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A Sound-Based Monitoring and Evaluation System for Small-Scale Dairy Operations

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Abstract − Continuous monitoring of livestock operations is vitally important for a sustainable production system. Monitoring systems based on cameras are not sufficient in livestock barns since they require visual inspection and ignore vocal conditions within the barn. These systems are also quite expensive for most small family operations. A prototype device that costed $ 470 developed to remotely monitor the barn based on sound sensors (microphones) data. This device also warns the operator by sending an SMS at sound intensities exceeding the predetermined durations and threshold values. It also makes it possible to listen to the barn by phone if needed. The device and associated web database was tested in this study. The main challenge was the determination of threshold values at which sensors are to generate warning SMS messages. As a method, Z-score of 2.33 which corresponds to area left of the 99% of the normally distributed data curve was determined representing the highest values with a possibility of 1% observation for each sensor. An average value of 97 dB was determined to be a threshold suggestion for future studies. A customizable web-based MySQL database was created to monitor and evaluate the long term data collected via the system.

Keywords − *Arduino, dairy housing, sound sensor, noise monitoring.*

1. Introduction

Modern herd management practices and technologies cause animals to become more sensitive to environmental stimuli and stress (Demirören and Taşkın, 2004). It may not be adequate to explain or reveal stress and animal welfare with discrete methods. For example, it is not enough to state that the animal is 'in harmony' with the surrounding conditions (Lorz, 1973; Hughes, 1976). Nor are these explanations useful in the scientific view of livestock wellbeing. Other measures related to the livestock's responses to control the relevant environmental conditions that cause stress and are more descriptive (Wiepkema, 1982; Broom, 1986). These terms measure the welfare of the animal and the effort of the animal to cope with the environmental factors that cause stress with perceptible parameters (Broom, 1996; Duncan, 1996).

In this context, there has been many research conducted to explain the stress-induced behaviors among livestock under the influence of environmental stimuli. If these behaviors are not detected correctly and in a timely manner, overall animal performance may be affected. In recent years, there are many studies on the use of information technologies to minimize these effects (Chung et al., 2013a; Chung et al., 2013b; Lee et al., 2014; Lee et al., 2015; Mendes et al., 2015; Ahmed, Mun, Islam, Yoe & Yang., 2016). Observing animal behavior by placing a camera in the barn for visual evaluation of livestock welfare is one of the simplest

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and first imaginable methods. Moreover, it is possible to obtain different information by analyzing animal behavior in computer using different algorithms (Rushen, Chapinal & Passillé, 2012).

One of the environmental factors that cause stress in animals is noise. Mammals show startle, freeze or move away from the sound source response above 90 decibel (dB). Animals are more comfortable at intensities below this value. It is also reported that reactive behaviors to sound vary according to sound type and content, and that mammals can adapt to sound with some minimal differences (Anthony, Ackerman & Lloyd, 1959; Bond, Winchester, Campbell & Webb, 1963; Ames and Arehart, 1972; Espmark, Falt & Falt, 1974; Ames, 1978). The acceptable noise level in the barns is reported as 85 dB in the regulations. However, it is reported that the measured intensity can reach up to 106.8 dB due to the different works done inside the barn with a background noise level of 72 dB. Hence, acceptable sound intensity in the barn may vary between 72 and 85 dB (Anonymous, 2006).

Animals not only develop stress due to environmental sound, but also make sound as an indicator of stress. Vocalization of cattle is an indicator of stress. The cattle sound has a frequency range of 50-1,250 Hz (Kiley, 1972; Watts and Stookey, 2000). Newly weaned calves have been noted to make sounds at frequencies as low as 31 Hz (Watts and Stookey, 2000). Average sound levels from cattle may vary between 80 and 90 dB (Weeks et al., 2009). In fact, cattle can detect sounds as low as 25-35 kHz (Heffner and Heffner, 1992). Therefore, knowing these threshold values reveals the potential of using today's technologies to determine stress based on animals' sound.

