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Exploring the Transformative Role of Artificial Intelligence in the Food Industry: A Comprehensive Review of Applications and Implications

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Abstract

Artificial intelligence (AI) is a technique and is a branch of computer science which includes various techniques such as machine learning, automation, computer vision, expert systems, natural language processing, etc. AI has the potential to provide unthinkable advantages in food sector. It can help reduce wastages, time and increase production as well as it can help maintain the quality and safety of food products during production, processing and transportation by inspection, monitoring and analyzing various parameters that affects the quality of food. Additionally, it helps predict precise and accurate market trends, patterns and customer preferences through which the food industries are able to manufacture more personalized products. It also suggests the food to the customers based on their preferences, needs as well as based on their inputs. However, there are certain limitations and challenges that may affect human intelligence such as data infrastructure and internet connectivity which makes AI more difficult to gather and send the data required for further application. Furthermore, the data generated may raise concerns of privacy and security so as it necessitates protection from cyber threats and unauthorized access.

1. Introduction

Agriculture contributes to a major share in the world and it is also a prime thing that nature has given only on our planet, Earth. It also the main source of income for many people. In the recent scenario, Production of agricultural crops has changed dramatically. This change may be caused by increase in population, changing environmental conditions as well as advancement in technologies.

The cultivation & processing of agricultural crops was begun from ancient times and today many technologies are being innovated, that can offer smooth working performance and can reduce the wastage as well as time and cost. The food industry plays a crucial role in our daily lives because it can satisfy our hunger by producing enough nutrition rich food. In food industries, new technologies are now being used that can help reduce time, manpower and can increase the production and eventually, profit.

The term artificial intelligence (AI) was first used in Dartmouth Conference held in the 1955, where John McCarthy suggested conducting research based on the hypothesis that "Every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it" (McCarthy *et al.*, 2006). Because of rapid advancements and changes, the definition of AI has evolved over time. However, AI is a system that thinks like a human, acts like a human, thinks rationally or acts rationally (Kaur, 2023). Artificial Intelligence is a technology that is transforming every aspect of life.

Essentially, AI is a subfield of computer science that focuses on the intelligence of machines where an intelligent agent is a system that makes decision to increase its likelihood success (Saini, 2023). AI has the power to change how we work, play, and live. In addition to performing data-oriented tasks and analyzing massive data sets, it can assist with product design, marketing, and training for the quickly expanding communities of generative AI technologies (Kaur, 2023).

1.1 Advantages and applications of artificial intelligence (AI) in food sector:

Artificial intelligence can be beneficial in many ways in the food sector. It can help reduce operating cost and time, precisely use encoded data to reduce wastages, accurately measure different parameters during the production or processing, it has ability to analyze the food that helps remove defected pieces without any human touch and reduces labors, boosts transportation practices with accurate measures, it can be used to predict market and consumer behavior as well as their preferences that may help to invent new products or developing new market strategy that make profitable business, automate processing steps and escalate overall production statistics.

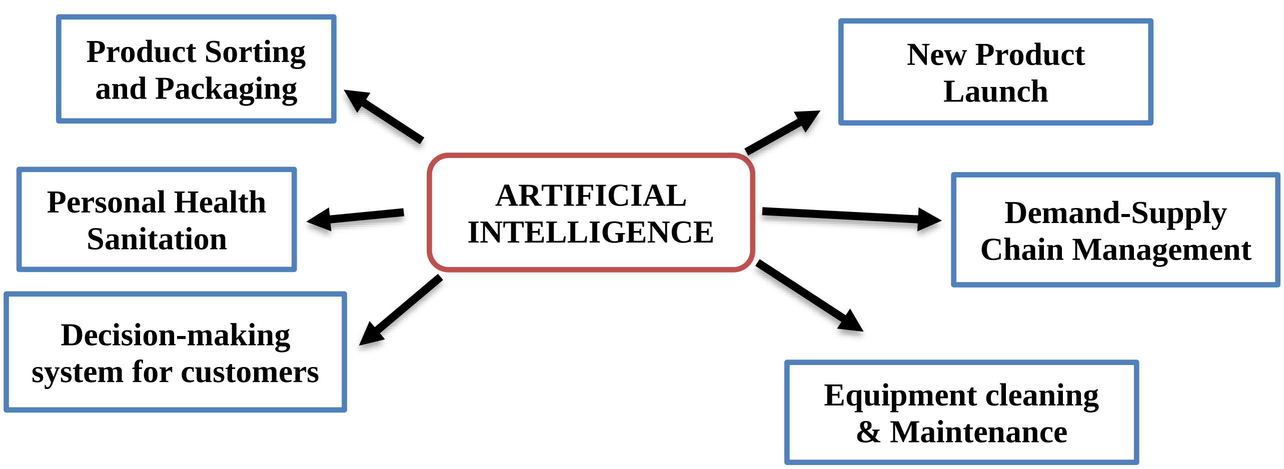

Figure 1.1 Applications of AI in food sector (Kumar *et al.*, 2021)

