2020 IEEE 17th International Conference on Smart Communities: Improving Quality of Life Using ICT, IoT and AI (HONET)

2020 IEEE 17th International Conference on Smart Communities: Improving Quality of Life Using ICT, IoT and AI (HONET) | 978-0-7381-0527-7/20/$31.00 ©2020 IEEE | DOI: 10.1109/HONET50430.2020.9322666

Internet of Things (IoT) and Machine Learning (ML) enabled Livestock Monitoring

Abdul Aziz Chaudhry
School of Electrical Engineering and Computer Science (SEECS),
National University of Sciences and Technology (NUST)
Islamabad, Pakistan.
achaudhry.bee17seecs@ seecs.edu.pk

Rafia Mumtaz
School of Electrical Engineering and Computer Science (SEECS),
National University of Sciences and Technology (NUST)
Islamabad, Pakistan.
rafia.mumtaz@seecs.edu.pk

Syed Mohammad Hassan Zaidi
School of Electrical Engineering and Computer Science (SEECS),
National University of Sciences and Technology (NUST)
Islamabad, Pakistan.
drzaidi@seecs.edu.pk

Muhammad Ali Tahir
School of Electrical Engineering and Computer Science (SEECS),
National University of Sciences and Technology (NUST)
Islamabad, Pakistan.
ali.tahir@seecs.edu.pk

Syed Hassan Muzammil School
School of Electrical Engineering and Computer Science (SEECS),
National Unniversity of Sciences and Technology (NUST)
Islamabad, Pakistan.
smuzammil.bee17seecs@seecs.edu.pk

***Abstract*— Livestock monitoring is one of the growing concerns in the present era mainly owing to the ever- increasing population and the ascending demand for dairy products. Further, to prolong the lifecycle and sustain the quality of livestock, the regular monitoring of cattle health is essential. Several diseases are transmitted from animals to humans, therefore, an early prognosis regarding the cattle health and disease is required. This paper reviews the existing technology-based solutions and related equipment and provides a comparison of the features offered by these systems and their limitations. In addition, we have proposed an Internet of Things (IoT) based real-time system for livestock health monitoring. The proposed system will consist of a custom-designed multi-sensor board to record several physiological parameters including skin temperature, heart rate, and rumination w.r.t surrounding temperature, humidity, and a camera for image analysis to identify different behavioral patterns. The measured data will be sent to the server using Wi-Fi/GSM technology, where data analytics will be performed using machine learning (ML) models to detect sick animals and predict cattle health overtime for providing early and timely medical care. For data visualization, a web portal and a mobile app will be developed, providing a dashboard of services to analyze and display the sensed data.**

Keywords*— *Internet of Things, multi-sensor board, machine learning, livestock monitoring

I. INTRODUCTION

Livestock has a value of $1.4 trillion as a global asset, where it supports livelihoods for 600 million families of small households globally. According to UNDP predictions, the world population will reach 9.5 billion by 2050, and the requirements for animal products globally (e.g. milk, dairy products, meat) will increase by 70% [1]. Moreover, Pakistan being an agricultural country largely depends on the livestock for its food production. Today, farmers are facing problems of infrastructure, connectivity, animal monitoring, and diseases in animals. As per the report of the Asian Development Bank (May 2004), livestock development effectively reduces poverty. Regardless of these facts, there are very few solutions currently working in the field of precision farming in Pakistan, with little or no focus in the field of health of livestock and its monitoring. This is the main motivation behind this paper to analyze the different research methods concerning animal disease prediction and present a solution which will monitor the cattle in real-time with the help of IoT and cloud-based technology. Following parameters can be considered to analyze animal behavior.

