Review Paper

Precision agriculture applications in horticulture

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ABSTRACT : Precision agriculture (PA) refers to the management of spatial and temporal variability of the fields using mechatronics. Horticultural commodity production and its quality are effected by many factors like proper planting, weeding and interculture, irrigation, attack of insects/pests and harvesting techniques. Precision agriculture is a pro-active approach that reduces some of the risks from these variables common to agriculture and horticulture. In addition, it lowers the environmental hazards in comparison to conventional systems. Precision agriculture precisely establishes various operations, such as tillage, sowing/planting, irrigation, application of fertilizer, weeding operation, disease detection, pesticide spraying, harvesting etc., and thus, turns traditional extensive production to intensive production according to space variable data. Various precision agriculture techniques such as RTK-GPS enabled seed planters or transplanters for geospatial mapping of row-crop plant/transplant, wireless sensor network (WSN) enabled crop stress monitoring systems, site-specific variable rate irrigation, robotic control systems for real time weed detection and control, microcontroller based variable rate herbicide/pesticide application systems, automated harvesting and yield monitoring systems not only perform various operations in horticultural crops precisely, but in a cost effective way by saving various agricultural inputs with lower human intervention.PA brings more or at least similar profit as compared to conventional practices, however, it needs to be supported and managed by government and private sectors to volunteer in its initial costs.

Key words: Precision Agriculture, horticultural Crops, mechatronics, Variable Rate Application

The intensification of agricultural production over the last few decades has greatly increased food production, but at a high environmental cost. In order to manage the resources and nutrients variable rate application systems were developed to apply inputs according to the actual requirements of the soil and plants in the specified management zones. Precision agriculture (PA) refers to the management of spatial and temporal variability of the fields using mechatronics. Agricultural field and crop related required data are collected from different sources, stored to GIS data bases, analysed using geostatistical methods to develop management zones and decision support systems (DSS). The controllers, actuators and applicators use the DSS to apply the agricultural inputs as per requirement of specific management zones. Precision agriculture precisely establishes various operations, such as tillage, sowing, irrigation, application of fertilizer, pesticide spraying, harvesting etc., and thus, turns traditional extensive production to intensive production according to space variable data (Shanwad *et al.,* 2004). PA benefits with increased yield and better quality produce and increases the profit to farming community with better environment conservation and working conditions (Zarco-Tejada, 2014).The application of mechatronics in horticultural crops has been mostly developed in the last fifteen years.

Horticultural commodity production and its quality are effected by many factors like proper planting, weeding, irrigation, attack of insects and harvesting techniques. The feasibility of RTK-GPS enabled seed planters or transplanters that can map the geo-position of crop seeds or transplants as they are released by the planter has been successfully demonstrated (Ehsani *et al.,* 2004; Sun *et al.,* 2010). Weeds, as one of the most significant factors in affecting yield quality and quantity, demand a holistic and interdisciplinary approach for their adequate control (Schans*et al.,*2006). It is known that weeds not only lower the yields, but they constitute one of the most important means for spread and survival of crop pathogens. In many cases weeds have been found as symptomless carriers of vector-borne viruses. Considering the worldwide average, about 10% of losses in the total yield are caused by weeds. Weeds affect crop yield about 45% more as compared to insects and diseases, due to competition to acquire plant nutrients and resources (Anonymous, 2013). Site-specific herbicide applicators not only control the weeds effectively, but also reduce the quantity of herbicide used thus, reducing the carbon footprints generated during its manufacturing.

In the perspective of harvesting of horticulture produce, 'handpicking method' is common practice for harvesting the fruits on the individual fruits trees. It is well known that large scale harvesting still requires technological interventions to reduce the cost of operation (Li *et al.*, 2011). There is rapid development of precise agricultural technologies for harvesting, threshing and yield monitoring of fruits and vegetable crops. Introduction of robotics in agriculture have played pivotal role to overcome the problem of shortage of labour and timely harvesting of horticulture produce. The techniques like vision based control and fruit recognition system has been employed to solve the two major problems of detecting objects in tree canopies and picking objects using visual information (Zhao *et al.*, 2016). Agricultural robots are perceptive and intelligent machines which are programmed to perform a variety of agricultural tasks such as transplanting, cultivating, spraying, trimming and harvesting (Edan *et al.*, 2009). Various sensors are used to detect the fruits and vegetable for harvesting. This recognition system gathers the information of position, orientation and size of the fruits. Control system sends the information to robot manipulator arm for picking, grasping, pruning or cutting. Harvesting robots for tomato, cherry tomato, cucumber, strawberry, grapes, and watermelon have been already commercialized. It is predicted that more robotic harvesting systems will be commercialized in early 21st Century (Umeda *et al.*, 1999).

Development of geographic information system (GIS), global positioning system (GPS), remote sensing and several intelligent devices and implements (IDIs) during 1960's to 1990's gave birth to the idea of aligning information technology (IT) with agricultural practices and methods. Although the method of collecting data and making decisions based on them has been the fundamental method in precision agriculture, but as the size of farm grew it became difficult to implement, and that brought the necessity of these techniques and tools. Precision machinery in horticulture is necessary to alleviate the above said problems. PA includes microcontroller, sensors, image processing, programming etc. to full fill our requirements. Thus, additional need-based research is required.

