

Data sensing and computation technologies for animal welfare

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Dairy farm management is becoming a knowledge intensive activity with global pressure to increase the milk productivity of animal with minimum inputs and maximum animal comfort. Knowledge on various aspects of livestock management is required to make it a profitable venture. The profitability depends upon quality of decision making which in turn depends upon the quality of information as well as the speed with which the required information is made accessible to the farm manager. The technological developments in field of artificial intelligence, block chain, cloud technologies and data science (ABCD technologies) are going to transform the practice of traditional dairy farming into smart dairy farming.

Key words: Animal welfare, Artificial Intelligence, Farm management, Smart dairy farming

SMART dairy farming takes care of dairy animals by automatic real-time monitoring/ controlling of production, reproduction, health and welfare of livestock. Smart dairy farming is a practice of intelligent dairy farm management based upon technological data gathering for the purpose of increasing production, quality, and maximising animal welfare.

Artificial intelligence (AI) and robotics mimics the functioning of human brain and tries to implement biological intelligence such as reasoning, problem solving mechanisms, knowledge representation, planning, learning, natural language processing, social intelligence, creativity and the perception and ability to move and manipulate objects in computers in various ways. Various approaches like Symbolic AI, artificial neural network, expert system, case based reasoning, machine learning, deep learning, and fuzzy system have been used to implement heuristic from biological intelligence. In the perspective of smart dairy farming artificial intelligence seems to address the learning and problem solving

techniques of complex varying circumstances on animals in a near 'real time' environment.

Significant advancement in digital electronics, wireless and internet technologies enabled the development of low-cost and small size web enabled sensing devices called as Internet of Things (IoT). Such devices (e.g. actuators, video, camera, voice recorder etc.) are capable to automatically collect, send and act on data they acquire from their surrounding environments using embedded sensors, processors and communication hardware. IoT is an interconnection system among the Internet and other sensing and actuating devices which are able to operate information across various platforms via a unified framework such as cloud computing with seamless information representation, data analytics, and ubiquitous sensing.

Data observed and collected on several parameters on animal health and welfare through IoTs powered with artificial intelligence applications and cloud technologies helped in developing improved decision support systems (DSS) for monitoring animal at field level

without human interventions. Such systems can potentially assist dairy managers in enhancing decision-making ability, enabling early detection of health or well being problems in individual animals, and bringing efficiency and profitability. Many recent applications have applied these technologies successfully to address problems prevailing in the field both at organized dairy farms as well as unorganized sector.

Connected cow

Development of customized sensing and computation technologies (IoT) for dairy animals has innovated to the concept of connected cow (Fig. 1). A cow loaded with sensing devices can be monitored remotely through mobile phones or computers and thus always connected with the owner. Continuous monitoring of various indicators on health/ physiological, behavioural and production can benefit the farmers to:

- Maximize individual animal performance.
- Detection of diseases at an early stage.

- Minimizing the use of medication.
- Minimizing the wastage of natural resources.

Challenging issues of dairy farming

The major challenge in dairy farming is to achieve the best possible standards of animal health and welfare together with high performance. Application of technologies can help to address following important issues to improve animal health and welfare:

- Heat detection in animals
- Finding and treating lame animals at early stage
- Udder health, finding and treating animals with mastitis at sub clinical stage
- Catching sick animal at an early stage
- Understanding the nutritional status of animals
 - Feed intake
 - Body condition (fat or thin)
 - Rumen health (pH/ rumination time)

Measurable parameters

Following are measurable parameters to monitor production performance, health, physiological and behavioral traits of the animal. IoTs and other sensing devices are being used effectively to collect and record qualitative and quantitative data on these parameters.

