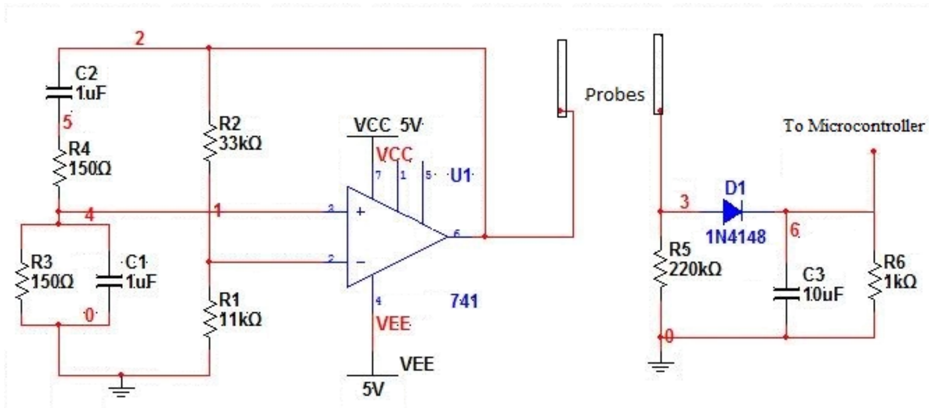


Figure 2. Moisture Sensor Circuit

III. ANN BASED TEMPERATURE DRIFT AND NON LINEARITY COMPENSATION OF SENSOR USING CONVENTIONAL NEURON MODEL

The Soil Moisture sensor designed does not give a voltage output linear to the relative moisture as can be seen from Fig. 3. Moreover, the moisture sensor suffers a temperature drift. In order to compensate for this non-linearity and temperature drift, the inverse modeling of the sensor has been done using an ANN to linearize the voltage output irrespective of the ambient temperature. Fig.3. shows the output voltage values proportional to moisture content of soil of the sensor at different temperatures.

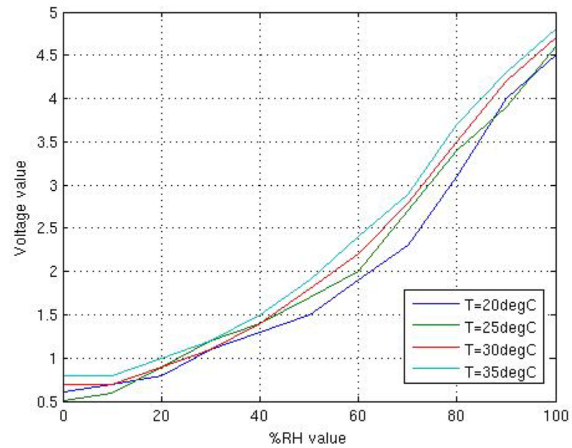


Fig.3. % Moisture content at Different Temperatures

For linearization of the sensor output characteristics as also temperature drift compensation, a multi layered perceptron based neural network has been used. The ANN consists of one input, one hidden layer and one output layer. The input layer consists of 2 nodes (for temperature and %moisture inputs), while the hidden layer consists of 4 neurons. The architecture of the neural network is shown in figure 4.