A. Physiological parameters

a) Body Temperature: Core body temperature is one of the most important parameters of animal health and welfare. The regular temperature of the cow is between 38℃ to 42℃. When their body temperature is below the core temperature range it may lead to indigestion, milk fever, and when it is above this range, it leads to influenza, or even cause death [2].

b) Humidity: Humidity is another crucial factor in cattle's health, especially in determining the heat stress. The normal humidity range of animals is between 1-72%, characterized as no stress. Humidity value between 72-79% indicates mild stress and severe stress is categorized above 80% which reduces heat exchange and causes weakness [2].

c) Heart Rate (Pulse rate): Heart rate is also used for evaluating animal health. The average heart rate of an adult cow is between 48 to 84 beats per minute (BPM). Stress, pain, respiratory, or other multiple diseases causes fluctuations in heart rate. In addition, BPM below 48 indicates low blood pressure, and BPM above 84 indicates high blood pressure [2].

B. Lameness

Lameness in livestock is one of the most common health issues that can cause laminitis, claw disease, digital dermatitis, and foot rot. It is estimated that diseases associated with lameness can decrease profit up to 40-50€/cattle and 100-300€/case [3]. Animals suffering from lameness show various symptoms like they lie down more, difficulty in walking, stand less, and graze less as compared to healthy animals.

C. Rumination

Rumination is one of the most common practices that veterinarians observe to determine the health status of the animals. Animals stop ruminating instantly when they feel uneasy because of some disease and is directly linked to digestion in animals. Usually, adult cows ruminate for 8-10 hours daily and mostly do it while lying [2]. Moreover, returning to the normal practice of rumination after treatment is the first indication of a successful cure.

D. Other Factors influencing Livestock Health

The environmental conditions greatly influence the livestock especially the grazing conditions, resting time, and surroundings. These attributes are related to the normal behavior of animals which can be compared to real-time data. Body condition score, demeanor, and other visual or physical changes can give detailed information about an animal's health which can be analyzed through visuals using ML analysis.

II. TECHNOLOGICAL SOLUTIONS FOR LIVESTOCK MONITORING

A. Use of IoT based sensor unit to detect Skin temperature, Heart Rate & its Variability

In IoT based sensor technology, temperature, and pulse rate are measured through wearable collar devices [4][5]. The test device for measuring consists of a sensor-based mobile unit mounted on the animal under study and a fixed base unit. A fixed-base unit is used to measure the ambient temperature while the mobile-base unit is used to measure the temperature and pulse rate of the animal as shown in Fig. 1. The wireless data communication between the two units is carried out by the Xbee module. The microcontroller is used to manage all the operations of the mobile unit base including data acquisition, storage, and transmission. The fixed unit communicating with the database and HyperTerminal software is used for real-time data visualization and analysis. For heart rate, the test equipment readings are compared against the control ECG equipment (Smart ECG portable electrocardiograph model SE-1) measurements. Based on the results of the heart rate values, there are no major differences observed between the data acquisition devices. For skin temperature, infrared (IR) cameras and thermometers are used as a control equipment. It is observed that the temperature readings obtained from the test device are slightly higher than the test readings. Contact sensors and air temperature are labelled as the main interferences.

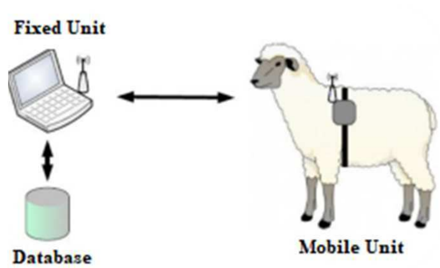


Fig. 1. Setup of electronic equipment for livestock monitoring. [5]

Thermal images obtained from the IR camera highlight the hot temperature areas of an animal body. IR radiations work on the principle of the black body radiation. Since animals are black bodies, thermal images give an insight into the skin temperature of an animal, that can also be compared to the sensor readings for accurate analysis [5].

