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Cattle health monitoring system using wireless sensor network: a survey from innovation perspective

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Bhisham Sharma[1] ✉, *Deepika Koundal*[1]

[1]*Department of Computer Science and Engineering, Chitkara University Institute of Engineering and Technology, Chitkara University, India*
✉ *E-mail: bhisham.sharma@chitkarauniversity.edu.in*

Abstract: Health monitoring of dairy cattle plays a vital role for increasing the dairy products supply worldwide. Nowadays farmers are showing less interest in dairy sector as animals are suffering from various ailing health issues, unpredictable killing diseases, and advanced breeding costs. Therefore, it is necessary for farmers to adopt efficient technical methods for cattle health monitoring to increase the milk production supply. This study documented various wireless sensor network (WSN)-based automatic health monitoring systems for monitoring various diseases of dairy cattle. The main objective of WSN-based intelligent monitoring systems in farm automation is to monitor the health of dairy cattle on regular basis. This monitoring system needs to be installed in local and remote locations of farms that will assist the concerned farmers in monitoring their cattle activities from diverse locations for the whole day. All collected factors from the automated system will be stored in a database. Subsequently, with the help of farm automation, farmers can retrieve information for the execution of correct farm control strategies. Moreover, WSN is low-cost technology which is specific for the identification of diseases in dairy animals. This revolution in advanced technological farm automation will aid in improving the productivity rate with the reduction of human intervention. This review study concludes all cattle monitoring systems along with various issues and challenges.

1 Introduction

A major portion of dairy farms contributes to betterment economies of developing countries including India. Production of dairy products is wholesome for food industry worldwide. India, one of the largest populated countries, has the highest milk production every year [1]. Milk is considered to be the major source of income over several decades among all available dairy products. The market size of dairy products especially of milk in India is approximately US$47.6 billion (Rs. 2000 billion). A large number of milk production plants are being installed in many places. According to that, India's milk production has almost trebled in last 40 years, increasing from 21 million tons in 1968 to 108 million tons in 2008–2009, annually. According to Animal Husbandry Department, Fisheries, and Dairying, Agriculture Ministry of India in 2014–2015, about 146.3 million tons of milk production has been seen [2]. Especially, value-added milk production demand such as Indian yogurt, cheese, and probiotic drinks are increasing at a double-digit rate. It has been observed that in recent trends to meet the recent demands of dairy products, there is a critical need to become self-efficient in the production of milk products. The frequent occurring killing diseases in cattle such as foot and mouth disease (FMD) hurdles the condition of farmers which directly impact national economies of many developing countries [3, 4]. There are other epidemic outbreaks in domestic animals such as bovine mastitis, anthrax, contagious bovine ablution, and black quarter (black hg) which also prevails basil FMD. In order to tackle these diseases, it is necessary to implement farm scientific technology for the monitoring of dairy animal health to reduce the production costs. The function of sensors is to gather information about diseases and to reduce long-term animal dairy healthcare costs. Farm automation using WSN determines the body temperature that plays an important role in the detection of ill health of animals. Directional antennas rely on transducers to measure direct sudden body temperature change within animal's body. Along with working of WSN, this paper discusses the wireless animal body temp-monitoring system that advances enabling computing technology to approximate continuous health data of animals. Related physiological measurements of animals, infrastructure cost help in advancing information amount to enhance productivity rate, the betterment of cattle health. It is quite reasonable to accept major aspects of farm automation scheme such as tracking animals, assessing conformation in animal's body, monitor efficient physiological factors. Information from sensors, knowledge databases, and mathematical models ensures the maximum information potential. However, continuous monitoring requires more time and manpower of farmers [5]. Continuous visual observation by farmers cannot be fully accurate as there are emerging various health issues of animals that are difficult to prevent [6]. Therefore, an intelligent approach for monitoring of cattle health needs to be developed to help rural people. As a result, latest information technologies are combined with precision livestock farming approaches that are used to process behaviour and monitor biological responses of animals. In literature, the given cattle health monitoring techniques generally include processing algorithms, monitoring tools and methodologies (distributed infrastructure software) that help animal's owners to pre-predict diseases for which outbreak results [6]. These techniques can analyse the health of every cattle and provide health details to the owner as well as to the doctors at the same time. Therefore, electronic livestock farming is one of the emerging areas which are considered as the biggest development. The presented paper emphasised on health monitoring of animals to prevent them from deadly diseases such as ketosis, mastitis, milk ferry through WSNs.

This paper is organised as follows: Section 2 discusses various cattle health events and Section 3 has presented various technologies to handle those events. Section 4 presented the mapping of diseases to various sensors. Section 5 reviews the related work of cattle health monitoring. Section 6 shows the various research issues and challenges, whereas Section 7 concludes the conclusion.

