Sensor Technology For Animal Health Monitoring

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Abstract— **The scale of dairy farming worldwide has changed significantly over recent years, with a move towards larger, more intensive, profit-driven enterprises, primarily due to market pressures. This change has resulted in demand for technologies that can reduce costs and labour inputs while increasing farm productivity. This is mainly achieved through the use of farm automation and advanced technological techniques.**

An important aspect of farm automation that is currently being researched is the area of automated animal health monitoring. In this research, we have identified specific diseases which are common in dairy animals which can be identified through the use of non-invasive, low-cost, sensor technology. These diseases have been mapped to specific aspects of animal behaviour that have been mapped to the three sensors which are most significant to identify these diseases. The identified sensors will be shown to be vital in the development of the next generation of health monitoring system for dairy animals. Such a system will allow the automatic identification of animal health events, greatly increasing overall herd health and yield while reducing animal health inspection and long-term animal healthcare costs.

Keywords- Embedded system, Intelligent system, Design, Development, Sensors, Animal health monitoring, Animal Diseases, Veterinary, Dairy farms, Sensor Box, Non-invasive, Wearable Animal Health Monitoring System

I. Introduction

In the last few decades, the quality of farming has immensely transformed with small sized, intensively labour based farms being replaced by much larger autonomous and industrialised farms. With these changing conditions, animal welfare becomes an increased concern.

Conventionally, an experienced herdsman would take care of a comparatively fewer cattle and would have direct contact with them, while, on modern automated farms, very few people look after a large number of cattle, hence decreasing the direct contact with them. Thus, this creates a greater need to monitor the animal's health.

In last two decades, researchers have developed several applications for sensor technology. The commonly researched fields in sensor technology are robotics, defence and military, industrial production processes, entertainment, which are comparatively less urgent than other bigger global issues such as natural disasters, determination of non-sustainable resources, health monitoring disease control, and many more.

Development of sensor system for animals has been limited, considering the use of sensors on them and the amount of influence they have on the daily aspects of our life. In the agenda of future research and development in sensor technologies, an increased emphasis should be given to these topics too. Hence, in this sense, this paper will focus on the determination and mapping of diseases in dairy cattle to the relevant sensors.

II. Why Use Sensors On Animals

There are numerous types of technologies that have been in practice for effective health monitoring, be it for humans or animals. Sensor is a device that measures a physiological or behavioral parameter (related to the health or estrus) of an individual cow and enables automated, on-farm detection of changes in this condition that is related to a health event (such as disease) and requires action on the part of the farmer(such as treatment).

Sensors fall into two categories: Attached and Non-attached.

A. Attached sensors:

They may be on-cow sensors that are fitted on the outside of the cow's body, or in-cow sensors that are inside the body (e.g., rumen bolus or implant).

B. Nonattached sensors:

They are off-cow sensors that cows pass by, over, or through for measurement. Two distinct forms of nonattached sensors are in-line and on-line sensors. In-line sensors take measurements in a continuous flow of product from the cow. The only available option for in-line measurement is in the milk line. On-line sensors automatically take a sample (milk, for example,) that is analysed by the sensor. [1]

Since the 1980s, a lot of work has been put into developing sensors that measure several parameters from an individual cow. The initial work recognised an individual cow followed by sensing electrical conductivity of milk and activity measurement using sensors like accelerometer and pedometers. [1]

The sensor systems development may be described in 4 levels:

(I) method that compute something about the cow (e.g., activity);

(II) Interpretation that abridge change in the sensor data (e.g., increased activity) to fabricate information about the status of the cow (e.g., estrus);

(III) Integrate information where sensor data is supplemented with other data (e.g., financial information) to advice for produce (e.g., whether or not to inseminate cow); and

(IV) The decision making depends on the farmer or the sensor system may do it autonomously (e.g., inseminator is called for). [1]

Four levels are defined here that describe the degree to which the sensor system informs the farmer. The sensor itself is only the first step in a sensor system. The second step is to use the sensor data in an algorithm that provides information about the health of the individual cows. In this step, it is possible to combine sensor data with non-sensor data about cow history. [2]

