A Zigbee-Based Animal Health Monitoring System

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***Abstract*— An animal health monitoring system for monitoring the physiological parameters, such as rumination, body temperature, and heart rate with surrounding temperature and humidity, has been developed. The developed system can also analyze the stress level corresponding to thermal humidity index. The IEEE802.15.4 and IEEE1451.2 standards-based sensor module has been developed successfully. The zigbee device and PIC18F4550 microcontroller are used in the implementation of sensor module. The graphical user interface (GUI) is implemented in LabVIEW 9 according to the IEEE1451.1 standard. The real-time monitoring of physiological and behavioral parameters can be present on the GUI PC. The device is very helpful for inexpensive health care of livestock. A prototype model is developed and tested with high accuracy results.**

***Index Terms*— Zigbee, sensors, wireless transmission, physiological parameters, temperature humidity index.**

I. Introduction

IN RECENT times, the livestock farmers faced cattle health problems around the world because of continuous rise in air temperature in the troposphere. The variations in temperature on animals health has harmful effect leading to diseases such as foot and mouth disease, swine fever, bovine spongioform encephalopathy (mad cow disease), bovine rhinotracheitis, squamous cell carcinoma, warts, web tear, necrotic pododermatitis, polioencephalomalacia, hypomagnesaemia, clostridia disease and hypoglycemia [1], [2]. WHO report stated that the severe acute respiratory syndrome corona virus (SARS-CoV) is said to be an animal virus that spread easily to other animals and have also affected human being directly. The evidence of humans getting infected is first reported in the Guangdong province of southern China in 2002 and since then till 2003 the 26 countries across the globe reported infections caused by SARS. This has resulted in the economic loss to the tune of approximately 2% of the total East Asian GDP (gross domestic product) [3]. For these reasons a system is needed to be in place for continuously monitoring the animal health and to control and prevent the eruption of diseases at large scale.

Technology is already part of modern farming and is playing an increasing role as more advanced systems and tools become available. In recent years, one of the biggest areas of development has been in electronic livestock farming. Many researches are focused on the development of animal health telemonitoring systems.

The health monitoring is depending on two methods such as direct contact (invasive) or in indirect contact (non invasive). Basically a prototype telemonitoring system consists of sensing unit and receiving unit with PC [4]–[7]. Smith *et al.* [8] proposed a cattle health monitoring system and they are focused on head motion, core body temperature, and heart rate. The core of the system is an AMD186 processor on a turn microcontroller board. Mottram *et al.* [9] proposed a measurement of the acceleration for the dairy cattle. They are give the mobility of the dairy cows and also acceleration correlated to the mobility of the cows. Janzekovic *et al.* [10] proposed a heart rate monitoring method based on polar sport tester (PST) for cattle. The body temperature and heart rate parameters are also used as a disease scrutinize for different animal. Wietrzyk and Radenkovic *et al.* [11]–[13] define the ad-hoc wireless sensor network based cattle health monitoring and concluded that by using measured data, the livestock farmers can prevent the spread of diseases. Analysis of measured data also related decreased productivity and death of valuable stock. Hopster *et al.* [14] proposed the two stress measurement techniques for dairy cows. The proposed techniques based on polar spot tester (PST) and electrocardiograph (ECG). They are also given the results of corresponding study. They found that PST is a suitable technique for the heart rate measurement of animal and also analyze the heart rate is relevant parameter for the animal behavioral study. Guo *et al.* [15] proposed a wireless sensor networks based livestock monitoring and control method. The proposed method is also suitable for easily classifying animal activates and behaviour. It is used the Fleck2 processor board and measured the four parameters such as GPS information, accelerometer, magnetometer, and temperature. Nadimi *et al.* [16]–[18] proposed ad-hoc wireless sensor networks based monitoring and classifying animal behavior. They used the 2.4 GHz frequency based communication module and the proposed design is the following advantages such as communication consistency, energy efficient and minimum packet loss rate. The multi-hop communication and handshaking protocol are used in the development of the system. The measured behavioral parameters are transformed into the corresponding behavioral modes using a multilayer perception (MLP) based artificial neural network (ANN). The ANN performance is achieved well in the terms of mean squared error and ANN also trained the algorithms such as Nguyen Widrow and Levenberg-Marquardt back propagation. Huircan *et al.* [19] proposed a zigbee based cattle monitoring in cropping fields and used the localization scheme in wireless sensor network. The ratio-metric vector