2 Cattle health events

Cattle health is of great significance in food production due to owner concerns for food quality and safety. Getting better-farmed cattle's welfare certainly affects disease resistance and pathology. From previous studies, it has been found that the physiological and behavioural responses of farmed cattle's has provided consistent

information about health statuses such as duration of grazing period which is a crucial behavioural factor (such as the animals' head movement or movement velocity) to ascertain the adequacy of offered food that influenced the health welfare and milk production. Any noteworthy variation in duration of grazing period disclosed the malfunctioning that entailed the farmer's consideration. Monitoring the behaviour of dairy cattle is useful to assess their health status, welfare, and comfort at the farm level. Certainly, changes in behaviour are clear indicators of dairy animal's health and welfare problems. Therefore, these can be used as input to an early warning system. The time spent by the animals lying or feeding plays an important role in terms of milk production. Thus, knowing their position is an important factor for monitoring and controlling their behavioural patterns and activities to obtain information for their health status and productivity [6]. Whether the diseases occur due to bioterrorism or naturally, they pose a serious threat to the dairy cattle's health. The most highly impacting condition which affects the animal health is abortion followed by internal parasites, footrot or lameness [7]. Farming industry gives significant income to the Indian nation but animals are mostly affected by FMD, anthrax, black-quarter (black-leg), contagious bovine abortion and bovine mastitis [8]. Form this study, it has been noticed that the diseases have a high negative impact on the cattle health and farmer's profitability. Additionally, the environmental conditions such as drought, heat or toxins from plants may create a problem. Thus, various studies have been focused on the deployment of systems for health monitoring that should be able to identify various behavioural parameters and transformation into corresponding behavioural modes (standing, walking, lying down and grazing). Such systems could assist the owner to increase milk production and animal welfare.

2.1 Body temperature

Animal stress is normally assessed by measuring the body temperature. Veterinarians commonly measured the rectal temperatures for the detection and diagnosis of febrile disease for many years [8]. The temperature has been measured at different anatomical positions of cattle such as vagina, udder (milk), ear (tympanic) and reticulum rectum. The normal temperature of animal is known to be 38.6°C. The temperature of body must be maintained within limits to sustain its physiological processes. From literature, it has been found that the range of normal temperature is 37.8–40.0°C [8].

2.2 Footrot

This disease is due to the pathogen presented in soil that contaminates the tissues of hoof when surroundings are muddy and wet [9].

2.3 Wasting diseases

Johne's disease and tuberculosis are due to the bacteria's of same species (Mycobacterium) which reduces the performance of cattle [10].

2.4 Production diseases

The production diseases include nutritional and metabolic diseases as well as genetic and infectious diseases including hanging placenta. The economic loss to the cattle welfare concern and dairy industry is mostly due to the production diseases. Abortion happens due to various factors such as bovine viral diarrhoea (BVD) on foetus during the gestation period [11]. Weak calves, ovarian cysts, foetal mummification and premature births are due to foetal infection with BVD virus. During gestation, heat stress and listeriosis exposure to toxins from forbs are also the conditions that may cause abortions.

2.5 Parasites

Two kinds of parasites that lead to performance losses in cattle and their calves are internal and external parasites [12]. Internal parasites often lead to the light weaning weights and reduced the milk production. Fascioloides magna and Fasciola hepatica disturb the liver functionality and lead to weight loss. External parasites like ticks and flies are also one of the causes which deteriorate the cattle health and their performance.

2.6 Transition/periparturient period

The major concern for veterinarians is to maintain good health of dairy animals during the periparturient/transition period. The transition period is described as the time duration from 3 weeks prior to parturition through 3 weeks after parturition [13]. The duration of periparturient of dairy animals is the time frame near parturition. During production cycle of cattle's, parturition is a critical time in which they are at extreme risk for manifesting production diseases. Insufficient nutrients given to the transition animals may result in reduced production potential and increased the costs for treatment. The nutritional diet should be fed during this time to ensure successful reproduction and maximise productivity.

2.7 Ketosis

It is associated with fatty liver. Animals developing ketosis have lower milk production, lower gluconeogenic capacity and reduced feed intake with high risk of developing infectious and other metabolic diseases. It is categorised by partial anorexia and depression. Rarely, it emerges in buffalos in late gestation. Additionally, with the loss of appetence in coordination and abnormal gait symptoms of nervous dysfunction as well as bawling, pica, anomalous licking and hostility are periodically observed [14].

2.8 Metabolic disease

These diseases usually spread with the rise of milk production as well as herds turn into a bigger size. Generally, subclinical disease frequency is more widespread than clinical mastitis. Often it is related to noteworthy financial losses that include reduced reproductive performance, impaired milk production, culling losses and increased clinical diseases risks [15, 16].

2.9 Mastitis

This is the most common leading endemic disease in which breast tissues in the mammary gland of dairy cattle are getting swollen. It is an inflammation of the mammary gland. It gives an immune response to a bacterial attack by several bacterial sources which may be the result of mechanical, thermal or chemical injury to the udder [10, 17].

2.10 Lameness

This is an unusual movement during locomotion related to either leg or foot [18].

2.11 Milk fever

It is also known as metabolic disease, parturient paresis or postparturient hypocalcaemia. It is represented by lower blood calcium level [19]. Hypocalcaemia reduced the level of blood calcium which lessens the productive longevity and reduced the yield.

2.12 Diarrhoea

This disease is spread by Pestivirus. It leads to weakness, loss of salt and water, in appetence, death and thinning if not diagnosed early and properly [20].