As more sensors become available and are tested more extensively, a need has risen for a clear overview of what sensors have been tested, how advanced the systems are, and the quality of the produced data, information, and devices. Such a structured overview is currently lacking within the scientific literature. As the idea of sensor research is to provide farmers with tools to improve their cow health management, the central question in research regarding sensors should concern what value (meaning the economic value, but also the usefulness for risk management and making labour easier) the sensor system adds to the farmer's decision making. [1]

III. TYPES OF SENSING TECHNOLOGIES

In order to aid the farmer, sensor systems have been developed to automatically determine the physiological and behavioural indicators. These indicators (or features or parameters) are used as input for subsequent data analysis methods. The existing approaches for sensor-based data acquisition could be classified in two categories:

A. Non-invasive

1) Immobile sensors located in the barn:

Cows in a barn usually have a repetitive daily routine, i.e. they are at known locations at fixed times (during milking and feeding). Therefore, sensors can be placed at fixed locations where the cows regularly have to pass. Typical sensors of this type are temperature measurements of the udder [3] or of the face in an automatic milking station. Another example is the measurement of breath composition [4].

Another kind of immobile sensors are **surveillance cameras**. When the typically occupied area is in the field of view of the camera, it can continuously provide information for the cows in the herd [5]. However, the reliability of this information is limited by the "optical" conditions in a barn: The similarity between the background and the cow's body colour hinders the detection of the cows. The ability of these systems for a long term identification of cows is still limited.

In general, the benefit of this "immobile sensor" approach is that only one or a few sensors are required to monitor a herd. The disadvantage is the limitation of available data sets: Physiological indicators are well assessed in this way. The availability of behavioural indicators is, however, limited (and better recorded on longer time intervals). Another disadvantage is the significant temporal gaps between observations (similar to the case of qualitative observations by the farmer) which prevent quick reactions by the farmer.

2) Mobile sensor boxes attached to the cow (external sensors):

In order to monitor cows throughout a day, the most reliable way is to attach sensors at individual cow (e.g. by a neck collar or an ankle ribbon). Typical sensors of this kind are accelerometers, pedometers, vibration sensors, thermometers for temperature measurements (at hypodermal level), humidity sensors (at skin level), etc.

Pedometers are cheap and simple sensors that give insight in the activity status of a cow. Recent scientific applications were used to identify oestrus behaviour with good prediction capabilities [6]. Pedometers are also part of more complex sensor system. In [7], a pedometer for three measurement parameters (activity, lying time, and temperature) including a real-time watch and a changeable measuring the time interval was developed. The purpose of the system was the identification of oestrus cycle times. In principle, the system may also identify several illnesses (according to the authors). This however was not yet confirmed by experiments.

Recently, low-cost and infrastructure-less **GPS positioning sensors** have been used to identify different motion states of cows [8]. The GPS sensors were attached to the animals' collars. They aimed at identifying the following activities: eating, seeking, walking, lying and standing. For these activities, the average classification success rate of around 85% was achieved. Therefore, the classification ability is promising but the rate is yet too low for practical applications. However, the success rate could be significantly increased by an integration of additional sensor signals (e.g. accelerometers).

Another class of sensors, **MEMS-based accelerometers,** are currently the most promising candidates for providing reliable data for activity monitoring. They offer an excellent compromise between contradictory technological conditions: Continuously high data rate on one side, low power consumption, on the other hand, (not to mention low costs for this type of sensor). The usage of accelerometers in activity monitoring in cows was proposed many years ago (see different patent application dating back to the 1990s, e.g. [9]). Recent advantages in the design of accelerometers, especially in the field of MEMS-based, accelerometers, has notable improved the reliability of measured data sets. In a recently published paper, an analysis of state of the art sensors for activity analysis has been conducted [10]. Good experimental results were already achieved with (rather simple) heuristic classification approach. Even better results are feasible when using multiple sensors at different positions (e.g. in order to differentiate between head and body movements).

