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Technologies used at advanced dairy farms for optimizing the performance of dairy animals: A review

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Abstract

Superior germplasm, better nutrition strategies, health care facilities and improved dairy husbandry practices have boosted milk yield and its quality with a rapid rate. Per cow productivity has risen up sharply with considerable increase in the population of dairy animals. Recent era has witnessed the extension of large dairy farms around the world. Demand for high quality and increased quantity of milk is of the prime concern for all the dairy farms. With an increase in the size of animals in a farm, the labour requirement also rises up. Availability of skilled labour at low wage rate is becoming difficult. In last couple of decades, the cost of microprocessors has been reduced to an affordable level. The economic availability of engineered processors, artificial intelligence, improved data statistics combined with expert suggestions has created a revolution in livestock farming. Advanced engineered devices have become alternative to reduce high labour cost. This review focuses on latest knowledge and emerging developments in animal's welfare focused biomarker activities and activity-based welfare assessment like oestrus, lameness and others. Use of enhanced sensors and data technologies with expert based solutions is anticipated to bring out a substantial improvement in existing dairy farming practices.

Introduction

Dairy cow's milk production across whole world has increased many folds and the number of dairy cows has increased considerably during last 5 decades. This shows the remarkable strength of world's dairy sector. Per cow annual milk has slowly risen from 1,800 to 2,400kg/cow on average in a lactation period (FAO Stat, 2016). The reason behind this is the advancement in the management of genetics, breeding, and advanced applied nutritional management of dairy animals (Capper *et al.*, 2009). The scenario of herd strength dairy farms is changing considerably now days. Traditionally, dairy owners had 2-10 dairy units at their farm but, as for now this management system has changed towards the creation of large dairy farms. We have witnessed that large dairy farms which utilize advanced engineering prospective in the routine operations are coming into play (Caja *et al.*, 2016). Some examples of such large dairy farms include: TH group's project in Vietnam with 29,000 dairy cows; Al Safi farm in Saudi Arabia having 40,000 milk cows; Modern Dairy Co. With 40,000 milking cows in China; recently collaborative project Russia-China (Zhong ding Dairy Farm) is under construction and is expected to have 1,000,000 milk cows. Under Indian conditions, the best examples can be the dairy farms of ICAR (National Dairy Research Institute, Karnal) having more than 2,500 livestock units. Other examples include Bhagyalakshmi Dairy Farm, Pune; Breeze Fresh Dairy Farm, Tamil Nadu; Sharda Dairy Farm, Nashik, respectively which have more than 2,000 animals at any point of time in their herd. In this article the synergism between mechanical, electrical and computer science engineering has been mentioned as "technologies".

Several factors are related with elevated production cost per kg of milk. These factors include high feed cost, labour cost, hormonal treatments, metabolic diseases, multi-factorial diseases, such as lameness, which may lead to several other diseases. Additionally, other farm factors associated with dairy production which lead to a sharp rise in cost of production at farm level are likely to increase. In order to meet high demand for milk, many times the welfare of farm animals may be in question. Advances in technological and mathematical approaches have opened a system for quantification of complex biological systems (Ji *et al.*, 2017) which was not possible earlier. Sensors now a days have become more precise with enhanced statistical and data processing technologies. This has rapidly enhanced husbandry practices at a dairy farm. Advanced applied engineered device-based husbandry support systems will aid up in optimum welfare for dairy animals and by using them, the profitability of the farm can be maximized. There is availability of several potential devices that may automatically collect data such as biomarker, behavioral and physiological parameters. Data set so obtained have the potential to help the farm manager to take decision for early detection of welfare complexities for an individual animal, thereby which corrective husbandry practices may be employed. These advanced engineering has led to a new era of communication and hence formed the basis of new farming concept, *i.e.* precision livestock farming. Precision livestock farming implies the accurate provision of animal requirement for optimal animal health, production, welfare based on accurate data acquisition, storage and processing and ultimately extracting the information of interest (Norton *et al.*, 2019).

There are several remarkable and published review manuscripts in consideration with engineering devices for animal health and animal welfare (Rutten *et al.*, 2013; Caja *et al.*, 2016; Mattachini *et al.*, 2016) but some latest and important findings have been done which needs to be addressed to mass scientific community of animal production management field. Therefore this review is framed with an aim of disseminating the inferences drawn from the major, latest and important studies regarding advanced applied and engineered devices for improved animal welfare. This paper reflects the area where necessary studies need to be accomplished in future. It is anticipated that this manuscript will act as a bridge for existing and advance knowledge base of concerned scientific community in broader way.

Methodology for literature review

Existing and latest papers were accessed through Google Scholar and scientific databases (Research Gate, Ebsco, Scopus, Science Direct, etc.). Important research and review articles from 1974 up to the year 2021 were rigorously studied. However, the constitution of the World Health Organization (WHO, 1946) is also referred. This review encompasses rich information resource from several important studies; however, it doesn't aim to present the whole literature review. The information gathered from the cited articles has been presented on inferences drawn from them. The consideration of articles was limited to those which were written in English language.

Some farm factors for the rise in cost of production

Present farming conditions have observed sharp rise in skilled labour cost with decline in their availability (Caja *et al.*, 2016). Reproduction technologies use hormonal and other chemical treatments for reproductive and health management of dairy animals (Mattachini *et al.*, 2016). Treatment of common and multi factorial diseases such as lameness, mastitis, etc. have elevated the cost of production for dairy operations (Sadiq *et al.*, 2019). These factors lead to discover new cost-effective alternatives options for efficient dairy husbandry (Akbar *et al.*, 2020). In this case, modern technologies have become the alternate option for dairy farming. Economical and easy availability of microprocessors have lead to improved data, storage, processing, and interpretation. In addition to this, high definition HD cameras and sensitive sensors have lead to the simplification of dairy operations (Caja *et al.*, 2016). There remains still a challenge to utilize poor quality feed resources, whatever available, towards quality milk production.

