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Soil Moisture Sensed Automatic Irrigation System

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ABSTRACT
Improving irrigation efficiency can contribute greatly to reducing production costs of crops, making the agriculture industry more competitive and sustainable. Through proper irrigation, average plant yields can be maintained (or increased) while minimizing environmental and other impacts caused by excessive application of water and subsequent agrichemical leaching. Many years ago, irrigation had to be done manually and it involved a lot of labour and material costs. However, recent technological advances have made soil water sensors available for efficient and automatic operation of irrigation systems. Automatic soil moisture sensor-based irrigation seeks to maintain a desired soil water range in the root zone that is optimal for plant growth. This report therefore illustrates how by using an automatic soil moisture sensor based irrigation system, the issue of water wastage, agrichemical wastage and time spent on irrigation can be effectively tackled without adversely affecting crop yield, leading to optimal irrigation and ultimately an optimal agricultural system as a whole. Here we make use of an Arduino microcontroller interfaced with a soil moisture sensor. The microcontroller triggers an electronic valve ON or OFF based on readings taken from the soil moisture sensor. The model used here is miniaturized for the purpose of demonstration. It can however be implemented on a larger scale as in a farm or garden to reap its full benefits.
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Key words: sensor, irrigation, arduino, optimal, miniaturized, microcontroller

INTRODUCTION

One of the main drawbacks with the old fashioned farming system that is experienced by the farmers themselves is that they do not accommodate for changing environmental conditions. Temperature, wind, rainfall and other elements can dramatically affect the amount of water needed to sustain a plant's health. If these elements were monitored and used to influence the watering cycles, then the water used should be more effective [1]. In this research, we make use of an intelligent irrigation system that operates using the soil moisture sensing technique [2]. An intelligent soil moisture sensed irrigation system is a system that is designed to operate autonomously. Using a valve mechanism, it automatically regulates the supply of water to plants on sensing the moisture level of the soil within the immediate surroundings of a soil moisture sensor [3]. This type of system adapts the amount of water applied according to plant needs and actual weather conditions throughout the season, which translates not only into convenience for the manager but also into substantial water savings compared to irrigation management based on average historical weather conditions [4]. This type of system can also be applied in the transportation of agrichemicals in plant operation processes [5]. Two of the most common problems with farm irrigation systems have to do with irrigation scheduling [6]. Irrigation scheduling is simply answering the questions of "When do I water?" and "How long do I water?" Starting an irrigation cycle too early and/or running an irrigation cycle too long is considered over watering [12]. This practice leads to wastage of water and money and can cause crop damage in the long run. In the same way, starting an irrigation cycle [7] too late or not running the system for a long enough period of time is considered under watering and can cause reduced yields and poor crop quality which can affect price [13]. The two most common methods for dealing with these problems are ET based control systems and soil moisture based control systems [8]. Evapotranspiration (ET) is the combined process through which soil moisture is lost directly to the atmosphere through evaporation and plants taking water out of the soil and transpiring it to the atmosphere [9]. This research is aimed at developing an automated irrigation system which regulates the moisture content of the soil using readings taken by a soil moisture sensor to automatically turn a water supply on or off depending on a predefined acceptable moisture range [10]. This will prevent water and nutrient wastage, and also tremendously reduce the cost and inconvenience of manual labour [11].

DESIGN METHODOLOGY AND IMPLEMENTATION

This section talks about the design strategy employed in the overall system development of the soil moisture sensed automatic irrigation system. It streamlines the overall view of the system design into discretized component level and tries to explain in detail the system intricacies.

The design method adopted in this work shall be discussed under the following headings:

- Hardware
- Software

Hardware Design

A block diagram and typical hardware circuitry for the system design is presented and all forms of connection between the segmented parts of the system are first presented here in Fig. 1 before being explained in details.