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iteration algorithm is implemented and modifies the work with localization measurements instead of the usual (RSSI) received signal strength indication. Handcock *et al.* [20] proposed a wireless sensor network, GPS collars and satellite based animal behavior monitoring and also proposed the environmental impact. They are combined the ground based sensors and sensed satellite images for realize the animal landscape interactions. Allen *et al.* [21] propose the heat stress versus cow behavior and also define the behaviour is a valuable parameter for the milk production. Lovett *et al.* [22] proposed an infrared thermography measurement technique for cattle. The proposed technique is helpful for examine the cattle foot and mouth disease. Stewart *et al.* [23] defined an infrared thermography based indirect stress measurement of dairy cows. Krishnamurthi *et al.* [24] X-Ray computed tomography based imaging for small animals and they are study of physiologic measurement reproducibility. With all these advancement in research the real-world application of the proposed system has not been done yet. There is no product in the market for the real time animal health monitoring. Mostly veterinary staff checks the physiological parameters through manually. Currently livestock farmer's faces lot of problem on monitoring the health of livestock and thus modifications are being persistently recommended in instrumentation. Mostly available system focuses only on heart rate measurement to predict of the animals. Literature review reveals that the wearable systems for real time animal health monitoring are a key technology in helping of the veterinary staff and measuring parameters can provide very accurate information of the animal health. In behalf of this the livestock health care would be inexpensive.

In this paper, we have reported a novel design goal of the animal health monitoring system with a capability to monitor heart rate, body temperature, and rumination with surrounding temperature and humidity according to the IEEE802.15.4, IEEE1451.2, and IEEE1451.1 standards. It has a variety of features such as high speed, energy efficient, miniaturization, intelligence, new materials at lower cost, portability, and high performance.

II. System Overview

Fig. 1 depicts the block diagram of the animal health monitoring (AHM) system. The AHM system has been developed according to the IEEE1451 and IEEE802.15.4 standards. The developed AHM system can be used of detecting the animal physiological parameters such as rumination, heart rate, and body temperature with the environmental parameters (surrounding temperature and humidity). The surrounding temperature and relative humidity based real time calculation of temperature humidity index (THI) and also has been classify the stress level of the animal. The output signal of the developed sensor modules are sent to a host computer through zigbee module. The values of body temperature, surrounding humidity, surrounding temperature, rumination, heart rate, stress level, and TH index (THI) can be displayed on the GUI PC. The design of AHM system is an autonomous device, if you need the monitoring of other health parameter which makes it comparatively easy to add extra sensor modules.

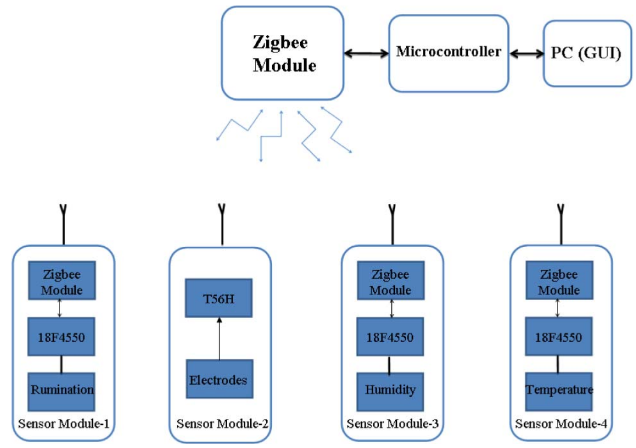

Fig. 1. Block diagram of animal health monitoring system.

III. Sensing Module

The sensing unit is the main components of the developed animal health monitoring (AHM) system. The sensing unit is consisting of sensor, processor, and zigbee module [25]–[28]. In this paper, we have used the four sensors such as rumination sensor, heart rate sensor, temperature sensor, and humidity sensor. Because, these measured parameter have been used for different animal species health judgment, as we can point out a quandary of the animal [23]. The analog output of sensors is fed to the inbuilt ADC of the microcontroller. The details design of the sensors module is subsequently.

