International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-8 Issue-3, September 2019

Design of Fuzzy Controller Based on Penman-Monteith Equation for Drip Irrigation

P. S. Vikhe, N. K. Palte, C. B. Kadu, V. V. Mandhare

Abstract: The agriculture sector plays vital role in overall socio-economic status of India. The involvement of Indian population in agriculture and associated activities is 54.6% (census 2011). The net cropped area is 43% of entire geographical region of India and area under irrigation is 68 million hectares. However, availability of water is an important for agriculture. The supply of water to agriculture field is known as irrigation, in traditional irrigation method there is wastage of water. The evapotranspiration (ET) is combined technique, in this wetness of soil is lost in the form of evaporation in atmosphere and plants absorbing water from soil is transferred to atmosphere. Evapotranspiration depends on uncertain parameters like radiation of solar, temperature of air, speed of wind and humidity. Thus, in this research work a smart fuzzy control water irrigation system is designed to tackle uncertain situations maintaining proper water level as per requirements of crops.

Index Terms: Evapotranspiration (ET), Irrigation, Penman-Monteith Equation, Soil Moisture.

I. INTRODUCTION

The irrigation system in agriculture is required to deliver adequate amount of water to crop with proper schedule, to meet crop water requirement. The quantity of water supplied through irrigation is determined based on ET. The transfer of water from surface of soil in terms of vapour is known as ET [1, 12]. Thus, evaporation of moist surface takes place until unsaturation of air. In agro-ecosystems, ET is essentially combination of evaporation and transpiration processes [2].

In process of transpiration plant roots absorbed water and percolate to leaves and stems, to build tissue of plants via photosynthesis. Further, it percolates through leaves to the atmosphere in form of watervapour [1].

Manuscript published on 30 September 2019

* Correspondence Author

Pratap S. Vikhe*,, Associate Professor in the Department of Instrumentation and Control Engineering, at Pravara Rural Engineering College, Loni, Tal: Rahata, District Ahmednagar

Nitin K. Palte , Department Of Instrumentation And Control Engineering (Specialization In Process Instrumentation) From Pravara Rural Engineering College, Loni, Tal: Rahata, District Ahmednagar. India

Chandrakant B. Kadu, Associate Professor And Head In The Department Of Instrumentation And Control Engineering, Pravara Rural Engineering College, Loni, District Ahmednagar. India

Vaishali V. Mandhare , Professor Department of Computer Engineering at Pravara Rural Engineering College, Loni District Ahmednagar. India

In evaporation process water evaporate from water surfaces, soil or plant leaf surfaces. Evaporation and transpiration of water from soil depends on air temperature, soil moisture, humidity, wind speed and solar radiation [3].The other factors along with ET affect irrigation planning, are crop coefficient *Kc*, soil moisture and irrigation system performance parameters. Crop coefficient *Kc* depends on type of crop and its growing stages. The crop coefficients Kc for different crop according are standardized as per growing stages. Soil is mixture of sand, silt and clay. The percentage amount determines texture of soil, based on different sizes of particles, like silt, sand and clay [4]. Soil texture indicates quantity of air and water it holds and rate of water that moves through soil. Thus, soil moisture depends on type of soil texture [5]. ET is derived based on climatic conditions such as, humidity, temperature of air, radiation of solar and speed of wind. Thus, increase in solar radiation and temperature of air cause increase in ET [6]. Wind speed usually causes ET to increase, but above a certain wind speed small pores on the top and bottom leaf surfaces known as leaf stomata, regulates transpiration get closed. The surrounding atmosphere surface reduces leaf demanding water vapor reduces ET due to high relative humidity. Thus, quantity of required water compensates loss of ET based on field defined as requirement of crop water.

The draining of water in deeper soil starts immediately as soon as irrigation or rain. In this, contents of water in soil can approximately reach to constant level for specific depth, to be examined and this arbitrary value of water content is called field capacity θ_{FC} usually expressed in percentage. The permanent wilting point θ_{WP} is water amount per unit volume or weight in the soil, tightly held with soil were roots of plants can't absorb water and it will start wilt [1].

