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Use of artificial intelligence (AI) in vegetable crops: A review

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ABSTRACT

Artificial Intelligence (AI) is emerging technology in vegetable production, enabling data-driven decision making and precision agriculture practices. AI refers to the intelligence exhibited by machines that can perceive their environment, process large datasets, and make decisions to optimize agricultural productivity. With the integration of technologies such as machine learning, sensors, drones, satellites, Geographic Information Systems (GIS), and Global Positioning Systems (GPS), AI enables efficient monitoring and management of crop production systems

In vegetable cultivation, AI technologies assist farmers in several critical operations including soil monitoring, climate assessment, pest and disease diagnosis, irrigation scheduling, and yield prediction. Sensors such as wind vane, cup count anemometer, rain gauge, lux meter, soil moisture sensor, and crop canopy sensors collect real-time environmental and crop data. These data was processed through data loggers and machine learning algorithms to provide accurate recommendations for crop management. Drone-based imaging systems and multispectral cameras further support precision farming by identifying weeds, nutrient deficiencies and disease symptoms at early stages.

The use of AI in vegetables also highlights image-based predictive agriculture systems where captured images are processed through stages such as. image cleaning, feature extraction, and model training to detect pests and diseases. Several case studies demonstrate the use of AI in vegetable crops such as tomato, capsicum, and chilli for monitoring canopy growth, irrigation management. Additionally, robotic technologies in harvesting address labor shortages in agriculture.

Crop yield prediction of AI in vegetables increases by 40% sensors and algorithms reduces labor cost by 30% moisture sensor increases water use efficiency by 40% spraying done reduces use of pesticide by 60% robotic arms increases harvesting accuracy by 40% artificial neural network data integration saves 25% cost in disease monitoring.

Keywords: Artificial intelligence, IoT, Sensors, Data, Machine learning

1. Introduction

The trend of farming is gradually shifts towards modern ways of practices. All holistic approaches of farming practices are aligns with technology called artificial intelligence. (Bhaskar and Gibson. 2011) [1] AI have ability to gather and evolve massive data on a digital platform such as computerized vision technology which have wide range of applications in soil, pest, disease crop growth diagnosis. India have recognized potential of AI tools and IoT devices, robotics and incorporated AI into agriculture sector via startup India projects. Maharashtra state reported that IoT automization technology saves water resources. (Chang *et al.*, 2018) [2]

2. Concept of AI

Intelligence is exhibited by machines, algorithms, programs, database. Agents perceives to their environment on the basis of provided information in the form of .csv format of excel sheets and take actions to maximize yield and production of crop. Data loggers collects data from sensors, probes and weather station into a microcontroller chip. (Abdullahi *et al.*, 2015) [3] Algorithms are set in a cloud setup software in the form of commands of codes which enables machines to analyze, think, perceive, learn to collected real time data and predict or suggest a solution. (Aitkenhead *et al.*, 2003) [4]

3. History of AI

Alen Turing had a thought in his mind "Can machines think ?" his thought gets mold into reality by working with his co workers Jhon Mecothi, Marvin Minsky, Alen Nevel and Hbart Saimon and first working model of AI with machine learning module was represented in 1956. Jhon Mecothi is known as father of AI.

India had introduced concepts, tools, devices and working set ups of AI into agriculture, medicine, health and education sector as a pilot basis. Since 2018 AI had introduced into agriculture sector (Al-Ali *et al.*, 2015) [5]

4. Status of AI

Traditionally farming practices was carried out by using bullock drawn cultivars, country plough desi plough and farming implements like hoe, spade and tools as population level boosts it triggers agriculture research sectors to feed sufficient food by introducing high yielding and resistant varieties along with tool of farming such as mechanical hardware oriented machineries, manual and onsite control of crop monitoring is possible with simple machines (Chaurasiya *et al.*, 2025) [6]. But tomorrow's farming will partially or totally reliable on types of AI assistant such as touch AI in which the elements which remains in contact with land are classified under category of touch AI (sensors, probes). Mid touch AI in which tools are not in contact with land but monitors weather parameters and growth parameters of crop are classified under mid touch AI (drones, NDVI sensors) are partially assist for remote sensing operation. Non touch AI are not in touch of land helps to give accurate information about metrological information of weather parameters by means of satellites (Mor *et al.*, 2021) [7]