- Production Performance:
 - Milk yield
 - Milk quantity
- Health/ physiological:
 - Mastitis
 - Fertility
 - Locomotion
 - Metabolism
- Behavioural:
 - Physical behaviour
 - Feeding/rumination
 - Spatial behaviour
 - Social behaviour

Emerging technologies

The new technologies are focusing on following emerging developments for animal monitoring and welfare:

- Radio-frequency identification (RFID) for identification of animals
- Development of welfare biomarkers (e.g. stress and

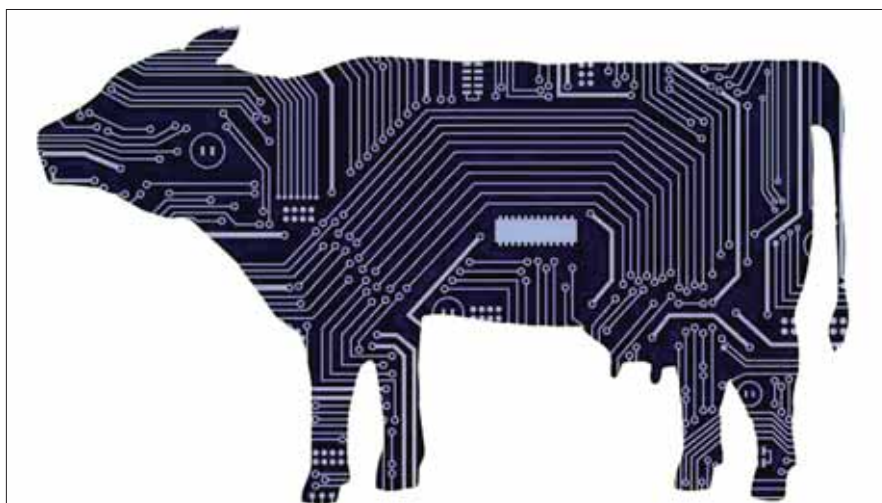


Fig. 1. Connected cow

Source: Meet the "connected cow", special report, <https://www.ft.com/content/2db7e742-7204-11e7-93ff-99f383b09ff9>, 2017.

metabolic diseases). A biomarker is a characteristic that is objectively measured and evaluated as an indicator of normal biological processes, pathogenic processes, or pharmacologic response to a therapeutic intervention. New biomarkers are usually interpreted as the discovery of a novel protein, peptide, metabolite etc., hence proteomics, peptidomics, metabolomics.

- Devices for recording activity of animal for activity-based welfare assessment (e.g. oestrus and lameness detection)
- Sensors for temperature and pH monitoring (e.g. calving alert and rumen function).
- Computer vision/ Video image analysis and speed measurement (e.g. behavior, socialization, locomotion, feeding habits, BCS)
- Acoustics/ Vocal measurement for animal welfare.

Sensor based devices

A large number of smart sensing devices (IoT) coupled with analytical models powered by AI and communication capabilities are commercially available to monitor the activities and production performance of animals. These devices can be categorized as wearable and non wearable devices.

- **Wearable sensor based devices**
 - In-cow sensors – placed inside the body (e.g. rumen bolus)
 - On-cow sensors - fitted on

the outside of the cow's body (e.g. pedometer/accelerometers)

- **Non-Wearable sensor based devices**

- In-line sensors – take measurements in a continuous flow (e.g. milk meter)
- On-line sensors - automatically take samples (e.g. herd navigator)
- On-site sensors - automatically measure cows' characteristics while they pass through (e.g. walk-through weighing system)

The wearable devices are attached or mounted on animals at different locations as shown in Fig. 2 are connected to RF networks or the internet. These devices are commonly used in dairy herds to monitor animal activities such that what the cow is doing and provide data for early detection of health or behavioral problems. Non wearable devices not attached on the body of animals rather these are placed in surrounding area of animal, automated milking parlor, path ways of milk parlors, animal sheds etc.