Sound levels of dairy cattle barns must be monitored, as it is a sign of conditions related to loss of life beyond the loss of productivity and welfare. Operations are usually monitored by security cameras. However, it is not possible to continuously monitor the security camera images. Therefore, they can't be aware of the conditions that may occur in the barn and to take the necessary precautions when the operator is out of the operation. Approximately 99% of dairy farms in Turkey are small family businesses with 50 heads or less. It is very expensive for these small businesses to have the technology to continuously monitor and evaluate noise in the barn. Producers are looking for low-cost solutions that can warn them based on the sound level inside the barn rises above normal levels and allow them to listen inside the barn. In this sense, the most important problem is the lack of technology to intervene in a timely manner in cases where animals get sick, injured or even when there are security problems in the barn.

In this study it was aimed to develop an easy-to-use; low-cost barn noise tracking system that can work with the most widely used smart mobile phones. The features of the system were to monitor the environmental conditions related to the sound in the barn via a mobile phone, to intervene in a timely manner when needed, to listen to the barn from outside the operation, and to collect sound-related data for further analysis. The proposed technology also provided a database to evaluate the overall noise level that cause environmental stress on both animals and workers.

2. Materials and Methods

2.1. Experimental Setup

The prototype device was developed in the Digital Agricultural Laboratory in Çanakkale Onsekiz Mart University, Faculty of Agriculture, Department of Agricultural Structures and Irrigation. The device was fixed in a double row free stall dairy barn housing 80 Simmental cattle located in Çanakkale Province, Biga District, Çınarköprü Village, Turkey. Average milk yield in the enterprise was 20 lt.day^{-1}. Seven microphone sensors were placed in the 30 m long and 15 m wide barn. The main station (prototype device) was fixed to the middle bar of the roof truss at the center of the barn on the service road. Microphones installation plan and cross-sectional view of the barn showing the microphones and main station is given in Figure 1. The microphone fixed to the main station is denoted as Mic-0 and the remainders are numbered through Mic-1 to Mic-6. It was observed that the replacement height (2.5 m from the ground) of the microphones had ignorable effects on the recorded data.

The main station device recorded microphone data in the database at specified intervals. In addition, the automatic answering system which was used to listen to any microphones was also in the main station.

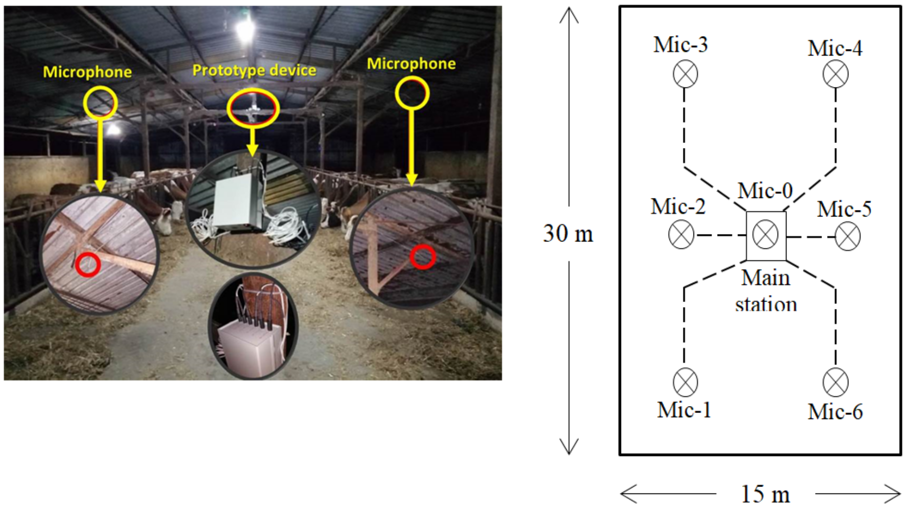

Figure 1. Microphone installation plan

2.2. Development of the Prototype Device

The system consists of a main station (prototype device), software, and a web-based database. It is essential that these three components communicate with each other continuously in order to allow real-time sound monitoring, collecting the sound data and generating instant alerts based on the alarm set points. The schematic representation of the prototype is given in Figure 2.