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2. Evolution of Artificial Intelligence in Food Sector:

Many researchers have started implementing AI in their work and developing new technologies to automate the different processes such as sorting, grading, inspection and analyses. Production economics, storage & transportation, etc. The first industrial revolution made achievable for the invention of steam-based techniques, especially thermal processing such as pasteurization and sterilization and to use steam engines for completing repetitive tasks in the food production process. In regards to mechanization, during the 18th century, grain milling transformed from systems powered by humans, animals, the wind, or water to machinery powered by steam. The implementation of electrical energy in food production begins straight to the early 19th century, throughout the second industrial revolution. The gradual extinction of steam-powered equipment with electrically-powered substitutes was accompanied by the creation of new equipment, such as the juice extraction machine invented by Normal Walker in 1930, the vacuum packaging systems developed by Karl Busch in 1960, and the first batch to continuous pasteurizing systems. A refrigerator, which can be used to store and chill food products, continued to be one of the vital pieces of equipment ever invented ([I]Hassoun *et al.*, 2023).

The invention of microchips during the 1970s established the birth of the third industrial revolution, which opened the door for better control over food processing lines. Moreover, the third industrial revolution is fostered by the developments which eventually resulted in the invention of irradiation systems for the microbial decontamination of spices and herbs. The 1960s & 1970s saw the earliest attempts to apply AI techniques or technologies in the food industry. Firstly, the expert systems were developed and used to analyze the data and to make predictions about the quality and safety of food products. The 1980s and 1990s witnessed the development of more intricate AI systems for food processing as a result of advancements in computer science (Kumar & Saha, 2023). The concept of advanced technology in food sector are being started evolving which give new pathway to boost the productivity, traceability, time, money and many more. It's nothing but 'Industry 4.0'. Food processing 4.0 is the use of Industry 4.0 to improve food quality and safety of food products while reducing expenses and waste. This is accomplished in the current digital era. It includes the use of smart sensors, internet of things (IoT), artificial intelligence (AI), big data, robotics, blockchain and much more ([II]Hassoun *et al.*, 2023). Implementation of robots in milking systems are one of the most successful inventions in a dairy industry.

Table 2.1 Some of publications on Industry 5.0 in the dairy sector (Hassoun *et al.*, 2023)

Author	**Tittle**	**Industry 4.0 Technology**
Le Tohic *et al.*, 2018	Effect of 3D printing on the structure and textural properties of processed cheese	3D printing
Liu *et al.*, 2018	3D printed milk protein food simulant: Improving the printing performance of milk protein concentration by incorporating whey protein isolate	3D printing
Liu *et al.*, 2019	Rheological and mechanical behavior of milk protein composite gel for extrusion- based 3D food printing	3D printing
Casino *et al.*, 2021	Blockchain-based food supply chain traceability: A case study in the dairy sector	Blockchain
Goli *et al.*, 2021	An integrated approach based on artificial intelligence and novel meta-heuristic algorithms to predict demand for dairy products: a case study	Artificial Intelligence
Newton *et al.*, 2020	Farming smarter with big data: Insights from the case of Australia's national dairy herd milk recording scheme	Big Data
Nilova *et al.*, 2018	IoT in the development of information support of food products for healthy nutrition	IoT
Khan *et al.*, 2020	IoT-blockchain enabled optimized provenance system for food industry 4.0 using advanced deep learning	IoT, Blockchain, Deep Learning
Arnaud and Costa, 2020	Ultra low-cost sensors using RFID standards for data collection, for IoT systems in food production and logistics	RFID, IoT
Lin *et al.*, 2016	Food safety traceability system based on blockchain and EPCIS	Blockchain
Tsang *et al.*, 2019	Blockchain-driven IoT for food traceability with an integrated consensus mechanism	IoT
Gonzalez-Buesa and Salvador, 2019	An Arduino-based low-cost device for the measurement of the respiration rates of fruits and vegetables	Micro-controller-based system
Haque *et al.*, 2023	Automatic product sorting and packaging system	Microcontroller based system