2.13 Pneumonia

It is a multifactorial disease that causes symptoms such as depression, fever, eye discharge, stiff gait, in appetence, serous

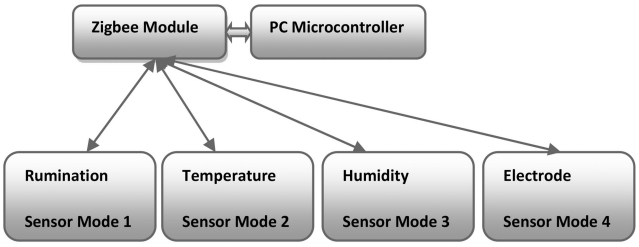

Fig. 1 *Zigbee-based animal health monitoring system*

nasal and cold which weakens the immune system of the cattle [18].

3 Technologies

To support this, sensor-based automated health monitoring is necessary to follow individual animal movement as well as to monitor the health conditions. Since the cost of digital storage and communication decreases and their availability increases, utilisation of these technologies is becoming very popular nowadays [21]. It is now become easy to monitor the conditions of an individual animal in detail that has so far been difficult. Mobile WSNs make continuous welfare monitoring easy with higher robustness as compared to manual observation. The global positioning system (GPS) enabled collars are able to measure the length of grazing period of cattle to help farmers for accurate decision making. However, real-time communication has several issues, particularly, welfare threatening conditions that need an appropriate warning at the rate of which deterioration occurrence and battery conservation. From literature, it has been found that for tracking cattle activity, GPS-enabled collars have been successfully used by several researchers [22, 23].

Sensor networks consist of several tiny low price devices that are logically self-organised *ad hoc* systems. The sensor network has been employed for monitoring the health parameters of cattle's to gather and convey information to other nodes. The sensed data from the node is conveyed in multi-hop manner hop by hop to the sink. WSNs can be deployed as static or mobile. Static WSNs are deployed to measure buffalo movement and soil moisture. Mobile WSNs are deployed on each animal to monitor their temperature, health, and behaviour.

Nowadays, inexpensive ear-tags are widely used instead of active leg-tags/active collars. Passive tags are generally used to identify cattle for tracking and tracing instead of sensing. Though, passive radio frequency identification (RFID) sensors are used for monitoring the cattle, whereas active RFID sensors are used for longer-range tracking [24]. Early and accurate detection of cattle diseases not only reduces the cost of unnecessary treatment as well as prevents the production losses. Rectal temperature is generally used to approximate core body temperature as it is difficult to obtain for proper cattle monitoring. The method of manual collection of rectal temperatures may lead to stress in animals that can alter the temperatures. Therefore, a reliable method is required that can provide a more accurate measure with no manual intervention.

4 Diseases mapped to sensors

In the above section, several cattle diseases and their effect on cattle's behaviour through symptoms and clinical signs are discussed. After considering those diseases, in this section, the conditions are mapped to the related sensors for analysing their behavioural changes and health, which cattle reveal in that particular disease [25–28]. Various types of sensors are available for different kind of applications. The sensors which are most widely employed are Microphone, Temperature sensor and Accelerometer (Pedometer) [29]. Fig. 1 illustrates a general framework of cattle health monitoring system which consists of accelerometer module, humidity, temperature, and electrode module.

The wireless system is generally categorised on the basis of technique, data, algorithms, and their performance. It consists of sensor type, sensor location, measurements type and the alerts given by the sensor for the occurrence of an event [25–28, 30]. In earlier days, the health of cattle has been monitored visually by veterinarians. As the demand for dairy products is growing day by day, it is vital for farmers to have effective means for cattle monitoring. Presently, WSNs have been employed to monitor vital factors of cattle such as heart rate, respiration, and temperature which are considered as early signs of diseases [31–38]. This section surveyed the impact of diseases and their measurable indicators for the detection of diseases with the help of sensors. Fig. 2 shows different areas for monitoring dairy cattle health.

(i) *The temperature of cattle:* The number of sensors has been considered for measuring core body temperature within a bolus and through anus or ear. As ear canal is adjacent to the ear tag to measure core body temperature, it is the least invasive and most convenient method. For quantifying body temperature of cattle, one of the sensor based devices used is FeverTag that is a tympanic thermometer device. It is fastened with a probe to the ear and located in the lower ear canal and whenever the temperature is above 103.6°F it flashes an indicator [38]. Other sensor-based device is CorTemp bolus which is employed to quantify core body temperature [33].

(ii) *Environmental humidity sensor:* Humidity strongly weakens the strength of signals causing loss of data while communicating between wireless components. The level of humidity obtained on the farm can be utilised to consider the dissipation of signal strength [21]. Furthermore, the recorded data of temperature provides a baseline for the temperature of cattle's during the whole day [39, 40].

(iii) *Heart rate:* CorTemp bolus has also been used to quantify heart rate with temperature of the body. This device is used to locate the commencing of each pulse using a microphone to ascertain and convert the time between consecutive pulses into a pulse rate [33]. Polar heart belt is also used to monitor heart rate, which attained heart vector of the animal using electrodes [41].

(iv) *Respiration:* Thermistor is used to quantify the respiration of cattle affixed to a nose stud in the nostril of animal [31, 32, 42]. The thermistor's temperature rises relating to the ambient temperature as the cattle exhales. The respiration rate can be determined by computing the number of times/minute as the temperature falls and rises [7].

(v) *Locations of tracking unit:* Triangulation is one of the most common methods, which is used to track the remote systems. It is the method of ascertaining the location of a point by quantifying the time difference of signal arrival to three different receivers. Presently, global positioning systems (GPS) are used to determine the position based on information from multiple satellites [37].