Khatri V. (2018) [7] designed fuzzy logic controller and simulated it using MATLAB. The inputs like soil moisture, relative humidity, temperature were fed to Fuzzy Inference System (FIS) decides valve opening for sufficient amount of water for an optimal output. Rajaprakash et al. (2017) [8], developed controller using fuzzy logic for effectual irrigation on availability of water and soil moisture. Fuzzy logic controller was designed using Mamdani type FIS and MATLAB tool, to switch on and off well water motor, based on soil moisture level and level. Abu and Yacob (2013) [9] designed GUI utilizing visual basic background for Fuzzy Expert System. This system recognizes change in temperature, humidity and illumination for area of plants to regulate light intensity level.

B. Centre and B. Verma (1998) [10] stated fuzzy logic provided methodology for describing complex approach based on qualitative relationships in analogous manner. This was a robust approach to handle non-linear, time varying and adaptive systems.

This permitted use of linguistic variables and indistinct relation behavior of modeling system. They observed that this technique was useful for complex agricultural and food systems.

Amthal et al. [11] put forward a fuzzy based decision support model for irrigation system management. fuzzy system uses ET model specified by Penman-Monteith equation. The output of system estimate irrigation time and schedules. V. S. Rahangadale et al. [2] designed a model using fuzzy logic for irrigation controller based on Penman-Monteith equation. Fuzzy system uses evapotranspiration model specified by Penman-Monteith equation.

It includes four input parameter blocks i.e. temperature, humidity, speed of wind and radiation for actual computation of ET_0. Furthermore, ET the actual value is computed using estimator ET_0 based on its parameters. The comparison is carried between error and desired value to obtain value of ET_0, used to fuzzy controller as one input and for crop period as sowing length as other input. Thus, position of valve is determined using controller output required to fulfill ET requirement of soil. Here, system uses ET model specified by Penman-Monteith equation. The output of the system estimate irrigation time and schedules.

II. MATERIALS AND METHODS

ET is integrated approach in which wetness of soil loss in atmosphere is based on evaporation and consumption of water by plants from soil transpiring to atmosphere. Thus, soil moisture is an important factor taken into consideration for irrigation.

- **Penman-Monteith equation**

An expert consultation held in May 1990, recommends FAO Penman-Monteith approach as only standard approach for computation of the reference ET_0 [2]. The FAO Penman-Monteith method requires air temperature, radiation, wind speed and air humidity data to calculate reference evapotranspiration ET_0.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T_{mean} + 273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

ET_0 - evapotranspiration reference value [mm day^{-1}],
R_n - crop surface net radiation [MJ m^{-2} day^{-1}],
G - Heat flux density of soil [MJ m^{-2} day^{-1}],
T_{mean} - 2 mts height daily air temperature at [^0C],
u_2 - Wind speed at 2 mts height [m s^{-1}],
e_s - Vapour pressure at saturation level [kPa],
e_a - actual vapour pressure [kPa],
$e_s - e_a$ saturation vapour pressure deficit [kPa],
Δ Slope vapour pressure curve [kPa $^0C^{-1}$],
γ - Psychrometric constant [kPa $^0C^{-1}$].

Here, ET unit is specified in terms of millimeters (mm) per unit time, and it can be measured for growth of entire crop period, a year, month, day or hour. It is the amount of water lost (evaporated + Transpiration) from a cropped surface in units of water depth. 1 mm/day is equivalent to 10 m^3/ha/day.

- **Crop evapotranspiration *ETc***

The evapotranspiration from large grown fields under a standard conditions such as optimum soil-water conditions, disease-free, well-fertilized crops and with full yield in a given climatic conditions, is referred as the crop evapotranspiration, and it is denoted as ET_c [1].

$$ETc = ET_0 * Kc$$

Where, K_c is dimensionless crop coefficient.