A. Temperature Sensor Module

Domestic animals have a core body temperature (CBT) range in which metabolism functions without modification, termed the thermo-neutral zone. Typically, core body temperature is higher than ambient temperature to ensure that heat generated by metabolism flows out to the environment. Deviation outside of this range which is relatively narrow leads to increases in resting metabolism, modifications to the biochemistry and cellular physiology as well as the behaviour of the animal. A healthy adult cow body temperature range is approximately 38.5°C (101.5°F) to 39.5°C (103°F) and if the cow body temperature is over that this range then can called the cow is not healthy [21]. According to the South African weather service, the daily extreme temperatures recorded across South Africa to date has been 33.7°C with the lowest being 4.8°C [29]. Therefore, with allowances taken into consideration, the good range to select for our ambient temperature monitoring application is −15° to +40°C. We have chosen the temperature sensor for this application was a thermistor (TTC05102). Thermistor is high sensitive resistor versus temperature (ΔR Vs temperature). It means that the most important function is to reveal a change in electrical resistance with a change in its temperature. An important characteristic of thermistor is their extreme sensitivity to relatively minute temperature changes. The resistance of an NTC (negative temperature coefficient) thermistor decreases as its temperature increases [30]. They have a fast response, small mass, less complex circuitry and lower cost than the

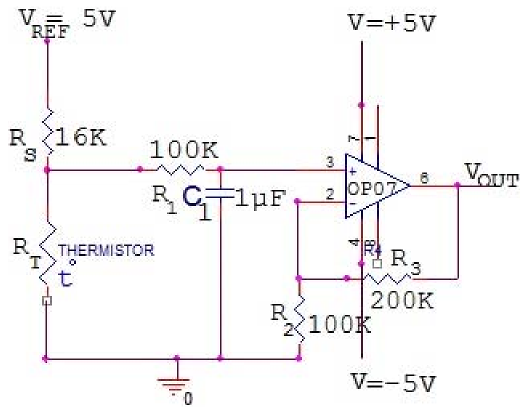

Fig. 2. Schematic diagram of temperature sensor module.

various other types of temperature sensors. The advantage and disadvantage of the temperature sensor was reported in [30].

The schematic diagram of the thermistor sensor is shown in Fig. 2. The signal processing circuit of the thermistor is divided into two parts such as voltage divider and a voltage follower. We have chosen the OP07 in the voltage follower circuit with the gain is three. The voltage divider network is main dependent on series resister R_S and reference voltage V_{REF}. In this circuit, the combination of R_1 and C_1 is formed a low pass filter and remove it's the noise. R_S was selected according to eq^n 1. The developed thermistor sensor module range was fixed at −15°C to +45°C therefore the thermistor resistance value (R_T), for three reference temperature were obtained [30], [31] such as the lower point (R_{T1} = 6.5K), mid point (R_{T2} = 3K), and upper point (R_{T3} = 0.450K).

$$R_S = \frac{R_{T1}R_{T2} + R_{T2}R_{T3} - 2R_{T1}R_{T3}}{R_{T1} + R_{T3} - 2R_{T2}} \quad (1)$$

Where R_{T1} = thermistor resistance at the lower limit; R_{T2} = thermistor resistance at the mid limit; R_{T3} = thermistor resistance at the upper limit.

$$V_{OUT} = \left(\frac{R_T}{R_S + R_T}\right) V_{REF} \quad (2)$$

The calculation of temperature is used the *Steinhart-Hart* equation. The *Steinhart-Hart* equation is

$$\frac{1}{T^I} = 1.5 \times 10^{-3} + 0.268 \times 10^{-3}(\ln R_T) + 3.558 \times 10^{-8}(\ln R_T)^3 \quad (3)$$

$$T^I(°C) = T^I - 273.15 \quad (4)$$

Where V_{out} = output voltage of the thermistor sensor; R_T = resistance of the thermistor; R_S = series resistor in the voltage divider circuit; V_{REF} = Reference voltage of the voltage divider circuit; T^I = Body temperature in K; T = Body temperature in °C.

