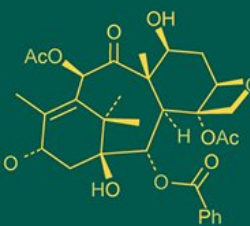
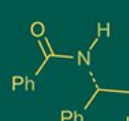


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A comprehensive review on advanced dairy technologies for increased milk production

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Abstract

Rapid advances in health care facilities, germplasm, nutrition, and dairy husbandry have increased milk output and quality. Due to dairy population rise, per-cow productivity has increased. Large dairy farms have proliferated worldwide in recent decades. Every dairy farm aims to produce more and better milk. A farm's work force grows with its animal population. Finding skilled workers at low wages is becoming harder. Over the last two decades, microprocessors have grown profitable. Affordable designed processors, artificial intelligence, improved data analytics, and expert advice have revolutionized animal husbandry. Innovative gadgets may reduce high labor costs. This review covers the latest findings and developments in activity-based wellbeing evaluation and animal welfare-focused biomarker activities, including oestrus and disability. Advanced sensors, data technology, and expert-based solutions could improve dairy production.

Keywords: Applied engineering; sensors; behavior; production; welfare

Introduction

Over the last 50 years, global dairy cow milk output and numbers have expanded manyfold. This displays the dairy industry's global strength. Milk production per cow has steadily increased from 1,800 to 2,400kg/cow each lactation (FAO Stat, 2016). This is due to advances in dairy animal genetics, breeding, and applied nutritional management (Capper et al., 2009). Today's herd-strength dairy farms are evolving. Once, dairy farmers had 2-10 dairy units, but today they have vast farms. Large dairy farms using sophisticated engineering in normal operations are emerging (Caja et al., 2016) [26]. TH Group's Vietnam project has 29,000 dairy cows; Al Safi farm in Saudi Arabia has 40,000 milk cows; Modern Dairy Co. in China has 40,000 milking cows; and the Russia-China Zhongding Dairy Farm is under construction and will have 1,000,000 milk cows. The greatest examples of dairy farms with more than 2,500 units in India are those of ICAR. This article mentions mechanical, electrical, and computer science engineering synergy as "technologies".

Several variables raise milk production costs per kilogram. High feed costs, labor costs, hormonal therapies, metabolic disorders, multi-factorial diseases like lameness, which may progress to other diseases, are among these causes. Other dairy farm elements that raise farm production costs may also rise. To fulfill milk demand, farm animals' wellbeing is sometimes at risk. Recently, technical and mathematical advances have made it feasible to quantify complicated biological systems (Ji et al., 2017). Modern statistical and data processing methods make sensors more accurate. This has improved dairy farm husbandry quickly. Advanced applied engineering device-based husbandry assistance systems improve dairy animal comfort and farm profitability. Biomarker, behavioral, and physiological data may be collected automatically by many technologies. The data collection might enable the farm management spot welfare issues early and implement remedial measures. Advanced engineering has ushered in a new age of communication and precision livestock production. Precision livestock farming requires precise data acquisition, storage, processing, and extraction to meet animal needs for maximum health, productivity, and wellbeing (Norton et al., 2019).

There are several notable and published review manuscripts on engineering devices for animal health and welfare (Rutten et al., Caja et al., 2016; Mattachini et al) [26], but some recent and important findings need to be shared with the animal production

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management scientific community. This review aims to disseminate the findings from the newest, most significant research on sophisticated applied and manufactured technologies for animal welfare.

This report shows where additional research is needed. This manuscript is expected to connect the scientific community's current and growing knowledge base.

Methodology for literature review

Through Google Scholar and scientific databases (e.g., Research Gate, Ebsco, Scopus, Science Direct), current and previous articles were obtained. Significant scholarly articles and reviews published between 1974 and 2021 were meticulously examined. Nevertheless, reference is also made to the World Health Organization's constitution from 1946 (WHO). This review incorporates a wealth of information from several significant studies; nevertheless, it does not intend to pre-send the complete literature review. The conclusions derived from the cited articles have been utilized to present the information gathered from them. The selection of articles for consideration was restricted to those that were composed in the English language.