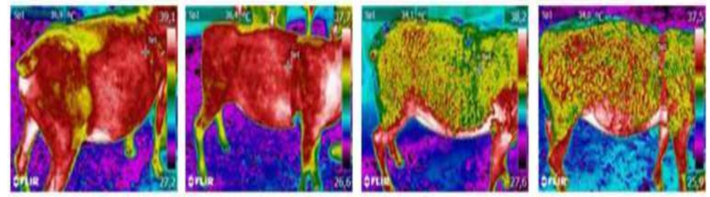


Fig. 2. Thermographic analysis of animals for measuring temperature [5]

Detecting THI (Temperature Humidty Index)

The temperature and humidity values can help to give a great deal of insight regarding animal health and its prediction [6]. The humidity and temperature of the cattle are measured by the DHT11 sensor placed on the cattle neck using a belt.

$$THI = T_{db} - [0.55 - (0.55xRH/100)] \times (T_{db}-58) \qquad (1)$$

where T_{db} is the bulb temperature in °F. RH is the relative humidity in %. Color-coded charts are also available which help in classifying the severity of the conditions.

B. Use of machine learning to detect lameness in cattle

To detect the lameness potential in cattle, the LP2 computational model best suits the needs and requirements based on the results [7]. This computational model lists four features: number of steps, walking distance in a day (m), lying per day (min), eating per day (min). For prediction and training, six cases for both positive and negative cases are used in the training set and two each in the test set. The model is examined using three different machine learning methods: Artificial Neural Network (ANN), Support Vector Machine (SVM), and Random Forest (RF). Convincing results are obtained with simple visualization techniques as it was noticed that healthy animals walked an average of around 3500m as opposed to the sick animals whose average is about 3000m. The amount of time spent lying in healthy cattle is mostly under 750mins/day while that of the diseased cattle is above 800mins/day. The eating minutes range for the diseased cattle per day is 150 to 180 while that of the healthy cattle is 200-300 approximately. The threshold used for converting probabilities to case identification is 0.5. A probability score that is greater than 0.5 is labelled as a positive test case. For further analysis, the confusion matrix is examined which displayed perfect results. The area under the curve (AUC) is 1 in the specificity against the sensitivity curve. In other words, there are no False Positive (FP) or False Negative (FN) events. Thus, all three efficient ML algorithms applied to the LP2 computational model perfectly distinguish between positive and negative diseased samples.

C. Use of IoT based Sensors to monitor Rumination

The cow monitoring system consists of a Cow Device, attached to the collar of animal, a cloud, and an end-user application [8]. The data collected from the sensors onboard the device is sent using opportunistic data transmission to ensure increased power efficiency. To compensate for the lack of reliability of measurements, the values transmitted inside the payload of Bluetooth low energy (BLE) messages are updated every 10s. The BLE packets are received by the Hub which forwards them to the server. The server communicates with the hub via the internet and manages data from the Cow Device. All the information is displayed in an end-user application where the information of each cow can be tracked. A three staged architecture is used to identify behaviors like rumination. Level '0' computes statistical quantities to identify behaviors, Level '1' predicts the present state of the cow, and Level '2' uses a reference model considering specific characteristics of the particular cow. The main task is to achieve the most reliable prediction for the current cow behavior.

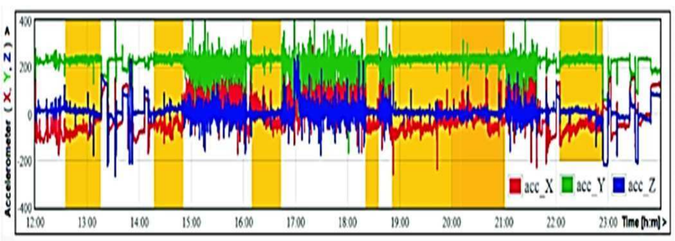


Fig. 3: Detecting rumination of axis movements through accelerometer [8]

D. *Use of Linear Regression Model to Predict Milk Yield*

Cattle production is directly proportional to the cow's comfort. This depends on a number of factors that include environmental conditions such as temperature, humidity, cleanliness of resting area etc., and stalking density. Milk yield has a linear increasing trend with stall stocking density [9]. ML algorithms like linear regression are used to predict milk yields.