Integrated concept of animal management and welfare

Smart dairy farming with Internet enabled sensors devices has redefined the concept of animal welfare and management. Combination of welfare biomarkers and activity data will be used to construct future

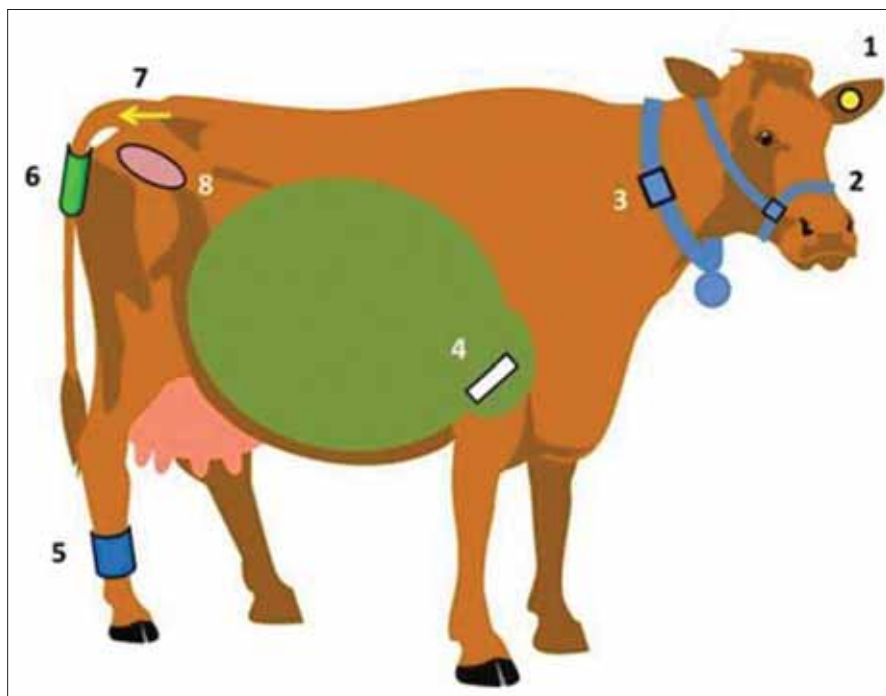


Fig. 2. Various locations for mounting wearable sensor devices on a cow: (1) ear tag, (2) halter, (3) neck collar with counterweight, (4) reticulo-rumen bolus (in reticulum), (5) rear leg pedometer, (6) upper tail ring, (7) tail head inject, and (8) vaginal bolus.

Source: Caja C, Castro-Costa A & Knight CH, 2016, Engineering to support well-being of dairy animals, *Journal of Dairy Research*, **83**, 136-147.

decision support systems that will assist farmers to optimize the well being of their dairy animals. Data collected from biomarker sensors and from activity sensors are integrated to know the current status of cow. This is compared with her previous state and the state that is desired for a healthy cow of the same physiological stage. In case of deviation from the desired range, cow ID is triggered for initiating appropriate action. The integrative concept of animal management and welfare of cow is shown in Fig. 3 given below.

RFID technology for identification

Radio Frequency Identification (RFID) may be defined as “A system that transmits the identity (in the form of a unique serial number) of an object (or person) wirelessly using radio waves”. This technology is commonly implemented using RFID tags (also known as transponders) mounted or attached on objects and readers/ writers (also known as interrogators). RFID tags consist of two parts - an integrated circuit (containing unique code, memory for storing and processing of data, modulating and demodulating radio signals etc.) and antenna for receiving

and transmitting signals. These components are enclosed in a tamper proof plastic cover of different sizes and shapes.

The first model of RFID system used in cattle was a glass encapsulated

rumen bolus powered by a battery which was administered orally. RFID is heavily used in the dairy sector, and facilitated by the fact that each lactating animal will regularly come to one specific point to be milked, regular data downloading allows for individualistic management. Current RFID of dairy cows is still based on large high-frequency transponders (i.e. neck collars) although miniaturized low-frequency devices of different ISO technologies are cheaper and readily available (ear tags, injectable devices or rumen boluses). RFID has improved the record maintenance of animals at field level.