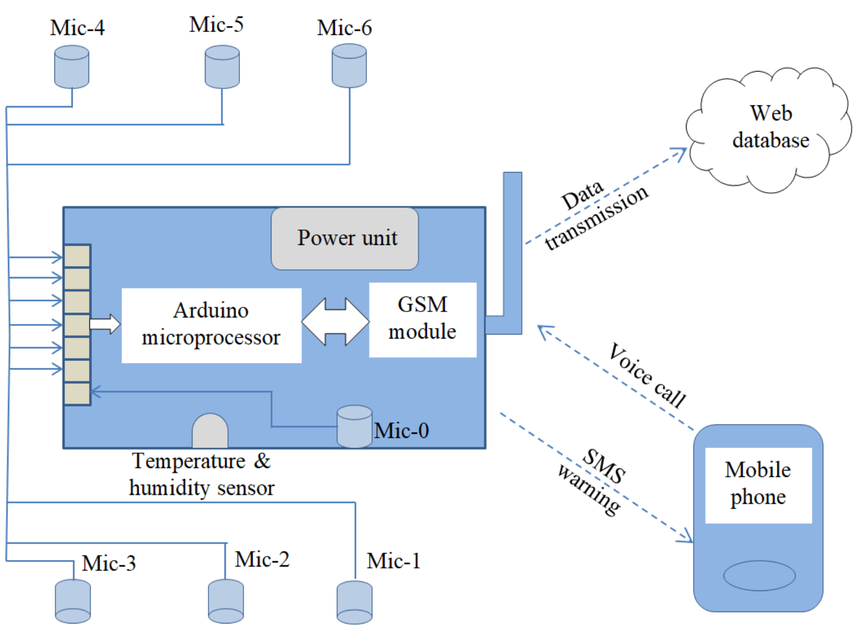

Figure 2. Schematic representation of prototype

An Arduino microcontroller was used to integrate all sensors and related electronics. Six sensors (Mic-1 to Mic-6) transmitting the sound data to the main station via cables and the central sensor (Mic-0) were soldered to the relevant analog inputs. It was also expected to listen to the real-time sound in the barn when needed. The microphone located near the loudest sound source should be selected automatically. Since there were 7 microphones connected to a single output, it was inevitable for the sounds at different points to overlap. To prevent such situation, a digital channel selector (multiplexer) was used to listen to the microphone closest to the sound source. This module has 4 selective channels depending on the sound data obtained from the analog inputs. Based on the combinations of on-off information sent to these channels, the relevant microphone was listened.

Microphone module (ON Semiconductors, Phoenix, Arizona, USA) integrated on the Arduino microcontroller is a low-cost technology consisting of an amplifier circuit card with three different outputs including analog audio output, sound detection and level outputs. In this way, the sound can be output directly, the presence of any sound in the environment can be detected and the level of the sound can be measured. Each output works independently of each other and can all be used at the same time. In this way, sound levels at different points could be recorded and the microphone that detects the highest intensity could be selected for listening. The components on the microprocessor have different energy demands in the stationary and active phases. It is vitally important to maintain consistent power to the system at all times. Using an external power supply module that only meets the energy needs of the sensors has eliminated the potential power problem.

The prototype system can also record the temperature and relative humidity at desired time intervals. The aim here was to observe temperature/humidity, which is another important stress factor, along with the stress that noise can cause. A SHT11 sensor that can measure both temperature and relative humidity (Sensirion AG, Staefa ZH, Switzerland) was used in the prototype. This sensor measures the air temperature and relative humidity with high accuracy and sends them to the microprocessor unit. Although temperature and humidity data were recorded, they were not evaluated in this study.

Arduino GSM Shield-Simcom/Sim800C unit was used in order to send the data received from the sound and temperature/humidity sensors to the server via the mobile network. Due to its ability to operate in four different bands and its internal antenna, data transmission can be prevented from being interrupted in areas where the network signal is weak. Unlike other components, the GSM module needs a consistent power supply. If it cannot get enough power, it stops the communication in order to protect the system. An uninterruptible power supply was built into the prototype device to prevent power surges and short-term interruptions inside the barn from blocking the system. This unit consists of 6 lithium batteries and a battery recharge module. This power supply not only protects the device from fluctuations caused by the city current, but makes it possible to operate during interruptions that may occur up to 4 hours.