E. *Use of Computer Vision & Deep Learning for Analyzing Other Health Factors*

The development of a system to detect conditions such as skin temperature, body condition score etc., consists of identifying the area of interest on the body in the photographs, developing a training set, and exploiting ML models to identify and predict further cases. Factors like body condition score are not practically examined in farm management but the development of an automated system could change that.

a) Image analysis for Demeanor and Body Condition score:

Normal monitoring of the animals involves the observation of the animal's eating habits if it is lagging its herd or being less responsive. These abnormal habits may represent symptoms of some diseases. Body condition scoring is a useful way to monitor the health and fat cover of a cow. Regardless of the body size, it is a visual assessment of the amount of fat that covers the cow's bones and is not affected by pregnancy. Simple 2D camera images from various angles can be used to realize thin or obese body sizes. Deep neural networks can also be trained to automatically detect body fat without the need for a chart or expert analysis. The body conditioning score is specifically defined on a scale of 1-5, as shown in Fig. 4.

b) Application of Computer Vision & Deep Learning to predict cattle movements and current positioning state:

Machine vision analysis has great potential in identifying the behavioral characteristics of animals. Images from simple camera video feed can be extracted, processed & passed through a deep learning network to detect behavioral features [11]. Valuable information like position, number, time, and posture of animals can be predicted.

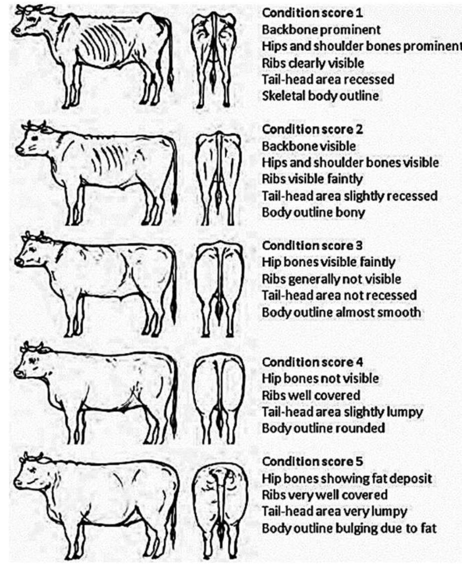
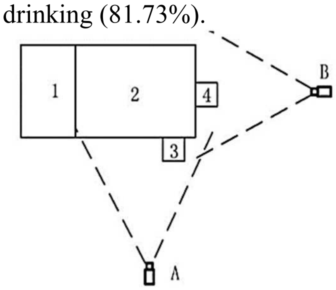


Fig. 4. Cows Body Condition scoring [10]

Fig. 5 and 6 show the setup environment of a cow, where different characteristics are observed, and its movement is recorded [12]. Front and side view cameras record the cow's position and movements. A new method is built to predict cow behavior which uses the phenomenon of background subtraction and inter-frame difference. The method successfully identifies the animal behaviors of moving into the resting area (94.38%), leaving the resting area (92.86%), turning around (96.85), remaining stationary (96.85%), feeding (79.69%), and drinking (81.73%).



1. Resting area of animal; 2. Normal activity area; 3. Feeding basin area; 4. Drinking basin. A. Camera for front View; B. Camera for Side View

Fig. 5. Video collection setup [12]

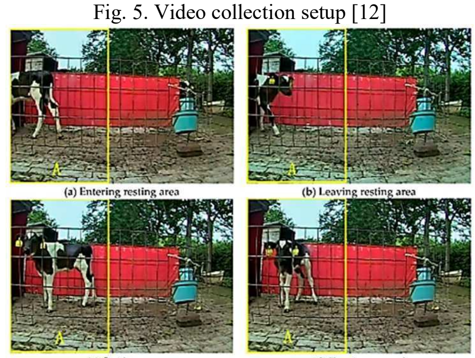


Fig. 6. Model of background updating [12]

Table 1 shows a comparative analysis of the related work in terms of methodology and hardware used, results obtained and their limitations.