Wearable sensor based devices

The availability of low-cost tri-axial accelerometers and wireless telemetry has allowed accurate models of behaviour to be developed and sometimes combined with rumination activity detected by acoustic sensors to detect oestrus; other measures (milk and skin temperature, electronic noses, milk yield) have largely been abandoned. Wireless telemetry has been applied to develop boluses for monitoring rumen pH and temperature to detect

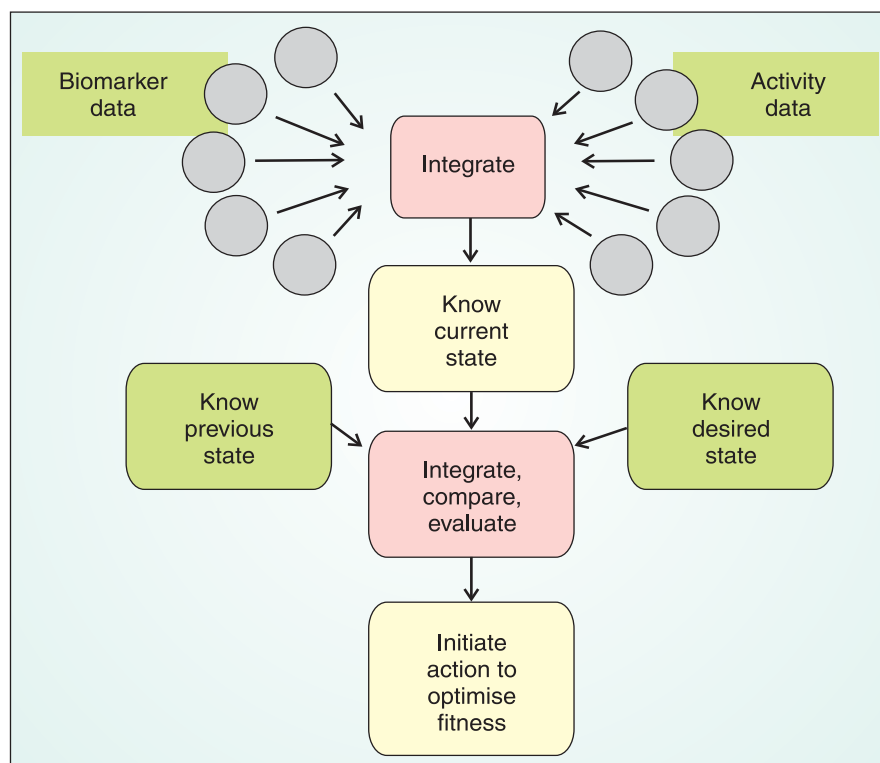


Fig. 3. Integrated concept of animal management and welfare

Source: Caja C, Castro-Costa A & Knight CH, 2016, Engineering to support well-being of dairy animals, *Journal of Dairy Research*, **83**, 136-147.

metabolic disorders. A few commercially available technologies using wearable sensor devices are listed in Table 1.

Most commercially available reproductive management technologies (e.g. oestrous mating, calving) listed in Table 1 are based on activity recording of one sort or using tri-axial accelerometers. They are offered to wear as an ear tag, nose halter, neck collar or leg (preferably rear) pedometer. MooMonitor+ is a wireless sensor device that allows farmers to detect individual cow heats and health events with ease through data analysis. It monitors cows on a daily basis and identifies specific types of behaviours such as:

Feeding, Rumination, Levels of activity. A special case of 'MooMonitor' uses pressure sensors for detecting the standing behaviour of dairy cows during oestrous.

Mating Alert (Celotor) is a simpler device for heat and mating activity detection which uses RFID transceivers. The transceiver fitted in a reader belt is attached on the chest of jumping bull or androgenised cows. The cow that is allowing mounting will have a chip (injectable tag) injected at the base of tail. During the mounting process, the belt reads the identification of the cow in heat. This identification is sent wirelessly to the Master Collar and this in turn originates alerts

through text messages in real time.