Some farm factors for the rise in cost of production

Quality labor has become more expensive in agriculture despite a shortage (Caja et al., 2016) ^[26]. Reproduction technologies use hormonal and pharmacological therapies to manage dairy cow reproduction and health (Mattachini et al.). Lameness and mastitis management expenditures have raised dairy production costs (Sadiq et al.). The above parameters help identify new, economically feasible dairy husbandry methods (Akbar et al). Modern technology may replace dairy production in this case. Due to their accessibility and cost, microprocessors have improved data storage, processing, interpretation, and analysis. In addition, HD cameras and sensitive sensors have streamlined dairy operations (Caja et al., 2016) ^[26]. Using inadequate feed resources to generate high-quality milk remains difficult.

Dairy animal wellbeing compared to dairy animal welfare

In 1946, the WHO defined well health as "a comprehensive state of physical, social, and mental well-being, extending beyond mere absence of disease or infirmity" (WHO). Gandhi, the creator of India, remarked, "Health, not gold or silver, is the true wealth." At a recent dairy care symposium on advanced engineering in Lisbon (2016), welfare and well-being were suggested as equivalent when they are separate terms that need be carefully interpreted. Welfare is multifaceted and complicated, making it difficult to evaluate at a single time. In contrast, animal well-being depends only on adequate physiological activity (Caja et al., 2016) ^[21].

Pet care is a top priority for EU people and the commission (EU-PLF, 2016). Duncan & Fraser (1997) ^[10] define animal wellbeing as satisfying the animal's body, mind, and nature. In addition to ideal physical activities, animal well-being depends on their ability to articulate their decision-making processes and feel behavioral pleasure. Evaluation, analysis, feedback collection, and interpretation of animal health and well-being results lead to farm-specific health and welfare recommendations. Tremetsberger & Winckler (2015) describe this process as continuous adaptation and optimization. Animal wellbeing may be estimated using behavior, resource, and health markers. Each measure

estimates numerous parameters. Everything gets difficult during evaluation. Increasing animal health and wellbeing has risks and rewards (Tremetsberger & Winckler, 2015). We will present a basic review of the technology used to improve animal welfare and performance for a complete knowledge.

Animal welfare is important

Dairy farms aim to create high-yielding animals (Singh et al., 2020a, g; Sriranga, 2021). These animals are susceptible to heat stress complications like metabolic issues like ketosis, acidosis, and hypocalcaemia; infectious diseases like mastitis and gastrointestinal tract inflammation; and multifactorial diseases like disability, which can increase the risk of other illnesses. Peripartum and early breastfeeding are when these difficulties are most common (Overton & Waldron, 2004; Singh et al., 2020b,h). High-yielding dairy cows typically produce for two to three lactations, but exceptional producers may produce for four. Although estimates range from 20% to 25%, culling rates have regularly exceeded 35% (Chiumia et al., 2013; Mohd-Nor, 2014). Larger and better-yielding cattle have higher culling rates (Hadley et al., 2006) ^[15], although dairy farmers try to induce oestrus sooner after calving. To boost farm profitability, dairy farms should prioritize female cattle. Research shows that dairy facilities have developed engineered devices faster than dairy farms (Sun et al., 2015). Industrial use of technological devices in dairy has grown beyond manufacturing. However, larger dairy farms are quickly embracing these advanced technologies.

Commercially available technologies for dairy cows

Robotic machine milking

Milk quality and performance must always improve (Kansal et al., 2020; Kumari, 2020; Singh, 2020b,i). Nursing dairy cows is laborious (Mc Bride & Greene, 2009). Milking takes approximately 25% of dairy farm labour time (Deming et al., 2018). This practice is important in farming and allows for frequent dairy heifer diagnosis (Martins et al., 2019). Over 8,000 advanced dairy farms use robotic milking systems (de Koning, 2010). Leading manufacturers include mi Robot, GEA, De Laval, Fullwood Packo, and Lely. This device automatically identifies cows' udders and teats for milking, keeping them clean before and after.