Table 1: Comparative Analysis of the Livestock Monitoring Techniques

System	Methodology	Hardware Used	Parameters Observed	Results Obtained	Limitations
Machine Learning based Computational Analysis Method for Cattle Lameness Prediction [7]	LP1 & LP2 models with ML algorithms (RF, SVM, ANN)	N/A	(Eating, walking, lying, steps) per day	The LP2 model with Random Forest accurately identifies cattle with lameness.	Only 4 features used in lameness detection model
IoT-Based Cow Health Monitoring System [8]	Three level architecture for processing the measured data: Level '0', Level '1' & Level '2'	'Cow-Device' of sensors and the infrastructure devices: The Hub, Wi-Fi access points, and routers.	Activity, feeding, rumination, heat, physiological behaviors like estrus etc.	Accurately monitors behavior of the dairy cows and detects some health problems (e.g., mastitis).	N/A
Temperature Humidity Index (THI) Calculation [6]	Automatic calculation of Temperature-Humidity Index (THI) to detect heat-stressed cows	N/A	Temperature, relative humidity	Accurately ranks the THI index into 3 distinct levels of heat stress.	Data on the amount of sunlight received by the animal, wind speed and rainfall are not publicly available.
Electronic Monitoring system for Measuring Heart Rate & Skin Temperature in Small Ruminants. [5]	Test the designed equipment with the control equipment and compute the difference in readings via statistical analysis (mean, std)	Mobile base unit of sensors and a fixed base unit with Xbee Series 2 radio frequency transceiver	Heart rate, skin temperature	Compact electronic monitoring device with comparable results for heart rate and mean skin temperature values.	Low energy autonomy.
Cattle health monitoring system using LabVIEW & Arduino for early detection of diseases [13]	Arduino to read, process real time sensor data, XCTU software to send and receive data between transmitting and receiving Xbees, and LabVIEW for graphical analysis and representation	Combination of sensors, Xbee Series 2, Arduino	Humidity, temperature, pulse, rumination	About 72–75 % accuracy in detecting health deterioration in 15 specimens of cattle.	Accuracy is not as high due to simplicity of the developed system.
Cattle Health and Environment Monitoring System [4]	Data is transferred from sensors to Arduino UNO and Sim module from the GSM to the monitoring website	Combination of sensors, Wi-Fi/GSM module, Arduino UNO	Temperature, humidity, heartbeat	Online tracking of any fluctuation of parameters from the desired range.	N/A
Recording behavior of indoor-housed farm animals automatically using machine vision technology [11]	Image based analysis of animals focused on detecting behavioral changes and their characterization	Sensors, RFID detectors, digital cameras (2D), depth cameras (3D)	Activity level, area occupancy, aggression, temperature, resource use, posture, rate of production	Location and tracking data used to detect health problems.	Lack of link between different studies. Mostly repetitive or completely different work
A Machine Vision-Based Method for Monitoring Scene-Interactive Behaviors of Dairy Calf [12]	Use of background subtraction & inter frame difference to predict cow movements and behavior	2D cameras	Calf entering & leaving rest area, turning, feeding, drinking, remaining stationary	Evaluation tool gave these accuracies. Rest area (94%), leaving (93%), turning (97%), drinking (81%), feeding (79%), stationary (97%)	Large dataset required to build and train the model. Some behaviors are predicted with less accuracy

III. HARDWARE COMPONENTS USED

A. Sensors and accelerometers

Different studies have used several sensors such as Xbee, DHT11, KG011, ADXL345 which are utilized in monitoring different parameters that determine the cow's health. Xbee has been used for wireless communication, DHT11 for temperature and humidity, KG011 for heart rate and ADXL345 for sensing rumination of cattle [13]. In areas without internet connection, GSM modules can be used for transmitting and receiving data.