B. Humidity Sensor Module

The environmental parameters are affected the performance and health of the animal both directly and indirectly. The environmental factor consists of air temperature, air movement, humidity, and radiation heat. In this paper, we have concentrated only on the environment temperature and humidity.

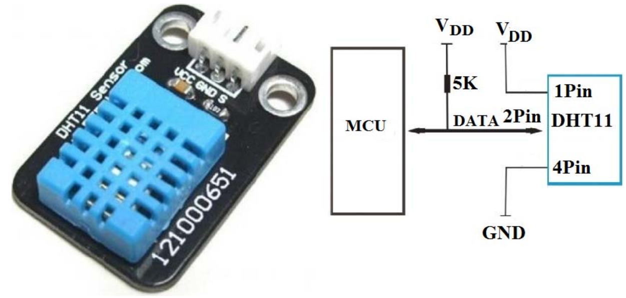

Fig. 3. Schematic diagram of the humidity sensor module.

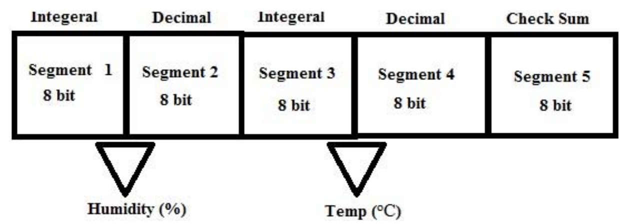

Fig. 4. Data receiving structure of humidity sensor.

Based on these parameters, we have calculated the thermal humidity index (THI) and also analyze the stress level of the animal. To sense the humidity of the surrounding area is used the DHT11 sensor. An overview of the DHT11 specification, advantage and disadvantage were reported in [32]. The circuit connection between the DHT11 sensor and the microprocessor can be seen in Fig. 3. The sensor data are received in the form of five segments (8 bit each). The first tow segments are represents the humidity (integral and decimal), third and fourth segments are represents the temperature in °C, and remaining (last) segments is the check sum. The last segment is the sum of the four first segments, if check sum value is not equal to the sum of four first segments that means that the received data is not correct. The received data structure is shown in Fig. 4. The operating voltage of the developed module is fixed at 3.3V. The surrounding humidity and temperature sensing range of the developed module are set from 20% to 90% and 0°C-50°C, respectively.

C. Heart Rate Sensor Module

The heart rate is the most important parameter in the health assessment. The adult healthy cow has a heart rate between 48 and 84 beats per minute. The variation in heart rate normally reflects the stress, anticipation, movement, exertion, and various diseases. Basically, the heart rate measurement is an indirect method.

Some researchers are used the polar spot tester (PST) for the measurement of heart rate and were reported in [33]–[38]. According to this we have choose the polar equine T56H transmitter device for the cattle heart rate measurement. The polar equine transmitter T56H is a fabric electrode based heart monitoring device. The heart rate sensor module is shown in Fig. 5.

The electrodes made from conductive flexible fibre are which acclimatize absolutely to the heart beat. The ergonomically design of this device is comfortable for animals.

Fig. 5. Polar equine heart rate sensor module.

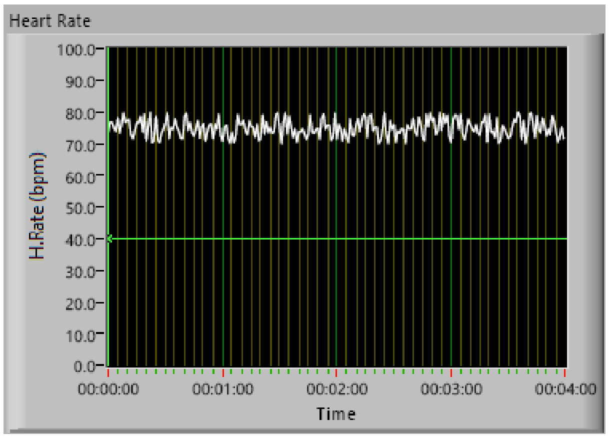

Fig. 6. The heart rate sensor output.