The advantage of this type of sensors is a continuous observation of the dairy cows. Especially the class of modern MEMS-based accelerometers is a promising candidate for successful commercial systems, presumably in combination with additional mobile sensors. The disadvantages are an increased effort for accessing the sensor data as well as an increased danger of damages to the sensor boxes (due to the movements of the cows in the barn). Both disadvantages are controllable by modern engineering.

B. Invasive

1) Mobile sensor boxes swallowed or implanted to cow (internal sensors):

High precision measurements of some physiological parameters require sensors that reside within the cow (e.g. in the rumen, under the skin). Typical sensors of this kind are thermometers for measuring the core body temperature or vaginal pressure during birth [11]. Sensors for measuring the electrical conductivity [12] and the pH-value [13] [14] [15] of rumen fluid are another examples.

The advantage of internal sensors is reliable measurement values that are unaffected by external conditions, in combination with continuous observation of the cows. The disadvantages are difficulties for reusing sensor, limited application time of the sensors due to the required energy and (at least for some sensor types) the placement inside the cow. Especially in the field of activity monitoring, mobile internal sensors only have limited added value when compared to mobile external sensors.

Each sensor system is described using five categories referring to the used technique, collected data, used algorithms, and performance. The first three categories provide a brief summary of the technical aspects of the device: type of sensor (1) sensor location (with respect to the cow); (2) type of measurements (3) Alerts given by the sensor are compared with the gold standard (4) which describes the occurrence of an event in reality [16]. The relation between the gold standard, sensor data, and possible data additional to the sensors' data that does not originate from the sensor under study (non-sensor data); (5) is described by an algorithm. [1]

IV. COW HEALTH EVENTS/DISEASES

The following health events will form the basis of this study as they all have a negative impact on cow health and welfare and on farmer profitability by increasing calving-to-conception intervals and reducing milk yield components.

1) Mastitis

Mastitis is a swelling of the breasts gland and tissue in the mammary gland and is a leading endemic disease of dairy cattle. It produces an immune response to bacterial invasion of the teat canal by various bacterial sources on the farm and may also happen as a consequence of chemical, mechanical or thermal injury to the udder.

2) Lameness

Abnormal movement during locomotion accredited to either the foot or a leg.

Table 1: Lameness Indicator.

Score	Description	Assessment criteria
1 – Non Lame	Normal	Walks and stands normally leveled back, confident long strides.
2 –Lame	Mildly lame	Stands with a flat back, walks with a slight arch, slightly abnormal Gait
3 - Lame	Moderately lame	Stands and walks with arched back, short strides with one or more leg, little sinking of dew-claws in appendage which is opposite to the affected limb is evident.
4 - Lame	lame	Arched back while standing and walking, leaning on one or more limbs but may still carry some weight on them, dropping of the dew-claws is apparent in the limb opposite to the affected limb.
5 - Lame	Severely lame	Distinct arching of back, unwilling to move, with complete weight transfer away from the affected limb.

3) Cystic Ovarian Disease

In Dairy cattle, the ovarian cysts are defined as follicular structures of size more than 2.5 cm in diameter that endure for least of 10 days in the absence of corpus luteum. [17]

4) Displaced Abomasum

The fourth chamber of the stomach of the cow that hangs loosely by the omentum is called abomasums. It can shift from its standard placement in the stomach and can displace right that may cause abomasal volvulus and torsion or may displace left causing its entrapment under the rumen.

Cow has decreased appetite with an audible, high-pitched ping created by tapping the left abdominal wall between the 9th and 12th ribs, for left displaced abomasum.

5) Ketosis

Ketosis is characterized by depression and partial anorexia. Seldom, it transpires in cows in late gestation. In adding to the loss of appetence, symptoms of nervous dysfunction, as well as pica, incoordination and abnormal gait, anomalous licking, bawling, and hostility are sporadically observed. [18]

6) Milk Fever

Milk fever also known as postparturient hypocalcemia or parturient paresis, portrayed by reduced levels of blood calcium. [19] It is a metabolic disease defined by decreased blood calcium levels (Hypocalcaemia) which results in decreased productive longevity by 3 years and decreased yield.