Dairy animal wellbeing compared to dairy animal welfare

In 1946, the constituting body of the World Health Organization (WHO) described good health as "a complete physical, social and mental well-being, and not only the absence of disease or infirmity" (WHO, 1946). Furthermore, the father of the nation of India, Mahatma Gandhi, stated that "health is the real wealth and not the pieces of gold or silver". In a recent dairy care conference on advanced engineering held at Lisbon (2016), it was suggested that welfare and well-being have been used interchangeably but they are different and should be understood accordingly (DairyCare, 2016). Welfare is multi factorial and hence cumbersome to asses on a given point of time; however, well-being has only one assumption, *i.e.* optimum state of all physiological activities of animal (Caja *et al.*, 2016). Moreover, animal well-being has become a top priority of European Union citizens and commission (EU-PLF, 2016). Duncan & Fraser (1997) stated that animal welfare comprises animal body, mind, and nature satisfaction. Apart from optimum bodily activities, the ability of animal for proper manifestation of decision making and their behavioral satisfaction forms the basis for animal well-being. Major aspects of planning

animal health and well-being include assessment of health and well-being state followed by analysis of outcomes, then feedback is drawn and report of results are interpreted, based on inference from data farm specific advices are given for health and welfare related issues. This process is continuous with constant optimization and adaptation (Tremetsberger & Winckler, 2015). There are several methods of estimating animal welfare consisting health related measures, behavior and resource-based measures. Each kind of measure includes several parameters' estimation. All this assessment becomes a difficult task. Furthermore, there are several success and risk factors associated with the enhancement of animal health and animal welfare (Tremetsberger & Winckler, 2015). However, for wholesome notion we will broadly discuss the technologies utilized for optimizing performance of animals along with enhanced animal welfare.

Animal welfare is important

High yielding animals are the prime focus of any dairy farm operation (Singh *et al.*, 2020a, g; Sriranga *et al.*, 2021). However, such animals are on risk of heat stress problems: metabolic problems such as ketosis, acidosis, hypocalcaemia; infectious diseases like mastitis and metritis; and multifactorial diseases as lameness, which may lead to risk of other ailments. These problems are mainly observed during peripartum and initial lactation period (Overton & Waldron, 2004; Singh *et al.*, 2020b,h). High-producing dairy animals are found most productive on an average of 2-3 lactations but some exceptional producers may goup to 3-4 lactations. Culling rates, which are suggested to be near 20-25%, are steadily crossing more than 35% (Chiumia *et al.*, 2013; Mohd-Nor *et al.*, 2014). These culling rates are even larger in high producing and larger herds (Hadley *et al.*, 2006); however, the dairy owners always strive for quicker onset of oestrus after calving (Mayo *et al.*, 2019). Hence, dairy operations should concentrate more on female animals for improved profitability of farm. It has been observed that the advancement in engineered devices in dairy plants is more than that of dairy farms (Sun *et al.*, 2015). The uses of engineered devices in dairy technology have increased much more than that of dairy production area. Larger dairy farms, however, are coming up with the increased use of these advanced devices with a rapid rate.

Commercially available technologies for dairy cows

Robotic machine milking

Improved milk performance with high quality is always in demand (Kansal *et al.*, 2020; Kumari *et al.*, 2020;

Singh *et al.*, 2020b,i). Milking of dairy animals is a labour exhaustive process (McBride & Greene, 2009), more than 25% of time of a labour is accounted during milking operation in dairy farm (Deming *et al.*, 2018). This becomes important activity on a farm and this period offers a great scope for routine diagnosis of dairy cows (Martins *et al.*, 2019). At present more than 8,000 advanced dairy farms are utilizing robotic milking system (deKoning, 2010); miRobot, GEA, DeLaval, Fullwood Packo and Lely and other companies are the prime manufacturers of robotic milking machine. This system identifies individual cows' udders and teats for milking automatically and helps in keeping teats and udders clean before and after the milking process. These machines not only help in labour cost cutting but also allows cows to be milked at their choice (Broucek & Tongel, 2017). The installment of this milking system requires a long term investment. This system allows the herdsman to spare more time on visualizing physical activities of dairy animals, thus allowing more flexibility in the working style in a dairy farm. Through this milking system, the decisions based on the ground reaching data set have been found to help in early detection and prevention of metabolic diseases such as lameness and mastitis among several others. For instance, the lame cow would be less likely to visit milking parlour and there will be a depression in milk production in the cases associated with mastitis in dairy animals. Changes in activity levels could also be helpful in detection of stages of oestrus in dairy animals (Butler *et al.*, 2012). However, robotic milking system requires an adaptation period of few months for dairy animals to get accustomed with this system. Thus, it may affect the milk yield during the initial months of newly installed robotic milking system. Automatic or robotic milking system utilizes data set for separate quarters of udder hence minimizing the chances of intra-mammary infection (IMI). In a recent review on the influence of robotic milking on udder health of dairy animals, Hovinen & Pyörälä (2011) remarked that there exists a negative correlation between using a robotic milking system and a simple machine milking system. Udder health has been seen more deteriorating in automatic milking systems for larger herds. The reason may be improper management conditions to control the subclinical mastitis (SCM) cases as other factors such as farm cleanliness, udder shapes, environmental bacterial load, diet regime, etc. Hence, it is recommended that while implementing a robotic milking system, herd manager must consider regular teat disinfection along with considering aforesaid factors that affect SCM in dairy animals.