(vi) *Reflective pulse oximeter:* Abnormal heart rate or low level of haemoglobin may be early symptoms of bovine illness. These vitals are generally monitored in humans with a transmissive pulse oximeter through the finger. However, in cattle, these vitals are measured by transmissive pulse oximeter through ear [38].

(vii) *Solar panel:* For remote WSN, the endpoints can be surplus of a sustainable energy source as the nodes may not be accessible regularly [43]. Thus, entails those nodes that incorporate battery supply to maintain a level of charge for circuitry or a method of battery recharge to avoid unwanted interference for the extensive operating period. For recharging of batteries, solar panels have been used over piezo-electric energy generation as solar power would give the predictable quantity of power for each cattle throughout the day [32]. Solar power has been determined as the only possible source of sustainable energy for various access points.

(viii) *XBee:* The XBee device is a wireless transceiver which is generally used as it works with a maximum operating radius of two miles with a maximum transmitting power of 67 mW. XBees are physically small, slightly larger than a quarter and fit well within the space of an ear tag. It has been decided that all the data obtained from WSN would be communicated back to a central location through a wireless network for the reduction of impact on the buffalos' normal activities [31, 38, 44].

5 Related work

In literature, various studies on physiological and behavioural responses of cattle have been reported. These studies provide reliable information about welfare and health status such as grazing duration which is a vital behavioural characteristic for the owner to know the adequacy of food provided to cattle that affects their production and welfare. According to the literature, the number of health monitoring systems for cattle has been reported. These systems give the idea for the detection of various health-related parameters of cattle. With the help of these systems, it becomes very easy to detect various diseases such as rumination, temperature, humidity and heart rate as well as nearby temperature. WSNs have attracted a great attention from technological and scientific research groups. The monitoring system utilising WSN will be useful to the farmers, ranchers, and pastoralists to observe their cattle. This can be carried out remotely employing wirelessly through nodes for giving alerts for any type of abnormalities such as critical levels of body temperature and early signs of illness.

For the consideration of various animal welfare issues, several external sensors such as neck collar, ankle ribbon, accelerometer, pedometer, and vibration sensor have been developed [45]. Automated tools are used for an early detection of metabolic disorders in cattle's. Tags or collars are placed on the neck of cattle which provided information to the user [32]. The microphone is incorporated in a plastic gadget, which is attached to the left side dorsally on the head collar. The sounds are analysed through a complex algorithm inside the tag. Based on validation trials from the developer, the tag is claimed to detect rumen activity with 97% of accuracy. WSNs have been used by several researchers in the form of sensory collars that are mounted to the neck to monitor the health of animals [46, 47]. One remarkable system is 'ZebraNet' which is generally used for monitoring [46]. The devices equipped on zebra transmit all measurements (GPS position) to all other devices within range. Various static and mobile nodes have been deployed. The static sensors quantify the moisture of soil, whereas mobile sensors study the behaviour of animals. This method is not scalable due to limited storage space on the device; also, the maintenance cost is also high as the retrieval of measurements required manual intervention. Handcock *et al.* [48] presented a satellite, WSN and GPS collars-based animal behaviour monitoring system with its environmental impact. They integrated the sensed satellite images and ground-based sensors for the realisation of the animal landscape interactions.

Global positioning systems (GPS) are the most widespread systems which are used to estimate the spatial and temporal distribution of herds and are deployed in outdoor environments [49]. Offline GPS systems are generally used to determine the spatial distribution of cattle [50]. The fusion of sensors is carried out to examine several behavioural modes using spatial distribution of dairy cattle [47]. Recurrent connection loss and high energy consumption with the satellites in the fields that are enclosed by obstacles such as trees are the foremost shortcomings of GPS-based systems. Thus, GPS is less reliable and practical for long-term behaviour registration. Further, the use of offline data loggers and accelerometers has been investigated by attaching them to the hooves of dairy cattle [51]. The animal behaviour is further classified as stationary or moving.

Mayer *et al.* have reported that the retrieval of real-time data from animal mounted WSNs devices is employed via global system for mobile (GSM) infrastructure. GSM-enabled collars are too expensive apart from battery life concerns while monitoring large numbers of animals [21]. They formed a WSN platform for monitoring behaviour and health of the animal. In this, cattle are equipped with both external and internal sensors with the help of motes to monitor their intra-rumenal activity [21]. The authors have introduced the system that is composed of two parts. The first part of the system is used to quantify the health parameters of animals in the grazing land. The second part of the system is used to measure health parameters of animals in the farm. Moreover, it has been used to manage the environment of the farm remotely in order to increase the production from the farm animals. External and farm environmental information are collected through WSNs installed in the farm and visual information about the farm is acquired through closed-circuit television (CCTV). All this environmental and image information about the farm assisted the user to control the farm facility from outside the farm. Additionally, SMS notice service should be given to the users when the unsafe condition has taken place [52, 53].

In [54], WSN and CCTV have been introduced that is installed on farms to gather ecological and image information to facilitate farmers for cattle monitoring via the Web outside the farm and for controlling the farm facilities in remote locations. Jegadeesan *et al.* introduced a WSN technology in which sensor nodes are deployed for computation and communication in various application environments [55]. This WSN technology resulted in high safety, human quality and high productivity of life through its various applications [55].

