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An Insight in to the Automation of the Dairy Industry: A Review

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ABSTRACT

The dairy industry was gaining enormous technical advances to meet out the targeted production quantity by converting the raw material into finished goods. Automation techniques have been implemented to ensure intense quality and safety for the desired food product. By entering this, automation technology for processing has gained great potential for improved safety, quality and profitability by optimizing process parameters and control. Automation technique involves multidisciplinary technologies such as robotics, Artificial Intelligence and several other mechanical, electrical, electronic devices and computers usually in combination. Among the various applications of automation in the dairy industry, Automatic milking systems or milking robots are very no table. It is also the most successful and significant in the current scenario of livestock management and maintenance. However, there is a broad range of applications for automation in the dairy industry for continuous operation without any deviations and adjustments with desired consistency and shape according to the nature of the product, which cannot be done manually.

Key words: Artificial intelligence, Automation, Dairy processing, Robotics.

Innovations in technology are gradually increasing and finding their implementation in various industrial applications. The food and dairy industries play a significant role in utilizing this automation technology to overcome various challenges and risks (Caldwell *et al.,* 2009). Programming the automation system entirely depends upon the type of industrial operation. Notably, the food industry is one of the top ten industries which utilizes plant automation. The ultimate aim of automation is to control the various steps involved in processing and eliminate the manpower because labor cost contribute about 50% of the total production cost (Singh, 2018). Also, it was noted that a higher level of manpower leads to a higher incidence of industrial accidents and lower levels of quality control which means a high Chance of contamination and microbial growth (Kulkarni *et al.,* 2014). Automation overcomes these challenges result in improved productivity and reducing labor costs therefore, it results in a significant impact on profitability. Handling milk and milk products include transferring fluid milk from one place to another by employing pumps (Bhavya *et al.,* 2018). In processing operations that included working in very low temperatures [*eg*. Hardening room and ice storage rooms which includes working in below zero degrees celsius], robots would be a good alternative with complete control on quality. This paper includes the need of automation, application and automation tools such as robotics, on-line sensors and machine vision technologies.

Need of automation system

Automation is a technology performed by the combination of computer systems and machinery was previously programmed and instructed by the human. Based on the nature of the product, the physical orientation of automation mechanism can be changed and instructions about the flow of the production process are completely fed by means of electrical and electronic devices (Jha *et al.,* 2019). Nowadays, consumers are highly concerned about the

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quality standards. Automation plays a significant role in ensuring a highly efficient and sophisticated dairy operation. To execute an automation process in the processing area, is driven by several key requirements for the competitive success of the operation (Sain *et al.,* 2020). This computer-aided operating system meet out so many privileges, some of them which include:

1. Reduce the risk of contamination.
2. Eliminate manpower from labor-intensive environments.
3. Flexibility in accordance with products size and production quality.
4. Ease of handling dairy cattle in the farm area.
5. Employment opportunity for professionals in agriculture sector and.
6. To overcome the difficulty in meeting specification consistency.

As the unit size of the processing area increases, it also results in difficulties in cleaning in place (CIP) technology. These involve close attention in pipeline configuration, a correct adjustment in handling acid-alkaline level and efficiency in cleaning. This can be overcome by

Table 1: Application of automation tools.

Automation tool	Application	References
Design of low-cost robots	Specific need for food processing	Moreno *et al*., 2010
Robotic food processing system	Serving softy ice cream	Friedrich and Lim, 2001
High speed picking robots	Pick and place operation	Derby *et al*., 2007
KUKA KR 40PA™	Case packing	Mullen, 2006
FANUC A-520 I robot	High capacity pelletizing system and high speed loading and unloading	Mullen, 2006
Apple picking-robot	Low cost gripper pick apples in three dimensional space	Setiawan *et al*., 2004
FAST-q biochip™	Instant detection system to monitor food borne pathogens such as *E. coli* O157:H7	Fung, 2002

implementing an automation system with interlocking arrangements results in ease of handling materials and high level of efficiency in cleaning. The various applications of automation tool are depicted in Table 1.