In line milk composition

Somatic cell count (SCC) counter Afimilk Ltd. (www.afimilk.com) utilizes infrared technology for estimating the composition of milk in-line, *i.e.* when it is been

collected (Heidrich *et al.*, 2019; Deng *et al.*, 2020). In infrared technology, specific wavelength lights are observed. Based on the wavelengths, those are reflected and are absorbed by the constituent particles of milk; the quantification is done for the compositional quality of milk. In a recent study by Fadul-Pacheco *et al.* (2018) a comparison between sensor-based and laboratory-based data was made and a high similarity between the results was observed. Hence, this method may be well utilized in dairy farms to access the quality of milk. Change in milk composition has been found associated with different problems in nutrition, health, and management conditions of dairy animals (Aeberhard *et al.*, 2001; Walker *et al.*, 2004). For instance, cows with fat: protein >1.50 are more on the verge of SCM (Duffield *et al.*, 2009; Singh *et al.*, 2020b).

DeLaval counter system (www.Delaval.com) utilizes the technology of analysis of cell components by UV-fluorescence method (Zajacl *et al.*, 2016). In this analytical device, a platform is provided in the counter where a disc is inserted for SCC counting. One milliliter of a composite sample of milk is put inside the disc and then inserted into the section, and within 1-min the device gives details about SCC in milk sample. Additionally it also shows whether the milk is of cow or buffalo. Several studies (Bharti *et al.*, 2015; Alhussien & Dang, 2018; Kumari *et al.*, 2019) suggest that milk SCC is one of the suitable diagnostic tests for SCM diagnosis in dairy cows.

In line milk composition with suitable diagnostic tools for SCM in a robotic milking system together may be anticipated to provide useful sets of data which would be of practical importance for a dairy farm manager

Automatic watering

Water is considered as the most important nutrient for animals. A dairy animal requires 2.5-140 L/day under free movement conditions (Khelil-Arfa *et al.*, 2012; Axegard, 2017; Singh *et al.*, 2020b,c). Singh *et al.* (2020e) suggested that the water intake is affected by several factors including milk yield, dry matter intake (DMI), potassium, sodium and nitrogen intake in the feed. Developed automatic systems for analysis of animal behavior and welfare are used with image analysis and machine-learned segmentation technique (Nilsson *et al.*, 2015; Axegard, 2017). Water intake may be effective in finding out the DMI (Lukas *et al.*, 2008) which may be helpful in finding the effectiveness of feeding strategies. Though indirectly, a significant change in water intake may indicate towards the potential physiological changes in dairy animals such as heat stress, oestrus stages, or any other health related aspects (Lukas *et al.*, 2008; Khelil-Arfa *et al.*, 2012; Axegard, 2017). Animals follow a specific hierarchical pattern wherein a dominant one has the opportunity of accessing major facilities in the farm premises and thereby creating a chance of depressing less dominant cow yet a high productive. This may hamper the production level of herd as well. Automatic waterers have specific sensors which may observe the behavioral activities such as number of times an animal visits the water troughs for how much time with different ways of interactions. Thereby, automatic waterers offer a scope of understanding behavioral patterns of different ranked animals during their interaction with water troughs. Thus, constructional modifications may be done for more effective grouping of animals. Moreover, measuring water intake has been suggested as one of the primary indicator for cows having metabolic disorders (Reith *et al.*, 2014). However, Pinheiro Machado *et al.* (2004) suggested that a heighted and larger water trough is more preferred by dairy animals for enhanced water consumption. Using advanced system for water prediction may help in estimating their behavior, management effectiveness and welfare of animals.

Reticulo-rumen bolus

SmaXtec sensor (www.smxtec.net), Well Cow (www.wellcow.co.uk), eCow Devon (www.ecow.co.uk) are some major brand names who manufacture reticulo-rumen bolus. These devices use radiofrequency, thermistor, electrode, short message service (sms), and 3-axial accelerometers for measurement of activity, temperature, and drinking and oestrus behavior of dairy animals (AlZahal *et al.*, 2011; Antanaitis *et al.*, 2020). Flow rate of different feed and fluid across reticulo-rumen, pH, and temperature data are continuously collected through this device and if sudden change occurs than normal values, a SMS is received by the concerned person on or off the farm. Furthermore, this device measures lying and standing behaviour of animals through the help of 3-axial accelerometers. Lying rumination represents comfortable conditions whereas more standing time reflects discomfort (Singh *et al.*, 2020d). Similarly, a comfortable cow shows slow feeding and drinking bouts than that of a cow with different degrees of discomfort. Discomfort postures of the dairy animals reflect the improper management conditions inside the farm premises. Housing conditions such as bedding material, ventilation rate, temperature humidity index (THI), feeding management facilities, may be enhanced properly in accordance with the data based expertise and experience. Antanaitis *et al.* (2020) observed that pregnant cows were likely to have higher reticulo-rumen pH as compared to non-pregnant cows during insemination time, and suggest that reticulo-rumen pH can be used for estimation of health status and reproductive success rate in dairy cows.