These gadgets allow cows to be milked at their leisure and save labor costs (Broucek & Tongel, 2017). Long-term investment is needed to implement this nursing system. This approach gives herders more time to examine dairy animals' physical activity, increasing dairy farm operational flexibility. This lactation system's ground-reaching data may help identify and prevent metabolic disorders including mastitis and impairment. Disabled cows visit the milking parlor less and produce less milk. Activity changes may help identify dairy animal oestrus phases (Butler et al., 2012). Before using this autonomous system, dairy cows must acclimate for a few months. Thus, a new robotic milking system may reduce milk output in the early months. An automated or autonomous lactation system minimizes intramammary infection (IMI) by using udder quarter data. A recent study by Hovinen and

Pyorala (2011) found a negative link between robotic milking and machine milking on dairy cow mammary health. Udder health declines more in bigger herds with automated lactation systems. Environmental bacterial load,

nutrition, farm hygiene, and udder shape may contribute to subclinical mastitis (SCM) instances, as may poor management. Thus, herd managers should consider frequent teat cleaning when deploying a robotic milking system in addition to the other variables that affect SCM in *dairy* cows.

In line milk composition

In their somatic cell count (SCC) counter, Afi Milk Ltd. uses infrared technology to evaluate milk composition in-line or during collection (Heidrich et al., 2019; Deng et al., 2020) [16]. Light of certain wavelengths is analyzed in infrared technology. Milk composition is measured by its particles reflecting and absorbing wavelengths. Fadul-Pacheco et al. (2018) observed that sensor and laboratory data were quite close. Thus, dairy farms may use this method to assess milk quality. Alterations in milk composition have been connected to dairy animal nutrition, health, and administration difficulties (Aeberhard et al., 2001; Walker et al., 2004). For instance, heifers with a fat-to-protein ratio above 1.50 are closer to the SCM threshold (Duffield et al., 2009; Singh, 2020b).

The DeLaval counter system analyzes cell components using UV-fluorescence (Zajac et al., 2016). This analytical equipment counts SCCs by inserting a disc into its counter. The disc holds one milliliter of composite milk sample, which is put into the section. The gadget detects SCC in milk samples in one minute. Additionally, it separates *buffalo* and *bovine* milk. Milk SCC may be a valid diagnostic tool for SCM in *dairy* heifers, according to many studies (Bharti et al., 2015; Alhussien & Dang, 2018; Kumari, 2019).

Appropriate SCM diagnostic tools and in-line milk composition in a robotic milking system may generate dairy farm manager-relevant data.

Automatic watering

Living creatures need water most. Dairy cows need 2.5-140 L day under free mobility (Khelil-Arfa et al., 2012; Axegard, 2017; Singh, 2020b,c). Dry matter intake (DMI), feed potassium, sodium, and nitrogen intake, and others affect water consumption, according to Singh et al. (2020e). Machine-learned segmentation and picture analysis are used in automated systems to assess harmful behavior and wellbeing (Nilsson et al., 2015; Axegard, 2017). Water consumption may determine DMI (Lukas et al., 2008), which can be used to evaluate dietary regimens. Significant water consumption fluctuations in dairy animals may indicate physiological changes like thermal stress, oestrus stages, and other health issues (Lukas et al., 2008; Khelil-Arfa et al., 2012; Axegard, 2017). The hierarchical structure of animals allows a dominant animal to access crucial agricultural infrastructure, threatening a less dominant but highly productive cow. It may also reduce herd productivity. Automatic waterers include sensors that may measure animal behavior, such as how long and how often they visit the water receptacles. Thus, automatic waterers allow researchers to study how different-ranked animals interact with water receptacles. To arrange animals more effectively, structural changes may be made. Additionally, water intake assessment may help diagnose metabolic abnormalities in heifers (Reith et al., 2014). In contrast, Pinheiro Machado et al. (2004) suggested that dairy animals prefer a raised and bigger water receptacle to boost water intake. Advanced

water prediction systems may improve animal welfare, management efficacy, and behavior estimates.

