscope in full operation does not exceed $850 \mu\text{A}$, and the current consumption can be lowered to $500 \mu\text{A}$ for fast start-up mode, additionally, the current consumption can even be lowered to $3 \mu\text{A}$ for low-power mode [13].

B. Microcontroller

Our WSN adopts a microcontroller with embedded Bluetooth radio, Texas Instruments CC2640R2F owing to low power consumption. Figure 1 shows a TI CC2640R2F launchpad. The CC2640R2F microcontroller supports BLE for wireless data transmission [14]. The microcontroller has a clock speed of up to 48 MHz, with 275 KB of nonvolatile memory and 128 KB of in-system program to flash [14]. It supports UART, I²C for on-chip data processing [14].

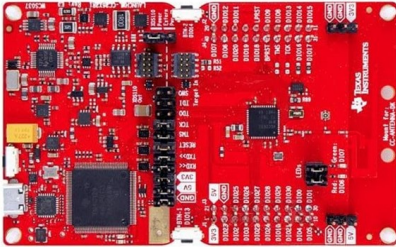


Fig. 1. TI CC2640R2F Launchpad [15].

III. PROPOSED WIRELESS SENSOR NODE

The proposed WSN collects 3-axis acceleration and 3-axis gyroscope data from pigs and wirelessly transmits the sensed data to a nearby PC. The sampling rate of the sensors is 10 samples per second.

A. System Overview

Figure 2 shows the overview of the proposed system. The sensor node is attached to the body of the pig for data collection, while a harness is used to stabilize the sensor node. The sensed data is wirelessly transmitted to the associated receivers connected to the host PC, which stores the sensed data. A camera on the ceiling records the pig activities for data labeling, and the images are also stored at the same host PC.

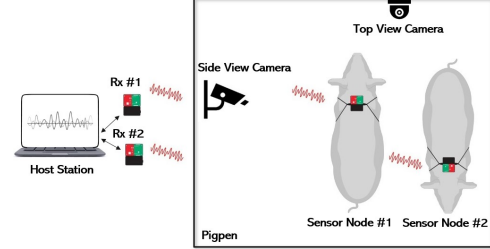


Fig. 2. System Overview.

B. Wireless Sensor Node

Figure 3 shows the proposed wireless sensor node. The bottom PCB (in red) is the TI launchpad, and the top PCB (in blue) is custom made to attach an accelerometer and an gyroscope. The microcontroller reads the data from sensors and transmits the data wirelessly using the embedded BLE radio. The sensors are wired up to the microcontroller with a I²C configuration. The program flow for the WSN and Receiver is shown below in Figure 4. To briefly summarize, the WSN initializes its program, performs a handshake with the receiver, starts I²C communication with the sensors, initializes the sensors, reads, processes, and transmits the data; then the program sleeps until it is time for the next transmission. The Receiver on the other hand initializes, performs the handshake with the WSN, and waits to receive data; then the data is formatted and outputted via UART to the central computer.

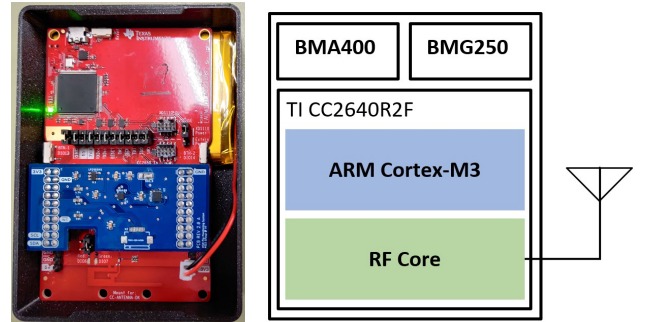


Fig. 3. Proposed WSN (left) and Block Diagram (right).

C. Data Transmission

The EasyLink data transmission architecture of Texas Instruments is the BLE transmission protocol adopted for the proposed design. The EasyLink architecture offers minimal delay for data transmission [16], and it is relatively easy to integrate with external sensors and process the data on-board.