Calving detection may be monitored by measuring tail movement patterns triggered by labour contractions, with devices attached to the tail head containing accelerometers ('Moocall') or by the dramatic change of temperature of a vaginal device using thermistors when it is expelled during labour ('Vel'Phone' and 'iVET'). Reticulo-rumen boluses ('eCow', 'WellCow', 'smaXtec pH') assess rumen function by specific sensors (e.g. temperature, pH, pressure) which might be related to rumen pH for SARA (subacute rumen acidosis) detection and with feeding and drinking behaviour.

Table 1. Currently available wearable sensing technologies for monitoring the well-being of dairy animals

Objective	Manufacturer	Type & features	Technology used	Reference link
Activity behaviour (oestrous, feeding and health signs detection)	SensOor, Cow Manager	Ear: activity, feeding, health	RF, 3-axial accelerometer	http://www.cowmanager.com/enus/
	Cow Alert, IceRobotics	Leg: activity, oestrous, health	RF, 3-axial accelerometer	http://www.icerobotics.com/products/
	CowScout	Neck or leg: activity, eating time, oestrous	RF, 3-axial accelerometer	http://www.gea.com/global/en/products/activity-detectioncowscout.jsp
	Silent Herdsman	Neck or leg: activity, oestrous, rumination	RF, 3-axial accelerometer	http://www.afimilk.com/products/cow-monitoring
	Afimilk	Neck: activity, oestrous, health	RF, 3-axial accelerometer,	http://www.dairymaster.com/heat-detection/
	MooMonitor,	Neck: oestrous, health	RF, 3-axial accelerometer	http://www.medria.fr/en_GB/produits/heatphone.html
	HeatPhone, Medria	Tailhead: oestrous	RF, pressure	http://www.cowchips.net/index.html
	HeatWath II, CowChips	Neck: activity, oestrous, health	RF, 3-axial accelerometer	http://www.efsltd.ie/
	Heptime, EFS (Westmeath,IE)	Leg: activity, intake, oestrous, lameness	RF, 3-axial accelerometer	http://www.boumatic.com/us-en/products/heatseeker1
	HeatSeeker, BouMatic			
	RumiWatch,	Nose and leg: activity, intake, drinking, lameness rumination	RF and USB, pressure, 3-axial accelerometer, thermistor,	http://www.rumiwatch.ch/index.html
Mating alert	Celotor	Harness reader and tailinject	RF, SMS	http://www.celotor.com/celotor/partes-y-operacion
Calving alert	Vel'Phone,	Vaginal temperature	Thermistor, SMS	http://www.medria.fr/en_GB/produits/vel-phone.html
	iVET birth-monitoring	Vaginal temperature	Thermistor, SMS	http://www.birth-monitoring.com/home/birth-monitoring/
Rumen function	Moocall	Tail ring	Accelerometer, SMS	http://www.moocall.com/
	eCow Devon	Rumen bolus: pH, temperature, drinking	RF, electrode, thermistor, pH,	http://www.ecow.co.uk/
	San'Phone, Medria	Rumen bolus: temperature, drinking	Thermistor, SMS	http://www.medria.fr/en_GB/produits/san-phone.html
	Well Cow	Rumen bolus: pH, temperature	RF, electrode, Thermistor, pH	http://www.wellcow.co.uk/bolus/
Integrated functions	SmaXtec Sensor,	Rumen bolus: activity, temperature, drinking, oestrous	3-axial accelerometer, thermistor	http://www.smaxtec-animalcare.com/en/products-services/smaxtec-sensor/
Position location	WildCell, Lotek	Neck	GPS, RF, temperature sensor, 2-axial accelerometer	http://www.lotek.com/wildcell.htm
	CattleWatch	Neck	ear GPS, RF	http://www.cattle-watch.com/

Source: Caja C, Castro-Costa A & Knight CH, 2016, Engineering to support well-being of dairy animals, *Journal of Dairy Research*, 83, 136-147.