2.3. Sensor Calibration

The microphones produce digital output of 8-bit integers varying between 0 and 1024. Therefore, the microphone data should be calibrated to obtain sound levels in decibel (dB). In order to develop a calibration setup, a unit that will produce constant sound and another unit where sound data can be monitored were designed. The sound generator to be used in the experimental setup must provide sound with a constant frequency and intensity. For this reason, active piezo speaker was preferred. The piezo speaker works with the logic that the two-layer plate inside is deformed under electrical load and then returns to its original form. Depending on the applied electrical load, the intensity of the sound produced remains constant. In addition, its active operation ensures that the sound frequency is equal to that of the electric charge.

The electric charge passing over the piezo speaker must be controlled in terms of frequency and intensity. These parts, called drivers in sound generators, require a microcontroller. Considering the power demand of the unit an Arduino Nano (Arduino LLC., Italy) control card working with ATmega328P microcontroller was used. The operation of the digital output terminal at 1 ms intervals was specified. In this way, it was ensured that the piezo speaker remains constant at a frequency of 1000 Hz. Another component required in the design of the unit is an interface where sensor data can be monitored simultaneously. In order to ensure the flexibility of the experimental setup and the continuity of the data flow, it was needed to be directed to a mobile device wirelessly. For this purpose, HC-05 Bluetooth Module (ITEAD Intelligent Systems Co. Ltd., China) was used. Since this module uses the serial communication channels of the microprocessor control card, it does not cause any interference in the sensor data. Schematic representation of the calibration unit is shown in Figure 3.

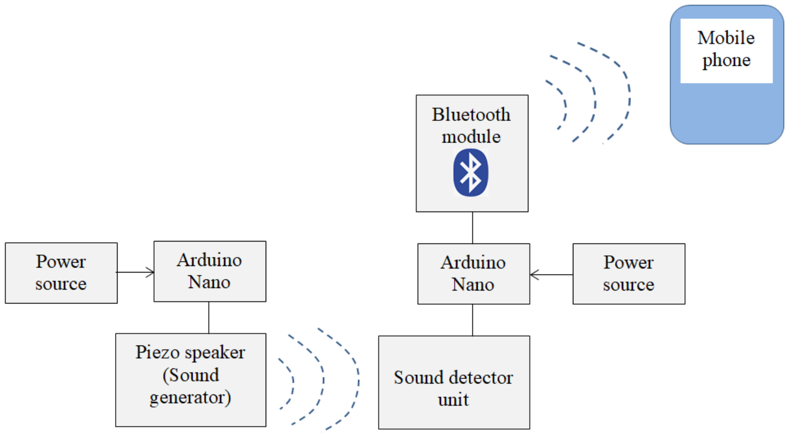

Figure 3. Assembly diagram of the calibration unit

2.4. Software and Database Development

The open source platform (Arduino IDE) provided by the microcontroller card was used to develop the software. Arduino IDE employs C/C++ programming language. Each microphone continuously transfers the sound data to the Arduino mainboard. In addition, they transmit the ambient sound to the audio input jack of the GSM unit. The sensor directed to the audio input jack of the GSM unit was also determined by the multiplexer module. On the other hand, the correct sensor command was given to the channel selector module via the Arduino. In this case, time should be allowed to channel selector to operate by monitoring the level data from the microphone modules in 3-second cycles. In each cycle, the selector combination required for the sensor module with the highest loudness was transmitted to the channel selector module. Apart from the resting cycle of the sensors, the frequency of the data to be transmitted to the database was another cycle in the software. The shortest interval allowed for login in the web database was 1 minute. Hence, data is recorded in 1-minute intervals.