Ipema *et al.* performed various experiments in which temperature sensor equipped into a bolus and located in the rumen of the animal. The results demonstrated that the capsule-based wireless technology performed well in cattle. In experiments, the mote in the rumen conveyed the data to the mote fastened to the front leg of the cattle to the base station [56]. The evaluation of cattle welfare has been carried out by wireless monitoring. This enabled the producer to make accurate decisions based on real-time management. Cai *et al.* introduced a WSN-based remote query ammonia sensor to trace high and low concentrations of ammonia [56]. Simultaneously, heating and ventilation must be minimised to save energy by keeping the temperature at sufficient level. Cugnasca *et al.* estimated the usefulness and capability of WSN for monitoring environmental variables in animal houses. The nodes were moved through the animal house to reveal various profiles of luminosity, humidity, and temperature [57]. Darr and Zhao presented a wireless-based data acquisition system to monitor temperature differences in swine barns [58]. Seasonal and environmental changes may influence haematological values in domestic animals. Another foremost issue that worsens the performance of cattle is the thermal environment, especially in high genetic value. The variation in environmental variables such as ambient temperature, relative humidity, wind, and rainfall is recognised as the potential hazards in livestock growth and production. Exposure of animals to the hot environment could stimulate thermoregulatory mechanisms and produces a reduction in the rates of metabolism, feed intake and productivity [59]. The cattle must be in thermal equilibrium with its environment including air temperature, radiation, humidity and air movement to maintain homeothermy [60]. Heat stress appears when there is any pattern of conditions that cause an effective temperature to be higher than the animal's 'thermoneutral' zone. Previous studies recommended that temperature-humidity index (THI) can be used as a sign of thermal climatic conditions and to measure stress degree in cattle [61].

Nadimi *et al.* introduced the on-line monitoring system for animals using ZigBee based WSNs. The authors have employed the 2.4-GHz ZigBee-based WSN in a single-hop network to quantify head movements of a herd of dairy animal [6, 29]. The issue of animal's presence and their pasture time using WSNs has been handled [6, 29]. To control the superiority of indoor environment is vital for cattle welfare and health as it directly influenced the productivity and its quality. Proper ventilation in the stables should be maintained so that long-term perilous exposure to ammonia which can lead to stress, health deterioration, and productivity reduction can be avoided. Huircan *et al.* [62] introduced cattle monitoring system based on Zigbee with the localisation scheme in WSN.

Currently, RFID device technology is employed in various agricultural fields to gain transparency of distribution routes and high productivity from the cultivation environment to distribution logistics and production management [24]. RFID/WSN technology in the livestock industry is used to monitor characteristics of each animal, their environment and to track breeding history. WSN-based monitoring of animal health using RFID has also developed [63]. Recently, the development of RFID has opened a new scope for real-time body temperature monitoring in human as well as

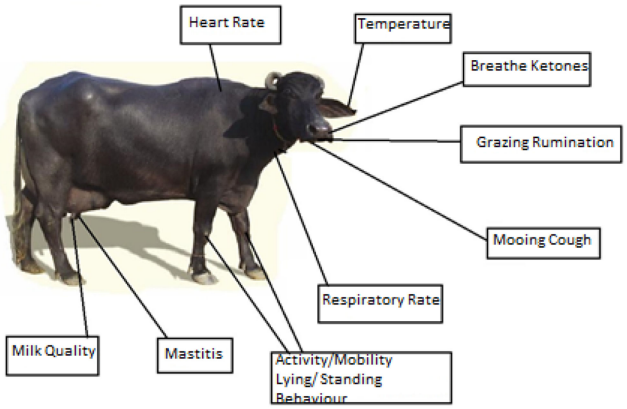

Fig. 2 *Areas to monitor dairy cattle*

livestock animals. RFID is a wireless system that sends out the identification of an object in form of a distinctive sequence of numbers using radio waves. Several researchers have used wireless RFID technology to automatically determine the physiological and behavioural activity for monitoring the health condition of each animal [46, 64]. The body temperature is an excellent indicator of animal's general health for quantifying stress of animals [59], shearing effect, warning for illness and diseases [65]. Rectal temperature also changes according to different ages in animals [66]. The shifts in body temperature are useful not only for identifying an animal experiencing disease events [67] but also identifying an animal with particular physiological conditions like oestrus state, approaching parturition [68]. The rectal temperature (RT) is used to show the body's peripheral temperature. RT is used almost exclusively because it is relatively simple, durable, and inexpensive equipment. Mercury bulb (MB) thermometer can be used to measure RT with a reasonable degree of accuracy. Veterinarians and dairy farmers used the rectal temperatures for the detection and management of febrile situations and variations in several animal's states (oestrus, the onset of calving and heat stress) [69]. However, the variation in body temperature requires frequent sampling and thus obtaining data in a continuous manner at the farm is time consuming, labour intensive as well as costly. Therefore, there is a need for solutions that can offer automatic acquisition of this parameter [70]. Thus, deployment of a monitoring system is necessary for quantification of behavioural parameters and their transformation to corresponding behavioural modes.