Reticulo-rumen bolus

Reticulo-rumen boluses are made by Well Cow, e Cow Devon, and Sma Xtec sensor. These devices use radiofrequency, thermistor, electrode, SMS, and three-axial accelerometers to measure *dairy* cows' activity, temperature, consumption, and oestrus patterns. This device collects p H, temperature, and feed and fluid flow rates throughout the reticulo-rumen continuously. An SMS notice is sent to a farm or off-farm location if values suddenly deviate. Three-axis accelerometers measure animal behavior when lying and standing. Increasing standing time indicates discomfort, whereas resting rumination indicates good circumstances (Singh et al., 2020d). A happy cow eats and drinks less than an unhappy one. The *dairy* cows' unhappy attitudes indicate poor farm management. Based on data analysis, bedding material, ventilation rate, temperature humidity index (THI), and nutrition management facilities may be enhanced. Antanaitis et al. (2020) [5] found that pregnant cows had higher reticulo-rumen p H during insemination. The authors suggest that reticulo-rumen p H might indicate dairy cow reproductive success and health.

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

Body condition score (BCS) is a simple, non-intrusive, and efficient way to assess dairy animal energy status (Singh & Kumari, 2019; Singh & Bhakat, 2021). BCS helps evaluate farm animal nutrition and health. BCS has been used to assess health, reproduction, and other factors (Singh et al., 2020b, 2020e). Previously, bodily condition grading was done manually. It may be evaluated using software and three-dimensional imaging. This method accurately evaluates dairy animal BCS. BCS is estimated using the digital three-dimensional picture active shape approach and convex hull method (Liu et al., 2017) using pre-standardized images compared to the target animal's image. The ultrasonic approach has been used to generate images in many research (Bell et al., 2018; Paul, 2019). Chay-Canul et al. (2019) [9] and Alic-Ural (2016) found that this app and the manual technique estimated BCS similarly among priority animals. Thus, this application may analyze BCS well. The BCS can predict dairy farm nutritional and health management actions (Singh et al., 2020b). Halachmi et al. (2013) used thermal imaging to estimate farm animal BCS. Before BCS estimation, biological models are applied to animal picture angular segments (Bewley et al., 2020; Liu, 2020).

Metabolites of milk

At different phases of production, *dairy* cows' blood contains metabolites, notably betahydroxybutyrate (bHBA) and non-esterified fatty acid (NEFA). These studies provide light on *dairy* cows' energy balance and other health concerns. Sun et al. (2015) found 108 or more metabolites in rumen fluid, urine, milk, and serum. Certain metabolites spend a lot of time in milk and fluctuate significantly as *dairy* cows' diets shift. This allows for a significant feeding strategy change to accommodate for low-quality fodder. The property may use moderate management tactics for optimum results. This approach needs a specialized lab and staff to progressively analyze and interpret findings. Milk

metabolite changes are predicted using statistical models. The short presence of metabolites in milk during which changes become evident requires quick and accurate testing. Glycolysis-produced milk metabolites may predict changes in *dairy cows'* mammary epithelial cells. Milk lactose, citrate, lactate, malate, Glu, and Glu-6-p concentrations may suggest glycolytic metabolism (Silanikove et al., 2014). These changes may cause SCC and milk composition and coagulation issues in *dairy cows*. Estimating milk metabolite concentrations, such as glucose and glutamate, may be a non-invasive way to predict *dairy cows'* energy and metabolic balance (Billa et al., 2020). Xu et al. (2020) measured 55 milk metabolites with negative energy balance in *dairy heifers* using liquid chromatography–mass spectroscopy and nuclear magnetic resonance. Energy balance was favorably or adversely correlated with these metabolites.

This section shows that measuring milk metabolite concentrations is a non-intrusive way to predict energy balance and metabolic changes in *dairy cows*, allowing for prompt remedial intervention.