5. Merits of AI

Farmers can improve the quality of their yield by fetching data of field. Farmer can monitors real time climate changes of weather parameters along with fluctuation pattern in inputs as well as production. Input variability affects physic biochemical growth of plant which affects morphological and physiological structure of crop development such issues are over come due to using of AI tools to bring precision in application of inputs such as water, fertilizer, pesticide, fungicide etc (Ahmad *et al.*, 2024) [8] Yield could be estimated by AI based IoT tools by analyzing recent trends in data of crop development. AI Increases efficiency in Effective seed sowing, crop harvesting field by using GIS (Global Positioning System), GPS (Geographic Information System), VRA (Variable Rate Applicator), NDVI (Normalized Difference Vegetation Index) and tools such as robotic arm used for mapping of plot for observation of crop maturity, soil monitoring and weeding (Singh *et al.*, 2022) [9] AI technology deals with labor shortages by increasing efficiency in task and saving time as well as energy of labours. DGCA (Directorate General for Civil Aviation) approved drone trainings are given to farmers, women's and emerging startups for promoting smart farming (Prakash *et al.*, 2022) [10]

6. Demerits

Skilled person is required to understand coding, programming, algorithms, software designing commands, excel sheet data Imputing (purification) and conversion excel sheet into .csv fotmat, and to resolve minor errors raised by sensor probe, coding commands and person who is handling this tools. Internet connectivity with intel i7 processors are required for enabling commands and upgraded version of windows with ether net connections are required for fetching to data and to store a massive data server rooms are requires (Jain *et al.*, 2025) [11]. Machine learning requires large amount of purified data to get trained for particular crop, condition prediction. To establish AI in a particular crop requires long term research because expected observation sheets. Each observation have 2200 – 2500 entries of observation. Season wise crop response pattern, biotic and abiotic stress trend of recent 4 years have to be uploaded to cloud database of AI. Establishment of AI hub for new sector is a intensive task because every person of that sector must have proper fundamental knowledge about workflow of AI. New sector must have bearable potential for establishment of Hub including server room, panel room, database management rooms, consultative team (Jorden and Mitchell 2015) [12]

7. Components of AI

7.1 GPS

GPS (Global Positioning System) is a satellite based negation system. GPS is major component of AI as it maps field dimensions and this co-ordinates are used by drones and sensors during their working. GPS sets boundaries of field to avoid invasion of AI tools into nebour's field. (Xu, 2007) [13]

7.2 GIS

GIS (Geographic Information System) is a satellite based information extracting system. GIS collects minor information about field profile. Q-GIS is a open source and ideal for flexible mapping. ARC-GIS can generate 3-D view of field map with filters such as satellite view, road view and traffic view. GIS plays major role to train AI-ML model to set algorithms. GIS is commercially use in a large scale research projects (Maguire, 1991) [14]

7.3 Satellite

Device which rotates around earth's gravitational field and collects Temporal, Spatial and Spectral data of specified object is known as satellite (Elbert, 2008) [15]. There are Indian satellites around earth launched by ISRO (Indian Space Research Organization) collects data related to agriculture. RISAT-1 (Radar Imaging Satellite) collects information about weather imaging for crop monitoring. INSAT-3DR (Indian National Satellite 3D Repeat satellite guides about drought and disaster management and provide estimated crop acreage estimation data. (SAR) Synthetic Aperture Radar penetrate cloud cover and gives appropriate information in cloudy and highly humid conditions. Cartosat Series used for Land mapping for drainage and irrigation network management. EOS-06 (Oceansat) oceanography performed by this satellite which studies sea winds flow pattern and provides suitable data for coastal agriculture farming practices (Maral *et al.*, 2020) [16]

7.4 Machine learning (ML)

Machine learning is consist of Artificial Neural Network (ANN), Feed Forward Neural Network (FFNN), MultiLayer Perception (MLP) which can perceive understand and act on provided data. Machine learning can do task of data representation, reasoning and planning by modeling to external world. Deep learning is a part of machine learning which deals with ability to take actions, solving new problems and decision making analysis, unexpected problems and uncertainties (Naga and Murphy 2015) [17]