Precision Agriculture Techniques for Horticulture Applications

RTK-GPS Based Vegetable Transplanter

Real-time Kinematic-Global Positioning System (RTK-GPS) mounted ontractor for geographical location mapping of planting events occurring on the tractor-drawn transplanter have been developed and successfully adopted. The mechanical hitch interface between the tractor and the transplanter is instrumented with orientation sensors (Fig. 1). A ruggedized, realtime, embedded control system has been used for monitoring of sensor and logging of GPS location, planting events and transplanter odometry data. The system is capable of producing highly accurate maps of crop plant location for subsequent precision plant care tasks conducted at the centimeter scale.

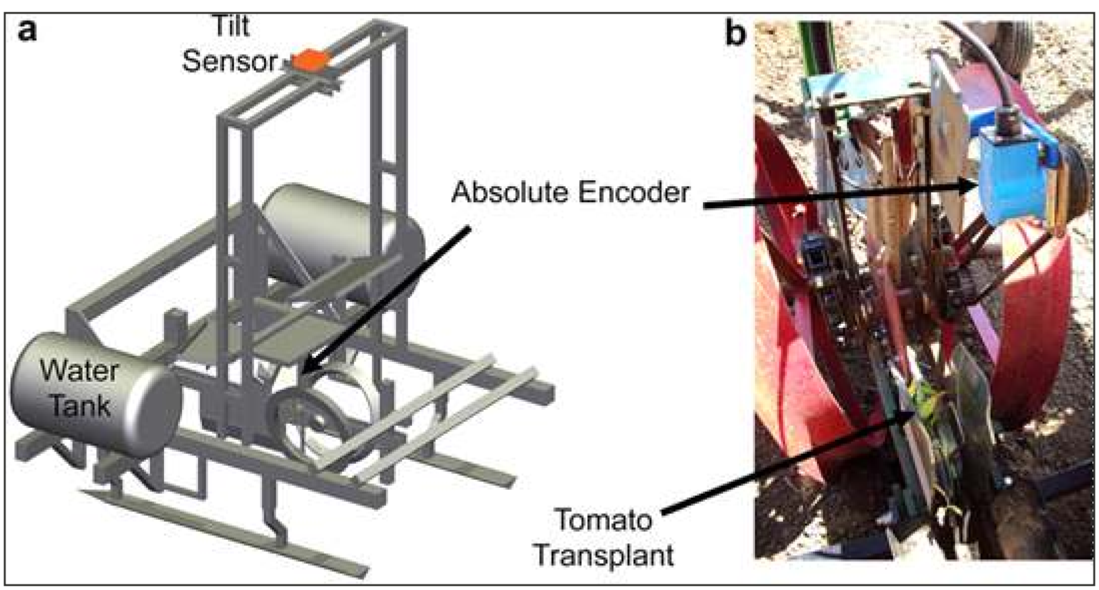

Fig. 1: Vegetable crop transplanter setup for geospatial mapping of crop plants (Perez-Ruiz *et al*., 2012)

Variable Rate Irrigation (VRI)

The site-specific or variable rate irrigation is considered as a necessary or essential component of precision irrigation. Most researchers expect a reduction in water use on at least parts of fields, if not a reduction in the value aggregated over entire fields (Sadler *et al.*, 2005). It has been reported that variable rate irrigation (VRI) could save 10 to 15% of water used in conventional irrigation practice (Yule *et al.,* 2008). Hedley and Yule (2009) demonstrated that water savings of around 25% are possible through improvements in application efficiency obtained by spatially varied irrigation applications. Osroosh *et al.,* (2016) compared irrigation automation algorithms for irrigation scheduling in apple trees and preliminary results supported the use of weather and plant-based algorithms, decision support and monitoring software, and wireless sensor network for automatic irrigation management of drip-irrigated orchard trees.

Wireless sensor network (WSN) is a network of small sensing devices known as sensor nodes or motes, arranged in a distributed manner, which collaborate with each other together, process and communicate over wireless channel about some physical phenomena. Irrigation control systems based on WSN and real-time soil moisture data are a potential solution to optimize water management by remotely accessing in-field soil water conditions and then site-specifically controlling irrigation systems (Kim and Evans, 2009; Hedley *et al.*, 2011). The system requires seamless integration of the real-time soil moisture data via a 3G cellular or ADSL network to control individual sprinklers on a precision irrigation system (Fig. 2).Peters & Evett (2007) used a slight warming of crop leaf to indicate water stress, and measure this on a fully automated center-pivot irrigation system, using infrared thermocouple thermometers attached to the trusses of the pivot. This canopy temperature method provides a useful indicator of the initiation of water stress, however, it does not indicate when a plant is approaching moisture stress. It can only indicate when the plant is suffering from stress, which