B. Recording Devices (Cameras, thermometer etc.)

Till 2014, mostly 2D cameras were being used for recording and analysis, either color or monochrome. After that, 3D cameras become popular due to their additional feature i.e. depth [11]. 2D cameras are generally less expensive and are more readily available. Although they are limited in their application due to only 2D projection of the object under observation, they can be used for either colorful or monochrome representations of the picture which are generally stored in MPEG-4 file format. 3D cameras permit wide applications; they encapsulate information of depth (between objects and camera), work in any kind of light settings and are less inclined to errors due to occlusion [11].

IV. PROPOSED SOLUTION MODEL

With rapid advancements in the field of IoT, there have been different ideas regarding the implementation of automated multi-sensor boards. Most common types of the boards include the boards like Turnkey Sensor Board [14], ROHM kit, etc. where different sensors are already mounted as SMD. However, on this multi-sensor board, different sensors can be connected to the microcontroller board, instead of already mounted sensors, offering users an enriched control. The methodology for collecting data will be implemented in two forms: 1. Mobile Base unit 2. Fixed Base Unit. The collar mounted on animal consisting of pulse sensor (SEN-11574), temperature sensor (MLX90614), accelerometer (GY521) will be Mobile Based unit and the LoRa module (SX1278) will be used as transceiver gateway for transmitting data from mobile unit to fixed unit. On fixed base unit, DHT22 sensor for measuring ambient temperature and humidity will be used and IP camera will be used for capturing visuals (images). Fixed Base Unit will also receive data from mobile unit through LoRa and from there all the data will be published to cloud with NodeMCU. The data collected will be of two types: sensor data (numerical) and videos (images). The data collected will be used to analyze the behavior of the cattle and based on that different ML algorithms will be employed to train the data set.