Behavioural parameters are like cattle's head movement or spatial distribution and behavioural modes such as lying down, grazing, walking and standing [6, 47, 50, 71, 72]. Such type of monitoring system could aid farmer in managing their farm in order to increase cattle production and welfare [71]. The behavioural parameters of cattle can be quantified by various kinds of sensors and strategies. Several researchers have suggested the classification tree, k-means classifier and multiple-model adaptive estimation approaches to performing data processing [47, 50, 71, 72]. These approaches have been used for measurement and transmission of behavioural parameters as well as processing of data and their transformation to corresponding behavioural mode.

Rumination is one of the significant parameters which can be considered in monitoring buffalo's health. Rumination duration is mainly decided by the amount of feed ingested together with the ration composition mainly fibre content and particle size. Excessive starch and easily fermented carbohydrates cause a reduction in chewing activity. As a result, the saliva production decreases and creates metabolic disturbances that deteriorate the buffalo health and production. Prolonged daily rumination resulted in higher milk yield. A drop in rumination is a clear indication of health problems which can affect milk production. Many sensors have been developed to monitor rumination. Umstatter *et al.* equipped the offline pitch-roll sensors around the necks of cattle for their monitoring [50]. Sallvik *et al.* introduced radio frequency synchronisation units (RFSU) with video processing techniques [73]. The animal behaviour in indoor environments (i.e. barns) has been evaluated by several authors [51, 70]. Online monitoring system has been developed by several authors, which has a capability of real-time monitoring and classification of animal behaviour [47, 50, 51]. The systems were based on the deployment of WSNs to measure certain behavioural parameters such as pH of the stomach, head movements, and spatial distribution and transmit them over a wireless network to a central base station. Ipema *et al.* tested a 434-MHz WSN in a single-hop network to quantify the pH of the stomach of a dairy animal [28]. The online monitoring system used to determine the inactive or active status of dairy animals by monitoring their head movements. Active status considered as dynamic movements such as walking or grazing. Animals which are not showing dynamic activities are considered as inactive such as standing or lying down.

Several authors have reported a high loss of data packets over the WSNs [6, 28, 29]. Moreover, frequent energy supplies are required in WSN because modern network structures and communication protocols are not used resulting in high-energy consumption WSNs. In addition, the health status of WSNs is not observed, therefore the performance and network congestion of node is not evaluated. Hence, the wireless node could not be substituted in the case of breakdown. The network reliability and reception rate of data transmission are two foremost issues that restrict the WSN application in monitoring animal behaviour, food production and biological systems [74]. To handle above issues, 2.4-GHz ZigBee-based mobile *ad hoc* WSN is designed using multi-hop mesh networking, relay nodes, and handshaking communication protocol in which low-energy consumption, a high rate of data packet reception and reliable communication have been achieved.

Schwager *et al.* classified the behaviour of dairy animals into active and inactive by k-means classifier [72]. One of the common diseases seen in cattle is bovine respiratory disease whose signs are fever, nasal discharge, and rapid breathing. Another disease is Leptospirosis whose signs are fever, bloody urine, and anaemia. Also, pregnant buffalos may get aborted. In such cases, monitoring of body temperature becomes very important. Several new technologies have been presented for measuring the body temperature of cattle at various locations including rectum, reticulum-rumen, ear, milk, and skin. Thermocouples determine the temperature by producing a small voltage signal proportional to the temperature variance between the junctions of the two divergent metals. First junction (the hot junction) is classically encased in a sensor probe at the point of measurement; the second junction (the cold junction) is linked to the measuring instrument. Thermistors, which are distant extra correct and stable than thermocouples, are semiconductors made from metal oxides that are pushed into a small wafer, bead, disk, or another shape. The thermistors sense temperature by connected to their electrical resistance; when located inside a small data recorder, they are supreme for separate operations such as thermal mapping. As compared to the previous types of sensors that require straight contact with the tissue to get temperature measurements, infrared (IR) technology does not require any contact with the animal, permitting remote measuring. From previous years, it has been observed that technology for thermal-based temperature measurement has been designed significantly. Various companies are today able to produce diverse devices for numerously varied usages of temperature measurements, extending from industrial to medical and veterinary issues. To quantify temperature of animals, two different categories of IR systems are commercially available, IR thermometers and thermal cameras [47, 72]. Brown-Brandt *et al.* introduced the comparative analysis of telemetry system for core body temperature measurements in beef cattle, poultry, dairy cattle and swine. The system is based on the overall accuracy of the system, specified resolution of temperature transmitters and flexibility of taking measurements on both free-roaming and housed animals. Transmitters are based on size, transmitting distance and battery life [75].