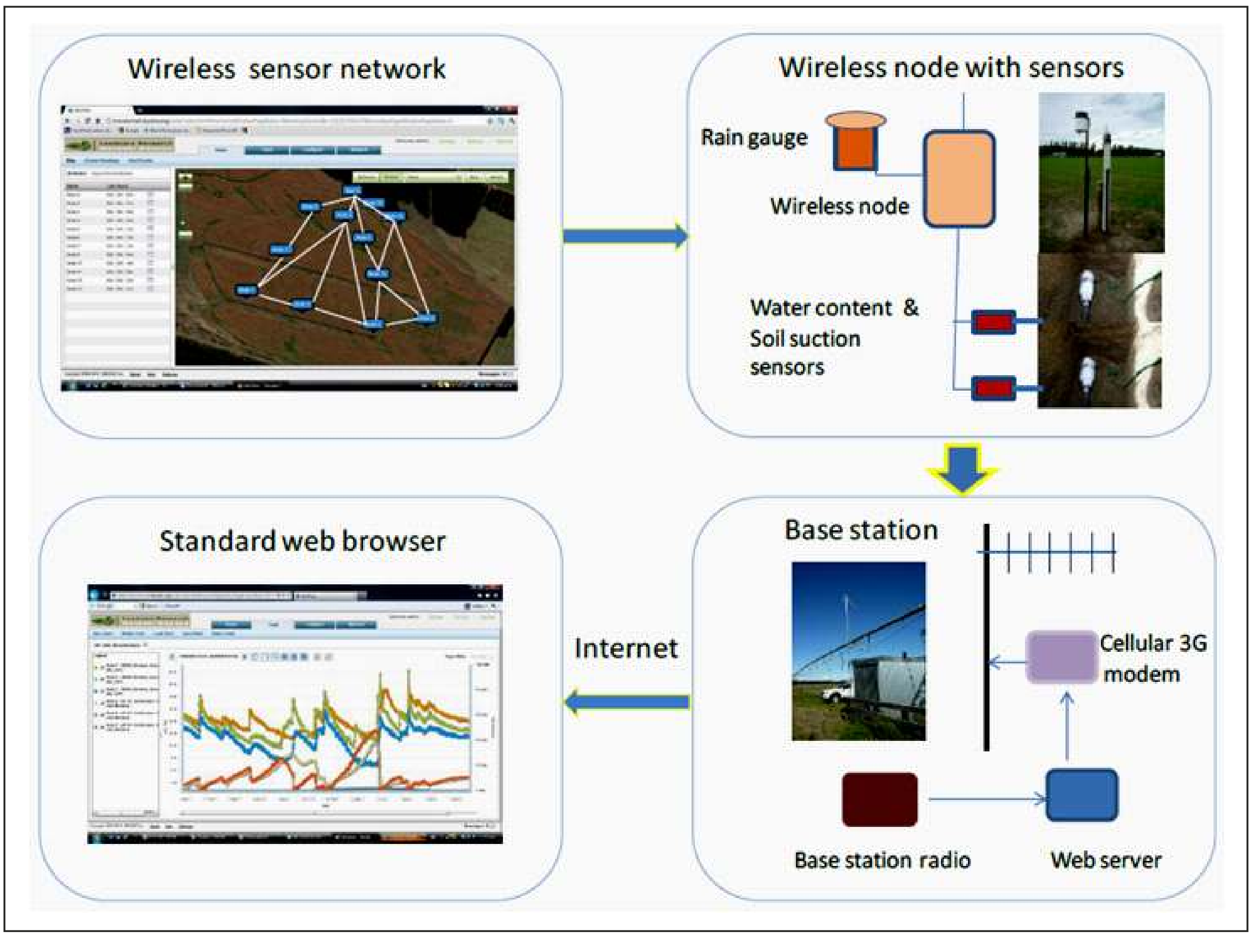

Fig. 2. Schematic flowchart of wireless soil moisture sensor network

could be too late for irrigation if we are aiming to eliminate water stress impact on yield reduction.

Precision Mechanical Weeder

Robotic control systems are also available for real time weed control. The direct chemical application end effector is used to directly apply chemical via a weed's vascular tissue by cutting the weed's stem and wiping chemical on to its cut surface. The robotic system consists of two micro-pumps, a custom-designed circular saw with a DC motor, an applicator, a chemical tank, a flow controller, and a micro reservoir (Fig. 3).

There are a number of machines available for inter-row weeding operation but machines for intra-row weeding are still very few. Both, inter-row as well as intra-row weeds affect the yield and quality of produce. Radis mechanization (FR) developed an intra-row weed control system, which consisted of blades mounted on a pivoting arm. A light sensor for detection of plant was used. Arm blade of weeding system was controlled by an air pressure cylinder. When no plant was detected the pivoting arm was moved in the intra-row area, thus cultivating and removing the intra-row weeds (Fig.4). Bakker (2003) expressed that if system is driven at a speed of 5 km/h then weeds are removed up to 20 mm from the plant. However, Bleeker (2005) reported that maximum speed of 3.0 km/h is suitable for weeding operation, because of more damage of plant due to mechanical transition of the intra-row hoe. The system is designed for wide spaced vegetables and the minimum intra-row spacing that the system can work is 220 mm (Bakker, 2009).The problem with system was in detection of plant in wide row crop and also speed limitation for intra-row weeding operation. Tillett (2008) reported that high accuracy can be obtained from ultrasonic guidance with accuracy of 99% at the distance range of 100 mm to 10 m. It was also reported that problems are encountered with stray foliage as distance is calculated from the time taken for an ultrasonic signal to reach and reflected back from the target, thus the reflected signal may bounce back from a weed rather than the crop.