Automation in the dairy farm operations

Earlier maintenance of dairy farms was completely based on well-experienced manpower to accomplish various activities such as milking, feeding, visual identification of oestrus detection, *etc*. By implementing an automation system to carry out these processes decreases the manual cost and prevents the loss of dairy cattle (Sarangi *et al.,* 2016).

Detection of oestrus in dairy cattle

Heat detection plays a major role in the maintenance of dairy herds. In early date visual detection is carried out which results in the low level of accuracy. Hence, it becomes a major limiting factor of reproductive performance in modern dairy cows (Firk *et al.,* 2002). As a result, several attempts were made to develop new automated devices to detect the oestrus period based on standing heat or increased activity, body temperature, or by the measurement of in-milk progesterone (P4) level (Michaelis *et al.,* 2014). The behaviors specifically expressed during oestrus were recorded using an electronic pressure-sensitive device. The activity triggers a radio wave transmission (0.4 km range) and several other mounting activities. Automated Activity Monitoring system (AAM) is commercially available for a long period. The schematic representation of automated activity monitoring system was shown in Fig 1. This system consists of HR tags (Heat and Rumination tags) and an identification transceiver. This HR tag sense the activity of dairy breed such as its intensity level, rumination characteristics and the collected data is stored for a period of time. The data were sent via infrared communication to the on-farm computer and the data were processed using customized software (Burfeind *et al.,* 2014) (Fig 1).

Automated milking system

Gascoigne melotte successfully developed a layout called GM 2000 consisting of various dairy farm operations such as GM milking technology, Feed system based on individual cow identification, MR 2000 milk yield registration system and dairy farm management program (Ipema and Benders 1992). At first Automated milking system was successfully implemented in North Western Europe. The increasing cost of land and labor leads to a decrease in milk price, forcing farmers to work excess per man-hour. After various research on implementing this system at the farm level, the first AM-System was commercialized in the Netherlands in 1992. Till 1998 adoption level of this system was low, more than 90% of almost all dairy farms adopted this technology in Netherland after that. In 2000, many countries like Denmark, Germany and France adopted the AM system (De Koning *et al.,* 2002). One specific module in AM system is the milk parlour intended for milking with desired hygienic milk production, more efficient milking, reduced risk of injury and increased labor efficiency (Pomies and Bony 2000).

Milking is a labor-intensive process that requires skilled manpower and acts as a source of microbial contamination and a time-consuming process (Giacomo *et al*., 2005). Dairying is well equipped and highly efficient with machine milking and mechanical aids. The milking machine consists of vacuum pumps and a vacuum vessel that serves as a milk collection vessel (Upton *et al*., 2016). The vacuum supply is the negative pressure that opens the teat. The rate of vacuum supply was around 11 to 14 inches of Hg. Milk from the udder is drawn utilizing the negative pressure and pulsation (50-60 cycles per minute).

Swedish dairy equipment company De Laval, Australia, introduced the world's first commercial robotic rotary milking. The robot rotary milking uses a laser sensing system to find the teats and the robot arm automatically connects the cups to the teats (Warrier and Minz 2014). Most advanced 'Milking Robots' made a significant technical advancement that gained hygiene milk production and monetary benefits. This technology has been successfully launched and carried out up to date. It is a voluntary milking system in which milking is done by electronic tag which, allows the robots to identify, clean the teats, attach the milk cups and start the milking process (Berington, 1979). Once milking is done in each quarter it is disconnected using robotic arms and this sequence of operation occurs throughout the day as it is already programmed in a database. This technology hits several advantages, including economic benefits, increased