7.5 Drone

DGCA (Directorate General of Civil Aviation) specifies drone parameter such as take off weight (45 kg), main rotator diameter (2.41 m), rotating speed (1350 rpm), BD difference positioning accuracy level (+- 1 cm), BD difference positioning accuracy in vertical (+- 2 cm), BD system data update rate (10Hz), flight height above canopy of crop (0.3m), flight speed (1 m/s) are taken into consideration during manufacturing of drone (Vergouw *et al.*, 2016) [18] DGCA provides trainings related to components, working, profiling of drone, flying techniques and provides 56% subsidy for agriculture graduates and 40% subsidy for non agriculture graduates along with authorized license of drone flying. Namo drone didi scheme was launched in 23 November 2023 for providing drone flying training to the women's Self Help Groups (SHG) for women empowerment. Namo drone didi scheme provides 80% subsidy (Kalita *et al.*, 2025) [19]

Image based predictive analysis is possible by mounting multispectral camera on drone which captures numerous images of field and foliage which are require to train ML module to get accurate results. UAV (Unmanned Arial Vehicle) drone are useful for such crop depth analysis. By using UAV drones real time alerts can given to farmers to accelerate precision farming (Yang *et al.*, 2023) [20]

Image captured by drone undergoes from cleaning, fetcher extraction, mapping, resolution, filtering, pixelization processing and then final

result could be displayed on a screen with results. Such image analysis is useful for weed, pest, disease detection processes (Le 2025) [21]. Intelligent spraying can be performed by using spraying drone. There are two types of drones: 6 armed (27 kg) 15 liter drone, 4 armed (20 kg) 10 liter drone. Used for spraying into field. Satellite sends field images to the database and multispectral camera uploads images of disease, pest incidence in percentage. GIS satellite makes 3-D model of provided information of obstacles, water bodies, storage structure in fields and GPS sets boundaries for drone to fly and by synchronizing this information drone take off and apply formulation only in infected area of field which saves farmers inputs and increases precision in farming (Jensen *et al.*, 2025).

8. Sensors used in agriculture

8.1 Wind vane

Sensor based wind vane rotates its tail with respect to north direction. Wind vane set up consists of rotating fin which is mounted on a rotating shaft which is connected to rotatory potentiometer. Rotatory potentiometer voltage corresponds to 0° to 360° direction (Wang *et al.*, 2025).

8.2 Cup count anemometer

Four cups are arranged on horizontally rotating arms connected with internal magnet and reed switch. Cup count anemometer converts wind energy to rotational motion and then into electrical pulses that can be processed by micro controller chips (Arduino USB 3.0). Wind speed is measured in m/s, km/hr. Wind speed sampled after every 10 seconds and this data is stored in data base of server. Cup count anemometer uses AI modules of time series analysis, wind trend prediction, weather forecasting (Bradley, 1969) [22].

8.3 Rain gauge

There are three main types of rain gauge: tipping bucket type rain gauge, weighing rain gauge, optical rain gauge. Tipping bucket type rain gauge has one small bucket with calibrated volumes. When rain water reaches at particular volume then probe sensors generate pulses from tips such pulses record rainfall. Weighing (pluviometer) type rain gauge consists of container in which rainfall is collected and load cells measure rainfall and precipitation weight continuously. Optical rain gauge uses infra red light beam. When rain drop interrupts beam then droplet size and precipitation rate is calculated (Hu *et al.*, 2022) [23].

8.4 LUX Meter

Photodiode or phototransistor converts incident light into electrical signals. ADC converts analog signals to digital signals by using algorithms of fuzzy logics. Lux meter helps to estimate photosynthetic activities, detect crop water requirement, to count amount of light absorbed by plants (Lemembang and Kolibu 2024) [24].

8.5 Crop canopy sensor

Infra red canopy temperature sensor measures canopy surface temperature by using thermal radiation camera. Infra red thermometry detects emitted radiations (8-14 micro meter). Converts radiation into temperature reading. Optical reflectance sensors are mounted on NDVI device which emits infra red light and measures reflected radiations to calculate vegetation index. Multi spectral canopy sensor measures blue, green, red, NIR, red edge bands (Lan, 2009) [25].

8.6 Soil Moisture Sensor

Sensing probes are dipped into soil at the depth of 5 cm, 10 cm and 15 cm. Signal conditioning circuits consists of analog digital output module collects data from (raspberry Pi 4) and wireless transmission module (GSM, WiFi) (Yu *et al.*, 2021) [26].