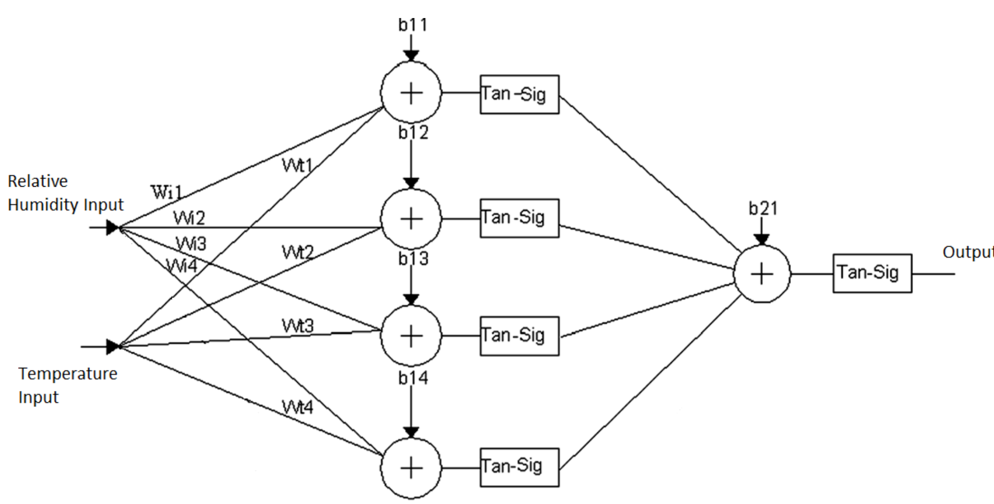


Figure 4. Artificial Neural Network Model for temperature drift and non linearity compensation of soil moisture sensor

The selection of neuron is done on the basis of minimum MSE, weight factor and bias values suitable for hardware implementation and its dynamic range [17]. Moreover, the number of neurons has been kept as small as possible for simplicity in circuit implementation at the subsequent stage.

The mathematical model of the neuron is given by the equation:

$\tau \frac{du}{dt} = f(\sum_j w_{ij} x_j + u_i)$, where w_{ij} is the synaptic weight between i[th] and j[th] neurons, u_i is the internal state of i[th] neuron, x_j is the output of the j[th] neuron, τ is the time constant of the neuron output, *f* refers to the tan-sigmoid activation function of the neuron. The chosen training method is back propagation algorithm and the simulation studies are carried out in MATLAB [18]. Table 1 shows the values of the synaptic weights and biases obtained while training the model.

Table 1. Synaptic weights and biases of the ANN

iw(1,1){input to hidden layer weights	iw(2,1){hidden to output layer weights	b(1){bias to hidden layer neurons}	b(2){bias to output layer neuron}
-0.7458; 0.097066	15.3497	-13.388	-13.5047
-0.26681; 0.0031053	-47.2423	-1.3565	
7.8241; -2.4914	0.099211	39.9804	
1.0265; 0.030163	-13.0118	9.5881	

The linearized output of the ANN is shown in the following figure 5.

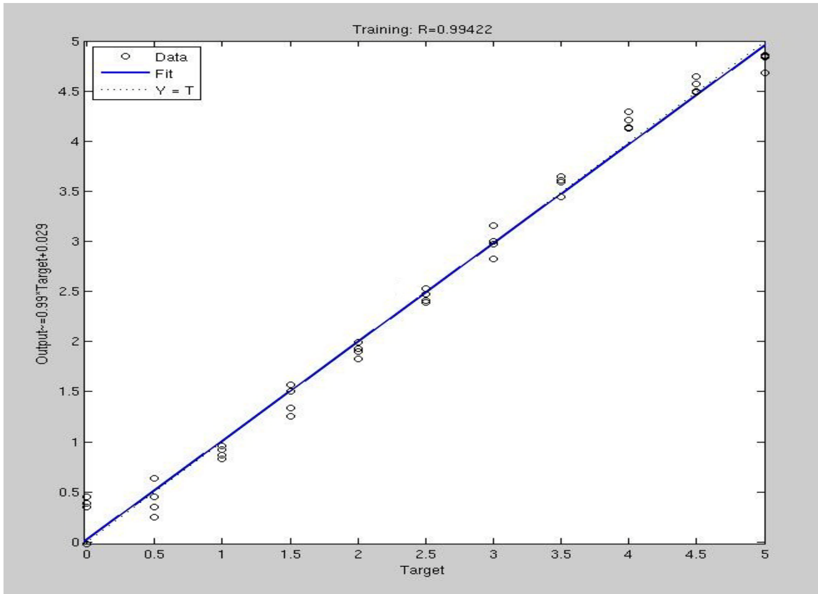


Figure 5. Linearized output after using the neural network

The % error in linearization has been found to be less than 1%, which implies the high degree of accuracy obtained with the ANN based linearization.