Digital body condition scoring - BCS cowdition app (Bayer animal health)

Body condition score (BCS) is an effective, easy and non-invasive method for accessing energy status of dairy animals (Singh & Kumari, 2019; Singh & Bhakat, 2021). BCS is helpful to estimate overall health and nutritional management of farm animals (Dann *et al.*, 2006; Beever, 2006; Berry *et al.*, 2007; Singh *et al.*, 2020b; Singh, 2021). BCS has been used to access several other productions (Singh *et al.*, 2020e), reproduction (Roche *et al.*, 2007; Butler, 2009; Drackley & Cardoso, 2014), health (Berry *et al.*, 2007) and other parameters (Singh *et al.*, 2020b). Earlier, body condition scoring was done manually. However, now, it can be assessed with software and 3-D imaging system. This method accurately measures the BCS of dairy animals. This utilizes the technique of digital 3-D image using active shape method and convex hull method (Liu *et al.*, 2017) in which pre-standardized images are present and comparison is made with respect to the captured image of target animal and then estimation of BCS is done. Ultrasonic method of image production also has been practiced in some studies (Bell *et al.*, 2018; Paul *et al.*, 2019). Alic-Ural (2016) and Chay-Canul *et al.* (2019) found that BCS estimation by this app and manual method had significantly no difference under different parity animals. Hence, this app can be very satisfactorily utilized for BCS evaluation. BCS so obtained can be helpful for prediction of nutritional and other health management operations of dairy farm (Singh *et al.*, 2020b). Halachmi *et al.* (2013) utilized thermal imaging for automatic estimation of BCS of farm animals. Biological models are applied to the angular portions from images of animals and then used for BCS estimation (Bewley *et al.*, 2020; Liu *et al.*, 2020).

Metabolites of milk

Several metabolites have been identified in blood mainly non-esterified fatty acid (NEFA), beta-hydroxybutyrate (bHBA) (McArt *et al.*, 2013; Amirifard *et al.*, 2016; Singh *et al.*, 2020b) which depicts the energy balance and other ailments in dairy animals in different stages of production (Adewuyi *et al.*, 2005; McArt *et al.*, 2013; Amirifard *et al.*, 2016). Sun *et al.* (2015) identified more than 108 metabolites in milk, urine, and serum and rumen fluid. They found that some metabolites have considerable life in milk and gets significantly changed with alteration in feeding regime of dairy animals. In this way a considerable and desired change in feeding strategy can be adopted for poor quality fodders. Management strategies on the farm may be moderated as per the optimal situation desired. This system needs a qualified lab and experts who may analyze and interpret the results in particular sequence. Then and there the statistical models are utilized for prediction of changes in metabolites in milk. The tests must be done in a short period of time with high accuracy, as metabolites´ life in milk when the changes can be noticed is short.

Potentially, there is an important role of these milk metabolites, which form out as a result of glycolysis, to predict the changes in mammary epithelial cells in dairy animals. The changes may occur in the levels of lactose, citrate, lactate, malate, Glu and Glu-6-p in the milk reflecting changes in the glycolytic metabolism (Silanikove *et al.*, 2014). After those changes, there can be increased cases of SCC and impaired composition and coagulating properties of milk in dairy animals. Moreover, the estimation of milk metabolites such as milk glucose and milk glutamate concentrations, may act as a non-invasive technique in predicting the metabolic and energy balance in dairy animals (Billa *et al.*, 2020). In a recent study, Xu *et al.* (2020) utilized liquid chromatography−mass spectrometry and nuclear magnetic resonance technique to quantify a list of 55 milk metabolites which were either positively or negatively associated with negative energy balance in dairy cows.

Hence, out of the discussion from this section, it may be inferred that estimation of metabolites in the milk is a non-invasive technique to predict the metabolic and energy balance changes in dairy animals so that the corrective measures can be adopted at an early stage.

Location positioning devices

Geo location tag (www.omnisense.co.uk), CattleWatch (www.cattle-watch.com) and WildCell (www.lotek.com) are examples of location positioning devices. These devices can effectively provide the location of the target animal, as they use gravitational positioning system (GPS) technology. Animals' coordinates are immediately accessed when required from a distant place (Turner *et al.*, 2000; Trotter *et al.*, 2010; Davis *et al.*, 2011; Soriani *et al.*, 2012). This may work from several thousand kilometers. Signals are connected with the satellite and the person associated with the device may know about the positioning, movements and several useful behaviors of animals (Veissier *et al.*, 1998; Gordon, 2001; Senneke *et al.*, 2004; Fogarty *et al.*, 2018; Maroto-Molina *et al.*, 2019). In farms where there are very large pasture lands and animals are let free to meet their most of the nutritional requirement by grazing, this device may be of great use. GPS has been already utilized for measuring grazing management and activities of farm animals on such grazing lands (Anderson *et al.*, 2012). Knight *et al.* (2018) found that these location tags may be useful to measure distance travelled by animals for water, feed, slope of area walked. However, battery charging and atmospheric

disturbances are some constraints in proper working of the device. They also suggested that this device may be useful for farm animals under rangeland management.

CowManager (www.cowmanager.com)

Since1974, ear tags have been used in dairy animals for identification purpose (Hanton & Leach, 1974). However, ear tags have now been much more enhanced with improved technologies to understand behavioral activities of animals in a better way. CowManager is a kind of device which may be helpful for obtaining location and health status data of concerned animal. Revolutionary changes in the identification facilities for farm animals have taken dairy farming to the next level and now it is possible to point out a particular animal from even several thousand kilometers connected to internet framework. This has become possible due to the advancements in the sophisticated and efficient devices, enhanced computer devices, internet of things, and artificial intelligence. Practical utility of ear tags can be more than just identification of farm animals. For example, ear tags can be helpful in determining the efficiency of vaccination or any health campaign in the farm; helps in maintenance of food safety (Lehane, 1996; Pluimers *et al.*, 2002; OIE, 2012). However, Britt *et al.* (2013) remarked that no electronic identification system is perfect. Hence, regular manual checkups should be carried out for working of ear tags adhered with animals, especially under loose housing conditions.

Ear tags are now endowed with several multipurpose technologies (Seroussi *et al.*, 2011). These ear tag devices utilize 3-axial accelerometer technology for measuring activity, feeding, and health of farm animals besides detecting location of target animals. Anziani *et al.* (2000) evaluated ear tags that contained ethion and they inferred that there was a remarkable reduction in the fly prominence over the body of dairy animals by more than 85% and up to 99%. Salina *et al.* (2016) compared the retention of visual ear tags and ear tags with radio frequency identification (RFID) and observed that RFID ear tags were better. However, they suggested that a combination of visual tags with RFID chips would be of more practical use for identification and retention of ear tags in dairy animals. Furthermore, they indicated that there could be chances of severe necrosis of ears when improper fittings of ear tags are done in the animals.