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3. Implementation of Artificial Intelligence in Food Sector for Various Operations

Pla *et al.*, (2001) developed an automation system using machine vision for sorting of fruits and vegetables. They found that in any processing industry, the unit operations like sorting and grading requires labors as well as labors takes more time to sort fruits as it requires visual inspection and removal or passing. Reviewing those problems, they developed a machine that can inspect and analyze fruit and vegetable based on their weight, size and color. The system consists of a central control unit, user interface and storage unit, a set of weight modules, set of vision modules, set of output control units. The central control unit manages all the information about devices and sensors. it also manages the encoder and generates synchronization signals to the weight, vision and output modules.

CAN (Control Area Network) and LAN (Local Area Network) is used to connect units with each other and it helps to store, monitor and transfer the data to another place. Infrared (IR) cameras are used to detect the fruit and its location which is more robust to segment the fruits from background using infrared image than doing it from a color image. Ultraviolet (UV) camera is also employed to detect the defects and it helps to categorize type of defect. Using image processing technique, fruits and vegetables are sorted by their weight, size and color properties. The developed system has ability to process 15 fruits per second per line (Pla *et al.*, 2001).

Hopper *et al.*, 2008 developed a wireless electronic monitoring system for securing milk from farm to processor. The study pointed the problem that the bulk milk transport sector requires a security enhancement that will reduce recording errors and unauthorized access. The system consists of a data server, a mobile handheld computer (MHC), and a computer processor installed on the tanker that operates the security monitoring system (SMS). Basically, the system requires information of particular hauler, tank/truck, time and place the tanker is assigned, time of pick up, and pick up farm name, etc. RFID tag and biometrics are implemented to identify the tanker, driver and other information. After demonstration, it was found a complete success of monitoring the truck and tanker during the transport.

Al-Marakeby *et al.*, 2013 developed computer vision-based food quality inspection system of food products to overcome the problem of maintaining hygiene and maintain the quality of fruits and vegetables during various processing operations such as handling, sorting, etc. Fast single camera and multiple cameras was implemented to capture the image of products. Single camera used to check different sides of the products whereas multiple cameras used to get more clear images of food products by fixing in different directions. Isolated box is attached that isolates the system from the excess light which cause problems in capturing the image.

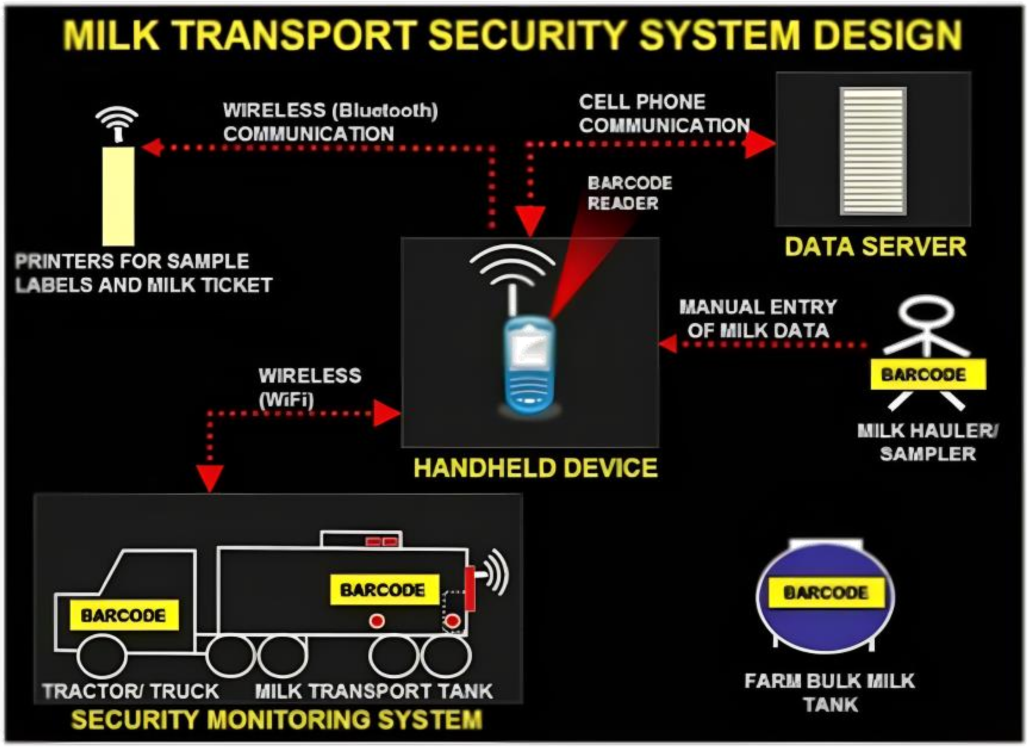

Figure 3.1 System design for milk transport monitoring (Hopper *et al.*, 2008)