IV. DEVELOPMENT OF THE SMART DATA PROCESSING UNIT

The data processing unit is centred on an Atmel AtMega 16 microcontroller [19]. The PCB for the microcontroller has been developed by us. The layout of the PCB and its actual image are shown below in figure 6 and figure 7 respectively:

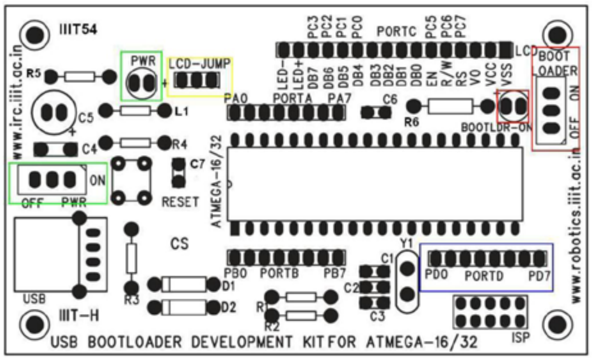


Figure 6. PCB Layout of the signal processing circuit

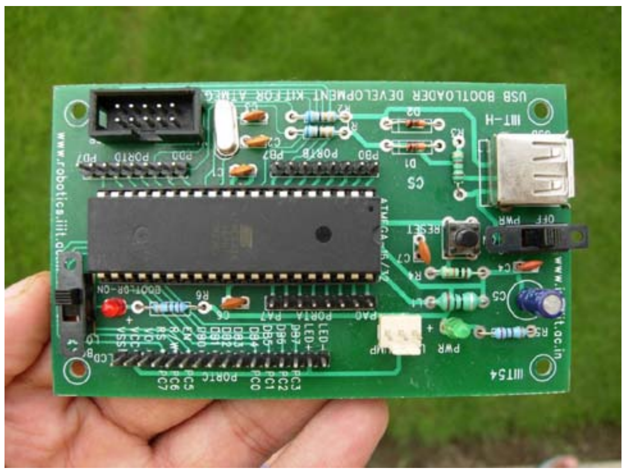


Figure 7. Picture of the signal processing circuit

Figure 8 shows the overall system architecture:

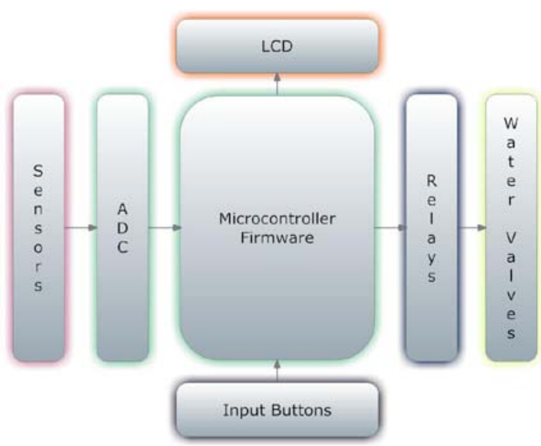


Figure 8. Overall System Architecture

The pin connections and their data direction that are used for connecting various sensors, input buttons, LCD and output to water valves is given in Fig.9: The whole circuit operates on a 5V power supply.