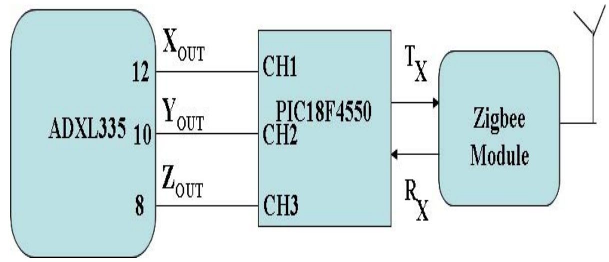

Fig. 7. Block diagram of rumination sensor module.

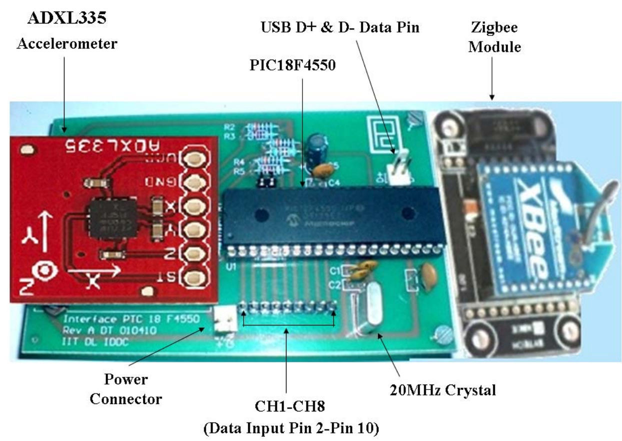

Fig. 8. Photograph of the rumination sensor module.

The fibres electrodes include a permeable to ensure a stable contact with the skin and pledge the essential dampness for communicates the heart rate signal. The transmitter T56H picks up very small electrical impulses emitted by the heart and for the T56H transmitter to read the heart rate properly. The transmitter T56H was supported at 2.4GHz frequency. The transmitter sends the real time data to the host computer. The heart rate sensor output window is shown in Fig. 6. During experiment, we have receive the heart rate of the dairy cows is approximately 75 beats per minute.

D. Rumination Sensor Module

Rumination is a direct indicator of animal wellbeing and health and also important part of the process by which animal digest food. The minimum ruminants are shown the Q fever [39]. According to veterinarians, the rumination is a function of what the animal has eaten and how well He/She has been able to rest. Normally, animals spend about one third of a day (9-10hours) in ruminating. The changes of rumination are indicating the disease such as mastitis, metabolic calving disease, food digestion, etc. Furthermore the return of rumination is an excellent sign of treatment success. The rumination monitoring of the animals is a need of the veterinarians because the rumination monitoring can provide a very accurate indication of the animal's health [40]–[43].

In the rumination monitoring we have used the accelerometer. The rumination sensor module has been developed according to IEEE802.15.4 and IEEE1451.2 standards for provides the three axis response of the animals. The block diagram and photograph of the developed rumination sensor module are shown in Figs. 7 and 8, respectively.

In the development of rumination sensor were used the ADXL335 accelerometer. Basically ADXL335 is a energy efficient, compact, and inexpensive device and can be measures the 3-axis acceleration with a range of $\pm$3g. In the addition the ADXL335 output signals are analog voltage that is proportional to the acceleration. The advantage, disadvantage, and specification were reported in [44]–[46]. And also can work in the static and dynamic measurement of the acceleration, basically, it is depends on the applications such as vibration, motion, shock, etc. In this paper, we have used the monitoring of mouth movement for the rumination time of the animals and it is fixed of the left hand side of the mouth.