Location positioning devices

Location tracking gadgets include Cattle Watch, Wild Cell, and Geo Location Tag. These gadgets use GPS to locate the target animal. Animals can be quickly located from afar (Turner et al., 2000; Trotter, 2010; Davis, 2011; Soriani, 2012). This can work from many thousand kilometers away. The satellite's signals allow an affiliated person to learn animals' locations, motions, and beneficial behaviors. This equipment might benefit agricultural companies with large grazing grounds and animals that graze for most of their sustenance. GPS has been used to track grazing management and farm animal activity on grazing grounds (Anderson et al., 2012)^[4]. Knight et al. (2018)^[19] found that these location markers could measure animals' water, food, and downhill trip distances. However, battery replacement and atmospheric disturbances hinder gadget functioning. They also thought this device may work for rangeland management-managed cattle.

CowManager

Dairy animals have been identified using ear tags since 1974 (Hanton & Leach, 1974). However, technology has improved ear tags to better understand animal behavior. CowManager devices may offer animal location and health data. Farm animal identification technologies have improved so much that an internet-connected system can find an animal from several thousand kilometers away, advancing dairy production. Intelligent and efficient electronics, enhanced computer devices, the internet of things, and artificial intelligence make this possible. Ear badges may do more than identify cattle. Ear tags improve food safety and evaluate agricultural health programs and immunizations (Lehane, 1996; Pluimers et al., 2002; OIE, 2012). Britt et al. (2013) say no electronic identification method is perfect. Therefore, animal ear tags must be manually inspected often, especially in informal living conditions.

Ear tags use many flexible technologies (Seroussi et al., 2011). These ear tags use three-axis accelerometers to track the farm animals' movement, nutrition, and health. Anziani et al. (2000) examined ear tags with ethion and found that dairy animal fly populations dropped 85–99%. In a

comparison of visible and RFID ear tags, Salina et al. (2016) found RFID to be better. However, they proposed using optical identifiers and RFID devices to identify and retain dairy animal ear tags. They also noted that incorrectly fitting ear tags might cause serious ear necrosis.

Pedometer

Cow Alert is a type of pedometer that is typically carried on the left leg for portability. Additionally, the study incorporates three-axial accelerometers to assess the health and activity levels of farm animals (Roelofs et al., 2005; Mazrier et al., 2006; Rao et al., 2013; Kerketta et al., 2019). In the form of data, a gravitational inclination from either axial position of the *bovine* is determined. Bovines commonly exhibit heightened levels of distress (Singh et al., 2020d) when in oestrus. An advance prognosis of the estrus stage in dairy animals is possible whenever these changes occur. Cows in oestrus exhibit various distressing behaviors, including prolonged periods of standing, diminished rumination, decreased milk production, increased limb activity, and so forth (vonKeyserlingk et al., 2009; MacKay et al., 2012; Rao et al., 2013; Kerketta et al., 2019)^[21]. This pedometer facilitates the precise measurement of these activities.

Vaginal thermometer

Numerous physiological processes of every species are associated with body temperature (Igono et al., 1985; Frazzi, 2001; Umphrey, 2001; Burfeind, 2011). High-yield *dairy cows* are more susceptible to physiological changes caused by internal and external stressors, which affect body temperature. Vel'Phone in Medria, Chateaubourg, France, makes Calving Alert, a vaginal thermometer for female *dairy cows*. It determines these animals' parturition stage 48 hours before calving. This kind of equipment sends data signals to a monitor-based system for processing, analysis, and prediction. Dystocia in high-yielding *dairy cows* causes significant losses for both the cows and their progeny, making dairy farms' operations difficult (Mee, 2004; Lombard et al., 2007). Along with sufficient monitoring, accurate prediction of advanced partum diseases should help avoid such deaths (Wehrend et al., 2006; Gundeloch, 2009; Burfeind, 2011). Thus, necessary veterinary aid may be planned. Implementing proactive preventative measures will reduce unwanted losses.