Pedometer

CowAlert (www.Icerobotics.com) is a kind of pedometer usually put in the left leg for ease in handling. It also utilizes 3-axial accelerometers for measuring activity, oestrous, health of farm animals (Roelofs *et al.*, 2005; Mazrier *et al.*, 2006; Rao *et al.*, 2013; Kerketta *et al.*, 2019). A gravitational tilt from either axial position of the cow is measured in form of data. Generally cows are seen with high activity of discomfort (Singh *et al.*, 2020d) during oestrus. Whenever these changes happen, a prediction may be done in advance for the stage of estrus in dairy animals. Discomfort activities such as increased standing time, reduced rumination, decreased milk yield, more leg activities, etc., are seen when cows are in oestrus (vonKeyserlingk *et al.*, 2009; MacKay *et al.*, 2012; Rao *et al.*, 2013; Kerketta *et al.*, 2019). This pedometer helps in measuring these activities with high precision.

Vaginal thermometer

Body temperature in many aspects is connected with many physiological activities of any animal (Igono *et al.*, 1985; Frazzi *et al.*, 2001; Umphrey *et al.*, 2001; Burfeind *et al.*, 2011). High yielding dairy animals are more susceptible to any physiological changes due to internal and environmental stimulus for expression in change of body temperature (Igono *et al.*, 1985; Frazzi *et al.*, 2001; Umphrey *et al.*, 2001; Tucker *et al.*, 2008; Allen *et al.*, 2015). Calving alert (Vel'Phone, Medria, Châteaubourg, France) is a kind of vaginal thermometer that may be placed inside the vagina of female dairy animals through which the status of parturition can be assessed 48 hr before the onset of calving process. This type of device sends data signals to the monitor based system where data are stored, processed and predictions are done (Aoki *et al.*, 2005; Vickers *et al.*, 2010; Burfeind *et al.*, 2011; Suthar *et al.*, 2011). Dystocia prevalence in high-producing dairy cows induces high losses in both cows and calves, thereby creating problems at any dairy farm (Mee, 2004; Lombard *et al.*, 2007). Accurate prediction of advanced partum conditions would be a great help to avoid such losses coupled with proper supervision (Wehrend *et al.*, 2006; Gundelach *et al.*, 2009; Burfeind *et al.*, 2011). If any veterinary assistance is needed, it can be planned in advanced this way. This would help in minimizing the unwanted losses through implementing advanced precautionary steps.

Tail ring for estrus detection

Timely detection of estrus is key for achieving high reproduction performance of dairy cows at any livestock farm (Norup *et al.*, 2001; Firk *et al.*, 2002; Chebel & Santos, 2010; Neves *et al.*, 2012; Fricke *et al.*, 2014). High reproduction efficiency of a farm is one of the prime concerns of a herdsman (Chebel *et al.*, 2010; Roelofs *et al.*, 2010; Abdullah *et al.*, 2014; Fricke *et al.*, 2014; Ulfina *et al.*, 2015). Automation in oestrus detection is studied to enhance the reproductive efficiency of many livestock

farms (Chebel & Santos, 2010; Fricke *et al.*, 2014). Economic automation in oestrus detection adds upto the profitability of the overall performance of a well-managed farm (Galvao *et al.*, 2013; Rutten *et al.*, 2014). Moocall (Dublin, Ireland) is an example of device that is tied over the tail head region of animals. It is a pressure sensitive device which is helpful in standing oestrus detection (Jonsson *et al.*, 2011) through radio-telemetry when any other cow or bull mounts on the particular cow.

Tail-head RFID chip

Heat Wath II, Cow Chips (www.cowchips.net) employs a RFID chip for the detection of standing oestrus of dairy animals when some other animal mounts over it. Pressure sensitivity of this device is considerable to be used for standing heat detection of a cow. This RFID chip is placed over the tail-head region of animals (Dizier & Chastant-Maillard, 2012; Rutten *et al.*, 2013) and the information is sent automatically to the system. However, it may give no information about the animal which mounted, and a chance to understand about the mounting animal may be missed. The mounting animal might be in pro-oestrus phase. Information about that may help in making required provisions for prophase animals also.

Celotor (www.celotor.com) utilizes two gadgets. One device for attaching on tail-head part of female dairy animal and other one over teaser bull for detecting oestrus condition in dairy females for proper timely artificial insemination. Presence of a teaser bull becomes necessary in this case. In this case also, the understanding of homosexual behaviors of the cows' may not be such effective. Efficiency of the teaser bull also affects the working of this management system. Hence proper sex ratio in the herds needs to be taken care.

Lameness detection

Lameness remains a problem of high concern at many dairy farms and has multi-dimensional effects on several other health and production parameters. Therefore, early estimation of lameness and curative measures become necessary for dairy animals (Bell *et al.*, 2006; Kristensen & Enevoldsen, 2008; Barker *et al.*, 2010; Leach *et al.*, 2010; Singh Y *et al.*, 2011; Singh M *et al.*, 2015; Tyagi *et al.*, 2017). Gait wise and Step Metrix are examples of devices which measure the interaction of feet of dairy animal over a sensor-based path utilizing several spatial positions of walking animal over it (Chapinal *et al.*, 2010; VanNuffel *et al.*, 2015, 2016; Jabbar *et al.*, 2017). Similar is the working principle for Step Metrix. The sensors present in this device sense the interaction of cows' hooves with the surface of device. For instance, if there is a deviation in the interaction of hooves with the platform then it predicts the health of cow based on data so

obtained. Recently, 3D vision cameras have been utilized for imaging position, postures of dairy cows and based on those informations, the estimation of health of animal hoof is determined (Song *et al.*, 2008; Hertem *et al.*, 2014; VanNuffel *et al.*, 2015; Gardenier *et al.*, 2018). Images of the animal's body regions of interest can be taken using 3D images. Standardized data are set into the system and whenever required, they are compared with the standard set of data and biological models following which estimation about the hoof health of present animal condition is done.