- **Soil water at root zone**

The water within the field capacity (θ_{FC}) and the permanent wilting point (θ_{WP}) is available for the plants. Water balance is the total amount of water S_i stored in a particular soil layer per unit area. This quantity is obtained by multiplication of the fraction of water (volumetric soil moisture content) in layer i (θ_i) by the depth of the layer z_i.

$$Si = \theta i.zi$$

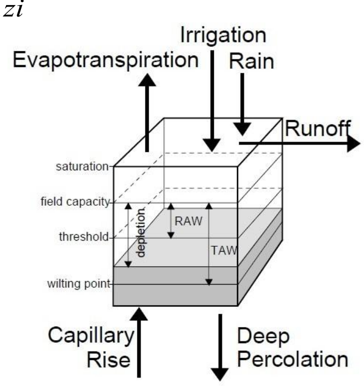

Figure 1: Soil water balance at root zone [1].

- **Soil moisture depletion (d)**

As shown in Fig. 1 quantity of water in root zone is expressed using root zone depletion. At field capacity, the soil moisture depletion is equal to zero. When soil water is extracted by ET, depletion increases and stress will be induced by crop. Soil moisture depletion (d) indicates % amount of water removed from soil.

$$d = \frac{(\theta_{FC} - \theta_{cm})}{(\theta_{FC} - \theta_{WP})} * 100$$

d = 0 and 1 is field capacity and wilting point respectively, and θ_{cm} is current water content in the soil.

- **Evapotranspiration under soil moisture depletion *ETc_adj***

Soil moisture for depth of root is very important factor determining net irrigation amount i.e. ET_{cadj}. The effect of depletion is described as

$$ET_{c\_adj} = ET_c * d; \text{ where } 0 < d < 1$$

So, net irrigation ET_{c_adj} required is equal to crop ET multiply by soil moisture depletion.

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- **Irrigation Time**

Irrigation time is the time, to supply required irrigation depth in mm. It is expressed in minutes or hours. The duration of each irrigation application is influenced by available water at root zone, evapotranspiration ET_c, and irrigation system efficiency.

Irrigation time (T) is time taken to apply amount of irrigation water. Irrigation time for drip irrigation system is as given

$$T = ET_{c\_adj} / (q * N * E)$$

where, T is irrigation time [minute], ET_{c_adj} is net irrigation [mm], E is system efficiency [%], q is nozzle discharge rate [l/s], N is number of nozzles.

III. RESULTS AND DISCUSSION

Fig. 2 illustrates the model of proposed approach, consist of four inputs i.e., temperature of air, humidity, net radiation and speed of wind. All these parameters are fed to *ETc* estimator block, that computes actual value of evapotranspiration *ETc*. For analysis purpose, designed system collects humidity, temperature of air, radiation of solar and speed of wind data from field Dapoli location, District Ratnagiri, Maharashtra. The lateritic soil in Dapoli region has generalized clay-loam soil texture [4]. Assume, field capacity θ_{FC} and wilting point θ_{WP} as 0.30 [m^3/m^3] and 0.17 [m^3/m^3] respectively. Root can easily absorb water from soil if soil water content is above wilting point θ_{WP}. The soil water content at root zone should be maintained between field capacity θ_{FC} and wilting point θ_{WP}.

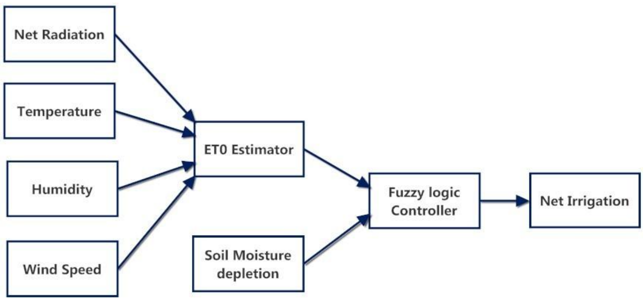

Figure 2: Schematic representation of proposed model for irrigation controller.

A. Fuzzy controller setup

Fuzzy controller is designed in Matlab-2017a using fuzzy toolbox. The fuzzy interface for designed system is as shown in Fig. 3. The universe of discourse of input variable crop ET_c is {0, 2.28, 3.97, 5.67} and the linguistic variables are {ET-Small, ET-medium, ET-High}.