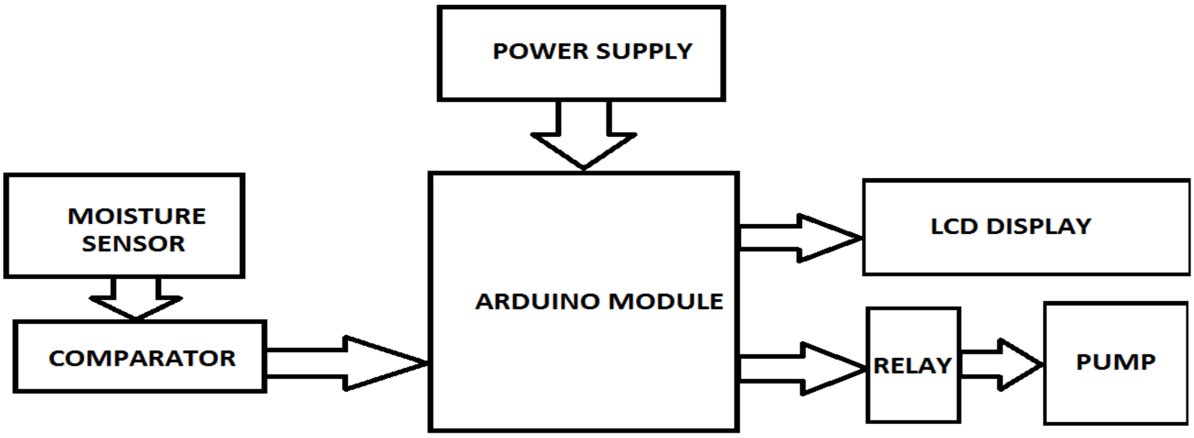

Fig. 1 Block diagram of design architecture

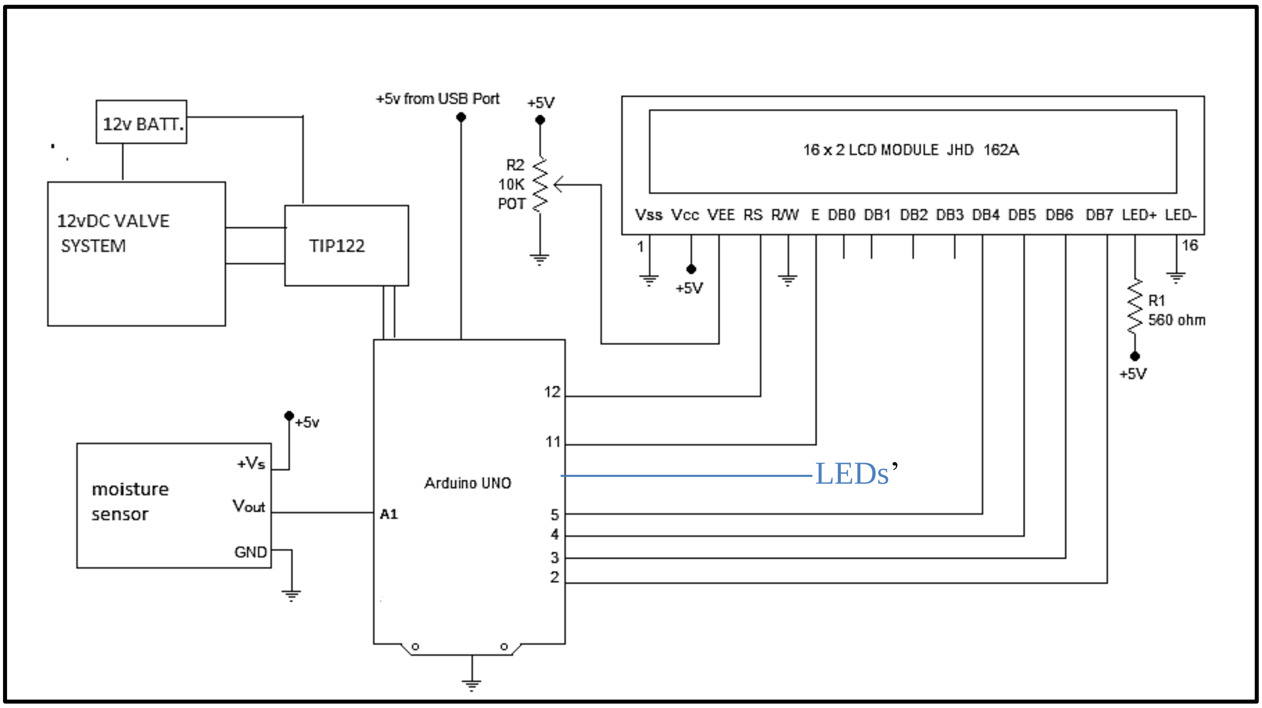

Fig. 2 Electronic workbench designed circuit diagram

For this research, the Arduino can be compartmentalized into the power segment, analog segment, digital segment and special peripherals which are powered by a voltage range of 5-9v dc. A fixed voltage regulator (LM7805) was also used to regulate the voltage supplied by a 9v dc battery to the controller board. The headers were soldered for the controller board to sit on, 10 on the digital segment, 3 on the analog segment and 4 on the power segment.

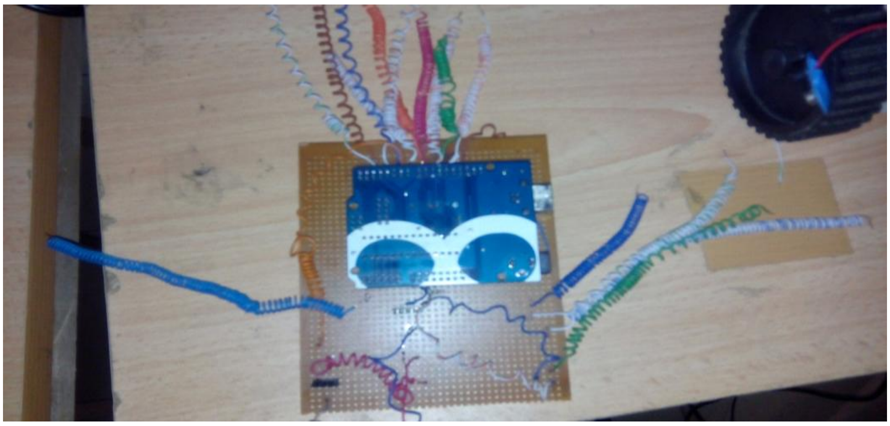

Fig. 3 Image of Arduino Uno micro-controller soldered on a Vero board

Liquid Crystal Display (LCD) Screen

The LCD is a digital display screen used to display alphanumeric characters and some special symbols. LCDs are categorized according to their screen resolution. The 16x2 LCD screen is used in this design and is capable of displaying characters on 16 columns and 2 rows. The LCD used in this work has 16 pins. The pin specification for all the pins is given in table 1:

Table -1 Pin specification for the LCD

PIN	SPECIFICATION
Pin1	Controller's ground
Pin2	5v dc
Pin3	Potentiometer for contrast variation
Pin4/RS	Controller's pin 12
Pin5/RW	Controller's ground
Pin6/Enable	Controller's pin 11
D4	Controller's pin 5
D5	Controller's pin4
D6	Controller's pin3
D7	Controller's pin2
Pin 15	5v dc
Pin16	Controller's ground
Other pins	Not connected

The display of the LCD screen is determined by the intelligence embedded in the controller.

12V DC Valve

The 12v dc valve is an electro mechanical device that switches ON when a 12v DC is applied across its terminals. It has two terminals, one of which is connected to a 12v battery and the other to the collector of the BJT (Tip122).
In our design, we have connected the negative terminal of the 12vdc battery to the arduinouno controller ground.

Fig. 4 12v dc valve

Software Design

The intelligence of the controller is written in C++ language over the Arduino IDE (Integrated Development Environment) which converts the C++ code (.cpp) to machine code (.hex) which the controller understands.