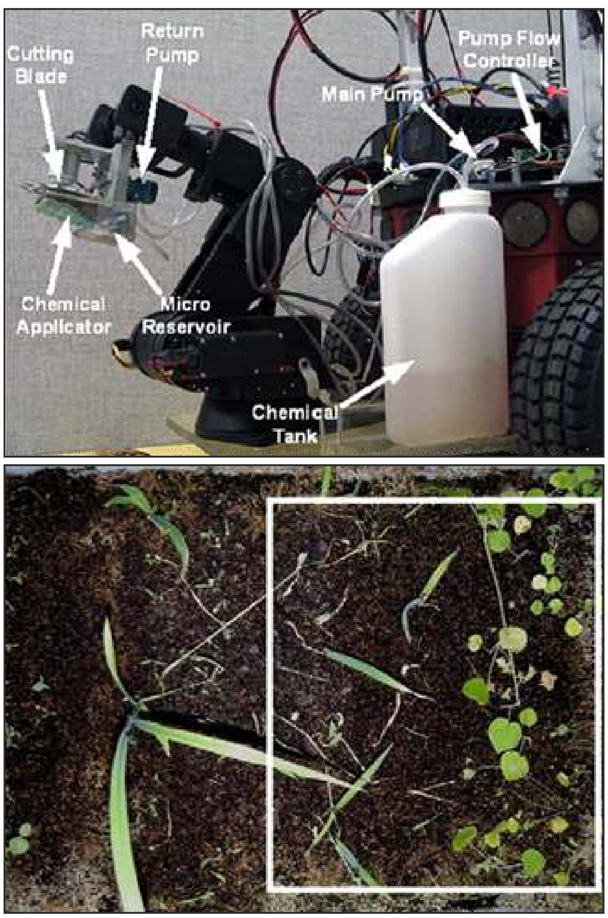

Fig. 3. Robotics control weeder with end effector (Jeon and Tian, 2009)

Tillett *et al.,* (2008) designed and testeda weeding machine based on computer vision to detect plants for removing intra-row weeds. This machine consisted of a rotating half circle disc that rotated to avoid contact with the crop plants during weeding operation (Fig.5). A camera was mounted centrally on the implement at a height of 1.7 m looking ahead and down for capturing image at a length of approximately 2.5 m.

An experiment conducted on a cabbage plot with plant spacing of 0.3 m and forward speed of 1.8 km/h at 16, 23,

Fig. 4: Sarl Radis intra-row weeder (Cloutier *et al*., 2007)

Fig. 5: Automated semi-circle disc weeder machine

and 33 days after transplanting indicated that best results are obtained at 16 days with weeding efficiency 77% and 23 days with 87% weeding efficiency.

Herbicide Application Techniques

A two-row tractor operated laser sensor based site-specific herbicide applicator (Fig. 6) was developed at ICAR-CIAE, Bhopal to spray herbicide on inter-row weeds. The developed herbicide applicator has two components, laser sensor for sensing the inter-row weeds and applicator part, which has controller, solenoid valve and nozzles for application of herbicide. The laser sensor is trained to sense green colour with a threshold of +10% (green colour for which it is trained). The missing percentage varied between 5 to 26%.

Fig. 6: Two-row laser sensor based herbicide applicator (Agrawal *et al.*, 2012)

A microcontroller based contact type variable rate herbicide applicator (Fig. 7) developed at IIT, Kharagpur was used to control the inter-row weeds. The system automatically computes the amount of herbicides to be applied on the weed present in real time image processing. In this system the amount of herbicide applied was based on weed density. The average reduction in herbicides application was 26% with weeding efficiency of 78%. Contact type roller application was also helpful for drift reduction.

Spectroscopy for Identification of Disease in Horticulture Crops

Sindhuja *et al.* (2013) developed and evaluated a computer vision and machine learning technique for classification of infected and healthy leaves using fluorescence image spectroscopy (Fig.8). Fluorescence images were segmented using normalized graph and texture features were extracted from the segmented images using co-occurrence matrix. The extracted features were used as an input in the classifier, support vector machine. In Florida for identification of disease of citrus, machine vision control system and artificial intelligence was used to detect the early diseases and to apply selective fungicide (Pydipati *et al.*, 2006). Indirect method of disease detection includes plant properties or