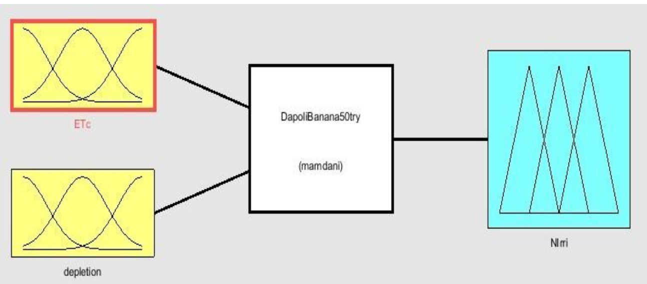

Figure 3: Fuzzy interface system to estimate net irrigation *ETc_adj*.

The universe of discourse of input variable soil moisture depletion are {1, 0.5, 0} and the linguistic variables are {DP-high, DP-medium, DP-small}.

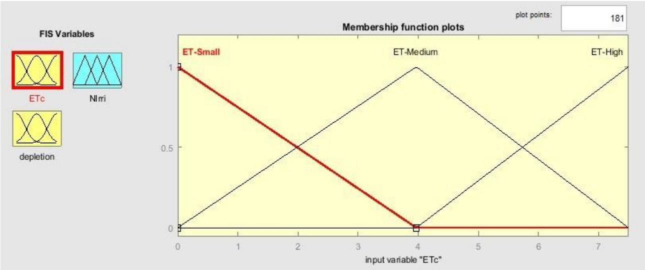

Figure 4: Membership function of crop *ETc*.

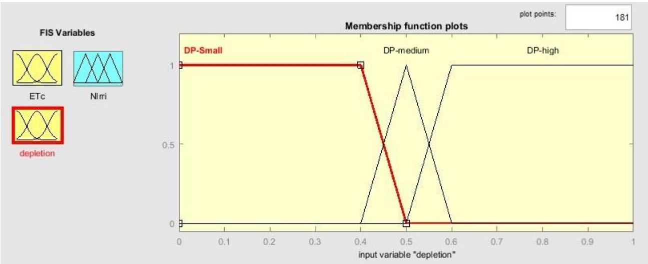

Figure 5: Membership function of soil moisture depletion.

The universes of discourse of output variable, adjusted crop evapotranspiration ET_{c_adj} are {0, 1.14, 1.98, 2.83, 3.97, 5.67, 7.5} and the linguistic variables are {NI-VVSmall, NI-Vsmall, NI-small, NI-Rmedium, NI- medium, NI-high, NI-Vhigh}.

Fuzzy rules are designed such that net irrigation - output of fuzzy controller will be zero for soil moisture depletion ranges from 0 to 0.5 (0 to 50%), and as soil moisture depletion rises more than 50%, the net irrigation will change depending on current crop evapotranspiration ET_c and soil moisture depletion.

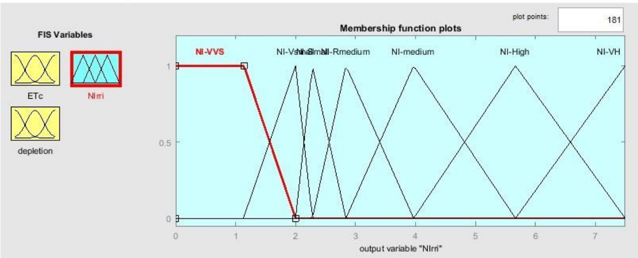

Figure 6: Membership function of net irrigation ET_{c_adj}.

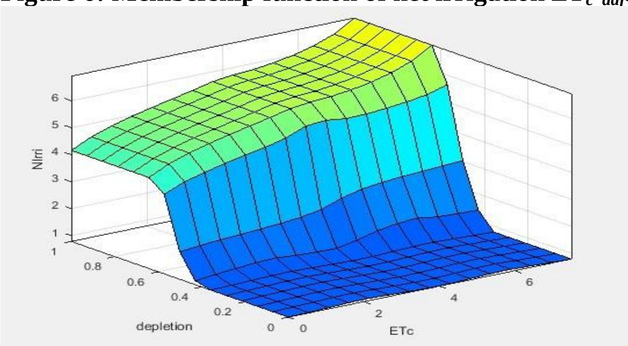

Figure 7: Fuzzy controller design surface plot.