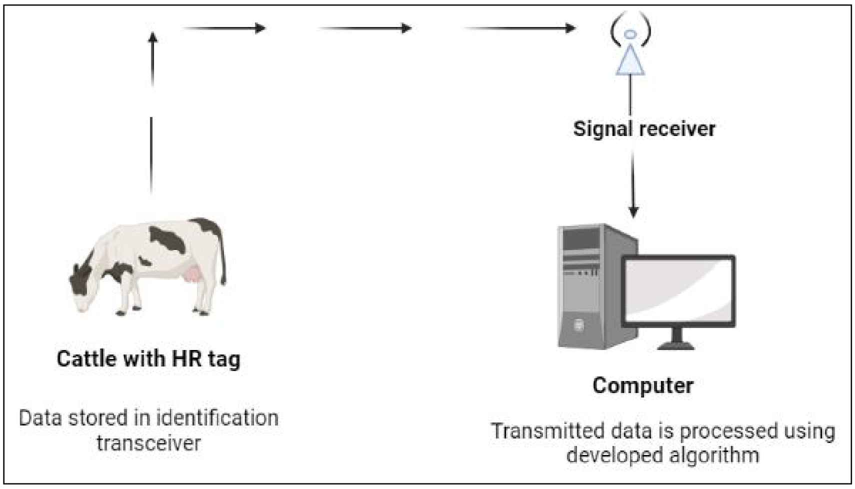

Fig 1: Schematic representation of automated activity monitoring system.

milking frequency and management benefits (Cosmi *et al.,* 1997). Automated milking device for goat and sheep is becoming more common nowadays. The devices most commonly used in goat and sheep farm are Automatic vacuum shut off, Milk meter and flow indicators, Electronic identification, Flock management software, Sort gates by using this system help to increase the farm efficiency and farm management decision making. The working principle of each system is reviewed by (Alejandro, 2016).

Automation in dairy industrial operations

Processing a food product involves various operations that also differ from product to product. All those operation parameters should have a control system to achieve quality products. Automation in the dairy plant is viewed as a versatile tool for solving various crucial problems (Grimsen *et al.,* 1987). Automation includes several other technologies to execute the programmed processing steps efficiently. Compared to the food industry, dairy gains the scope of handling automation technology that can take raw milk in bulk without considering biological variations in size, shape and homogeneity of raw material (Judal and Bhadania, 2015).

Machine vision system

It is one of the food industry's rapid and economical evaluation techniques. This technique is employed in the processing area for continuous monitoring of product quality in which all the parameters are set as per the final requirement of the product (Gunasekaran, 1996). The principle of a machine/computer vision system (MVS) is that system equipped with a camera that captures the image of the product and analysis two-dimensional image, then processing the image to measure the desired parameters, subsequently comparing the obtained measured parameters with predefined values. By using the obtained data, corrective actions are taken. The whole system is done through PLC (Programmable Logic Controller) based image analysis system. The benefit of using a machine vision system in the dairy industry includes that this system does not inhibit the normal workflow and carries out the work in a fully automated manner (Shelley, 2016). The image processing technology is now widely used to detect health problems in dairy cattle earlier; it is not easily detected as cattle usually live in groups especially, in case of mastitis. The strategies involved in this image processing technology for detecting health problems are well explained in the literature (Nasirahmadi *et al*., 2017 and Loshkarev *et al*., 2019).

Automation by robotics

To date, food industries raised curtains for the entry of "Robotics" in food industry operations globally. An industrial robot is an automatically controlled, pre-programmed computer system that can be utilized either in a fixed or mobile mode (Carolan, 2020). Most robots are being used and found significant applications at the end of processed food products such as packaging, palletizing. Robots consist of various components including manipulator, end effector, power supply, programming, commander system, sensors, amplifiers and actuators (Sistler, 1987). Each component has a unique role. The controller in the robot coordinates all the mechanical movement of the system. The actuator that converts power into robot movement, which is initiated by a set of instructions and all those movements are stored in the controller's memory. The manipulator is the robot's arm which is programmed to perform various motions to provide useful work.

End effectors are the robot's hand or the end-of-arm tooling on the robot, the power supply provides the energy for the robot, which converts the AC voltage to DC voltage required by the robot's internal circuits, overall all the actions or movements are recorded and stored in the robot's memory. Moreno *et al*., (2010) designed a low-cost robot for the food industry that fulfills specific requirements such as ease of maintenance, safe operation, high operational speed, ease to reprogram. The designed prototype is programmed through a programmable logic controller (PLC). Research has been done to develop a robotic food processing system for soft-serve ice cream (Friedrich and Lim, 2001).