Another method to retrieve data from animal mounted devices employed an existing global system for mobile (GSM) infrastructure facilitated real-time communication [46]. Nevertheless, battery life issue is there, this method became too

Table 1 Health monitoring systems for cattle

Reference	System	Parameters detected	Sensors
[31]	ZigBee-based animal health monitoring system	rumination, body temperature, and heart rate with surrounding temperature and humidity for analysing the stress level	IEEE802.15.4 and IEEE1451.2 standards-based sensor module, ZigBee device and PIC18F4550 microcontroller
[33]	cattle-worn system	core body temperature, heart rate, GPS location, ambient temperature and humidity and motion	telemonitoring system utilizing wearable technology
[45]	sensor technology	dairy farms	sensors and embedded system
[83]	cattle health monitoring system	humidity, temperature, heart beat, respiration and rumination sensors	Arduino UNO, sensors, IoT
[84]	smart animal monitoring system	temperature, humidity, rumination and heart rate	(temperature, heart rate, rumination) sensors, zigbee device and Ardiuno microcontroller.
[85]	NodeMCU	temperature, humidity, heart rate	nodeMCU microcontroller, WiFi router and cell sensors
[86]	wearable sensors	temperature, humidity	ZigBee, posture sensing
[87]	Moomonitor	physiological conditions of animal	biosensors and wearable technologies
[88]	silent Herdsman	behavioural parameters	collars
[89]	Moosense	ambient temperature, humidity, nutrient intake and activity	stationary sensor node-enabled devices, smart nodes and a set of relay nodes
[89]	WSN-based feedlot animal health monitoring system	animal feeding behaviour monitoring	battery powered IEEE 802.15.4, ear tag, feed bunk and water trough routers and database server

expensive while monitoring large numbers of animals. Smith *et al.* introduced another health monitoring system for cattle which focused on heart rate, core body temperature, and head motion. The system is based on AMD186 processor on a turn microcontroller board [33]. The heart rate monitoring method for cattle based on polar sport tester (PST) is introduced by Janzekovic *et al.* [76]. The heart rate and body temperature parameters are also used as a disease examination for several animals. Wietrzyk and Radenkovic *et al.* described the *ad hoc* WSN-based cattle health monitoring which concluded that by measured data, the livestock farmers can prevent the expansion of diseases [27, 34].

Hopster *et al.* introduced two techniques for measuring stress in dairy cattle. The presented methods are based on electrocardiograph and PST. From experiments, it has been observed by authors that the PST is a suitable technique for quantifying and analysing heart rate of animals [77]. Guo *et al.* presented a WSNs-based livestock monitoring and controlling method. The method is also beneficial for classifying animal behaviour and their activities. It used the Fleck2 processor board and measured the parameters such as an accelerometer, magnetometer and temperature for GPS information [78]. Nadimi *et al.* presented an *ad hoc* WSNs-based monitoring and classifying animal behaviour using 2.4 GHz frequency-based communication module [16, 29, 60]. This scheme is able to achieve communication consistency, minimum packet loss rate and energy efficient. The handshaking protocol and multi-hop communication are used in the system. The multi-layer perception-based artificial neural network transform is used to transform the measured behavioural parameters into the corresponding behavioural modes. Allen *et al.* [79] reported the buffalo behaviour versus heat stress to define the behaviour as a valuable parameter for producing milk. Lovett *et al.* [80] introduced a measurement technique base on IR thermography for cattle. This method is useful for examining the FMD of cattle. Stewart *et al.* [81] described an IR thermography which is based on indirect stress measurement of dairy cattle. Krishnamurthi *et al.* [82] presented X-ray computed tomography-based imaging for small animals to study their physiologic measurement. Any substantial variation in the grazing duration can show anomaly that needs the attention of farmer. Table 1 shows the various health monitoring systems reported in the literature.

The Zigbee device is an energy efficient, high accuracy, self-configuring, low cost, communication technology. Zigbee-based animal health monitoring system has sensor, processor and ZigBee module. It generally used four different types of sensors such as rumination sensor, heart rate sensor, temperature sensor and humidity sensor. It is used in well-known applications such as smart building, environment monitoring, military surveillances, smart farms, telemedicine services and other industrial applications [31]. Cattle-worn system is generally used to determine the behavioural observations of cattle that are important for detection of illness, injury and estrus as well as to verify that the cattle are behaving normally or not. In cattle-worn system, data loggers have been developed that can automatically detect and record animal behaviour [33]. Sensor technology-based health monitoring systems for cattle simplify the requirement for endlessly assessing the state of individual animals, aggregating and reporting this data to the farm manager [45]. In cattle health monitoring system, Arduino UNO microcontroller is used to sense various activities of animals such as body temperature, respiration, humidity, heartbeat and rumination. The wireless sensor node comprised of hardware part which contained four sections: a microcontroller, a sensor, power administration unit and wireless transceiver [83]. In the smart animal monitoring system, the information is transferred through embedded hardware which is going to be added to the animal body and data transfer will be done. So that the current health status of cattle could be easily monitored and preventive measures for that can be taken [84]. The nodeMCU has been used in several applications of wireless sensor networks (WSNs)-based health monitoring systems for cattle. The nodeMCU provided open-source, interactive, low-cost programmable and WI-FI enabled which is flawless for cattle health status monitoring. NodeMCU is an open source IoT platform and included firmware which runs on the ESP8266 Wi-Fi SoC from Espressif systems [85]. Wearable sensors for cattle are becoming increasingly important for cattle health management. These devices, if manufactured exactly and used properly, can offer a timely diagnosis of diseases in cattle, ultimately decreasing financial losses. Such devices are mainly useful for dairy cattle and poultry farms [86]. MooMonitor is a wireless sensor that helped farmers to find individual cow heats and health events with comfort through data analysis. It screened cows on a daily basis and classified the definite types of behaviours such as feeding, rumination, and levels of activity [87]. Silent Herdsman provided a solution that enabled the farmers to accurately predict their milk production for each year. The cows attired a collar that comprised a 3D accelerometer which conveyed data back to the base station in the farm. Naturally, when dairy cattle are on heat she will move much more than usual, so the cattle's actions are monitored to allow the farmer to determine the optimal time to milk. It similarly helped in categorising of sick animals as soon as possible [88]. Moosense is one of the primary functioning multi-objective WSNs in India being energetically used for careful dairy research [89]. It is a cluster of sensor networks where each cluster has a list of specialised systems fitted on the ground or mounted on the