The air temperature, humidity, solar radiations, wind speed and soil moisture data was collected in field. The one hour average data for 2nd and 3rd April 2019 is shown in Fig. 8 and 9 respectively.

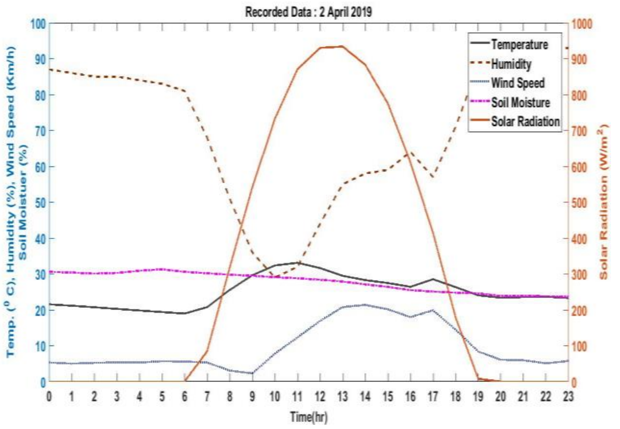

Figure 8: Data recorded of soil moisture, wind speed, temperature, humidity and radiation on 2/04/2019.

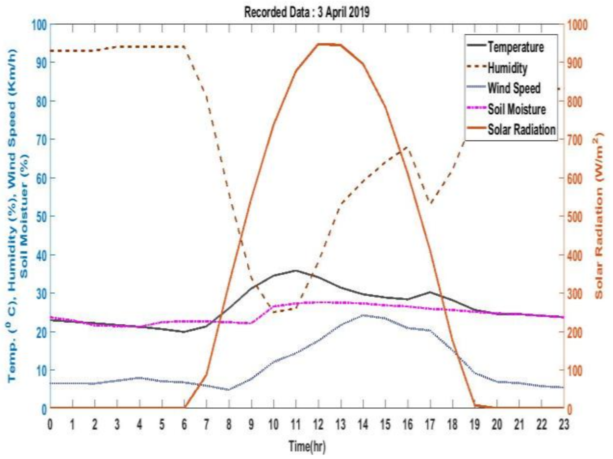

Figure 9: Data recorded of soil moisture, wind speed, temperature, humidity and radiation on 3/04/2019.

Graphical representation of outputs like soil moisture depletion, crop evapotranspiration *ETc* and net irrigation from simulink blocks is shown in Fig. 10 and 11.

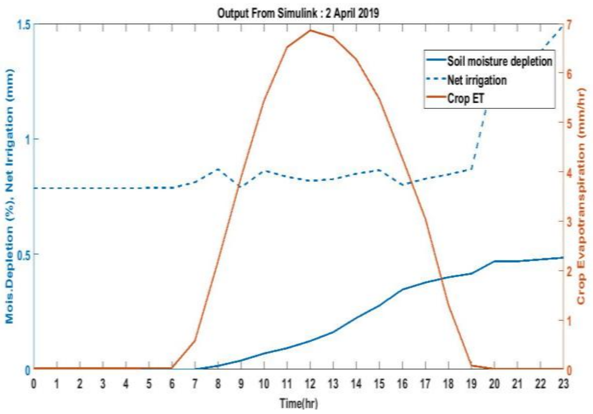

Figure 10: Soil moisture depletion, crop evapotraspiration and net irrigation output from simulink on 2/04/2019.

Designed model continuously monitor soil moisture depletion, as and when soil moisture depletion reaches 40%, program start averaging of humidity, temperature of air, radiation of solar and speed of wind for time up to soil moisture depletion increase to 60%. Based on these average data, current crop ET_c is calculated. Current crop ET_c and % soil moisture depletion (d) are then feed as input to designed fuzzy controller, to estimate net irrigation (mm) i.e. water to be supplied to plant. Soil moisture depletion reached to 40% on 2nd April 2019 at 18 hr. and increases to 60% on 3rd April 2019 at 02 hr. So, based on data between mention period, designed fuzzy controller estimate net irrigation and total irrigation time. Considered the drip irrigation system having 20 lit/h discharge rates (0.005 l/s), 20 numbers of nozzle and 80% efficiency. Irrigation time for analyzed data is equal to 15.57 minutes (15 min and 34 sec) as shown in Fig. 12.