Tail ring for estrus detection

Detecting estrus in *dairy cows* early is crucial to their reproductive success on any animal operation. Herdsmen value farm reproductive efficiency. Automated oestrus detection is being used to study cattle ranch reproductive effectiveness (Chebel & Santos, 2010; Fricke et al., 2014). Effectively managed farms optimize performance by integrating economic automation in oestrus detection (Galvao et al., 2013; Rutten, 2014). The Moocall (Dublin, Ireland) is attached to an animal's tail tip. When another cow or bull mounts the targeted cow, the pressure-sensitive device detects standing oestrus using radio-telemetry (Jonsson et al., 2011).

Tail-head RFID chip

Heat Wath II, Cow Chips uses an RFID chip to detect dairy cow oestrus in the presence of a mounted animal. This sensor can detect *bovine* residual heat due to its high

pressure sensitivity. The RFID device, placed above the animal's tail-head (Dizier & Chastant-Maillard, 2012; Rutten et al., 2013), enables autonomous data transfer to the system. It may not give any information about the mounted animal, losing a chance to learn more. The rising animal may be pro-oestrus. This information might also help prepare prophase animal supplies.

Celotor uses 2 devices. One gadget is attached to the tail-head of female dairy animals, while the other is put over a luring bull to detect oestrus in dairy females for timely and successful artificial insemination. This circumstance requires a teaser bull. Understanding cows' gay behavior may be impacted again. This management approach also depends on tea bull production. Having a proper sex ratio in animals is crucial.

Lameness detection

Lameness affects several health and productivity parameters, which worries many dairy farms. It's important to quickly detect and treat dairy animal impairment. Gait Width and Step Metrix analyze a dairy animal's many spatial locations on a sensor-based route to assess its interaction with the way. Step Metrix works similarly. Calf hooves are detected by sensors on the device's surface. For instance, if hooves interact differently with the platform, the system collects data to predict *bovine* health. In recent years, 3D vision cameras have been used to scan *dairy cows'* positions and postures to check hoof health. Animal body areas of interest may be recorded using 3D pictures. Standardized data is fed into the system and compared to the standard set of data and biological models to estimate animal hoof health.

Vocal cues based oestrus detection

Voices may indicate discomfort, estrus, weaning, hunger, age, animal hierarchy, and uniqueness (Watts & Stookey, 1999; Chung et al., 2013; Dreschel, 2014). Weaning may disturb mother and foal (Singh, 2018). Feed anticipation may produce vocalizations (Green et al., 2018) ^[12]. Computer and electronics engineering have progressed. Rapid resource depletion in animal management methods. Few studies of acoustic phenomena and voice signals exist (Green et al., 2018). These devices enable animal behavior research. Sexual receptivity modifies vocalization patterns as compared to normal living (Schon et al., 2007; Meen, 2015). Devi et al. (2019a) developed a voice signal frequency-based automated oestrus assessment method for dairy *buffalo*. They compared *buffalo* voice sounds throughout the oestrus cycle using high-quality veterinarian estrous detection instruments. Devi et al. (2019b) discovered a significant ($p < 0.05$) increase in dairy buffae vocalizations during estrus compared to other phases. Device with good sensitivity and specificity identified. This procedure is 95% accurate. However, environmental noise complexity may impede these acoustic sensors. Improved software and sensors may make audio recorders sensitive and specific (Devi et al., 2019b). To enhance dairy animal oestrus detection, acoustics research is required.

Infrared-thermography

Without touching the animal, infrared thermography may identify mastitis, oestrus, and impairment. The temperature range of colored lights sensed on target animals' surfaces was determined by Naas et al. (2014). Humans cannot see

light wavelengths from 2 to 14 microns (Harrap et al., 2018; Sinha, 2018) ^[23]. Polat et al. (2010) say infrared thermography is as accurate as the modified *California mastitis* test. In *dairy heifers*, Colak et al. (2008) found a substantial association between SCC and udder skin surface temperature. A 1°C rise in udder skin temperature above normal predicts mastitis in *dairy cows* (Scott et al., 2000; Colak et al., 2008; Metzner et al., 2014; Sinha et al., 2018). Numerous infrared-thermography studies show a temperature range of 0.7°C to 3°C in many dairy kinds (Colak et al., 2008; Metzner et al., 2014; Bortolami et al., 2015; Digiovani et al., 2016; Sathiyabarathi et al., 2016; Sinha et al.).