The operating voltage range of the ADXL335 module is 1.8V-3.6V and it is operated at a fixed voltage of 3.3V. At the 3.3V, the maximum output voltage of the accelerometer are $-$560mV for the X-axis, $+$560V for the Y-axis, and $+$960mV for the Z-axis. The capacitors $C_X = C_Y = C_Z = 0.1\mu$F have been connected to the output signals X_{OUT}, Y_{OUT}, and Z_{OUT} of the accelerometer, respectively. The 0.1μF has been removed to the low frequency noise otherwise create the errors in the measurement of acceleration. The PIC18F4550 microcontroller interfaced to accelerometer with zigbee module. The outcome are sent through the zigbee module to a graphical user interface running of the host computer and also save the real time data into the access data base of the host computer. The developed ruminant sensor output signals are display on GUI in the form of waveform. The ruminant sensor output is shown in Fig. 9. If the sensor output signals are up and down corresponding to the x, y, and z directions. It means that the animal is doing ruminant and

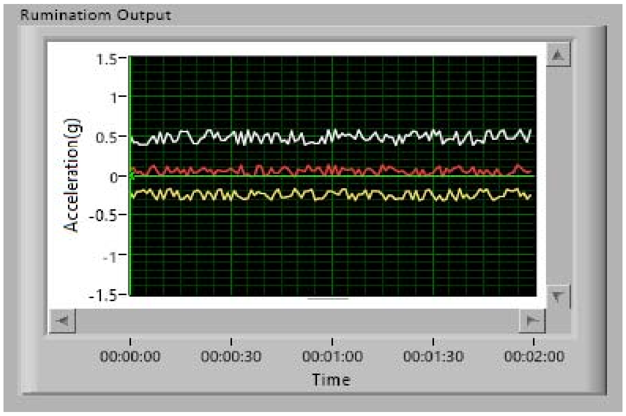

Fig. 9. The rumination sensor 3-axis output.

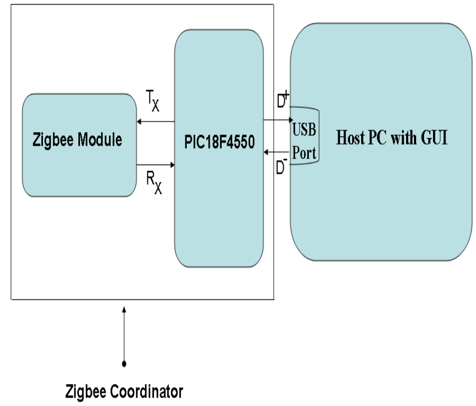

Fig. 10. Block diagram of sink node.

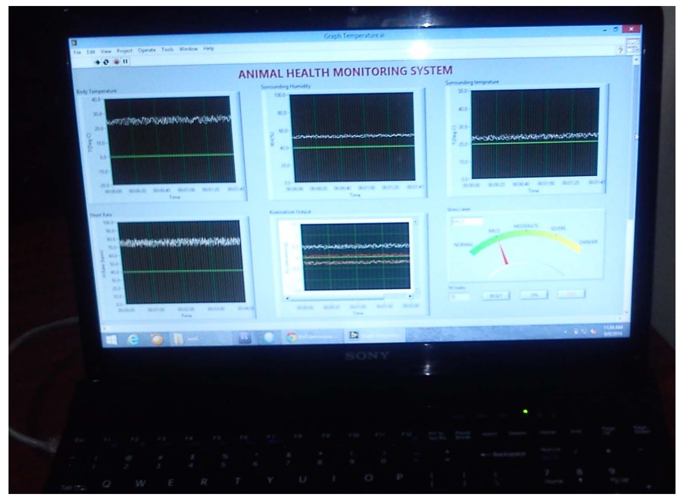

Fig. 11. The front panel of the AHM system.

that the animal is well being otherwise the animal is in poor health. This results has been received during cow is resting of afternoon time.

IV. Wireless Communication

In the development of animal health monitoring system (AHMS) has been used the zigbee communication. The zigbee device is an energy efficient, high accuracy, self-configuring, low cost, communication technology [47], [48]. Zigbee communication has well-known applications such as environment monitoring, viginet (military), smart farms, smart building, telemedicine services, and other industrial applications [49]–[56]. Recently, animal telemedicine is one hot application in the area of wireless sensor network. The communication between the sensor module and sink module is performed from side to side a zigbee module. In this paper, we have chosen the XBee-PRO S2 module. The specifications, working modes, advantages, and disadvantages were reported in [47]. The zigbee module working on the 2.4 GHz band, but is data transmits and receives serially through UART (universal asynchronous receiver transmitter). They also serially data transfer between zigbee coordinator and graphical user interface PC. We have configured the zigbee module through X-CTU software. In our system networks, the four sensor modules data converse to the single sink module which is coupled to a PC. The private area network ID is same of the developed sensor and sink modules. If the working of the setup is correct, the automatic establish the network connection between the sensor modules and sink node. Every sensor sends their data every 4 s to the coordinator and we have used the unlicensed 2.4GHz frequency band.