8.7 AI Set up Estimation

Costs upto 25,000 rs. subsidy is paid by Vasant Dada Sugarcane Research Institute (VSI). Rest of 6,000 rs are paid by farmer for 18 months. Area covered by AI set up is about 2.5 km and cluster of 25

farmers. Individual farmer gets soil moisture sensor. This AI setup is ideally installed for sugarcane crop. Vegetable crop like onion is in the process of establishment phase in Maharashtra state. (Das *et al.*, 2024) [27].

8.8 Work profile of AI set up

Soil moisture, soil pH, soil EC sensors are placed in a soil at recommended depths. Air temperature, air humidity, rain gauge sensors are installed at recommended locations. All these sensors collect soil and air images and data which sends to cloud database management. Database integrates collected data with recent and older data and interprets to on field conditions. Machine learning (Artificial Neural Network) makes decisions, predictions and solutions which are sends to server and farmers connected phone, laptop. Farmer takes actions according to suggestions of AI and remotely starts or stops functioning of any device installed in field (Muangprathub *et al.*, 2019) [28].

8.9 Agriculture robots

Robotic technology in agriculture has four various operations like seed sowing, weeding, transplanting and harvesting. Robotic sensors such as VRA (Variable Rate Applicator) applies fertilizers according to need of field locations which saves fertilizers of farmer. Weed killing robots use NDVI sensors which identifies difference between crop stand and weed canopy and kills weed with the help of laser technology mounted on NDVI sensors (Fountas *et al.*, 2019).

9. AI – Start UPS in agriculture

Croo robotics company manufactured robotic arms in California country to harvest cucumber crop. This robotic arm can harvest up to 8 acres a day and replace 30 human labors (Bergerman *et al.*, 2016) [29]. PEAT machine vision for pest developed by plantix company. PEAT machine can identify foliage of diseased samples and pests on crop and gets information related to which pest or disease has occurred on crop. ML algorithms suggest solutions and recommendations to farmer. Plantix app can give information to farmer about incidence through images captured by user's smart phone (Samal *et al.*, 2024).

9.1 AI start UPS in India scenario

Various business models are working currently in India such as crop advisory (Plantix, Cropin, Agrostar). Supply chain technology and output market linkage (Ninjacart, Waycool, Dehaat). Agribiotechnology (Greenpoo labs). Finance and services (Jai kisan, Unnati). Consultancy services (Krishify, Farm bee). Input market linkage (Bighaat, Gramophone). Allied sectors (Aqua connect). Integrated services (Innoterra, NAPANIA) (Gupta *et al.*, 2025) [30].

9.2 AI start ups in Maharashtra

Map my crop, Agri pilot AI, Microsoft Azure collect on field data with the help of sensors installed in field and gives outputs to the users phone. All these data can collectively gathered at Krushik app platform (Raj *et al.*, 2025) [31]. Anaconda software can train to ML with the help of .csv format excel sheets. Orange software interprets purified excel sheets having recordings of observations gathered by sensors and probes is pooled and creates statistical output data in the form of graphs, regressions, co-relations (Bothelo *et al.*, 2025) [32].

10. Role of AI in Weed Management

Precision weed management was conducted in capsicum plant by using machine learning algorithms which performs weeding by spraying method with efficiency (70.5%). Autonomous weeding uses machine vision algorithms in sugar beet crop performs weeding by using high power lasers for inter rows with accuracy 84%. Weeding in cotton crop by spraying was done with the help of weeding robotic arm which uses mathematical morphology algorithm with accuracy 88% (Partel *et al.*, 2019) [33]. Smart weeding followed in sugarcane crop which uses color and texture based algorithms syncs with robotic arm. This method can evacuate 92.9% weeds from sugarcane fields (Raja *et al.*, 2025) [34].

11. Role of AI in Water Management

PLSR, Artificial Neural Network, Fuzzy logic, Multi layer Neural Model and machine learning algorithms are used for water management in fields (Adewusi *et al.*, 2024) [35]. All these algorithms use technologies such as IoT sensors which seems that economic feasibility were increased and prediction algorithms help to tackle drought conditions, prevent wastage of water and evaporation, saving was observed in electricity as well as in water use efficiency (Ye *et al.*, 2024) [36].