Early detection of foot and mouth disease (FMD) cases

For the early detection of FMD, mastitis, lameness, and other health issues in farm animals, thermography of dairy animals is a rapid diagnostic tool (Berry et al., 2003; Stokes et al., 2012; Alsaad et al., 2014, 2015; Gibbons et al., 2014; Sathiyabarathi et al., 2016) ^[7]. Utilizing infrared thermography to assess potential health issues in dairy animals is a practical and noninvasive process (Alsaad et al., 2014; Gibbons et al., 2014; Sathiyabarathi et al., 2016). The images depict lower temperatures, which are indicated by blue-green pigmentation in animals devoid of fever or viraemia, in contrast to higher temperature regions characterized by orange-red hues in animals with fever or viraemia. These differences were quantified (Rainwater-Lovett et al., 2009). This system necessitates the implementation of security measures or the separation of animals in a designated area so that thermal images can be acquired with greater precision, enabling the detection of FMD cases.

Automatic blood sampling in dairy cows

Consistent manual blood sampling is recorded. This lets you compare blood components across circumstances. Manual blood storage and collection are tedious. Blood sampling requires planning. A unique blood sampling technique automatically collects and saves samples at the appropriate time. To optimize facility and labor use. Left thoracic vertebrae form a shoulder backpack. IceSampler and others are included. While the IceSampler is inactive, heparin is used to collect blood. After filling the instrument, samples are extracted using a syringe in a blood tube and debris is emptied into trash bags. This approach may be useful on farms with many animals and lax housing arrangements that make blood sampling challenging. The storage facility helps this system. According to Fønss and Munksgaard (2008), automated blood sampling has several advantages over trained operators in blood collection. Since manual and automated blood sample collection procedures were similar, blood parameter analysis was simplified (Kaufmann et al., 2011).

Monitoring CO₂ ventilation in farms

Livestock farm gaseous emissions have been studied for decades to evaluate their environmental and animal implications (Garnett, 2009). Gas concentrations in ventilated stables are difficult to measure (Kiwani et al., 2012). Well-organized dairy stables prioritize bedding materials, moisture, air circulation, microbiological burden, and gaseous load, according to Singh et al. (2020f). Pressure difference, hot wire or ultrasonic anemometers, and tracer gas may identify dairy barn gaseous emission, according to

Ogink et al. (2013). As a tracer gas, NO₂ is often used (Estellés et al., 2010; Ogink, 2013; Patra, 2016). Persily & Jonge (2017) recommend measuring animal housing ventilation and CO₂ emissions with CO₂. According to Hassouna et al. (2012), a Photo Acoustic Spectroscopy (PAS) gas analyzer can measure CO₂ in farms and animal habitats. NDIR sensors can estimate cattle building CO₂ concentrations instead of PAS (Hassouna et al., 2012).

Accelerometers and magnetometers

Free range circumstances make manual locomotive behavioral activity monitoring almost impossible, but loose housing makes it difficult (Müller & Schrader, 2003; Spigarelli et al., 2020). According to Mattachini et al. (2016), accelerometer sensors can accurately track dairy cow eating and other behaviors. Inert gravity and dynamic animal acceleration are measured using accelerometers. This approach also measures animal identification, grazing behavior, and vegetation height preference. Recent study shows that accelerometers cannot detect nonanimal low-velocity behavioral behaviors. Tri-axial magnetometers can monitor animal motion with or without acceleration due to gravity. This applies to *dairy cows* except at the magnetic poles. Magnetic sensors are noise-resistant because body components move less (Williams et al., 2017). So, magnetometers and accelerometers are better for monitoring farm animal mobility.