Another expected capability from the prototype was to create a warning SMS in case the threshold values are exceeded, which is provided by another cycle specified in the software. Accordingly, 5 minutes of sound level above the threshold values should create a warning SMS. When the GSM module is called to listen to the voice in the barn after the warning SMS is received, the call should be answered automatically. The command to provide automatic response must be active continuously between sending data and sending SMS. Therefore, this command is associated with the starting point of the first loop of 3 seconds. Thus, when the barn is monitored, it was automatically directed to the microphone with the loudest sound, and as long as the call continues, all microphones were tested every 3 seconds and if the sound source was in motion, the relevant microphone was activated.

It was aimed that the sensor data obtained from the barn is collected in the web database. There are different options for creating and running an online database. However, in the selection of database management system, bandwidth demands of the collected data and easiness of the transmitting the data in a uniform variable format was considered. Hence, PHP that creates customizable databases associated with MySQL, which is the most preferred open source management system for the creation of web interfaces was selected. The PHP can work with all internet-enabled devices. In this respect, a customized table has been created in the PHP database, which allows the data to be followed from almost any device. The data transferred over the GSM unit were analyzed in a table format and placed in the relevant columns together with the timestamp for further data processing. The flowchart of the software is given in Figure 4.

3. Results and Discussion

3.1. Calibration Results

The units prepared for the calibration experiment were fixed to the upper edges of the 65 cm high stands. The stands were aligned so that the direction of the generator was right between the sound sensor and the

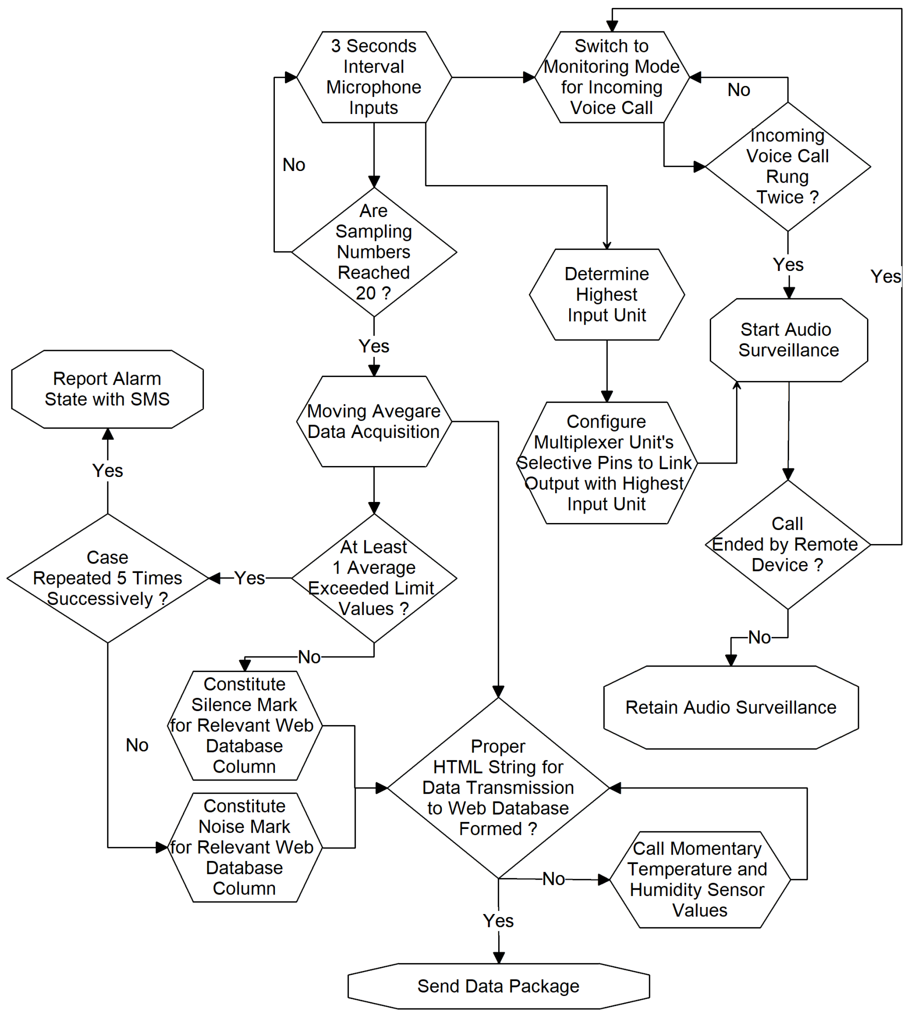

Figure 4. Flowchart of the software

UT-353 decibelmeter (Uni-Trend Technology Co.Ltd., China). In this way, it was ensured that the sound intensity can be perceived equally by both devices.