Soft serve ice cream is a type of ice cream directly drawn from the freezer without hardening is mostly dispensed manually. Later robotic technology was developed, which automates the delivery and significantly impacts material saving and operating cost. Compared to several other industries food industry is a highly competitive area in which a product's size, shape, consistency pays significant attention from the consumer's point of view. So far robots application is significant at end of the processing line like packaging and palletizing (Jamshed *et al.,* 2017).

In the cheese industry, robots are programmed to handle a massive amount of stirred curd, turning, cutting, transferring cheese molds which are labor-intensive processes. So, all those actions are wisely altered by automated robots. Lobasenko *et al.,* (2019) have mentioned in his research work about the role of automation in cottage cheese making using ultrafiltration method that using automation tool saves the energy consumption compared to machinery. Automation in cheese making involves continuous process monitoring and persistent process control ensures the maximum high-quality product (Olson, 1975). Tetra Damrow™, one of the leading food processing industry came up with an automatic mechanized system for various types of cheese making like cheddar, Emmental, Feta *etc* which handles a huge quantity of cheese curd and whey. Another invention by Tetra Tebel® designed a continuous cheddaring machine with four conveyors; each conveyor possesses a unique operation role such as self-stirring to facilitate whey removal, efficient matting and fusing, milling the curd mass and salting. The other mechanized system for continuous mozzarella cheese making is manufactured by GEA, which offers a compact standalone unit system for continuous str*etc*hing and molding which retains the consistent gentle curd handling with desired cheese texture, flavor and texture. This system also provides a control range of dry and liquid salt dosage integration. The whole unit cheese making production was managed using PLC automation and control with remote assistance.

In baking lines, robot arms are used to handle hot trays that ultimately resist humans' hazardous operations and safeguard them from industrial accidents (Soliman, 2000). Another area of approach for automation is using online sensors have a significant role in food processing. For a broad range of measurements in food quality, sensory parameters, these cost-effective smart sensors and field network technologies have been implemented and pursued successfully to date (Purnell, 2013). Many foods and dairy companies have successfully implemented and gained many advantages by utilizing industrial robots for palletizing, inspection, quality assurance. Vision-assisted robots have the potential of identifying product arrays or stacks within the standard operation, placing the finished goods or product into the packaging material such that loading the feed of a flow wrapper (Prasad, 2017). Working in cold storage in ice cream industries (*i.e* -18°C) by manpower leads to adverse consequences like stacking to the uppermost part on the cold room is very much labor-intensive and hazardous. Autobag AB 145 was introduced in November 2005 as a semi-automatic bagging system that offers high productivity and reliability in packaging. This Autobag AB 145 is capable of bagging at speeds up to 45 bags per minute in a semi-automatic fill and seal operation. KUKA KR 40PAtm was launched in 2005 by KUKA Robotics Corporation. This robotic arm is made up of carbon fibre composite the lightest material that ultimately increases throughput (Mullen 2006).

Sensor network system

With the increase in wireless communication systems the utilization of these technology has gained more in food industries in various aspects. The most challenging part of the food industry is the prevention of contamination throughout the food supply chain to ensure food safety. For finding the traceability this intelligent sensor network is used widely. Almost every food industry started using the PDAs (Personal Digital Assistance), variable mobile device used to find traceability and logistics. Wadalkar *et al*., (2019) developed an electronic impedance sensor to detect adulteration in A1 and A2 milk. This electronic impedance system is developed by IC AD5933 which is high precision impedance converter with control systems. This portable sensor type analyzer gains advantages over chemical laboratory methods that lack milk testing in real-time and further analysis of milk is difficult and inaccurate (Ruiz-Garcia *et al.,* 2009). The wireless sensor network system compresses a variety of sensor nodes that enabling monitoring and recording the processing parameters such as temperature, relative humidity, compound monitoring in the food industry. Callaway and Stojmenovic (2005) described the technology available for WSN, which includes ZigBee and Bluetooth, both operated with 2.4 GHz. Compared to Bluetooth, ZigBee is gaining advantages being less expensive and simple. ZigBee is more suitable for industrial equipment which require short-range low-rate wireless data transfer. One widely used technology for stock re-organization, inventory control, checking the nutritional information of packaged food products is the barcode technology. Development in barcode technology is a invention of barcode system with a temperature sensor facilitated by a handheld scanner. Later this system is replaced by RFID (Radio Frequency Identification), which involves the data collection from food products throughout the supply chain and is favorable for traceability. This is an essential factor in food safety management avoids potential food-born risks to safeguard consumers (Bibi, 2017). Van den Berg (2013) reviewed the PAT (Process Analytical Technology) in the food industry which was originally introduced for the pharmaceutical industry in 2004 by the United States Food and Drug Administration. This technology makes use of spectroscopic sensors, which detects the process variations at the time of food processing also the on-line detection of chemical variations, oxidation and other core parameters is a favorable one for quality control when compared to off-line detection of quality testing after food processing which is a time consuming process.