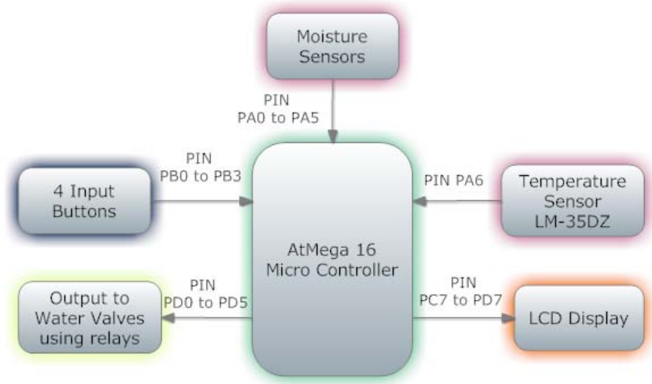


Figure 9.Circuit connections of the microcontroller

The microcontroller has a program running on it, which acts as a small Operating System. It has a user interface, and takes inputs from the user and accordingly takes actions. The temperature sensor output is directly applied to the ADC of the microcontroller and stored in the internal register. The microcontroller takes the analog sensor output of the moisture sensor and converts them into a digital value ranging from 0 to 1023 using its Analog to Digital Converter (ADC). These ADC values are linearized using the ANN based inverse model. For different crops, the humidity and temperature requirements for optimum growth are different. In our current research, we have performed experiments with rice, wheat, maize, sorghum, sugarcane and groundnut. Table 2 shows the soil moisture requirements for different crops. If the soil temperature rises above the threshold value and the moisture content falls below the threshold, the water supply is turned on by issuing a control signal from the microcontroller. This is achieved by turning on a relay, which in turn opens a water valve, and water is given to only to that area of the field.

Table 2: Water requirements and corresponding soil moisture requirements 6 crops.

Crop	**Water Requirement (mm)***	**Soil Moisture (%V/V)****
Rice	900 – 2500	31.03 – 55.55
Wheat	450 – 650	18.36 – 24.52
Maize	500 – 800	20.00 – 28.57
Sorghum	450 – 650	18.36 – 24.52
Sugarcane	1500 – 2500	42.85 – 55.55
Groundnut	500 – 700	20.00 – 25.92

*Water Requirement in mm has been referenced from an online resource [20]. **Volumetric water content and soil moisture are given by the following formulae respectively. For calculations, Soil Depth is taken as 2 meters.

Volumetric Water Content= (Volume of Water) / (Volume of Soil + Volume of Water)

*Soil Moisture % = (Volumetric Water Content)*100*

The overall software architecture is given in Fig.10. The software architecture is so designed to make usage simple and easy to understand and debug. The arrows in the figure indicate the dependence between the different modules.

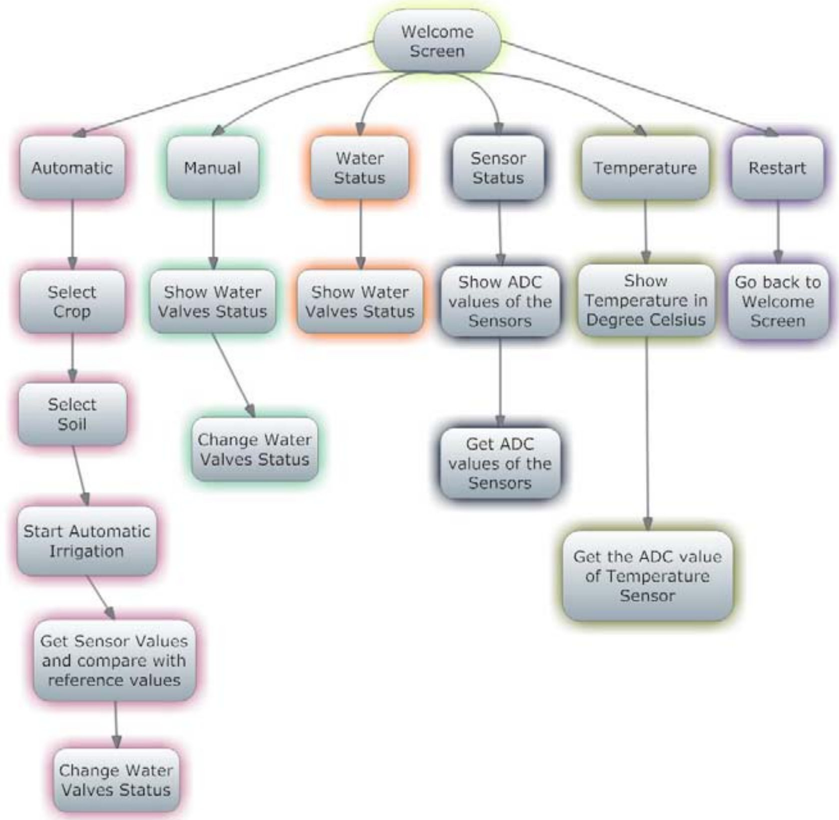
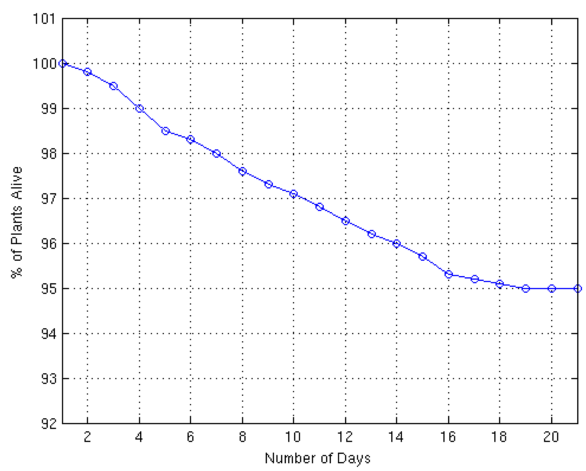