A standard 5V power supply was connected with a USB cable to provide the energy needed by the sensor unit and the sound generator during the experiment. Then, a mobile phone was connected via Bluetooth and placed on the stand where the decibelmeter was located (Figure 5).

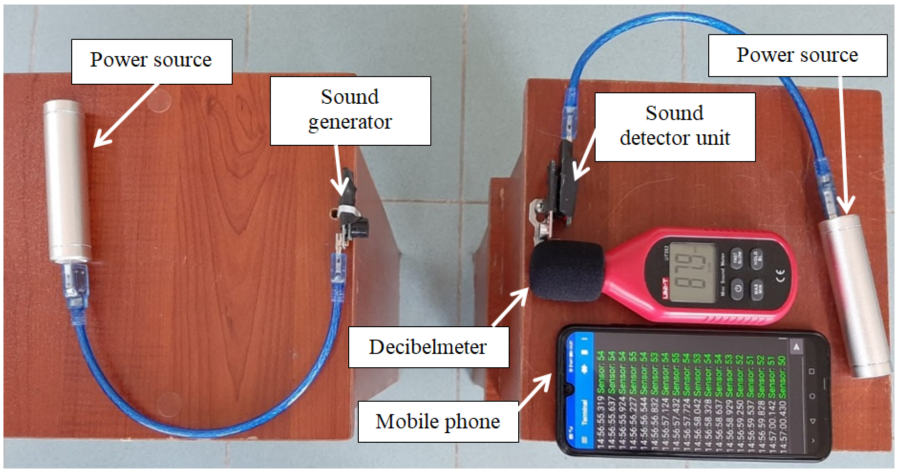

Figure 5. Calibration experiment

During the experiment, generator unit was removed from the measuring unit to create decreasing amplitudes. The sound generator unit produced 20 measurements per second. The moving average method was used to calculate average sound intensity for each second. In this way, the effect of instantaneous fluctuations that may cause deviations in sound intensity data was eliminated. Each 1 dB change in the decibel meter and corresponding 8-bit integer values were monitored and recorded to create a calibration equation. Using the logarithmic calibration equation each sensor readings were converted to dB units for further processing (Figure 6).

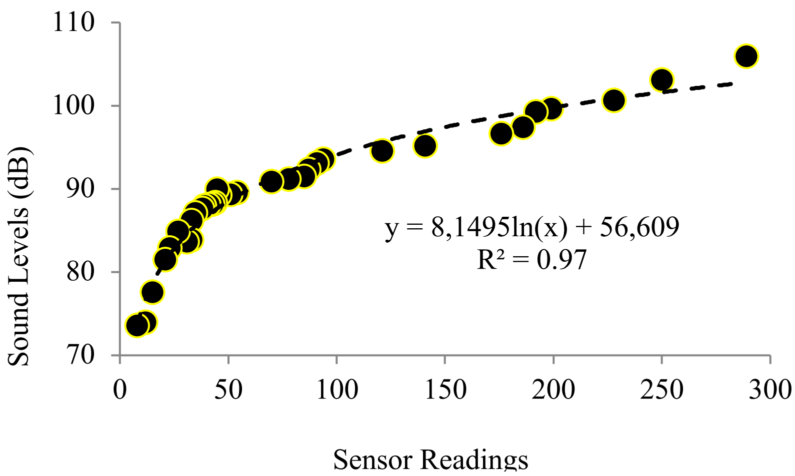

Figure 6. Calibration equation

3.2. Statistical Analysis

The main purpose of the developed prototype was to monitor the unusual changes in ambient sound level regarding animal and barn safety and send a warning SMS to the producer. The most important challenge faced with the developed method was the determination of threshold values for warning SMSs. No such threshold value has been found in the literature. As an approach, using the highest recorded value in the barn could be considered. Anonymous (2006) stated that the noise level in a dairy barn can reach up to 106 dB. Therefore, when the system was installed in the barn, 106 dB was used as the threshold until sufficient data was obtained. It was observed that in the first 4 months of the study 106 dB was exceeded only by Mic-5 and Mic-6, 1 and 25 times, respectively.