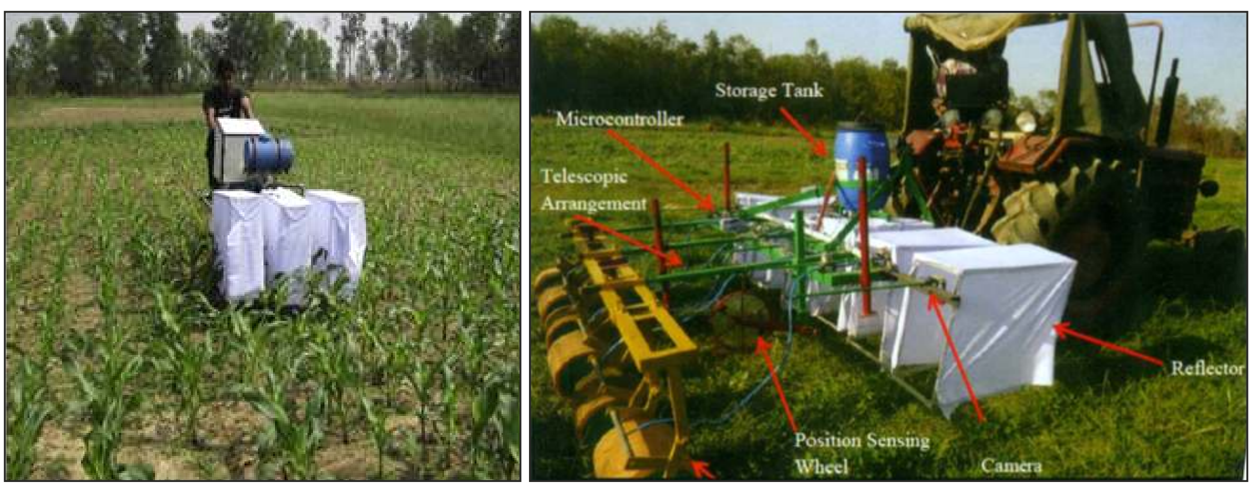

Fig.7: Microcontroller based variable rate herbicide applicator (Tewari *et al.*, 2014)

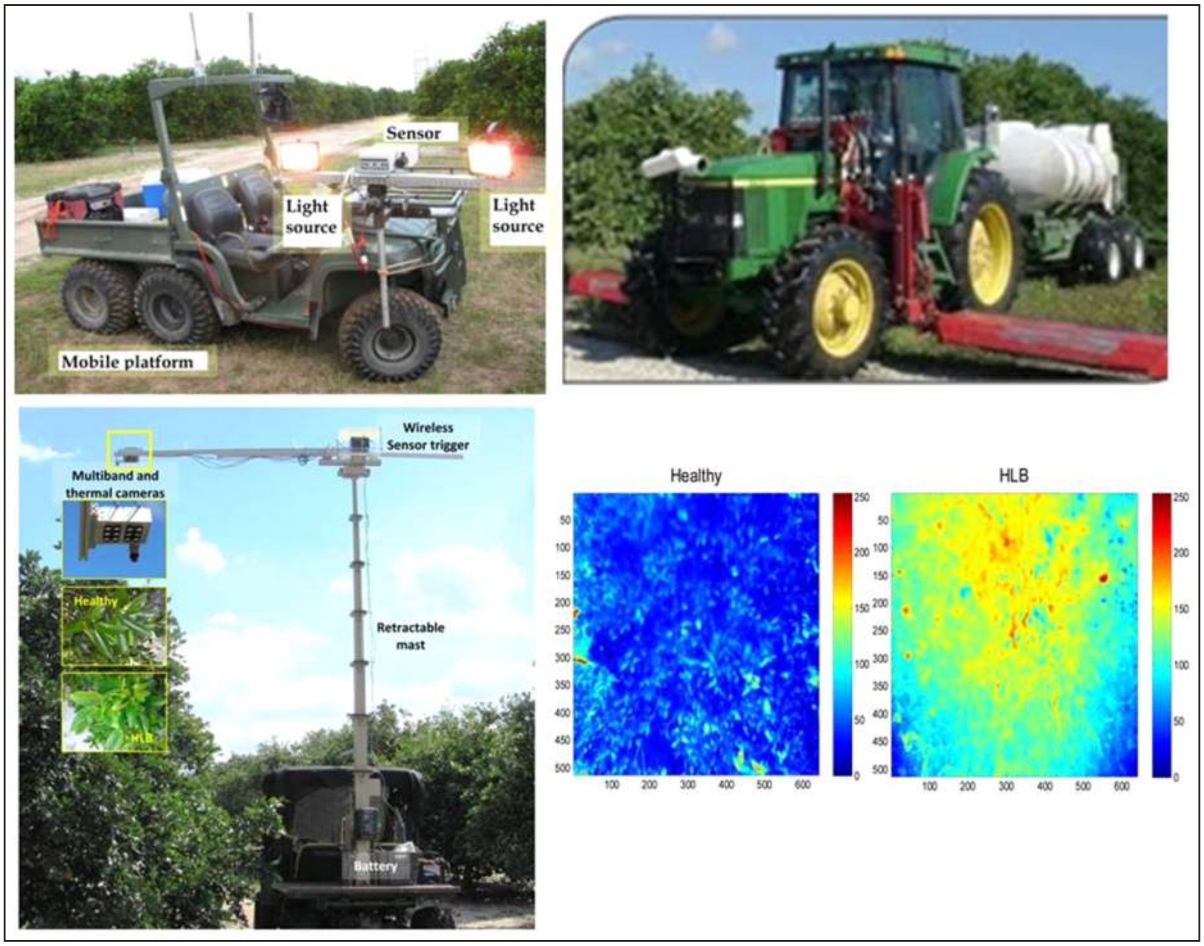

Fig. 8: Spectroscopy and artificial intelligence for detection of disease in orchards

stress based disease detection imaging techniques like hyper spectral and fluorescence imaging.