Vocal cues based oestrus detection

Generation of data based on vocal cues are used to estimate the different conditions of animals such as pain (Watts & Stookey, 1999), estrus (Chung *et al.*, 2013; Dreschel *et al.*, 2014) weaning response, hunger, age determination, hierarchy of animals (Hinch *et al.*, 1982) and may be well used for individuality of the animals (Singh *et al.*, 2013). Weaning conditions may have painful experience for both calf and dam (Singh, 2018). In addition to these points, feed anticipation may also cause vocal cues (Green *et al.*, 2018). Significant advances in computer and electronics engineered devices have been done. In animal management systems these are used up at a highly increasing rate. However, acoustic studies or the studies based on vocal cues have not been done in abundance (Green *et al.*, 2018). These devices have opened a great scope for understanding animal behaviour in a better way. Vocalization during sexual receptivity also differs with that of normal days' activities (Schön *et al.*, 2007; Meen *et al.*, 2015). Devi *et al.* (2019a) generated a digital support system for estimating oestrus condition in dairy buffaloes based on the frequency of their vocal cues. They recorded the frequency of vocal cues of buffaloes during different phases of oestrus cycle and cross checked it with expert veterinary estrous detection aids. Devi *et al.* (2019b) observed a significantly ($p<0.05$) higher frequency in voices of dairy buffaloes during estrus phase as compared to other oestrus phases. They found a high sensitivity and specificity of the device. The observed accuracy was 95% in this system. However, a practical complexity of surrounding noise may hinder proper working of these acoustic sensors. Nevertheless, improved sensors and software in audio recording devices may work with high sensitivity and specificity (Devi *et al.*, 2019b). Further researches are required to understand more about the acoustic features of dairy animals to improve the oestrus detection in dairy animals.

Infrared-thermography

Infrared-thermography has been termed as non-invasive technology for early diagnosis of potential physiological changes such as mastitis, oestrus and lameness

without contacting the target animal (Naas *et al.*, 2014; Harrap *et al.*, 2018; Sinha *et al.*, 2018).Wherein, different colour lights observed from surface temperature of target animals have different and specified temperature range (Naas *et al.*, 2014). These light wavelengths are invisible to humans and they fall in the range of 2-14 μm wavelengths (Harrap *et al.*, 2018; Sinha *et al.*, 2018). Polat *et al.* (2010) suggested that the accuracy of infra-red-thermography is similar to that of modified California mastitis test. A high corroboration among SCC and udder skin surface temperature was investigated in dairy animals by Colak *et al.* (2008). A temperature rise of 1ºC than that of normal udder skin of cow was considered as a cut-off value for the predictor of mastitis cases in dairy animals (Scott *et al.*, 2000; Colak *et al.*, 2008; Metzner *et al.*, 2014; Sinha *et al.*, 2018). However, there are several other studies which indicate that a change from 0.7ºC to 3ºC in different breeds of dairy animals are observed by different company infrared-thermography cameras (Colak *et al.*, 2008; Metzner *et al.*, 2014; Bortolami *et al.*, 2015; Digiovani *et al.*, 2016; Sathiyabarathi *et al.*, 2016; Sinha *et al.*, 2018).

Early detection of foot and mouth disease (FMD) cases

Thermography of dairy animals is a rapid diagnostic tool for early detection of FMD, mastitis, lameness and other health problems in farm animals (Berry *et al.*, 2003; Stokes *et al.*, 2012; Alsaaod *et al.*, 2014, 2015; Gibbons *et al.*, 2014; Sathiyabarathi *et al.*, 2016). Infrared-thermography is a non-invasive and a handy tool for measuring potential health problems in dairy animals (Alsaaod *et al.*, 2014; Gibbons *et al.*, 2014; Sathiyabarathi *et al.*, 2016). In the images, lower temperatures are reflected by blue–green pigmentation in the animal without fever or viraemia *vs* higher temperature areas with orange–red shades in the viraemic and feverish animal were noticed and quantified (Rainwater-Lovett *et al.*, 2009). This system requires securing or making animals to pass through animals in separate place where thermal images are obtained for more accuracy in order to detect FMD cases.

Automatic blood sampling in dairy cows

It has been observed that the blood samples are collected manually on regular basis. This provides a great scope for analyzing the changes which may happen in blood constituents under different circumstances. However, manual system of blood collection and storage is quite labour and time exhaustive. Advanced provisions are required to be made for blood sampling. A new concept of blood sampling has been developed which automatically collects and stores samples on the desired period of time. This method attempts to

fulfill the need to optimize the work and use of other facilities. A back pack type system is placed near the shoulder region on the left side of the thoracic vertebrae. It contains IceSampler with other components. Basic working principle of IceSampler includes standby state whereby blood is collected in line containing heparin solution; filling; sampling by inserting needle in the tube filled with blood; flushing of waste materials is done into waste bags. This method of collecting blood samples may be of great importance at farms which follow loose housing systems where the number of animals is large and it is difficult to secure desired animals for blood collection. Storage facility also aids up in this system. Comparisons done by Fønss & Munksgaard (2008) suggested that automatic blood sampling as compared to an experienced handler offers a great alternative option for blood collection with several aforementioned benefits. There was significantly no difference among manual and automatic method for collecting blood samples and using this technique, the analysis of blood for different parameters may be simplified (Kaufmann *et al.*, 2011).