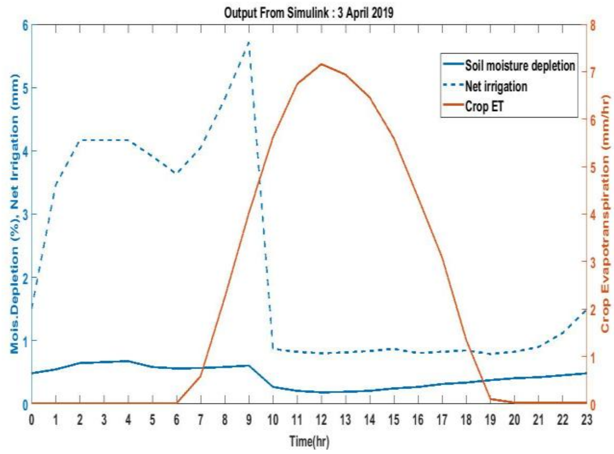

Figure 11: Soil moisture depletion, crop evapotraspiration and net irrigation output from simulink on 3/04/2019.

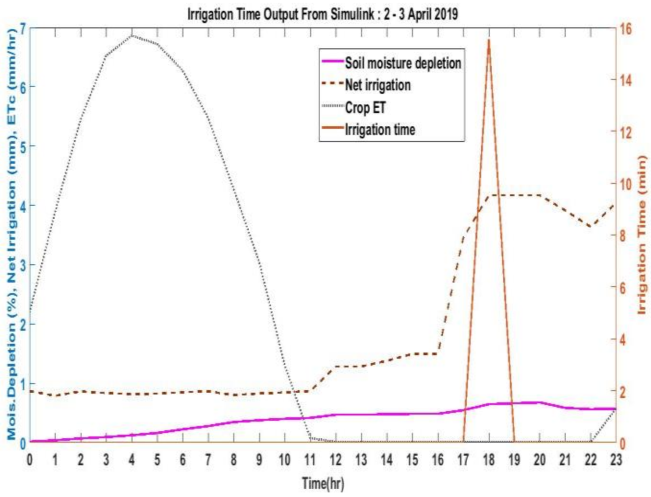

Figure 12: Irrigation time-output from simulink block (2-3, April 2019).

IV. CONCLUSIONS

The proposed system estimates crop water requirement, based on environmental parameters like air temperature, humidity, solar radiation, wind speed , using well established Penman-Monteith equation for evapotranspiration.

The designed system manages irrigation through computing "ON" time of irrigation system, to supply required amount of water. To maintain moisture (wetness) in soil. It also schedule irrigation when moisture removed from soil reaches to define level (60%).

Thus, designed system estimate crop water requirements based on Penman- Monteith evapotranspiration and current soil moisture depletion, results in saving of irrigation water and energy.