Operation and sensor calibration

The reading of the analog input (soil moisture sensor) is calibrated from 0 to 1024. These values were mapped from 0 to 100%. If the reading of the moisture sensor falls between 0-300, the soil moisture level is considered below 30% and thus is said to be dry. The appropriate signals are thus sent to the pin 13, 8 and 6 to turn on the valve. This implies that irrigation can commence. Indicators (white LED and buzzer) are to indicate the soil moisture level as dry and also to show that irrigation is in progress. The 16x2 LCD displays "SOIL DRY" on the first row, and on the second row "MOISTURE < 30%". If the moisture reading is greater than 300 but less than or equal to 400, an equivalent signal is sent to pin 10 to switch on the appropriate indicators for that category, being the yellow LED, and a LOW signal is sent to the pins 8, 6 and 13 to switch off the valve through the TIP122 transistor operation and also the white LED and buzzer indicators. The LCD displays "SOIL WET" in the first row, and on the second row "MOISTURE ≥ 30%", else a HIGH signal is sent to pin 9 to switch on the red LED while the yellow LED stays on and LCD displays "PUMP TURNED OFF" and "NOT WATERING" on the second row to indicate that the soil is water logged. A 5 five-step flow chart algorithm to represent the working and operation of the system design is given

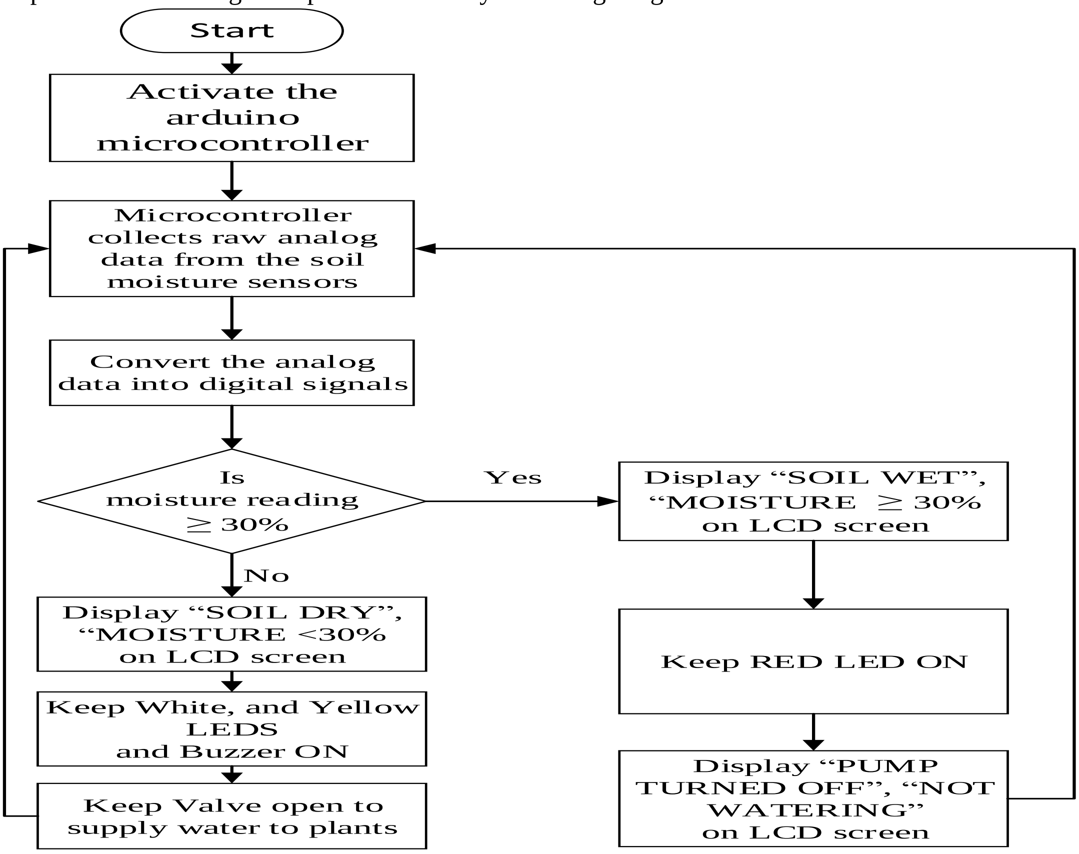

Fig. 5 Flowchart algorithm

Test and Results

The test and result carried out in this research were very precise and were done over two (2) platforms as is done in most design related works. Furthermore, a prediction model for soil moisture formulated on the premise of these tests and result is attached to this chapter as well.