7) Retained Placenta

The inability to shed the placental membrane even after 24 hours after birthing. A part of the placenta is seen loosely hanging from the birth canal after the birthing.

8) Diarrhea

Pestivirus is responsible for this disease. If infected cow passes watery stool with mucous several times a day. It causes loss of water and salt, weakness, thinning, inappetence and death if not treated properly and in time.

9) Pneumonia

It is a multifactorial disease. It weakens the immune system of the cattle and causes symptoms like fever, depression, serious nasal and eye discharge, inappetence, stiff gait, cold and cough in the cattle.

V. DISEASES MAPPED TO SENSORS

We discussed several cow diseases and how they affect the cows' behaviour through the symptoms and clinical signs the disease present in the affected cow. After carefully analysing the diseases, a table for mapping these conditions to the relevant sensors considering the aspect of animal health and coherent behavioural changes the cow exhibits in that disease, sensors were mapped to it.

There are various types of sensors available in the market for different applications. The sensors most commonly appearing in most diseases are Temperature sensor, Accelerometer and Microphone. Also, another common type of sensor appearing was Pedometer, which can be built from accelerometer.

Table 2: Diseases and sensor relation

Disease	Aspect Of Animal Health	Behavioral Changes	Sensor
Fever	High Temperature	High/Low Temp	***Temperature***
	Discomfort	Less Activity	***Accelerometer***
		Mooing	***Microphone***
Lameness	Motion Changes	Standing Or Sitting	***Accelerometer,*** Pedometers
		Less Grazing	Load Sensors
		Abnormal Back Arch	GPS
Oestrus	Hormone Level (E.G. Progesterone)		***Accelerometer*** (Around Neck)
Mastitis	Yield	Behavioral Changes Not Well Defined	***Accelerometer*** (Pedometer)
Ovarian Cysts	Yield	Less/ More Grazing	Pressure Sensor
	Temperature	High/Low Temp	***Temperature***

	Milk Quality	Electrical Conductivity	Electrical Conductivity Sensor
Displaced Abomasum	Feeding		***Accelerometer***
Ketosis	Breathe Ketones	Grazing	***Accelerometer*** (Pedometer)
		Eating, Rumination	***Microphone***
		Breath smell	Gas Sensor
Milk Fever	Movement / Motion		***Accelerometer***
Retained Placenta		Excitement/ Stiffness	***Accelerometer*** (Pedometer)
		Mooing	***Microphone***
	Weight	Weakness/ Weight Shifting	Load Sensors
	Fever	Temperature	***Temperature Sensor***
	Heart/ respiratory rate	Pulse	Heart Beat Sensor
Heifer Diarrhea	Fever	High Temperature	***Temp Sensor***
Heifer Pneumonia	Nasal Discharge	Running Nose	
	Cough	Coughing Sound	***Microphone***
	Increased Respirator y Rate	Sound Of Breathing	***Microphone***
	Decreased Appetite	Less Grazing/ Feeding	***Accelerometer*** (Pedometer)

VI. CONCLUSION

This research has been undertaken in order to establish specific sensor technologies as a significant means to monitor animal health and to ensure animal well-being in the fast changing conditions of automated farms. Due to the high demand and supply of dairy products, dairy cattle are in a constant demand for high yield, leading to the need of continuously monitoring of their health to ensure their fitness as it directly affects the health of the consumers. Moreover, the overall economy in the dairy farming industry depends on the herds' health.

Several cattle diseases have been studied in depth and analysis of the symptoms associated with these conditions. These symptoms were then mapped to the type of sensors that would be able to measure the said behaviour as shown in the table 2 above.

This research has identified three primary sensors; Temperature, Accelerometer and Microphone (marked as bold in table 2) that are essentially required to determine the health quotient of the cattle. Further work on the system utilizing these three sensor types will lead to the develop of the next generation, noninvasive, wearable animal health monitoring system which will gather relevant sensory information, such as activity, and alterations in head and neck movement and relate the gathered animal data to predict or identify animal health events.

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