Whole system is connected to the PC which analyzes the captured images and takes the decision either to pass or fail the captured image of particular food product. Image processing techniques was integrated to capture, analyze and categorize the food product based on pre-loaded data. The classification mainly done by viewing different parameters of the fruit including the color, texture, edges, etc. the system was experimented on fruits like apples, lemons, tomatoes, and eggs having 1000 datasets (250 images for each system) used to train and test the system. The accuracy and speed of operation was found 97%, 96%, 96.5%, 96.6% and 176, 120, 150, 210 images per minute for eggs, apples, tomatoes, and lemons, respectively.

Dube & Jalal, 2016 developed apple disease classification system using color, texture and shape features from images. In this study, K-means clustering-based defect segmentation technique is utilized for region of interest extraction and background subtraction for the apple disease

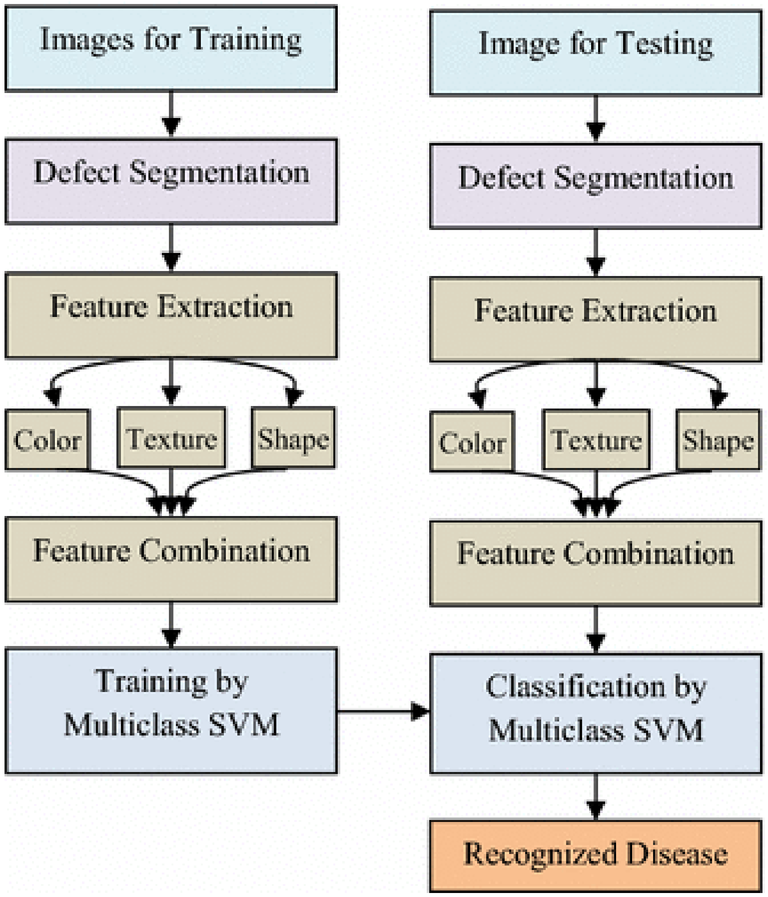

Figure 3.2 Apple disease recognition system using color, texture and shape features

classification. The apple diseases were recognized using a multi-class support vector machine (MSVM). Mainly, three types of apple diseases namely blotch, rot and scab and normal apples were used to verify introduced method. The K-means clustering-based approach works by firstly reads the input image and then transform it into the L*a*b* color space and then apply the K-means clustering in 'a*b*' space to generate the different regions and then extract the images containing the different regions and finally select the segmented image containing most of the diseased portion manually.