Figure 10. Overall Software Architecture

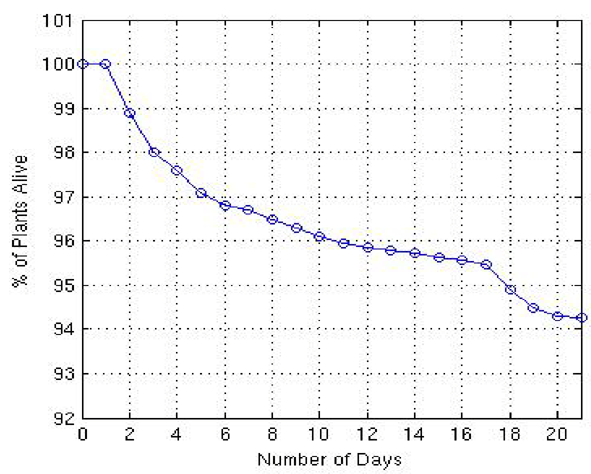
V. RESULTS AND DISCUSSION

The moisture sensors being developed give an analog value ranging from 0 to 5V for different moisture levels. Figure 3 shows the output performance of the soil moisture sensor. As evident from the figure the increase is non-linear in the region of 30 to 100. An ANN based model has been used to compensate this non-linearity. The linearized output is shown in Figure 6.

Experiments were carried out over rice and maize fields spanning over an area of 1 acres of land each for 3 weeks. The sensing units were placed at distances of 10 meters. They were all networked with the smart signal conditioning unit that samples the sensor outputs in a round robin fashion. The number of plants that remained alive as a result of the irrigation approach was monitored. A graph has been plotted showing the percentage of plants alive after a certain number of days. Figure 11 shows the graph percentage of plants alive versus number of days:



(a)



(b)

Figure. 11 Graph showing percentage of plants alive over time (a) Rice (b) Maize

From figure 11 it is evident that even after 21 days more than 94% of plants on average were alive and were found to grow normally using the proposed irrigation approach. Moreover, it is also clear from the curve that the curve almost settles to a constant value after 16 days which implies almost no more plants die after 18 days. The system is very useful for agriculture applications particularly in semi arid areas that are sparsely populated, so that human involvement and intervention is not needed for irrigation purposes.

VI. CONCLUSION

The current work aims to develop a smart irrigation system using soil temperature and moisture sensor. The proposed system enables irrigation of the field only when it is needed and thus serves to conserve water. Also, the proposed system eliminates the intervention of human being for irrigation purposes. The reliability of the sensing system is justified by the percentage of plants that survived even after 3 weeks. The system based on a microcontroller has been applied on a rice and maize fields spanning over an area of 1 acres for 3 weeks and more than 94% of the plants were found to be alive after experimentation. The system is particularly useful for agriculture applications in sparsely populated semi arid areas since human involvement and intervention is not needed for irrigation purposes. Further works are going on to increase the efficiency of the moisture sensors so as to minimize the effects of fertilizers on the value of soil moisture.

VII. ACKNOWLEDGEMENTS

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