Non-wearable sensor based devices

Automated milking systems (AMS) is a good example of integration of non-wearable devices for automatic and real-time data collection. Different type of in-line sensors can be placed to record quality and quantity of milk. Pathways fitted with online weight recording system and infrared cameras to captured images can automatically validate animal health with body weight and BCS. Udder health requires a multi-sensing approach due to the varying inflammatory responses collectively described as mastitis. Mastitis detection has been developed such that a low-cost screening by conductivity and behavioral analysis can be enhanced by automated SCC to validate diagnosis. A few commercially available technologies using non-wearable sensor devices are listed in Table 2.

Sensor based video cameras are used to record locomotion of animals for automatic lameness detection. Mainly three techniques kinematic, kinetic, and indirect are used for detection of lameness. Most of the studies are based on comparison with some kind of visual locomotion scoring. Researchers at Osaka University developed a method for early detection of lameness in cows by applying techniques of gait analysis and AI-powered image analysis. The article reported development of various wearable and non wearable sensors developed including online weighing sensor with four quadrants for recording of weight of each leg for early detection of lameness.

Acoustic and voice recording

devices installed in cowshed or attached on cow for sound analysis are used for detecting respiratory diseases and stress conditions of animals. An early warning system using automated continuous monitoring of calf cough sounds through microphones has been developed for recognition of bovine respiratory disease in calves at early stage. It has been reported that vocal cues analysed using machine learning algorithms can be used for identification and different stress conditions of animals.

AI powered dairy farm management applications

A number of application software MIS and DSS were developed in the past to manage the dairy farms operations. Only a few most significant applications are mentioned below.

The first computer based farm management system “AfiKim” for cattle herd was developed in 1984 by Afimilk Company of Israel. It was the microcomputer-based expert system for evaluation of reproductive performance and general management to find out the major areas responsible for reproductive inefficiency and to determine whether a problem exists or not. A few years back the company has redesigned the software and renamed it as AfiFarm by incorporating the latest technologies for farm automation such as RFID and sensor based devices for monitoring animal activities, inline sensors for monitoring milk quality and quantity, etc. The software is also integrated with mobile applications to generate alert messages about the status of

animals. It is most comprehensive, flexible and user friendly software for the automation and management of dairy farms with a whole set of new capabilities.

The Dutch company, Connecterra, has developed an application “Intelligent Dairy Farmer’s Assistant” (IDA) for smart dairy farming. The main philosophy for developing IDA was that farmer’s don’t need more data, farmer’s need deeper insight into their farm activity. IDA bridged the technology gap for farmers who seek advice on how to increase productivity, improve efficiencies, reduce health incidents, and better care for a more fertile and happier herd. Through a combination of advanced sensor hardware technology and state of the art deep-learning algorithms, IDA has taken lead in the advancement of farming for the future.

IDA uses a motion-sensing device attached to a cow’s neck to transmit its movements to a program driven by AI. The sensor data, when aligned repeatedly with real-world behaviour, eventually allow IDA to tell from data alone when a cow is chewing, lying down, walking, drinking or eating. Main features of IDA are:

- IDA is an artificial intelligent system designed to go beyond the alert-based systems.
- Assists in the area of fertility, health, calving, feeding, heat stress, and finding herd’s top performer.
- Learns from the behaviour of cows and daily operations performed by a farmer.
- Data is extracted to provide tailored and easy to interpret recommendations and actions to

Table 2. Currently available non wearable sensing technologies for monitoring the well-being of dairy animals

Objective	Manufacturer	Type & features	Technology used	Reference link
Milk composition	AfiLab	In-line milk composition	Near-Infrared spectroscopy	http://www.afimilk.com/products/milking-parlor-automation/integrated-milking-point-analysiscontrol
Somatic cell count (SCC)	OCC, DeLaval	Milk SCC by udder quarter	Analysis of cell ADN by u.v. fluorescence	http://www.delaval.com/en/-/Product-information1/Milking/Products/Stallwork/VMS-station/DeLaval-online-cell-counter-OCC/
Body condition scoring (BCS)	DeLaval BCS	Lower back image (loin,rump, hook, tailhead,fatness)	3D imaging	http://www.delaval.com/en/-/Product-Information1/Management/Systems/DeLavalbody-condition-scoring-BCS/

Source: Caja C, Castro-Costa A & Knight CH, 2016, Engineering to support well-being of dairy animals, *Journal of Dairy Research*, 83, 136-147.

smart devices.