Dewi *et al.*, 2020 developed fruit sorting robot based on color and size for an agricultural product packaging system. It was observed that agriculture confronts the problem of old farming as young people lack interest in it. To deal with this issue, they discovered an approach: the implementation of emerging robotics technologies. 4DOF (4 degrees of freedom) named fruit sorting robot was integrated that uses image processing technique for sorting of fruit. The developed robot was tested for its accuracy and precision in detecting and sorting of red and green tomatoes as well as red and

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green grapes. The robot consists of an electrical parts and hardware parts. The electrical parts consist of an Arduino Uno – microcontroller, Battery, Raspberry Pi, Proximity and Camera sensors, Servo motors. On the other hand, the hardware components involve base material and end-arm with 2 mid-joints which helps attach it to the base material.

The image analyses can be done in two ways, deciding color using HSV analyses and recognizing the size using the diameter calculation from gray-scale image of the fruit. The developed robot sorts the fruits by HSV analyses by capturing 640x480 pixel image that decides the color, thresholding and edge detection which gives the size. The effectiveness of proposed method in sorting, picking and placing the fruit was noted about 80% for red and 90% for green tomatoes and 70% for red & 60% for green grapes and the time required during the process was noted as 11.91 s, 11.76 s and 12.56 s, 12.92 s, respectively. Sometimes, the failures in sorting caused due to the different sizes of the fruit and illumination in the experiment (Dewi *et al.*, 2020).

Gao *et al.*, 2020 proposed real-time hyperspectral imaging (HSI) system for in-field estimation of strawberry ripeness with deep learning. Spectral feature wavelengths were selected using sequential feature selection (SFS) algorithm in which two wavelengths for field (530 & 604 nm) and for laboratory (528 & 715 nm) samples were chosen. The reliability of such features was validated based on support vector machine (SVM) classifiers as it has good results with receiver operating characteristics values for both samples higher than 0.95. AlexNet convolution neural network (CNN) was integrated to classify the early ripe and ripe stage of strawberry samples and the accuracy was found to be 98.6% for test datasets.

Bahera *et al.*, 2020 proposed machine learning and transfer learning-based approach for maturity status classification of papaya fruits by reviewing that the manual grading of papaya fruit based on human visual perception is time-consuming and destructive. The classification of papaya fruit maturity level was carried out in two approaches namely machine learning and transfer learning. The maturity stage of papaya fruit is defined as per visual aspects of flesh color. The images of fruits were captured in 13 Megapixel resolution in natural light of the day. The fruit was then classified in three stages like, immature, partially mature and mature as per visual characteristics. 300 samples (100 of each) were examined by dividing them for training, validation and testing with 70%, 20% and 10%, respectively.

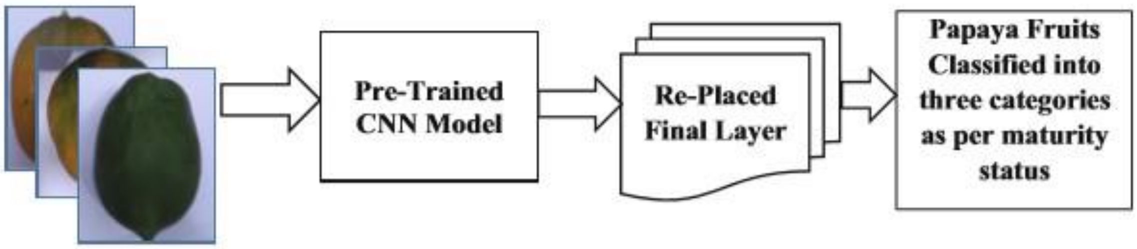

Figure 3.3 Machine learning approach for papaya fruits maturity status classification

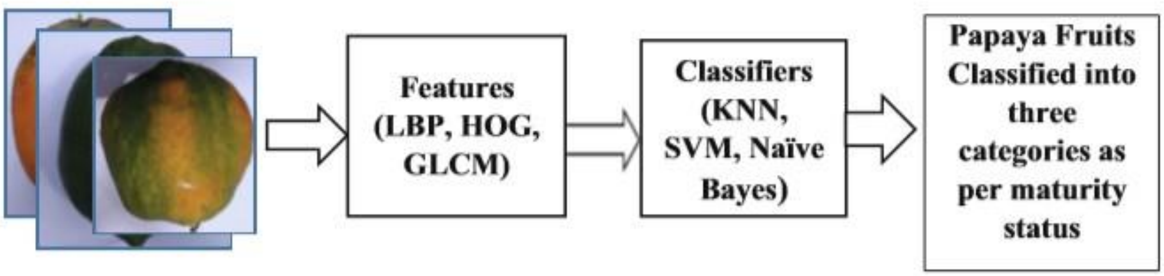

Figure 3.4 Transfer learning approach for maturity classification of papaya fruits