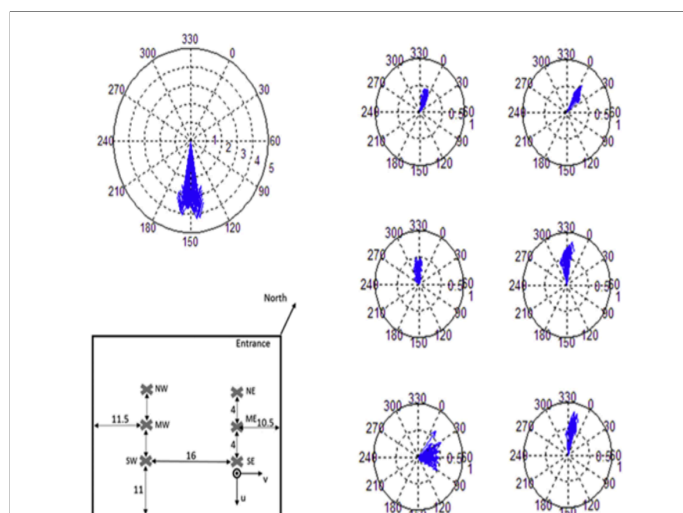


Fig. 3 – Horizontal air velocity at the six positions inside the house. Based on 246 observations of 10 min each, filtered for external wind azimuth between 320 and 340°, from data of 16 days (8–23 July, 2014). On the left, external wind speed and direction is plotted together with a top view of the anemometer positions in the greenhouse.

12.2 Case study - 2

Automatic irrigation system with rainfall detection in agriculture field

Abstract: Bucket type rain gauge installed in tomato fields at TNAU, Coimbatore. Bucket type rain gauge records rainfall occurred in field this data is collected at a data processing unit where irrigation water

12. Case studies

12.1 Case study 1

Air flow pattern and turbulence characteristics above the canopy of a tomato crop in a roof ventilated insect proof net house

Abstract: 3D sonic anemometers are placed at a height of 2.5m above ground in insect net shade house. Which records wind speeds from NE, ME, SE, NW, MW, SW direction. Sampler records air velocities in data logger memory card at 10Hz frequency at 10 min interval. Meri *et al.*, reported that when wind speed was parallel to tomato rows. Lower wind velocities are $3.0 \pm 0.88 \text{ m s}^{-1}$ increases water use efficiency within canopy of tomato crop. Same trends observed by Tammy *et al.*, in capsicum crop. When canopy air flow is constant and warm it enhances canopy elements (leaves, twigs and branches).

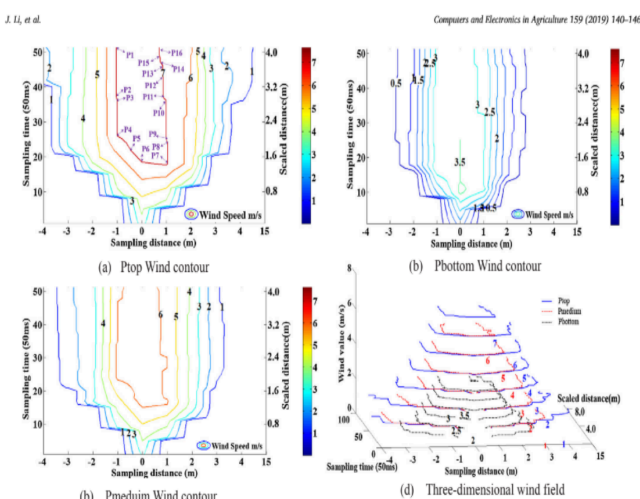
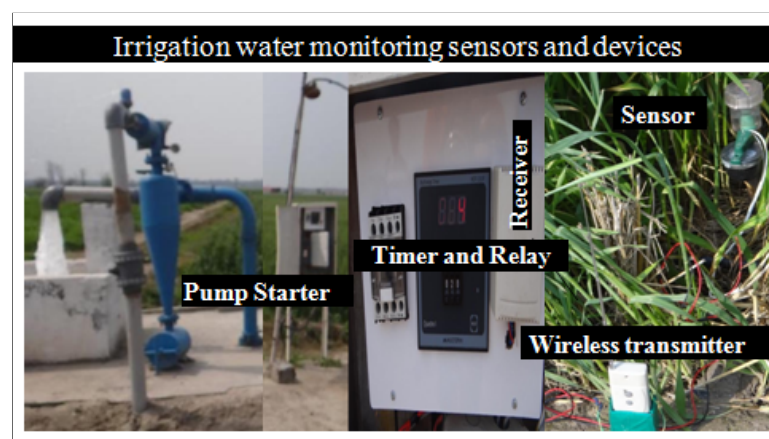
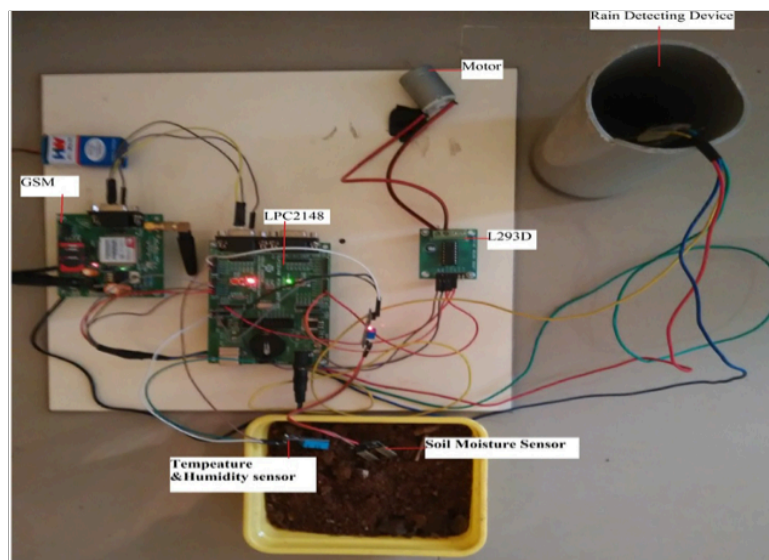