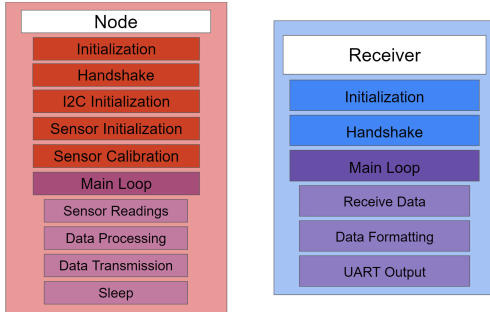


Fig. 4. Program Diagram for Node and Receiver.

The sampling rate of each signal for the 3-axis accelerometer and the the 3-axis gyroscope is 10 samples per second (SPS).

D. PCB Design

We designed a custom PCB of size 58.50×28 mm for the proposed WSN as shown in figure 5. The PCB includes both the accelerometer (BMA400) and the gyroscope (BMG250) for data collection. Two 2×20 female pin sockets were soldered on the PCB to achieve connection with the TI-CC2640 launchpad. Additionally, a 10-pin FFC connector was reserved on the printed circuit board for future extensions for the node array, namely a planned temperature sensor and a heart-rate sensor.

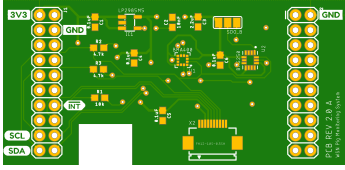


Fig. 5. Printed Circuit Board Layout.

IV. MEASUREMENT RESULTS

A. Field Testing

Figure 6 shows the field test to verify the operation of our WSN system initially and then collect data to classify behaviors of pigs. To verify the operation, WSNs and receivers were tested using a simple python program to visualize the data. Then the nodes underwent a series of test motions to verify functionality of the sensors. These test motions were performed alongside the data visualization program which displayed and graphed the values transmitted. After that, the nodes were attached to the harnesses and the harnesses was attached to the pigs. Finally, the data capture program was initialized and a video feed of the pigs was recorded alongside the data transmitted by the node. In total, approximately 131 hours of data was collected using this method. This total accumulation of data occurred over several weeks in chunks ranging from a twenty-four hour period to shorter two to four hour periods a day. These shorter periods were performed in order to collect data from the pigs during periods of the day where they were more active, as we quickly found that data collected during a 24 hour unsupervised period would result in the pigs sleeping or lying down for the vast majority of the time. Though an amount of sleeping or lying prone data

was useful to us the majority of useful data was only obtained during supervised portions of the test.



Fig. 6. Field Test.

During most of the field testing the pigs were supervised to ensure useful data was obtained. This supervision involved having one or more members of the project inside the pig house observing the pigs in real time. This observation had an added benefit in the opportunity to prevent the pigs from interfering with the harnesses placed upon each other, As the pigs were often very inquisitive and would examine the harnesses during the field testing. Additionally, during the field testing two cameras were used to record the actions of the pigs and were synchronized to the sensor data streams. This allowed for later verification of the pigs activities and the sensor data generated by those sensor readings.

B. Data Verification

Data verification for the proposed WSN system occurred in two phases. Before field testing occurred lab tests were conducted in order to verify accurate reading from the WSN sensors. After field testing data labeling was performed to show a direct and accurate correlation between pig activities and our derived sensor readings.

Before field test data acquisition testing was performed using a simple data capture program and a series of controlled test motions to verify the accuracy of the accelerometer and gyroscope present on the WSN. During the course of this testing the WSN underwent controlled rotations and axial movement and the retrieved data was observed to match expected values. Once the validity of the WSN sensors was established field testing was performed to verify that the WSN would be able to capture relevant data in practice.

After data had been acquired during the field test, its authenticity was tested by labeling the data and checking the correspondence between recorded video actions and the values obtained from the sensor node at that time. As an example of our data verification process, an accelerometer and gyroscope sensor output of a pig from moving around to lying down and shaking the body is shown in figures 7.