Canopy Sensor Based Pesticide Applicator

Orchard crops suffer from insect and pest attacks and indiscriminate spraying of pesticides causes environmental problems. In order to solve this problem an ultrasonic canopy sensor based pesticide applicator (Fig. 9) has been developed at IIT, Kharagpur. The sensor based automated orchard sprayer, delivers pesticide spray only when it senses the canopy of the targets. The tractor mounted sensor based system for spraying saves 45-50% insecticide/pesticide.

Fig. 9: Canopy sensor based spraying system (Tewari, 2015)

A sprayer using ultra sound sensors (Prowave 400EP14D) with appropriate electronics to detect the canopy has been also developed abroad. Ultra sound signals are processed by a personal computer and fed in real-time to solenoid controlled spray nozzles, which open and close in relation to the canopy structure (Fig. 10). The demonstrated concept of precise application of pesticide sprays supports a decrease in the amount of delivered spray, thereby reducing both costs and environmental pollution by plant protection products.

Fig. 10: A prototype sprayer with ultra sound sensors (Jejčič *et al*., 2011)

Hočevar *et al.* (2010) developed a prototype of automated orchard sprayer, which can deliver pesticide spray selectively with respect to the characteristics of the targets (Fig. 11). The shape of the apple tree canopy was detected by a machine vision system using an RGB camera and appropriate image analysis. Information captured by RGB camera and processed by specific software was fed in real-time to a spraying arm, with three individually controlled sections, which adapt the pesticide spray flow to the canopy shape. The system allows variation in the liquid flow rate and volume of chemicals by means of controlled electric valves, whereby the amount of spray depends on the shape of the tree crowns.

In order to identify the characteristics of the target canopy, in terms of its size and density, a Crop Identification System (CIS), based on ultrasonic sensors, was studied and produced (Fig. 12). The results indicated that, by adapting the application rate to the characteristics of the target, the CIS enabled the amount of spray deposited on the leaves to be maximised with respect to lower and higher volume rates.

Automated Harvesting System

Different methods have been proposed, investigated and practiced since early 1960s for mechanical harvesting of fruits. The mechanical harvesting methods consisting of limb shaking, air blasting, canopy shaking, trunk shaking, and the use of an abscission chemical agent to loosen the fruits have been used (Li *et al.*, 2011). The quality and size selection cannot be maintained by mechanical harvesting

Fig. 11: A prototype automated sprayer mounted on the tractor

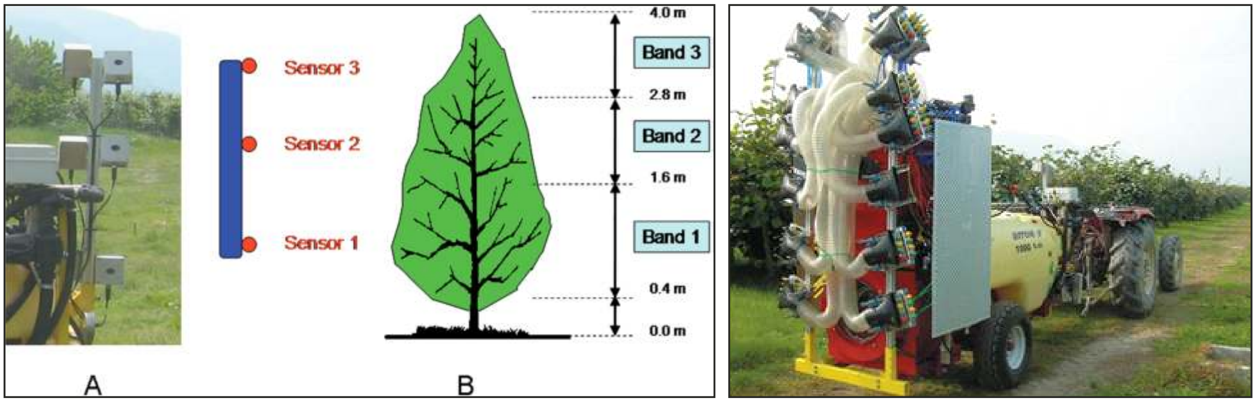

Fig. 12: Concept of CIS sprayer and prototype ISAFRUIT (Balsari *et al*., 2009)

systems. On the other hand a vision control system can maintain the quality and do the size selection. The automated harvesting system for horticultural crops has been considered as an alternative solution for mechanical harvesting system (Schertz and Brown, 1968). Automated harvesting system consists of machine vision control system for recognizing the fruits in tree (Fig. 13). The vision control system consists of colour camera for providing the information of the location and distance of the fruits to the control system (Li*et al.*, 2011). Automated harvesting systems are not ready to commercialization stage because of their low efficiencies, low intelligence, and high initial investment (Zhao *et al.*, 2016). Many researchers are working to design efficient harvesting robots for horticultural crops. Details of major efforts made for development of horticulture harvesting robots are given in Table 1.