Machine learning approach was tested with nine classifiers such as Fine-KNN, Medium-KNN, Coarse KNN, Weighted KNN, Linear KNN, Quadratic SVM, Fine Gaussian SVM, Cubic SVM, Kernel Naïve Bayes. It was observed that the weighted KNN performed better with use of LBP, HOG and GLCM features individually with 100% accuracy. Fine-tuning based on transfer learning using pre-trained CNN networks was performed and observed that the VGG19 performed better among the other classification models of transfer learning with accuracy of 100% (Bahera *et al.*, 2020).

Helwan *et al.*, 2021 developed deep learning based on residual network for automatic sorting of bananas. ResNet-50 was designed using transferred learning which uses stored knowledge of deep structure to sort out fruit into healthy or defective classes. The evaluation of the performance of developed model was done by training and testing the model using learning algorithm in which 40% of images were used for training and remaining 60% were used for testing. The stimulation result in terms of accuracy was noted 99% when tested of unseen banana images.

The organization of agricultural production and sales is carried out through the vertically integrated operation mode known as the food supply chain. Liu, (2015) proposed research on the food safety supply chain traceability management system based on the IoT. During supply-chain of food products or raw material which is to be processed, it requires high priority security to reach the location safely while maintaining the quality and hygiene. After reviewing the issue, he suggested a solution that would safeguard consumer interests by strengthening the transmission of information about food security, reducing the risk of food-borne illness, and safeguarding the information recording system. It performs three functions. First of all, it monitors the process used to process and recall products where there is a quality security issue.

The system tracks where the problem originated in the second place, and logistics management comes in third. Seven logistics functions—transportation, storage, distribution processing, handling, packaging, and information processing, among others—are integrated into this traceability system. The suggested system uses an RFID-based system to address the aforementioned issue. One of the most important aspects of our everyday lives is food. The primary consideration at every stage, from harvesting and monitoring to processing and storage, is the quality of the food products. One of the main issues is that foods, whether processed or raw, change in quality while being stored because foods undergo ripening or respiration in presence of gases or the atmosphere. Reviewing above noted critical situations, [II]Khan *et al.*, (2021) developed a robot *Vibhishan* that can monitor and inform the owner during the storage of food products as well as the warehouse. The developed robot consists of ultrasonic sensor, passive infrared sensor, raspberry pi, ESP8266 wi-fi module and ESP32 cam.

The intruder is used to detect the objects/unauthorized person that comes in a range of camera during its surveillance. The robot also detects the food that is in good condition or not. The developed system camera captures the image of food product and uses image processing techniques to analyze the food product.

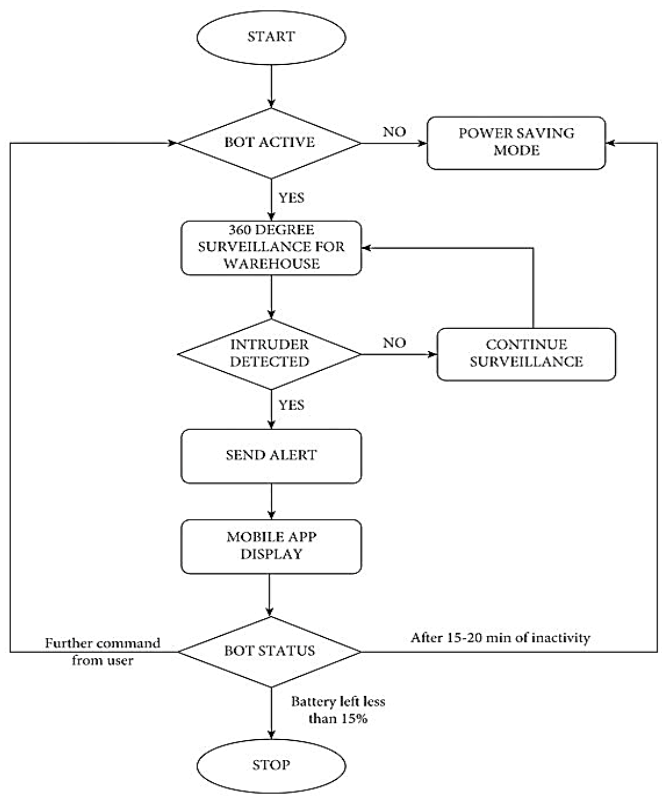

Figure 3.6 Flowchart of intruder detection using robot ([II]Khan *et al.*, 2021)