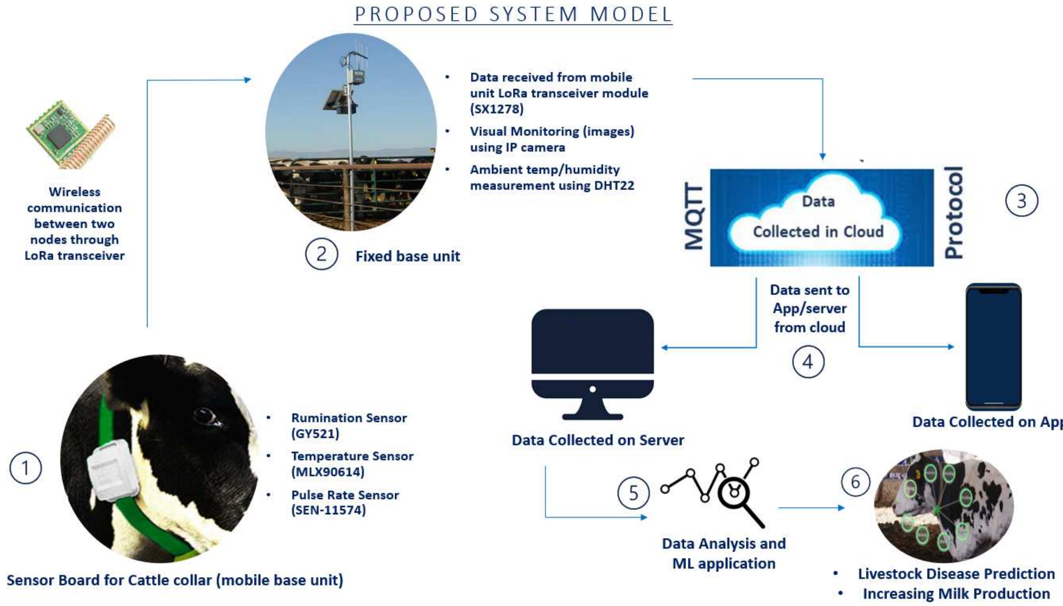


Fig. 7. Proposed System Architecture

V. CONCLUSION

Based on this discussion and review, we conclude that livestock health monitoring is a necessary advancement in the field of technology. Precision cattle farming is a handy tool for veterinarians to monitor the crop's health and a ML-based predictive technology can help to predict an early detection of cattle diseases. This is crucial since many diseases are transferred from animals to humans and this can prevent such happenings in the future. It has been shown through several studies, a loss of 1 hour of animal rest results in a loss of 1.7kg of milk. And careful monitoring can increase milk production up to 35 liters/day on average. So, technology-based solutions like IoT and ML can assist farmers in the monitoring of herds and at the same time meet the ever-increasing dairy requirements around the world. Sensors provide a useful way of monitoring the health of animals against pre-developed standard values and collection of real-time data of different factors for ML analysis, while cameras can be used with computer vision technology to predict animal behavior.

REFERENCES

[1] Thornton P. K., (2010), "Livestock production: recent trends, future prospects", in *The Royal Society Publishing*, 2010. doi:10.1098/rstb.2010.0134

[2] Saravanan K., Saraniya S., "Cloud IoT based novel livestock monitoring and identification system using UID", in *Sensor Review*, 2018. doi:10.1108/SR-08-2017-0152

[3] Ózsvári L., "Economic cost of lameness in dairy cattle herds.", in *J Dairy Vet Anim Res* 6(2): 00176, 2017.doi:10.15406/jdvar.2017.06.00176

[4] D.Aswini, S.Santhya, T.Shri Nandheni, N.Sukirthini, "Cattle health and environment monitoring system",in *International Research Journal of Engineering and Technology,* 2017. [e-ISSN: 2395-0056].

[5] Costa, Daniel dos S., Turco, Silvia H. N., Ramos, Rodrigo P.,Silva, Flaviane M. F. M., & Freire, Murilo S., "Electronic monitoring system for measuring heart rate and skin temperature in small ruminants", in *Engenharia Agrícola*, 38(2), 2018.

[6] Todd Bilby, "How do I determine? How do I calculate temperature-humidity index?", in *Progressive Daily,* 2014

[7] Liakos, Konstantinos & Moustakidis, Serafeim & Tsiotra, Georgia & Bartzanas, Thomas & Bochtis, Dionysis & Constantinos, Parisses, "Machine learning based computational analysis method for cattle lameness prediction", presented at the *8th International Conference on Information and Communication Technologies in Agriculture, Food, Environment*, 2017.

[8] Unold O. et al., "IoT-Based cow health monitoring system", presented at *Computational Science – ICCS 2020*, Krzhizhanovskaya, June 3-5, 2020. doi:10.1007/978-3-030-50426-7_26

[9] Rick Grant William H. Miner, "Economic benefits of improved cow comfort", in *Agricultural Research Institute*, *(NOVUS),* 2015.

[10] Howell, Alison, "Snail-borne diseases in bovids at high and low altitude in Eastern Uganda: Integrated parasitological and malacological mapping", 2020.

[11] Wurtz K, Camerlink I, D'Eath RB, Fernández AP, Norton T, Steibel J, et al., "Recording behaviour of indoor-housed farm animals automatically using machine vision technology: A systematic review", in *PLoS ONE 14(12): e0226669,* 2019. doi:10.1371/journal.pone.0226669

[12] Yangyang Guo, Dongjian He, Lilong Chai, "A machine vision-based method for monitoring scene-interactive behaviors of dairy calf" in *M. Young, The Technical Writer's Handbook: University Science*, 2020.

[13] Kunja Bihari Swain, Satyasopan Mahato, Meerina patro, Sudeepta Kumar Pattnayak, "Cattle health monitoring system using Arduino and LabVIEW for early detection of diseases", presented at *IEEE 3rd International Conference on Sensing, Signal Processing and Security (ICSSS),* 2017.

[14] Majeed Ahmad, "Multi-sensor board speeds up wearable, IoT designs", 2017.