V. Sink Module

The sink module is used to collect data from different sensor modules. The developed sink module is consists of zigbee coordinator and graphical user interface running on PC. The transceiver unit is the main device of the zigbee coordinator and the transceiver unit is serially interfaced to the microcontroller. The microcontroller is serially interfaced to the PC through USB. The serial data converses depend on the UART. The sink module is shown in Fig. 10.

A. Graphical User Interface (GUI)

The LabVIEW 9.0 was used to the development of graphical user interface. The graphical user interface program is running on PC and to communicate with the zigbee coordinator [48], [57]. The graphical user interface two main sub program, one is block diagram and other is front panel. In the development of AHM system, we have used the communication between GUI PC and Zigbee coordinator through USB and follow the IEEE 1451.7 standard. The USB based interfaced have the following advantages such as cost, reliability, energy efficient, hot pluggable, etc. The main advantage of the USB based interface, the USB support the 100mA at 5V for external used and according to this there is a sufficient power of the zigbee coordinator. The USB based advantages, disadvantages, and protocol were reported in [58]. In this paper, we have used the interrupt driven transfer protocol. In the LabVIEW based instrumentation, the I/O communication software is needed and we have used the VISA communication software. The detailed information of the communication software as well as VISA sub palette, advantages, and drawback were reported in [59]. The front panel of the developed AHM system is shown in Fig. 11.

TABLE I
ANIMAL STRESS VERSUS TH INDEX [61]

THI	Stress Level	Comments
<70	None	
70-79	Mild	Increasing respiration rate
80-89	Moderate	Increasing respiration rate and saliva production. And also increased the body temperature.
90-98	Severe	Increased the respiration, body temperature and excessive saliva
>98	Danger	Animal death can occur

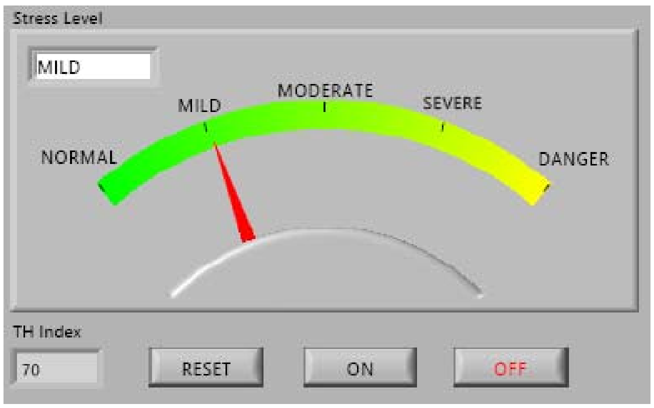

Fig. 12. THI and heat stress output.

VI. Heat Stress Indicator

Heat stress is an adverse effect on animal health such as reduces the milk production, weight gain, feed intake, reproductive efficiency, and increasing susceptibility to disease.

The measurement of heat stress is a non-invasive method and can be calculated through thermal humidity index (THI). The calculation of THI is the real time monitors of the animal surrounding environmental parameters such as temperature and relative humidity. In the calculation of THI, we have used the equation 5 [60].

$$THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26.8)] \quad (5)$$

Where T is the surrounding temperature in °C and RH is the surrounding relative humidity in %.

The principle of THI is that as the relative humidity at any temperature increases, it becomes progressively more difficult for the animal to cool itself [61]. If the THI value is greater than 70 then animal feel uncomfortable [19]. Table I represents the THI versus heat stress. If increased the value of TH index then change the behaviour of animals and has been increased the irregularity. Fig. 12 shows that the TH index and stress level of the animal during experiment.