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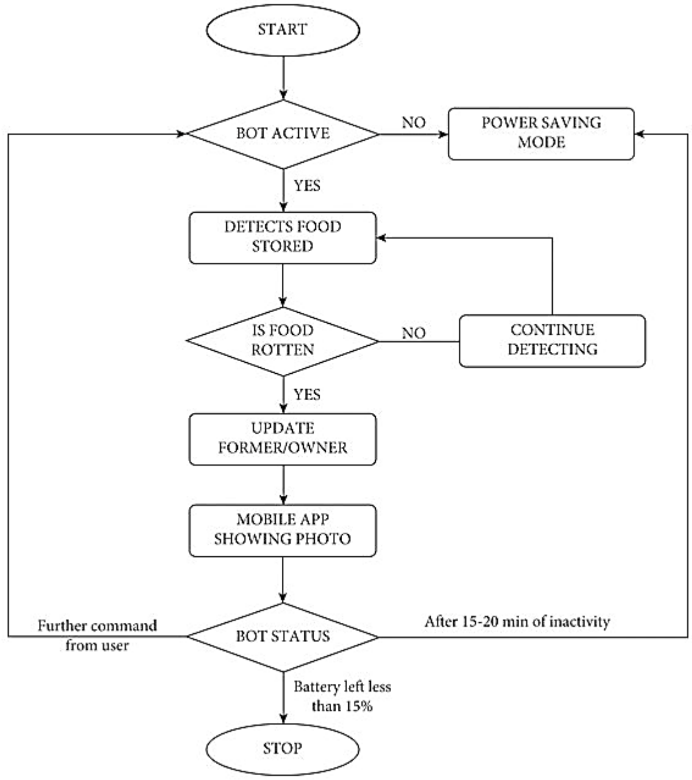

Figure 3.7 Flowchart of food safety using robot (Khan *et al.*, 2021)

Image processing techniques, which involve four steps to ensure food safety by detecting food, were used to train the model. During the image acquisition process, a 1024x1024 resolution image is first captured and subsequently downsized to 512x512. This study looked into a variety of foods, including bananas, apples, beets, paprika, onions, peas, pears, oranges, potato chips, mangos, hawthorn, tomatoes, doughnuts, peanuts, and so on. identifying various regions of an image and making it from an RGB to a black

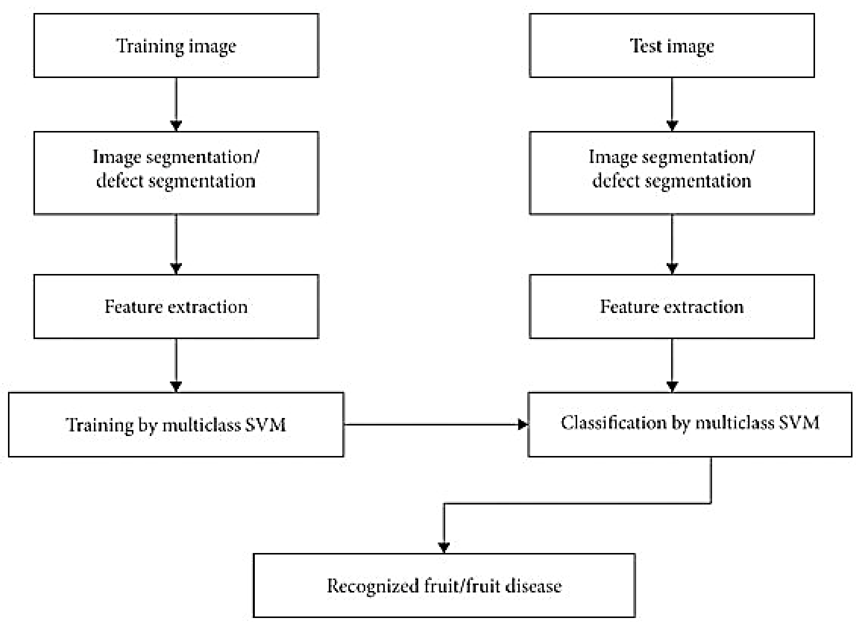

Figure 3.8 Flowchart of image processing ([I]Khan *et al.*, 2021)

and white (colored to monochromatic) image is the process of image segmentation. The model is trained to describe or extract features from an object in the subsequent step, shape detection. Food recognition is the final step in the technique. The food products are validated in this step using the pre-loaded data (Kumar *et al.*, 2021).