Individualized animal welfare through integrated actions

Data generated by technology should be tailored to the unique characteristics of each animal and provide practical utility for producers. According to Caja et al. (2016), the promotion of animal welfare necessitates the collaboration of agro-engineers, ethologists, animal scientists, and veterinarians, as it is a multidimensional endeavor. Constantly prioritize the interpretation of data by a proficient statistician following its generation. Biomarker-based, activity-based, and system-level welfare technologies are required to achieve benign outcomes (DairyCare, 2016). The utilization of animal individuality is implemented to guarantee the welfare of dairy animals. The data set pertaining to a specific animal symbolizes its virtual duality. This data set is regarded by statisticians and data managers as an identical representation of the target animal, enabling the formulation of numerous predictions and estimations.

Assessment of present technologies in commercial use for dairy animals

A variety of devices are currently in use to generate data on a variety of activities, including feeding, estrus, lying, standing, walking, mastitis, milk circulation, and farm animal navigation (Rutten et al., 2013; Chan-vaillon et al., 2014; Lyons & Kerrisk, 2017; Grodkowski et al., 2018; Mayo et al., 2019) ^[13]. It has been observed that farms managing larger livestock employ more sophisticated technology (Gargiulo et al., 2018). Concerns exist regarding the accuracy of such readily available technologies. Mayo et al. (2019) conducted a comparative analysis of the efficacy of prominent medical devices and determined that they were significantly beneficial. They proposed that commercially available devices have a reasonable capacity to provide dairy owners with valuable data. Nonetheless, complete reliance on the data produced in this manner is not

recommended. Constantly required is the presence of an expert team, including a statistician with expertise in the data upon which management decisions may be made. A comprehensive knowledge base comprising professionals in animal physiology, ecology, gynecology, health, animal nutrition, livestock management, agriculture, and expert statistics may yield favorable outcomes.

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

Two categories of engineered devices are those that are worn on or off the cow's body. Offcow body apparatus consists of an SCC counter, inline milk analyzer, and so forth. Conversely, various devices are utilized on the body of cows, such as halters, neck collars, ear tags, automated blood samplers, reticulo-rumen boluses, pedometers, and ventral boluses. Figure 1 illustrates a diagrammatic representation of the placement of engineered devices on and within various anatomical regions of a dairy *bovine*.

Proposed working model

Optimization is required at this time, possesses a data set encompassing various facets of the biomarker and activity data. The aforementioned data kinds can be analyzed properly. Data sets for each cattle are created regularly. The system may save created data automatically, creating the animal's virtual identity periodically. Using pre-processed data, one may compare the target animal's current state to its past status across time. According to database specialists, fast steps may be implemented to maximize animal status after comparing the present condition to the ideal scenario. This methodology would simplify long-term dairy animal welfare improvements. While efficient, this networked system would need a large data storage infrastructure. Installation costs for different gadgets will be a problem again.

Recent study suggests that this strategy may reduce labor costs in the long run due to rising labor costs. By using this operational paradigm, recurring expenditures may be decreased and productivity increased. To preserve such massive investments, big-scale farmers would use this strategy. As milk output and market milk prices rise, most farms will adopt this operating structure within 10–20 years.

Animal welfare implications

Numerous studies predict that most farms will be larger and contain more animals in 20 years. More advanced and effective animal welfare methods are needed now. The structural working model in our study seems promising for animal welfare optimization. Modern manufactured devices have improved mastitis, lameness, and oestrus control, but they may be used synergistically to improve animal wellbeing. Thus, animal psychology and behavior must be studied extensively to better comprehend their wellbeing. Additional study is needed to determine the economic effects of installing these designed devices on dairy farms to improve animal wellbeing. This will be a comprehensive animal and farmer welfare approach.

Conclusion

Improved information, communication, and internet of things paired with agricultural technology have produced a data-driven communication era. Using data-driven communication, any individual or organization may give

targeted animals a virtual "personality." These may give trustworthy animal welfare data. According to the extensive analysis above, several technologies are suitable for animal welfare preservation, and more may be developed. Animals take time to adjust to human technologies. A device may first disturb animals, but it should ease agricultural activities. However, the dairy farm will require a trained manager and statistician to analyze the data and provide outcome-driven animal management recommendations. These technologies and zebu animal adaptation will be studied economically to help dairy operators determine their worth.

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