VII. Results and Discussion

The main aim of this research paper is to develop an animal health monitoring system (AHMS) which is capable to the measuring of body temperature, rumination, and heart rate parameters with environmental parameters (surrounding temperature and humidity). The system is based on the IEEE 1451.2, IEEE 802.15.4, and IEEE1451.1 standards.

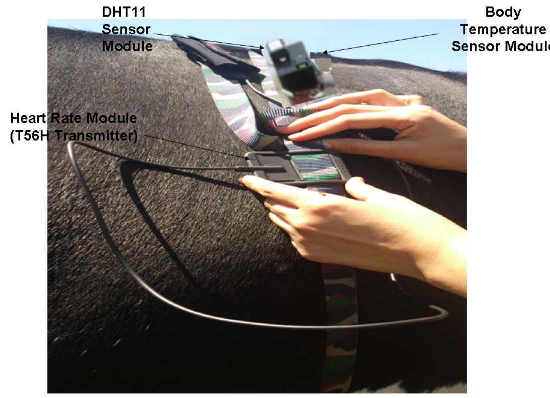

Fig. 13. Experimental setup of heart rate, body temperature, and surrounding temperature and humidity.

Fig. 14. Experimental setup of rumination sensor module.

The PIC18F4550 microcontroller and XBee-PRO S2 module were used to the development of AHM system. The four sensor module such as body temperature, heart rate, surrounding humidity and temperature, and rumination has been successfully developed. They measuring parameters will be helpful to analyze the animal disease or health condition of the animal.

We have designed the LabVIEW 9.0 based front panel. The front panel of the AHM system handles functions of the measuring parameters such as settings the time interval, start button (ON), OFF, data saves for the access memory of the PC or in the data base, and a digital and a graphical output. Here the developed GUI module can perform for four sensing module and display the seven valuable physiological and behavioral parameters. The USB slot of the PC is present the 100mA at 5V and it does not require any external power source in the sink module during the experiments. The power consumptions in the AHM system is depend only on the wireless sensing modules. During experiment, the 11.1V battery (rated 350mAh) is used. The each sensor module could be run incessantly for 60 hours without necessitate recharge. The prototype setup with dairy cow is shown in Figs. 13 and 14. The system has been developed ergonomically with the reference of the animal, the veterinary staff and primary user of the device. The following points are fallowed by the designing of the system in terms of the reduction of environmental factors, such as, the module is protective covering of PVC (Polyvinyl chloride) to shield it from rain and insects as well as the design of the casing for the collar to be threaded through, minimum noise is achieved in the case of the developed multilayer circuit board which includes a ground plane, and sensor and its associated circuitry are connected through wires with grounding connection.

VIII. Conclusion

In this paper, we have presented a prototype of an animal health monitoring system. The prototype system consists of the sensor module and sink module. These modules were abundantly urbanized according to the IEEE1451.2, IEEE802.15.4 and IEEE1451.1 standards.

This prototype system is tested for the real time monitoring of physiological parameters such as body temperature, rumination, and heart rate as well as monitor the surrounding humidity, and temperature. And based on these environmental parameters are automatic analyze the TH index (THI) and stress level. In the development of sensing device, we have used the low power electronic components to minimize the power consumption and the device could be run continually maximum times. The developed sensor module is low power consumption, miniaturization, intelligence, easy to operate, new materials at lower cost, portability, and high performance. The major cost of the developed system is comes form the use of zigbee modules and T56H transmitter.

For future study, the exploration of ultra wide band (UWB) radio based wireless sensor network for animal health monitoring. It will be specifically targets health monitoring during races, animal location and tracking applications. This technology presents very high low power consumption, low complexity, and time domain resolution. In the heart rate sensing module we have used the T56H transmitter and the developed module has been transmitting data only upto 5 meters. They will need the modification of the heart rate sensor module and could be increased the transmission range. The design and development of the PCB will be focus on the flexible PCB's to reinstate the rigid card, so that it might be ergonomically beneficially for animal.

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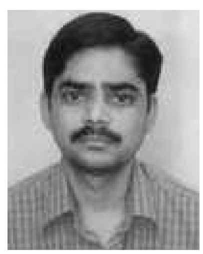

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