The 4-month-data were used to calculate the maximum, minimum and mean values for each sensor. The aim here was to determine whether the mean or maximum values could be used as threshold. The statistical parameters and the number of times they were exceeded calculated in MS Excel (Table 1).

Table 1

Statistical parameters for the first 4 month of study

Parameter	**Mic-0**	**Mic-1**	**Mic-2**	**Mic-3**	**Mic-4**	**Mic-5**	**Mic-6**
Average:	86.0	93.6	90.2	93.0	93.8	91.0	94.0
Maximum:	96.8	103.6	105.4	105.9	102.2	106.0	107.3
Minimum:	79.2	79.2	79.2	78.1	79.7	79.2	79.2
Times average value exceeded:	47,313	44,165	51,486	51,896	48,666	48,241	48,566
Times maximum value exceeded:	0	0	1	0	1	1	6

As can be seen from Table 1, if the sensor average values are accepted as the threshold, more SMS will be sent than necessary. On the other hand using the maximum values may cause almost no warnings. It is very difficult to determine a realistic threshold value. Considering the past experiences of the owner, unusual conditions such as sick animals or the entry of other animals such as dogs or wild birds into the barn are observed about a few times a month. It was aimed to determine the noise level that continues for 5 minutes and above, which will cause an average of 2-3 SMS to be sent per month based on the producers demand and experiences.

For this purpose, Z-score test was applied. For each sensor, it was determined by trial and error method that the highest decibel value, which is likely to be seen with a probability of 1% was selected as threshold. Normality test (confidence level 95%) applied to the sensor values for testing the suitability of Z-score test in MS Excel (Table 2). Considering the values listed in Table 2, all sensor values were normally distributed.

Table 2

Normality test results

Parameter	Mic-0	Mic-1	Mic-2	Mic-3	Mic-4	Mic-5	Mic-6
Mean	86.0	93.6	90.2	93.0	93.8	91.0	94.0
Standard Error	0.0037	0.0087	0.0069	0.0085	0.0086	0.0066	0.0094
Median	85.8	93.6	90.1	93.0	93.9	91.0	93.9
Mode	85.6	93.3	88.3	91.6	93.6	89.7	93.3
Standard Deviation	1.1596	2.7512	2.1886	2.7121	2.7226	2.0829	2.9800
Sample Variance	1.3447	7.5690	4.7903	7.3554	7.4128	4.3383	8.8774
Kurtosis	6.1307	0.7127	1.0434	0.4918	1.1364	0.7973	1.6521
Skewness	1.3299	-0.5455	0.1524	-0.4241	-0.71624	-0.0020	-0.6275
Range	17.6	24.4	26.2	27.8	22.5	26.8	28.1
Minimum	79.2	79.2	79.2	78.1	79.7	79.2	79.2
Maximum	96.8	103.6	105.4	105.9	102.2	106.0	107.3
Confidence Level (95.0%)	0.0072	0.0170	0.0135	0.0167	0.0168	0.0129	0.0184

With Z-score which corresponds to area left of the 99% of the normal distribution curve of 2.33 was determined representing the highest values with a possibility of 1% observation for each sensor. Then the following equation was applied to determine actual sensor values corresponding to this Z-score (3.1) (Blaisdell, 1998).

$$Y = Z_{value} \times \sigma + \mu \tag{3.1}$$

where, Y is the sensor value observed with a possibility of 1% of all population, σ is standard deviation, μ is mean sensor value. Based on the Z-score test threshold values were determined for each sensor. The system generated SMS messages when the threshold values exceeded for 5 minutes. The threshold values and the number of SMSs that producer received during the second 4-month-period study are listed in Table 3.