Scada

Supervisory Control and Data Acquisition, known as SCADA is a system that evolved over several decades. This control system is now widely used in dairy and other food industries to carry out complex processes especially in the dairy industry that deals with huge productivity. Operations are monitored by master terminal unit (MTU), referred as RTUs (remote terminal units). Despite many challenges, several food industries initiate this SCADA system for quality production (Holmes *et al.,* 2013). One crucial operation involved in every food industry is CIP (Clean-In-Place) which includes the sequence of steps such as pre-rinse, alkali rinse, acid rinse, detergent washing after completion of each batch. Dhage and Dhage (2016) have developed a modular and flexible CIP system using PLC and SCADA automation systems.

Automation control system in the dairy industry

Food and dairy industries involve various unit operations and all those combined unit processes are run at controlled process conditions. To carry out safe and controlled operations which are greatly assisted by "process control technology" and "Fuzzy logic technology" a computer-based process control system is used for longer times as an essential tool for almost most industries (Peacock and Boyce, 2003). Computer control-aided automation systems facilitates accuracy and reproducibility. By make use of automation technology results in less utilization of machinery in dairy plant. Control system is a set of mechanical or electronic devices that regulates other devices or systems by way of control loops. The schematic representation of open and closed loop control system was depicted in Fig 2 and 3. For simple operations PLC is more adaptable for production whereas complex system needs advanced automation to carry out the process. Uzam and Jones (1998) introduced a new method for design and implementation of discrete event control system (DECs). Earlier APN (Automation Petri Nets) system does not involve sensors and actuators later on research work carried out on extending the APN system by accommodating impulse and sensors. This petri nets is most suitable for multiproduct system. Documentation is one of the dominant checklists to be maintained for recording all the process operations carried out at the time of product manufacturing. By utilizing robots it can record all the operations and reinvigorate weekly, monthly and yearly basis records. This kind of action is highly proficient at the incidence of finding root cause checking. The sensor feedback system is given to the control system so that raw materials are checked accurately compared to manual quality control checking and also further responsible for the adjustment of variables in the quality of material used for batch processing Fig 2 and 3.

Cost economics

Economical assessment of automation technology plays a vital role in establishing the process associated with that. Eliminating labor cost doesn't mean the higher investment in automation should be required. Overall cost benefits should be assessed for efficient operation in processing of dairy products. Robotic milking cost investment includes only the capital needed for the technology installation. This technology prices are down from 12 to 15% whereas labor cost rising up 12% through the years (Jack, 2021a). Similar management can also be done with fully automated milking system and swing parlor with minimum automation. Capital cost involved in fully automated milking and swing parlor