- Also allows farmers to simulate the effect various operations on potential yield and provides a “best practice” model based on other more productive farms.

Indian company Infovet developed software “**Herdman**” for herd health and productivity management. It is designed to be used in conjunction with the animal RFID tags and cell phones’ text messaging capability, in order to access information regarding the cows and buffaloes. This software not only stores and shares data regarding each cow’s or buffalo’s health and services, it can also send alerts. For example, if an animal has given birth, an alert can be sent after a specific amount of time (120 days, for instance) has passed, to remind farmers and service providers that the cow or buffalo should be inseminated. The software is being updated from time to time by adding new features along with technological advancements:

- Addition of QR coding based ear tags for animal identification. On scanning the QR code through mobile application, details of particular animal is fetched from the central server for further necessary action.
- A cloud network based module introduced for farmers having few number of animals. Farmers can register on this module by paying nominal fees per animal through mobile application to avail advisory services.

New Zealand farmers are using AI mobile app “Betty” as veterinary diagnostic tools. The Betty app uses machine learning algorithms to diagnose sick cows in their herd. Farmers using the app are presented with series of questions, with the response combined with regional farm and weather data to produce a list of the most likely causes of disease in their animals. After analysis Betty app can help the farmer to decide whether or not their sick cow

is an emergency and to take immediate action, or connect them with a local veterinarian if needed. Such artificial intelligence applications may automatically diagnose a sickness and administer remedies/cures to the affected animal without any human involvement which will strengthen the concept of creation of “Smart Dairy Farms”.

Advantages of sensing devices

Following are the advantages of applications of smart sensing devices:

- Automatic recording and transmission of data without human intervention.
- Wireless technology reduces maintenance complexity and costs
- Suitable to monitor dangerous, hazardous, unwired or remote areas and locations
- Faster deployment and installation
- Flexible extension of the network
- Sensor based devices can be mounted on moving objects
- Provide *ubiquitous (anywhere everywhere) computing* environment
- AI applications learn from the data itself and update with new set of data

Limitations of sensing devices

Even though emerging data sensing devices powered by AI have great potentials as recognized and supported by many enthusiastic industry alliances and users, adoption of such devices has not been as fast as one would imagine. Main obstacles are as follows:

- Although manufacturers often claim to offer ‘complete solutions’, no one system individually offers everything
- Almost without exception, the different technologies operate ‘standalone’, and will not communicate with each other.
- Claims made for accuracy, precision, false positives and negatives are in most cases have not been tested independently.

- Standardization is not yet completed. The system need standardization in different situation, different breed, and in different seasons.
- Acceptance due to high cost.
- Cost benefit analysis data is not available
- Security issues need to be resolved
- Power supply is always a great concern for wireless systems
- The reliability of wireless sensor system remains unproven
- Lack of experienced staff for troubleshooting.
- Long-term investigation is required to validate the claims of these technologies to improve welfare and production under field conditions.

CONCLUSION

Wireless data sensing and computational technologies powered by IoTs and AI are enabling applications that previously were not practical. These technologies provide massive qualitative and quantitative data which can be used for finding hidden patterns and developing intelligent decision support systems. Sensing devices have proven its utility in studying the behavior of animals which was otherwise difficult in the manual system. The combination and integration of these technologies into ‘smart dairy farming’ system will ensure optimum wellbeing for dairy animals and thereby maximize farm profitability. Use of novel sensors combined with new technologies for information handling and communication are expected to produce rapid and dramatic changes in traditional dairy farming systems. The overall objective is to assist good husbandry, not replace it, and the deliverable must be as simple as possible.

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