Table 3

Threshold values

	Mic-0	Mic-1	Mic-2	Mic-3	Mic-4	Mic-5	Mic-6
Threshold value (dB)	89	100	95	99	100	96	101
No of SMSs sent	21	13	15	25	11	12	9

As explained above, the multiplexer used in the system does not allow the sensors to send SMS simultaneously. Therefore, the values in Table 3 were obtained with the largest sensor values recorded for 5 minutes. This means more than one sensor may reach the threshold values but only the highest was allowed to generate SMS. Based on the data the prototype caused total of 106 SMS during the 4-month period.

3.3. System Performance

The producer reported that the warning SMS was sent generally during the feeding and milking times when the animals were active. This is an expected result due to the use of machinery and staff mobility in the barn. During the study no SMS received at night when there were almost no activities. Although there was a power outage at least once a week, continuous data could be obtained from the system, which can work with both AC and DC power supplies. Minute-based data is collected for 8 months, yet the database limits were not exceeded. Collected daily data volume was around 76 bytes which is an acceptable capacity. In addition, the data in the database can be downloaded in MS Excel format, allowing it to be used directly for data analysis for various purposes. Accordingly, the existing database can be recorded for more than 10 years without any limit problem. When the minimum and maximum sound intensity values created by the sensors were compared, there was a ±8% difference, including the module inside the device whose microphone was not removed. This difference decreases to 2% between the sensors on the right and left of the service road and which were symmetrical to each other. In this case, it can be concluded that the length of the cable used for the microphones has some ignorable effect on the generated sound intensity data. The fact that each sensor was handled separately while determining the threshold value for the sensors prevented possible errors.

The most important factor determining the performance of the system was the threshold value to be used. As a method in this study, the values corresponding to 1% or less of the recorded values were accepted as the threshold. However, it should not be forgotten that different times and lower sound levels may also indicate unfavorable conditions in the barn. In such cases, if the owner or employees are in the business, the device can be completely deactivated and unnecessary SMSs can be prevented. In addition, both shorter alerts (less than 5 minutes) and lower threshold values can be easily defined in the system when the owner is outside and has to check the barn more often. Hence the developed system provides a flexibility to monitor the barn under various situations. The overall cost of the system should also be considered in the performance evaluations. All the electronics and associated materials that were needed to assemble the system can be easily obtained from the electronics market at low costs. The prototype costed $ 470 including the 1 year webhosting service fee for database.

4. Conclusion

One of the most important problems encountered in small livestock operations is the remote monitoring of the barn, especially regarding safety and animal health. Visual monitoring based on cameras is not possible when the producer is out of operation. It is also an expensive solution for small scale operations. Based on the principle that animals make sounds at different frequencies and durations when under stress, a low-cost sound-based monitoring system was developed. The device was assembled in the laboratory and sound data was collected in a small-scale dairy barn for 8 months. It was aimed to send SMS warnings in case of emergencies when the pre-set threshold values are exceeded and listen to the barn if needed. The main challenge was the determination of threshold values for each microphone sensors that causes SMS warnings. It can be suggested to adjust threshold values depending on the presence of operator within the operation. Accordingly, the SMS warnings should be suspended for the time intervals in the daily routine of feeding, manure cleaning and milking processes. This may be a solution to unnecessary SMS warnings or missed situations. The prototype device not only provides a tool to monitor noise conditions it is also a useful tool to evaluate the overall noise levels within and outside the barn. The results show that this particular operation maintains the limits of noise exposure for both animals and labors.

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Author Contributions

Ünal Kızıl: Planned the study, established the design criteria.

Sefa Aksu: Designed the electronics/sensors, applied the system to the dairy barn.

Ahmet Cumhur Kınacı: Designed the database.

Ertuğrul Bilgücü: Helped finding experimental barn and collecting data.

Songül Şentürklü: Helped design, conducted literature review, and collect data.

Conflicts of Interest

The authors declare no conflict of interest.

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