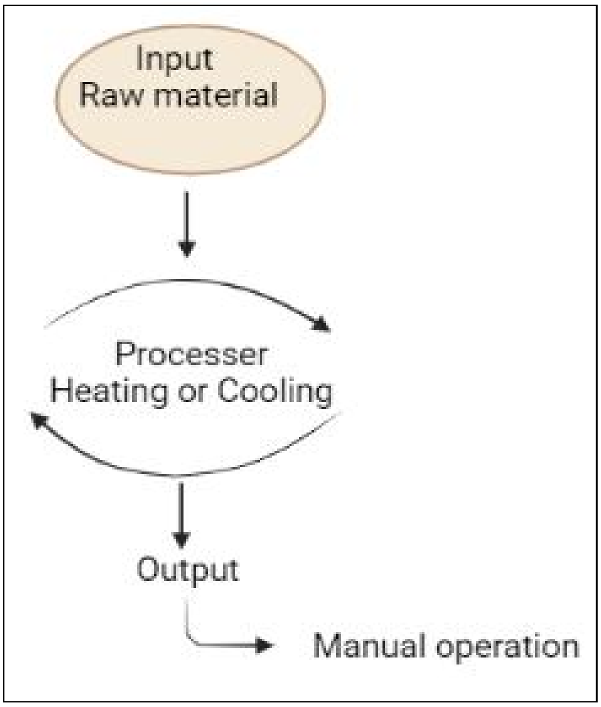

Fig 2: Open loop control system.

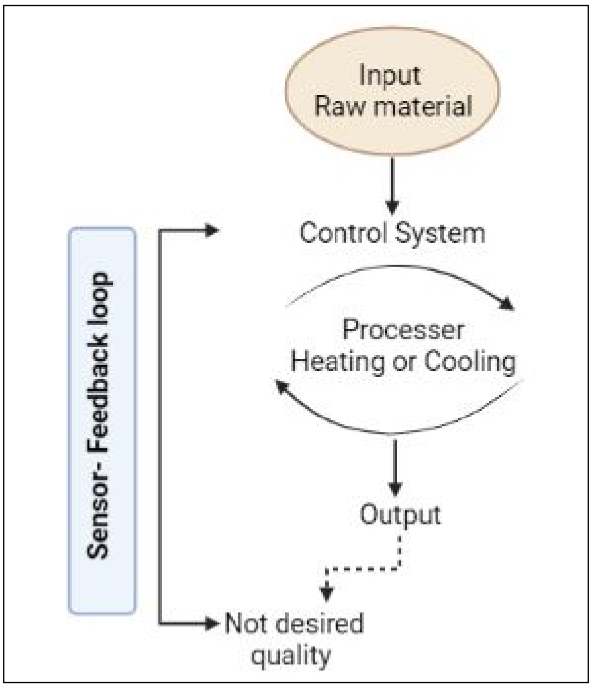

Fig 3: Closed loop control system.

was $ 295,000 (43 × 80 feet) and $ 125,000 (43 × 60 feet), respectively. This high cost initially declines the profitability of milk production. Later decrease in the labor cost can compensate the higher investment in milking system. However proper utilization of robot capacity is needed for efficient operation and higher benefits (Heikkila *et al.,* 2010; Jack, 2021a). Automatic milking can milk three times per day and also increases milk production by approximately 12% (Brady and Fetzer, 2017; Jack, 2021b). Many factors are included in the increase in milk production *viz*., age of dairy cows *etc*. This technology increases not only productivity but also profitability in the long run.

Challenges associated with automation

Al though the rapid development of technology leads to the introduction of various biosensors which is commercially available to monitor the various process in the dairy industry but in some cases this automation technique is difficult to handle, for instance, the sample preparation for finding the targeted pathogen in food matrix (Vasavada, 1993; Fung, 2002). The cost for most of the biosensors used in monitoring various processes in food production is not economically feasible. The electrical devices used in sensors are not suitable for on line monitoring for sterilized products like UHT, Sterilized flavor milk because it is composed of biological materials (Kulkarni *et al.,* 2014). Dairy industry which is fully automated may provide a huge scope for the employment of professionals but leads to less opportunities for non-technical manpower. Though the implementation of this technology is a complex process and costly but it holds the capability to create a revolution in various aspects of dairy industry.

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

Food industry is still lagging behind other industrial sector for implementing automation technology because of the changes in consistency and shape of the food product. The explosive growth in computer hardware and software technology paved the way for its exertion in the food and dairy industries to meet various challenges. But in many dairy plants, the utility of this modern technology remains backward due to its complexity of implementation and adequate knowledge and the requirement of skilled engineers. Research has to be conducted to make ease of handling these technologies in farm-level dairy management. Dairy and food-related industries and universities have an equally important role in imparting new ideas related to advance knowledge and its better utilization.

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