Monitoring CO_2 ventilation in farms

Livestock farm gaseous emissions have been studied from several decades (Garnett, 2009) in order to study its impact on both animal and its surrounding environment. Measuring concentrations of different gases in a ventilated barn is quite cumbersome and difficult task (Kiwan *et al.*, 2012). Maintenance of proper air flow, moisture, THI, microorganism load, gaseous load, proper bedding materials are of prime focus of a well-organized dairy barn (Singh *et al.*, 2020f). Ogink *et al.* (2013) suggested that measuring pressure difference, hot wire or ultrasonic anemometers and tracer gas methods may well help in detection of gaseous emission in a dairy barn. NO_2 is used as tracer gas traditionally (Estellés *et al.*, 2010; Ogink *et al.*, 2013; Patra, 2016); however, Persily & Jonge (2017) suggested that CO_2 may also be used to measure ventilation rate, and also the emission of CO_2 in the house of animals. Hassouna *et al.* (2012) remarked that Photo Acoustic Spectroscope (PAS) gas analyzer can be employed to estimate the CO_2 concentrations from animals´ buildings as well as agricultural facilities. Furthermore, non-dispersive infra-red (NDIR)-based sensors may be used as an alternative for PAS for the estimation of CO_2 concentrations in livestock buildings (Hassouna *et al.*, 2012).

Accelerometers and magnetometers

It has been observed that the assessment of locomotory-behavioral activities is a difficult task for manual observations under loose house settings and may become almost impossible in free range conditions for manual assessment

(Müller & Schrader, 2003; Spigarelli *et al.*, 2020). Accelerometer sensors can be a reliable and suitable technology for monitoring feeding and other important behavioral activities of individual dairy cows (Mattachini *et al.*, 2016). Measuring static acceleration, which occurs due to gravity, and dynamic acceleration through animal movement, is accessed by the accelerometers. Along with identification, this technology is used to measure grazing behavior, such as preference of animals for different heights of grasses, etc. Some other recent studies suggest that accelerometers are deficient in measuring some behavioral activities which are low in acceleration and not produced by the animals itself (Halsey *et al.*, 2011; Williams *et al.*, 2017; Chakravarti *et al.*, 2019). Tri-axial magnetometers are influenced by acceleration due to gravity, so they may be used in combination or without acceleration for measuring movement behaviour of animals (Williams *et al.*, 2017; Chakravarti *et al.*, 2019). This may be applied to different locomotory behaviour of dairy animals with exception on those magnetic poles of Earth. However, magnetometers are less sensitive to noise due to minute body part rotations (Williams *et al.*, 2017). Hence, the combination of magnetometers and accelerometers would be more effective for quantification of different locomotory behaviours of farm animals.

Individualized animal welfare through integrated actions

Technology driven data should be based on individuality of animals and it should be useful for the farmers. Caja *et al.* (2016) suggested that animal well-being is a multidimensional approach and hence requires synergism between ethologists, animal scientists, veterinarians, and agricultural engineers. After the generation of data, a proficient statistician is always on top priority for interpreting the data. In order to obtain benign results, biomarker based, activity based and system level welfare technologies become necessary (DairyCare, 2016). Individuality of particular animal is employed for ensuring well-being of dairy animals. The data set of a particular animal represents its virtual individuality. Statisticians or the data managers consider this data set as identical object of the target animal through which several possible prediction and estimations can be done.

Assessment of present technologies in commercial use for dairy animals

There are several devices which are employed these days for data generation on different activities such as feeding, estrus, lying, standing, walking, mastitis, milk change, navigation of farm animals (Rutten *et al.*, 2013; Chanvallon *et al.*, 2014; Lyons & Kerrisk, 2017; Grodkowski *et al.*, 2018; Mayo *et al.*, 2019). Larger herds have been found to utilize more advanced technology at their farms (Gargiulo *et al.*, 2018). The area of concern is the precision of such available technologies. Mayo *et al.* (2019) in a recent study compared the efficiency of the major commercially devices and found them considerably useful. They proposed that the devices which are commercially available have fair utility for generating useful data for dairy owner. However, 100% dependency upon the data so generated is not advisable. The need for the presence of an expert team is always there with expert statistician who may make out management decision based on those data. Cohesive knowledge base from animal physiologist, ethologist, gynecologist, health expert, animal nutritionist, livestock management person, agricultural engineer, and an expert statistician may bring out the desirable results.

Location of engineered devices in a cow for collection of useful data

Engineered devices could be of two types, on cow body and off the cow body. Off the cow body devices include inline milk analyzer, SCC counter, etc. However, on cow body devices include ear tags, halter, neck collar, automated blood sampler, reticulo-rumen bolus, pedometer, vaginal bolus, among several others. The diagrammatic view for the location of engineered devices over and inside different body parts of a dairy cow is presented in Fig.1.