Hardware Test

From the mathematical analysis seen in chapter three of this work, the following tables of values and graphs were generated. Table 2 gives the reason for choosing a height of five feet (5ft). We see from the table that as we increase the height, the velocity of flow increases. The velocity of flow at a height of five feet was seen to be acceptable when the system was set up and tested. Thus, our mounting height for the water reservoir was selected to be five feet. Also, table 3 shows that the velocity is constant at the given height and irrespective of the mass of water present in the reservoir. This was also confirmed in reality.

Table 2 Table of Values for height and velocity of flow

Height(ft)	Height (m)	Velocity(m/s)
1	0.305	2.444994888
2	0.61	3.45774493
3	0.915	4.234855369
4	1.22	4.889989775
5	1.525	5.467174773

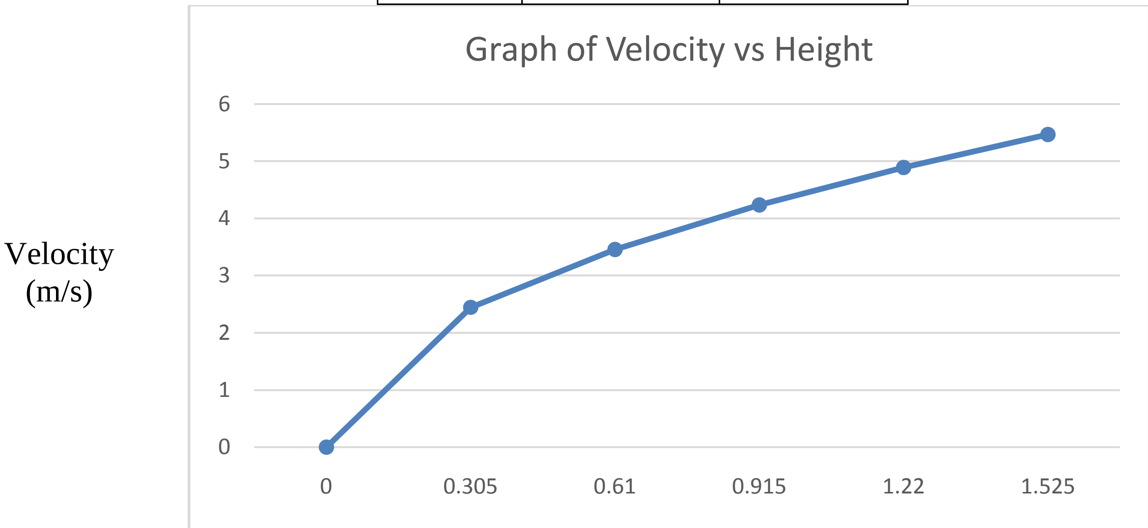

Fig. 6 Graph of Velocity (m/s) against Height (m)

Table -3 Table of Values for Mass, Force, Pressure and Velocity of flow

Mass (Kg)	**Force (N) =mg**	**Pressure (N/m^2) =F/A**	**Velocity (m/s) =$\sqrt{2F * d/m}$**
18.9	185.22	23.59490446	5.47613002
18	176.4	22.47133758	5.47613002
17	166.6	21.22292994	5.47613002
16	156.8	19.97452229	5.47613002
15	147	18.72611465	5.47613002
14	137.2	17.47770701	5.47613002
13	127.4	16.22929936	5.47613002
12	117.6	14.98089172	5.47613002
11	107.8	13.73248408	5.47613002
10	98	12.48407643	5.47613002
9	88.2	11.23566879	5.47613002
8	78.4	9.987261146	5.47613002
7	68.6	8.738853503	5.47613002
6	58.8	7.49044586	5.47613002
5	49	6.242038217	5.47613002
4	39.2	4.993630573	5.47613002
3	29.4	3.74522293	5.47613002
2	19.6	2.496815287	5.47613002
1	9.8	1.248407643	5.47613002