Fig. 3. Wind field distribution. Note: Sampling distance refers to the sensor distribution distance, sampling time refers to capture time and its interval, scaled distance refers to the moving distance of the drone relative to the sensor which is multiplying the flight speed of UAV by the corresponding sampling time, its also the moving distance of the center of the rotor wind field relative to the sensor. P1-p16 is the inflection point in the contour line of 7 m/s.

requirement amount was feed according to crop growth stages. LPC 2148 analyzes water requirement of crop, rainfall precipitated and amount of water needs to be provide by starting pump. All these information delivers to GSM module which starts and stop pump according to command send by L-293-D sensor. Research work reported that water use efficiency was increased after using this circuit in tomato crop.

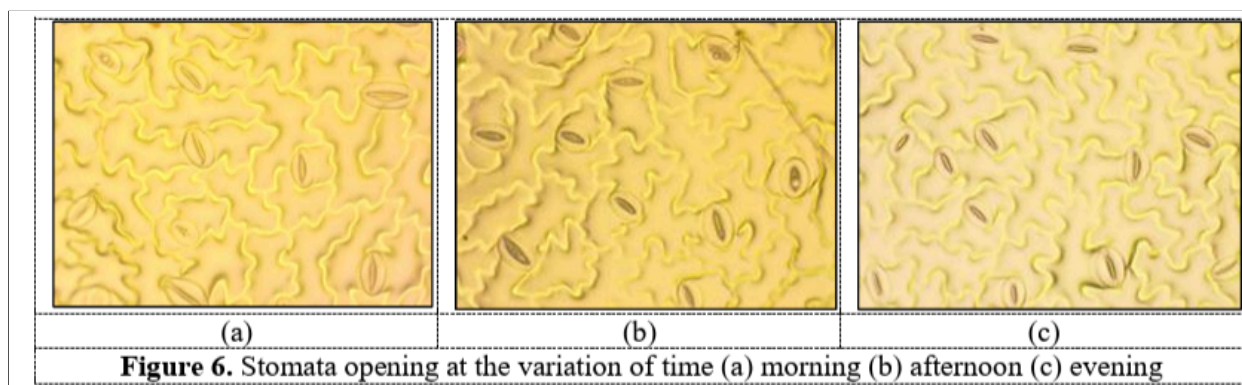


12.3 Case study -3

Application of machine learning to study effect of environment manipulation in frame of smart agriculture on the stomata of *Capsicum annuum*

Abstract: research work was conducted at Indonesia in *Capsicum* crop. Solar radiation measuring GY-49 sensor is integrated with lux

meter. Arduino Uno microcontroller hard were syncs data with 20 x 4 data logger sheet and web cam captures photographs of stomata. Machine learning data interprets that when light is available at low compensation point red capsicum crop grows well



Parameter	Unit	Morning			Afternoon			Evening		
Light intensity	lux	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
		12687	2557	7049	147756	3773	86218	12836	909	5136

12.4 Case study - 4

An image processing approach for measurement of chilli plant height and width under field conditions

Abstract: research work was conducted at UAE and reviewed by IIT Kharagpur, India in Chilli crop Longitech webcam pro 9000 camera

covered physical area of 1.2 (H) X 0.9 (W) m² Behind chilli plant. Camera is connected to laptop through USB 3 interface and program was compiled in Python platform. Program captures images automatically and measured chilli Crop canopy height and width.