From the accelerometer waveform shown in figure 7, the waveform swing was high for the first five seconds, which matches up with the pig's behavior of moving around. For the later ten seconds, the accelerometer output tends to a more steady waveform, but a smaller data swing still exists, which matches up with the behavior of lying down and shaking. The gyroscope output shown in figure 7 also clearly demonstrates the pig's behavioral change. A huge swing during the first

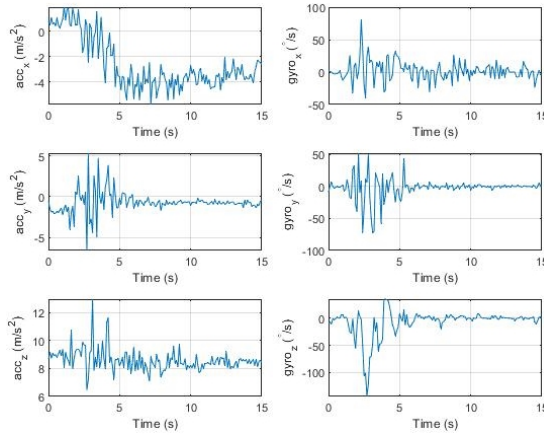


Fig. 7. Accelerometer and Gyroscope Sensor Waveform Outputs.

five seconds compared with a smaller swing in the later ten seconds matches up with changing from an active behavior or a lying behavior.

Multiple field tests were conducted to ensure that the data was both valid and significant. Field tests were conducted over the course of a month and were all of the variable length, ranging from a minimum of an hour and a half to at most twenty hours worth of data being recorded in a single day. After the completion of the testing period, a total of 14 individual field tests were completed. Data from two pigs at a time was collected during each of these tests. The total sample size of the project was four individual pigs, which we believe is enough to generalize our results to a larger population. In total, 140 hours of data were collected from the wireless sensor nodes, and verification of the data was completed using the method mentioned in the previous paragraph.

C. Power Measurements

The proposed system's power consumption measurement was completed with an Analog Discovery 2 (AD2) scope, under the condition of removed connection between XDS 110 debugger chip and LEDs. A voltage of 3.4 V from the AD2 scope is supplied to operate the system.

Four milliseconds of power measurement are taken for analysis, where four data packages are measured and sent to the receiver, with a power measurement waveform output shown in figure 8. Each subplot describes the voltage, current, and power measured across the microcontroller power input. A pulse is detected every 10 milliseconds indicating a data package is transmitted to the receiver, while the non-pulse waveform shows the power consumption when the MCU is computing. As a result, when the proposed system is not transmitting data to the receiver, the computational power consumption can go as low as 6 mW with a current consumption of 1.8 mA. The power consumption when the proposed system is transmitting data can go up to 40 mW with a current consumption of 12 mA. With consideration of both computing and data transmission, the proposed system has an average power consumption of 6.285 mW with an average current consumption of 1.852 mA under a voltage of 3.393 V, which

means the proposed system can approach a battery life of roughly 22 days using CR2477 coin cell battery.

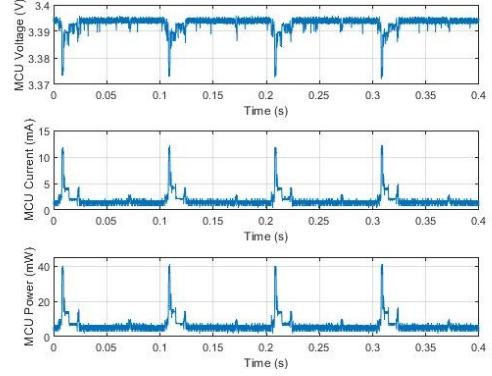


Fig. 8. Power Measurement Results.

V. CONCLUSION

This paper presents a WSN system to monitor activities of pigs. The proposed WSN system collects acceleration and angular velocity of pigs and transmit the sensed data to the host PC wirelessly. We verified of operation of the WSN through the field testing and successfully collected data from pigs about 131 hours in total over two month period. and the collected data was processed to classify pig behaviors with machine learning models. The proposed WSN dissipates 6.29 mW, on average, and the peak power dissipation is 41.01 mW during transmission of the sensed data. The WSN is estimated to operate for about three weeks with a coin cell battery CR2477. The measurement result shows the proposed WSN dissipates low power, which leads to less frequent change of the battery.

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