animals, which are accountable for live-monitoring of a variability of cattle-health parameters. WSN-based feedlot animal health monitoring system is designed to monitor the animal's feeding and drinking behaviours. A guiding antenna is used to permit one router to monitor numerous animals simultaneously and an energy efficient mesh routing approach is defined to combine the monitoring data [89].

Presently farmers face a lot of challenges for monitoring the cattle health. Most of the available system has focused only on the measurement of heart rate to predict the health of cattle. The presented monitoring systems according to literature only allow data to be downloaded at a fixed point only once. However, only subsets of animals pursue the ordered pattern of dairy cattle. These systems also exhibited a long delay as the detected event can [90, 91].

From this literature review, it has been observed that the wearable systems are key technologies for real-time health monitoring of cattle in aiding the veterinary staff and measuring of parameters that can provide accurate information of cattle health. Therefore, it can be concluded that with the advent of WSN technologies, the cattle health care would be less expensive [92, 93]. Hence, the monitoring system is required that should be capable of monitoring, rumination, heart rate and body temperature with surrounding humidity and temperature. It should have a variety of features such as new materials at lower cost, energy efficient, high speed, miniaturisation, high performance, intelligence, and portability. With all these innovations in research, the real-world applications of the introduced systems have not been done yet. There is no real-time animal health monitoring system in the market. Most of the veterinary staff determines the physiological and behavioural parameters manually. The other issue of above health monitoring solutions for cattle is the robustness of the installed device on cattle. If cattle are not comfortable with devices, they are prone to get rid of those sensor devices fastened to their bodies. Most of the available systems focus only on the measurements of heart rate to predict the health of cattle. This survey reveals that the wearable sensors for real-time cattle health monitoring systems are a key technology in helping veterinary staff for measuring parameters to provide accurate information about cattle health.

6 Research issues and challenges

i. Monitoring, anticipation, and treatment of transmittable and metabolic illnesses characteristic of premature lactation (e.g. ketosis, retained placenta, metritis, mastitis, hypocalcaemia) decline the incidence of banished abomasa on dairy farms, become challenging.

ii. Cattle suffer from stress-inducing situations, i.e. when they cannot adapt behaviourally or physiologically to environmental or physical challenges. Those challenges trouble homeostasis and an adaptive reply are stimulated in an attempt to restore balance.

iii. One of the major issues in the management of group-housed livestock is to make an initial finding of abnormal behaviours of cattle. Mainly failure in noticing estrus inappropriate and correct way can be a stern reason in accomplishing effective reproductive performance.

iv. To determine lameness behaviour in an accurate time is a serious health and welfare issue in current intensive dairy farming.

v. Wireless communication is a serious issue in cattle monitoring systems because cattle are free to roam. Wireless technology measured the individual practicable technique to start and sustain communications among a base station and collars attached to cattle.

vi. Data on endemic diseases are sparse and unreliable and data on health and welfare issues are mostly absent which is a very challenging issue.

vii. Cross-immunity studies presented that immunity is strain-specific, as cattle immunised against one strain of the parasite are not necessarily protected against challenge with heterologous parasite strains.

vii i. The major challenge of monitoring cattle with GPS technology is the ability to have real-time updates, spatial accuracy and decreased battery life.

ix. Despite the progress of statistical methods in cattle health monitoring system for linking genetic variation to phenotypic traits and to disease pliability and infectivity is still considered as a big issue.

x. Depth observation is reduced while viewing videotape in cattle health monitoring system related to live observation and making it difficult to observe if animals are actually drinking or eating or just outlay time close to water or feeder. An additional challenge with video observation is the labour required to document and views all the cattle behaviour movement desired.

7 Conclusion

In this paper, cattle monitoring system and their related issues have been reported. Though some health monitoring systems have been developed for cattle, but still, there are a lot of challenges faced by farmers. Therefore, there is a need for utilising WSN for monitoring cattle health for early and accurate detection of diseases and their prevention from spreading. With the help of WSNs, network setups are flexible without any fixed infrastructure. Several researchers are there that are using different methods for monitoring and collecting the information. Moreover, several commercial companies are also there that are developing and selling their monitoring solutions in the market. This is a rapidly rising market which is moving from passive solutions to more advanced monitoring elements. This paper provides a review of various existing solutions for animal monitoring system by using low-power consumption and low-cost sensor nodes. In future, the routing protocol is likely to be used in the farm trial to study its process in the related field. Further, there is the possibility of using drones to assist human beings for the identification of cattle that are not eating or drinking properly. Also, solar power can be used as the energy source of the routers to make the system more environmentally friendly. Additionally, the concept of wake-up radios can be used. Moreover, the ultra-wide band radio-based WSN for animal health monitoring can be explored. These technologies will present very high low-power consumption, low complexity and time-domain resolution.

8 References

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