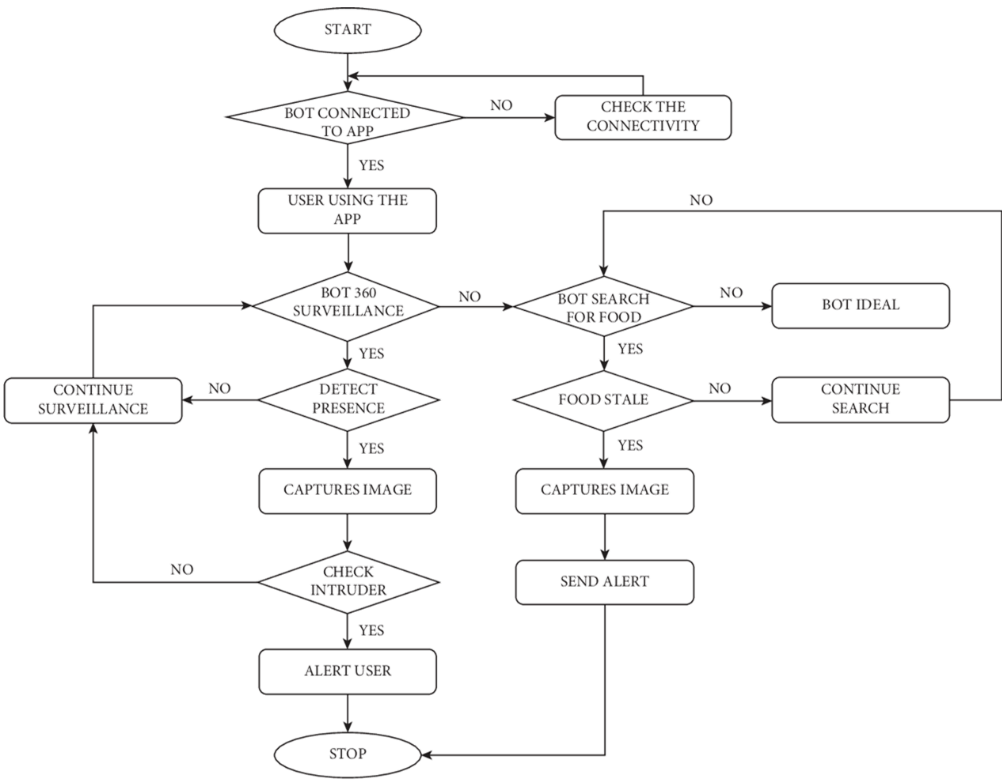

Figure 3.8 Flowchart of image processing ([II]Kumar *et al.*, 2021)

4. Challenges

The initial installation and investment costs associated with implementing AI technologies present a significant challenge for the food industry. Owing to these problems, implementing AI in the small-scale food industry is expensive and presents a barrier to entry, especially in developing nations. Moreover, the existing equipment may not be compatible with AI technologies, which necessitates costly upgrades and modifications. The data infrastructure and internet connectivity are also significant issues that make it more difficult to gather and send the data required for further application. Furthermore, the collection and sharing of sensitive food raise concerns about data privacy and security. Therefore, protecting the data from cyber threats and unauthorized access is a significant challenge.

5. Future Prospects

while examining a plethora of literature, it was discovered that artificial intelligence is among the cutting-edge technologies that will enable the food industry to become more sophisticated and innovative. By accurately predicting various parameters and increasing the speed of operation, the adoption of AI in the food sector decreases time spent during operations and transportation while also improving quality and safety. Furthermore, the development of expert systems has made it possible to predict consumer demands and preferences as well as market trends and patterns. As a result, producing customized food products based on consumer preferences could assist companies in developing their marketing strategies, elevate profits, and acquire market share.

6. Conclusion

Artificial Intelligence has the power to completely transform the food industry. Even though the food industry has begun to use AI methods and technologies, the field is still developing. While AI technologies offer unimaginable benefits, there are also drawbacks that might negatively impact the economy and human brain, such as issues with data security and privacy. Therefore, it is essential to establish strong data security measures into operation while making sure that the AI systems are readily apparent in order to overcome these barriers and fully realize the potential of AI in the food sector. Furthermore, based on the literature studied above, artificial intelligence (AI) techniques and technologies have the potential to completely transform the food industry.

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