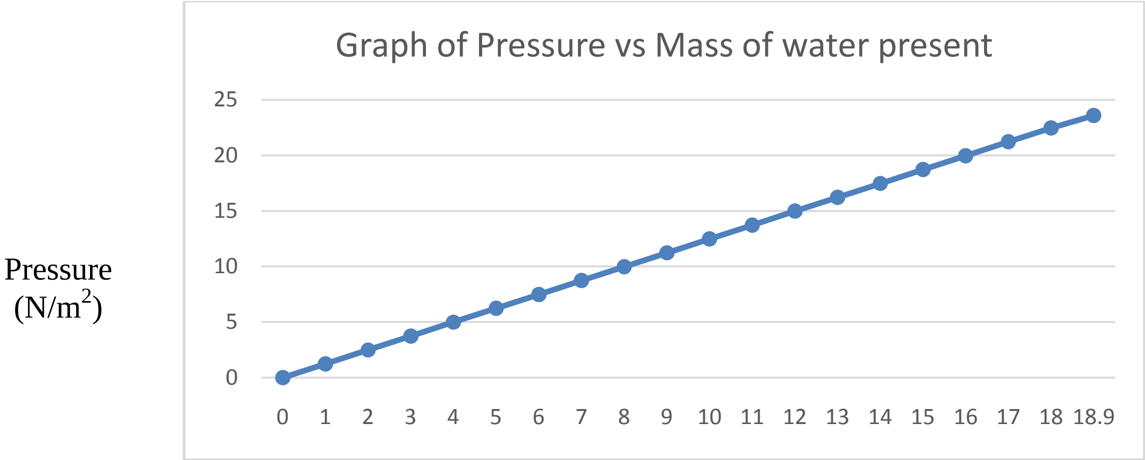

Fig. 7 Graph of Pressure against Mass of water present

We also see from the above table of values and graph that at the chosen height (5 ft or 1.53m), the velocity of water is constant and irrespective of the pressure head.

Software Test

The software test covers the serial monitor tests and sensor calibration test.

Serial Monitor Test

The serial monitor was interfaced to our already developed system over the Arduino Integrated Development Environment and all analog signals from the sensor within the range of (0 byte to 1kilobyte) were observed on the serial monitor screen. This was done in a bid to ensure that the sensor is working optimally, and that no form of latency is experienced by the entire design as a result of the sensor.

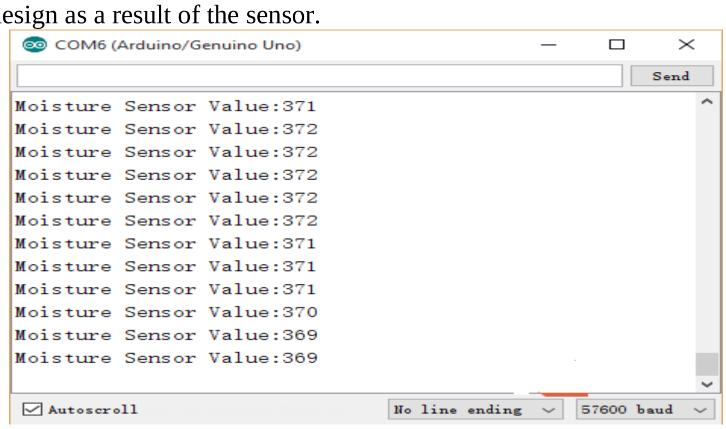

Fig. 8 Screen-shot of serial monitor reading

Sensor Calibration Test

The sensor calibration test was done to group all the analog values within the range of one kilobyte into different compartments that can serve as readable signal for the opening and closing of the valve system for water flow control as shown in table 4.