REFERENCES

1. Crop Evapotranspiration, "Guidelines for computing crop water requirements, FAO Irrigation and drainage paper-56".
2. Rahangadale V S., Fuzzy Logic based Model for Irrigation Controller using Penman-Monteith Equation. 2nd National Conference on Information and Communication Technology (NCICT) 2011.
3. Ingale P. M., Mohite K. R. and Mahale D. M., Determination of Reference Evapotranspiration of Harnai and Wakawali station using FAO-56 Penman-Monteith model. Research Journal of Recent Sciences, ISSN. 2277(2502) (2015):81–86.
4. Borkar V. S., Gokhale N. B., Dhopavkar R. V., Khobragade N. H., More S. S. and Kasture M. C., Distribution of nutrients in different soil types in Konkan region of Maharashtra, International Journal of Chemical Studies. 2018:6–1.
5. Soil Moisture measurements, Climatological and hydrological field work. Swiss Federal Institute of Technology, Zurich.
6. Davis S., Mane M. S., Patil S. T. and Ingle P. M., Evaluation of three methods for estimating reference evapotranspiration (ETo) at Dapoli. Journal of Agrometeorology. 18(1) (2016 6):157–158.
7. Khatri V., Application of Fuzzy logic in water irrigation system. International Research Journal of Engineering and Technology. 5(4) (2018):3375.
8. Rajaprakash S., Jaichandran R., Ponnusamy R. and Nagappan A., Fuzzy Logic Controller for Effective Irrigation Based on Field Soil Moisture and Availability of Water. Journal of Advanced Research in Dynamical and Control Systems. 9(1) (2017).
9. Abu M. A. and M. Y. Yacob., Development and Simulation of an Agriculture Control System Using Fuzzy Logic Method and Visual Basic Environment. International Conference on Robotics, Biometrics, Intelligent Computational Systems (ROBIONETICS), Yogyakarta, Indonesia, November 25-27, 2013.
10. Brian C. and Verma B. P., Fuzzy Logic for Biological and Agricultural Systems. Artificial Intelligence Review Kluwer Academic Publishers Printed in the Netherlands. 12 (1998):213–225.
11. Amthal K. Mousa, Fuzzy based Decision Support Model for Irrigation System. Management International Journal of Computer Applications. 975 (8887 10).
12. P. S. Vikhe, N. K. Palte and C. B. Kadu., Design of Ardiuno based Wireless Distributed Sensor Network (WDSN) for Smart Agriculture. International Journal of Advance and Innovative Research. 6(2) (2019):85–89.

AUTHORS PROFILE

Pratap S. Vikhe received the M. Tech and Ph. D degree in Instrumentation engineering from SGGS Institute of Engineering and Technology Nanded affiliated to University of Shri Ramanand Teerth Marathwada University, Nanded in 2009 and 2018 respectively. He has completed his Bachelor's degree in Instrumentation engineering from PDVVP, Ahmednagar affiliated to University of Pune in 2003.

He works as an Associate Professor in the Department of Instrumentation and Control Engineering, at Pravara Rural Engineering College, Loni, Tal: Rahata, District Ahmednagar affiliated to University of Pune. His research interests include biomedical signal and image processing. He is author of few research papers published at national and international journals, conference proceedings. He is life member of ISTE, IAENG and IARA.

Nitin K. Palte he has completed his B.E in Instrumentation Engineering from Vidyaverdhini's College of Engineering and Technology, Vasai, Palghar, Mumbai in 2003 affiliated to Mumbai University and pursuing his M.E. in Instrumentation and Control Engineering (Specialization in Process Instrumentation) from Pravara Rural Engineering College, Loni, Tal: Rahata, District Ahmednagar affiliated to University of Pune. He is currently working as Instrument Mechanic in College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist: Ratnagiri since 2005. His research interests include agriculture instrumentation. He is author of few research papers published at national and international journals, conference proceedings.

Chandrakant B. Kadu received the Ph. D degree in Instrumentation and Control Engineering from College of Engineering, Pune (COEP) affiliated to Savitribai Phule Pune University in 2018. He has completed his Bachelors and Masters degree in Instrumentation and Control Engineering from Pravara Rural Engineering College, Loni affiliated to Savitribai Phule Pune University in 1998 and 2005 respectively. He works as an Associate Professor and Head in the Department of Instrumentation and Control Engineering, at Pravara Rural Engineering College, Loni, District Ahmednagar affiliated to Savitribai Phule Pune University, Pune. His research interests include control systems, sliding mode control and process control. He is an author of few research papers published at national and international journals, conference proceedings. He is a life member of ISTE, ISOI, and IAENG.

Vaishali V. Mandhare received the Ph. D in Information Technology from S. G. G. S. Institute of Engineering and Technology, affiliated to S. R. T.M University, Nanded and had received her B.E and M. Tech in Information Technology and Computer Science Engineering from Shivaji University, Kolhapur and Dr. B.A.T.U, Lonere in 2005 and 2009 respectively.

She is working as Associate Professor in Department of Computer Engineering at Pravara Rural Engineering College, Loni, affiliated to Savitribai Phule Pune University.

Her research interests include issues related to Wireless networking, Image processing Mobile Communication, Networking etc. She has published paper in national, international conference and journals. She is life member of ISTE and IAENG.