Fig. 13: Robotic harvesting of sweet pepper and citrus fruits
Source: http://www.crops-robots.eu/ and http://www.energid.com/experience/citrus-harvest

Automated Yield Monitoring System

A yield monitoring system is vital element in the precision agriculture. Farmer can get direct feedback for

Table 1: Details of harvesting robots for horticultural produce (Zhao *et al.*, 2016)

Products	Robots	Vision scheme	Success Rate, %	Speed, s/fruit
Fruits	Apple harvesting	Camera-in-hand and positioning sensor	77	15
		Camera-in-hand and laser range sensor	>90	7.1
	Citrus harvesting robot	A fixed camera and a camera-in-hand	NR	<8
		A fixed camera	50	36
	Melon harvesting robot	A far-vision CCD and a near-vision CCD	>85	<22
	Strawberry harvesting robot	A stereovision system and a central camera	<41.3	11.5
		A stereo camera, a camera and a laser sensor	NR	7.0
	Watermelon harvesting robot	A stereo vision sensor and a camera in hand	100	12s
		A stereo vision sensor	66.7	NR
	Kiwifruit harvesting robot	Eight cameras (four stereo vision systems)	NR	NR
	Grape harvesting robot	A camera-in-hand	NR	NR
	Cherry harvesting robot	A red and infrared laser active sensor	66.7	14
Vegetables	Tomato harvesting robot	A binocular stereo vision sensor	70.0	3-5
	Cucumber harvesting robot	A fixed camera and a camera-in-hand	80.0	74.4
		A near-infrared camera and a camera	45	65.2
	Mushroom Harvesting robot	A monochrome camera in hand	>80	6.7
	Sweet-pepper harvesting robot	Two cameras, a stereo camera and a camera	79	NR

variability in his field by quantifying the variability in yield within the field (Pelletier and Upadhyaya, 1999). It is a tool to reduce costs, increase yield, and increase efficiency of the system. An automated yield monitoring system consists of color cameras, real time kinematics-global positioning system, custom software, and laptop computer which are mounted on a Specialized Farm Motorized Vehicle (SFMV) for real-time fruit yield mapping. An automated yield monitoring system can perform well to estimate the yield of fruits and vegetable crops. A yield monitoring system was developed using optical sensors for measuring the yield of wild blueberry (Chang *et al.*, 2012). Yield monitoring of horticultural crop can be easily done on mechanized crop harvesting. Research work needs to be carried out on yield mapping of harvesting fruits and vegetables.

CONCLUSION

Precision agriculture in India is capable of bringing next green revolution to produce food security as well as rural wealth. Although it is in dawning stage in India, but has lot of adoption opportunities. Scarcer inputs like labour, water, fertilizer and change of weather pattern affecting majority of the farms in India because they are rainfed and seek help of engineers, scientists and agriculturists together with government's intercession to take application of PA forward. Progressive farmers in India have adopted mechanization, are identifying better crops to use the seed to be propagated further and likewise if they adopt PA, it would help Indian agriculture in increasing yields and economic returns per field with minimized harm to environment. But Indian farmers will adopt PA only if it brings more or at least similar profit as compared to conventional practices and supported/ managed by government and private sectors to volunteer in initial costs. Also training centers to train implementation of these technologies and guidance to use them is very much required. Therefore an organized structure of researchers, engineers, industries and growers can coordinate to implement PA and achieve sustainable agricultural production.

REFERENCES

Anonymous (2013). http://www.dwr.org.in/AICRP-WM%20Document/AICRP-WC-ANNUAL REPORT - 2012-13.pdf.

Agrawal, K.N., Singh, K.; Tiwari, P.S. and Chandra, M.P. (2012). Laser sensor based tractor mounted herbicide applicator. *Proc. of AIPA 2012*, India.

Bakker, T. (2003). Autonomous weeding. *Literature review. SCO report 03-01*, Wageningen Univ. Systems and Control group, 43p.

Bakker, T. (2009). An autonomous robot for weed control: design, navigation and control. Wageningen Univ.

Bleeker, P.(2005). First experiments with intra-row weed control with a camera. *Proc. of the Spatial and dynamic weed measurements and innovative weeding technologies*, Bygholm, Denmark, European Weed Research Society.

Balsari, P.; Marucco, P. and Tamagnone, M. (2009). A crop identification system (CIS) to optimise pesticide applications in orchards. *The J.of Hor. Sci. and Biotechno.*, 84(6):113-116.

Chang, Y.K.; Zaman, Q.; Farooque, A.A.; Schumann, A.W. and Percival, D.C. (2012).An automated yield monitoring system II for commercial wild blueberry double-head harvester.*Computers and Electronics in Agr.*, 81: 97-103.

Cloutier, D.C.,Weide, R.Y.V.D., Peruzzi, A. and Leblanc, M.L. (2007). Mechanical weed management. *Non Chemical Weed Management. Oxfordshire, UK: CAB International,* Pp.111-134.

Edan, Y.; Han, S. and Kondo, N. (2009). Automation in agriculture.*In Springer handbook of automation.*Pp. 1095-1128.

Ehsani, M.R.; Upadhyaya, S.K. and Mattson, M.L. (2004). Seed location mapping using RTK GPS. *Trans. of the ASAE*, 47(3), p.909.

Hedley, C.B. and Yule, I.J. (2009). Soil water status mapping and two variable-rate irrigation scenarios. *Precision Agriculture,* 10(4): 342-355.

Hedley, C.; Bradbury, S.; Watson, E.; Dalrymple, H. and Wright, J. (2011).Farm scale trials of variable rate irrigation to assess the benefits of modifying existing sprinkler systems for precision application. *Intl. J. of Agr.Mgt.*, 1(2): 51-55.