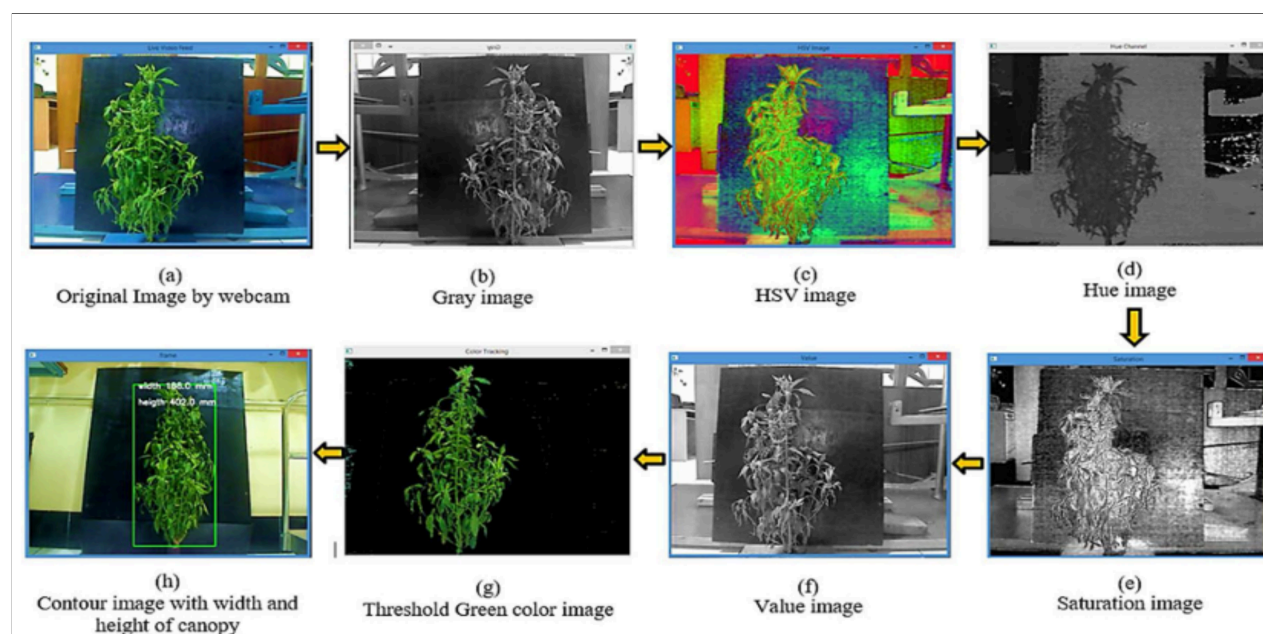


Fig. 2. Flow chart of different image segments used for canopy size determination.

173

12.5 Case study -5

Design and development of machine vision robotic arm for vegetable crop in hydroponics

Abstract: research work was conducted at Pakistan in hydroponics Tomato crop. Due to labour shortage robotic arms of CROO company

was used for harvesting of tomato with the help of controllers, grippers and programming languages used in arm which integrate with mechanical sensors, camera, ML calculation skills and saves time of tomato harvesting.

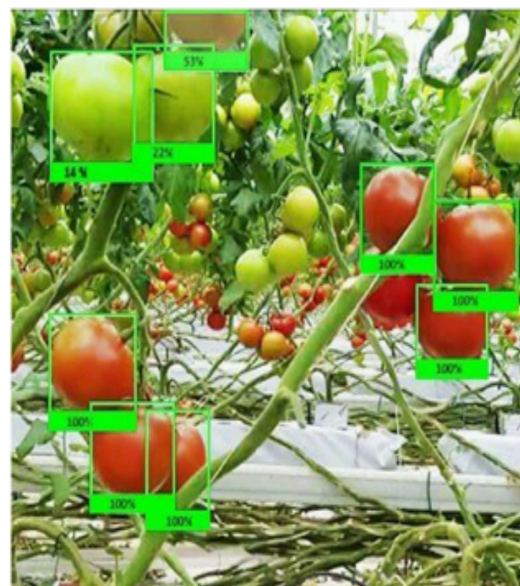


Fig. 8. Real-time detection of tomatoes using YOLOv3.