Proposed working model

Optimization needed in the current situation requires data set of different aspects of biomarker and
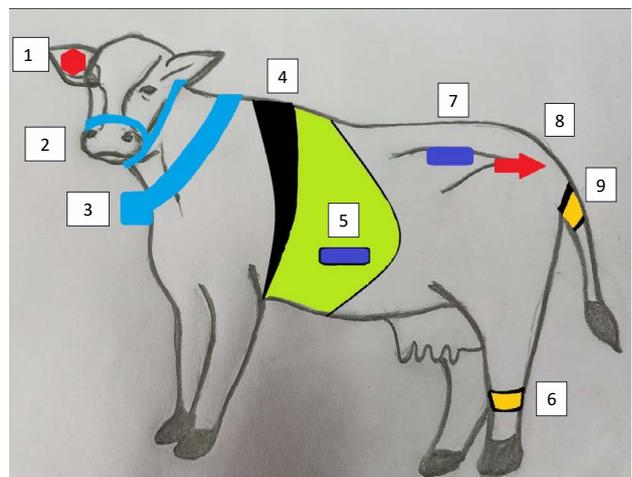

Figrue 1. Proposed engineered devices in a dairy cow for continuous observation of well-being status: (1) ear tag, (2) halter, (3) neck collar, (4) automatic blood sampler, (5) reticulo-rumen bolus, (6) pedometer, (7) vaginal bolus, (8) tail-head chip, (9) upper tail ring.

activity-based data (Fig. 2). Proper data analysis may be done for the above mentioned data types. Data set is created for individual cows on regular intervals. These generated data may be automatically saved in the system and hence the virtual identity of animal is created on regular dates. Pre-processed data helps in knowing the current status of target animal as compared to previous state on a particular time period. Furthermore, the optimal situation of animal, as suggested by database by different experts, is compared with current situation and then prompt actions can be taken to optimize the status of animals. Animal welfare through this model would be simplified in enhancing welfare practices for dairy animals in longer perspectives. This connected system would be quite effective; however, it would require setting up large data storage base. Initial or installation cost of different devices will again be a matter of concern. However, recent studies, as discussed above, have suggested that in long run this model will be helpful in cutting the labour cost as labour cost is increasing day by day. With this working model, several recurring costs will be minimized with increased working efficiency. However, this system would be utilized by the farms which are large in size to sustain with such investment. It is proposed hereby that in coming one or two decades, majority of the farms will have this kind of working model at their farm with increase in milk yield and market milk price.

Animal welfare implications

It is proposed by many studies that in next two decades most of the farms will be of big size, having more number of animals than what is prevailing in the present conditions. Improved and advanced approaches for animal welfare practices are of immediate requirement. Structured working model as suggested in this review (Fig. 2) appears to be an encouraging approach for optimization of animal welfare. Much improvement in mastitis, lameness, and oestrus management has been achieved through advanced engineered devices but, still there is great scope for synergistically using them for improved animal welfare. Therefore much more studies are required to explore the activities, psychology of animals for understanding their welfare in a better way. Similarly, further investigation is required to study the economic aspects of employing such engineered devices on dairy farm for improved animal welfare. This will form a holistic approach for both animal and farmer welfare.

Conclusion

Advances in agriculture technologies coupled with enhanced information, communication and internet of things has opened a new era of data based communication. This data based communication can be utilized anytime,
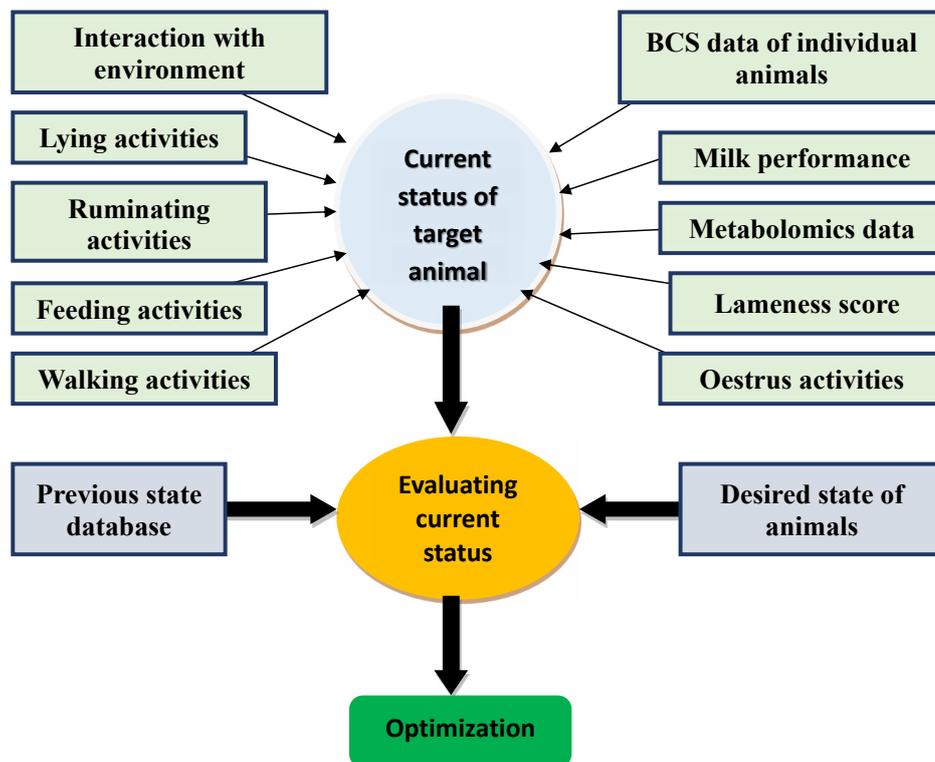

Figrue 2. Proposed working model through database of engineered devices. BCS: body condition score

anywhere, by anyone and anything, thereby providing targeted animals with an individual identity and virtual 'personality'. These may act as a reliable source of information for maintenance of animal welfare. From the above exhaustive review, it is clearly implied that there is no inadequacy of appropriate devices and some other advanced device may also be invented in future as per the need for animal welfare maintenance. Animals need considerable time to adapt with such engineered devices adhered to their body. Sudden change in the form of utilizing an engineered device may be disturbing initially to the animals but, in long it is expected that they will simplify the farm operations. However, there is always a requirement of a proficient manager and an expert statistician for the dairy farm who may interpret the gathered information into a useful result based decision for the improvement of animal management practices. Studies on adaptation behaviors of zebu animals and economical aspects of these devices will provide a complete scenario of utility of these engineered devices for the dairy owners.

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