Hočevar, M.; Širok, B.; Jejčič, V.; Godeša, T.; Lešnika, M. and Stajnko, D. (2010). Design and testing of an automated system for targeted spraying in orchards. *J. of Plant Dis. and Protection*, 117(2): 71-79.

Jejčič, V.; Godeša, T.; Hočevar, M.; Širok, B.; Malneršič, A.; Štancar, A.;Lešnik, M. and Stajnko, D. (2011). Design and testing of an ultrasound system for targeted spraying in orchards. *Strojniškivestnik-J.of Mechanical Engineering,* 57(7-8): 587-598.

Jeon, H.Y. and Tian, L.F. (2009). Direct application end effector for a precise weed control robot. *Biosystems Engineering*, 104(4): 458-464.

Kim, Y. and Evans, R.G. (2009). Software design for wireless sensor-based site-specific irrigation. *Computers and Electronics in Agr.*, 66(2):159-165.

Li, P., Lee, S.H. and Hsu, H.Y. (2011). Review on fruit harvesting method for potential use of automatic fruit harvesting systems. *Procedia Engineering*, 23: 351-366.

Osroosh, Y.; Peters, R. T.; Campbell, C. S. and Zhang, Q. (2016). Comparison of irrigation automation algorithms for drip-irrigated apple trees.*Computers and Electronics in Agr.*, 128: 87-99.

Peters, R.T. and Evett, S.R. (2007). Spatial and temporal analysis of crop conditions using multiple canopy temperature maps created with center-pivot-mounted infrared thermometers. *Transactions of the ASABE,* 50(3): 919-927.

Pelletier, G. and Upadhyaya, S.K. (1999). Development of a tomato load/yield monitor. *Computers and Electronics in Agr.*, 23(2), 103-117.

Perez-Ruiz, M., Slaughter, D.C., Gliever, C. and Upadhyaya, S.K. (2012).Tractor-based Real-time Kinematic-Global Positioning System (RTK-GPS) guidance system for geospatial mapping of row crop transplant.*Biosystems Engineering*, 111(1): 64-71.

Pydipati, R.; Burks, T.F. and Lee, W.S. (2006). Identification of citrus disease using color texture features and discriminant analysis. *Computers and Electronics in Agr.,*52: 49–59.

Sadler, E.J., Evans, R.; Stone, K.C. and Camp, C.R. (2005). Opportunities for conservation with precision irrigation. *J. of Soil and Water Conservation*, 60(6): 371-378.

Schans, D.A., Bleeker, P.O, Molendijk, L.P.G., Plentinger, M.C., Van Der Weide, R.Y., Lotz, L.A.P., Bauermeister, R. and Baumann, D.T. (2006). Practical weed control in arable farming and outdoor vegetable cultivation without chemicals (No. 352). *Wageningen UR, Applied Plant Research.*

Schertz, C.E. and Brown, G.K. (1968). Basic considerations in mechanizing citrus harvest.*Trans. of the ASAE, 11(3): 343-0346.*

Shanwad, U.K., Patil, V.C. and Gowda, H.H. (2004). Precision farming: dreams and realities for Indian agriculture. *Map India.*

Sindhuja, S; Joe, M.M; Sherrie, B; and Reza, E. (2013).Huanglongbing (Citrus Greening) Detection Using Visible, Near Infrared and Thermal Imaging Techniques. *Sensors,* 13: 2117-2130.

Sun, H., Slaughter, D.C., Ruiz, M.P., Gliever, C., Upadhyaya, S.K. and Smith, R.F. (2010). RTK GPS mapping of transplanted row crops. *Computers and Electronics in Agr.,* 71(1): 32-37.

Tewari, V.K., Kumar, A.A., Nare, B., Prakash, S. and Tyagi, A. (2014). Microcontroller based roller contact type herbicide applicator for weed control under row crops. *Computers and Electronics in Agr.,* 104, 40-45.

Tewari, V.K.; Nare, B.; Prakash, S.; Chandel, A.K. and Tyagi, A. (2014). A six-row tractor mounted microprocessor based herbicide applicator for weed control in row crops. *Intl. Pest Control*, 56(3): 162-164.

Tewari, V.K. (2015). Progress Report, IIT, Kharagpur centre of AICRP on Farm Implements and Machinery.

Tillett, N.D.; Hague, T.; Grundy, A.C. and Dedousis, A.P. (2008). Mechanical within-row weed control for transplanted crops using computer vision. *Biosystems Engineering*, 99(2): 171-178.

Umeda, M.; Kubota, S. and Iida, M. (1999). Development of "STORK", a watermelon-harvesting robot. *Artificial Life and Robotics*, 3(3): 143-147.

Yule, I.J.; Hedley, C.B. and Bradbury, S. (2008). Variable-rate irrigation. *In 12th Annual Symp. on Precision Agr. Research & Application in Australasia.* Sydney.

Zarco-Tejada, P.; Hubbard, N. and Loudjani, P. (2014). Precision Agriculture: An Opportunity for EU Farmers—Potential Support with the CAP 2014-2020. *Joint Research Centre (JRC) of the European Commission.*

Zhao, Y., Gong, L., Huang, Y. and Liu, C. (2016). A review of key techniques of vision-based control for harvesting robot. *Computers and Electronics in Agr.*, 127: 311-323.

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