Produce Type	Actual Fruits on Plant	Detected fruits	Picked quantity	Time taken (sec.)	Vision System Efficiency (detected/actual)	Kinematics efficiency (picked/detected)	Efficiency
Tomatoes	200	180	150	1800	90	83.333	75
Tomatoes	210	200	180	2100	95.238	90	85.714
Tomatoes	230	210	200	2400	91.304	95.238	86.956
Tomatoes	190	180	160	1920	94.737	88.889	84.210
Tomatoes	220	200	180	2220	90.909	90	81.818
Tomatoes	190	180	170	2040	94.737	94.444	89.474
Tomatoes	210	190	180	2160	90.476	94.737	85.714
Tomatoes	190	170	160	1980	89.474	94.118	84.210
Tomatoes	220	200	190	2280	90.909	95	86.364
Tomatoes	200	190	180	2100	95	94.737	90

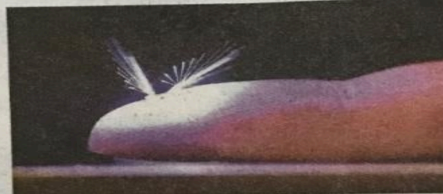
Fly robot as pollinator

कृत्रिम कीटों से बड़ेगी फसल की पैदावार !

वैज्ञानिक दावा कर रहे हैं कि उन्होंने 'फ्लाई' नाम का रोबोट बनाया है। अत्याधुनिक तकनीक से लैस यह रोबोट हवा के ज़रिए पराग को उन पौधों तक पहुंचा सकेगा, जिन्हें इसकी आवश्यकता है।

ज लयायुष पवित्रता के काव्यका दुनिया भर में प्रसिद्ध (परमाण्वर्धन) की संस्था में कभी आ रहा है। खोती में फसल का उत्पादन बढ़ाने के लिए कोट भी जरूरी है, जो 'पराग' को एक से दूसरे पौधों पर ले जाता है। ऐसे में इनकी संस्था में आती कृषि को हमें 'पराग' द्वारा फलित करने के विषयवस्तु पर विशेषज्ञों ने ध्यान आकर्षित कर रोस्ट कर दिया है। 'पराग' नाम के द्वारा कृषिज कोट को 'फेसदी परियोजना' के तहत बना दिया है। बेबीनको की दाया है कि यह रोस्ट न सिर्फ इनमें से तेर संस्था है, बल्कि प्रकार के द्वारा तेर आराम से निर्मित भी किया जा सकता है।

अध्यापिका तनवीक के रोस्ट के अर्थ में परग को उन पौधों के अर्थ में, जिन्हें इसकी आवश्यकता होती। परग, कभी इसकी



द्वारा उत्पादित पाउडर होता है, जो पौधे का पुनरुत्पादन संभव बनाता है। कीटों या हवा द्वारा इस पाउडर को एक से दूसरे पौधों पर ले जाया जाता है। कीटों की कम होती संख्या के कारण ऐसे सूक्ष्म रोबोट का लाखों की संख्या में उपयोग कर खेती की जा सकती है। प्रकाश द्वारा संचालित इस



यूएच आई परिवोजना के वैज्ञानिक जय रोबोट को पूर्व के प्रकार से संशोधित करने के लिए स्थान बनाने पर ध्यान केंद्रित करना चाहते हैं। वे संरचना में भी सुधार करना चाहते हैं, ताकि यह सेंसर और जीपीएस सहित छोटे उपकरणों को भी साथ ले जा सके। वैसे तो इस रोबोट के अग्नौ तक जिएए गत, यह परिवोजना सरफल माने गए हैं, लेकिन अभी इसके कुछ परीधियों से गुजरना है, ताकि इसकी सटीकता को और प्रभावी बनाया जा सके। संभव है कि आने वाले समय में यह तकनीकी भोजन के लिए खेती करने के तरीके में क्रांति ला सकेगी। फेबरी परिवोजना कम से कम 2026 तक प्रौद्योगिकी का विकास करने रही रहेगी। जिएए गत, आने वाले समय में दुनिया के साथ-साथ भारत में भी इस रोबोट का इस्तेमाल फसल को उत्पादन करने में किया जा सकेगा।

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