Table -4 State of valves

SENSOR READING	STATE OF VALVE
0-100	OPEN
100-200	OPEN
200-300	OPEN
300-400	CLOSED/OPEN
400-600	CLOSED
600-800	CLOSED
800-1024	CLOSED

The prediction model is designed to estimate the soil moisture content at any instant of time, determining whether to irrigate or not. The system is considered to be controllable by mere observation but however, a mathematical proof of controllability is added to the model formulation.

Modelling of Soil Moisture Content

Setup two interconnected beakers such that the first beaker empties into the second, while the second beaker empties out. Follow these steps to carry out the experiment:

1. Fill the two beakers half way with soil
2. Measure and record the height of the soil without water
3. Pour water into the first beaker as for (rain or irrigation)
4. Measure and record the height of the soil with water
5. Open the tap of the last beaker for water to run out (all losses; evaporation, transpiration, leakages etc.)

This model is based on the water balance model

nzr$\frac{ds(t)}{dt}$ = R(t) - E(t) – L(t) – Q[s(t), t]………. (**)

nzr$\frac{ds(t)}{dt}$is total amount of water in the soil rooting zone

R is rain or in our case irrigation

Q is runoff or run in (in case of mountain or valley region)

E is evapotranspiration

L is any other form of leakage.

The two-coupled beaker system has two state variables, h1 and h2 and each has unit cross sectional area. It was set up to mimic natural soil under conditions where an overhead tap supplies water to the soil in the beaker, where the R represents rainfall, irrigation and run in as the case may be. L represents all manner of water losses from the soil such as evapotranspiration, leakage, leaching, and run off.

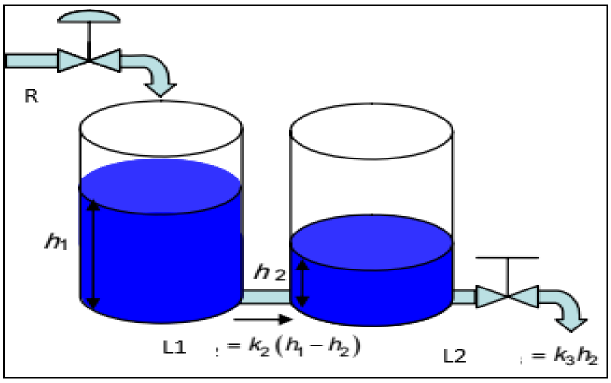

Fig. 9 The two-coupled beaker system

Two State System: The coupled two-beaker system shown in Figure 9 is the representation of a set up for this study. The coupled two beaker system has two state variables h1 and h2 and, if the beakers each have unit cross sectional area (i.e. $A_T = 1$), the state equation is:

$\frac{dh1}{dt} = -\mathrm{K2(h1-h2)} + \mathrm{R}$ ……….. (1)

$\frac{dh2}{dt} = \mathrm{K2(h1-h2)} - \mathrm{k3h2}$ ……….. (2)

From the above equations, we see that the state equations are given by:

$$\begin{matrix}\frac{dh1}{dt}\\ \frac{dh2}{dt}\end{matrix} = \begin{pmatrix}-K2 & K2\\ K2 & -(k2+k3)\end{pmatrix}\begin{pmatrix}h1(t)\\ h2(t)\end{pmatrix} + \begin{pmatrix}1\\ 0\end{pmatrix}\mathrm{R}$$

Expanding out the matrices and rearranging shows that the state equation is nothing more than a volumetric balance for each beaker.

Thus, there is no new physics in a state equation. The reason why control engineers use it is that is a convenient way of studying the mathematical properties of the physical equations. Using state-space leads to some very powerful controller designs that would be too cumbersome to consider without the compact matrix formulation. Referring back to the general state equation:

$$\frac{d\mathbf{x}}{dt} = \dot{\mathbf{x}}(t) = \mathbf{Ax}(t) + \mathbf{Bu}(t)$$

In the two-beaker example, the state vector x (t) is

$\begin{pmatrix}h_1\\ h_2\end{pmatrix}$, the input $\mathbf{u}(t)$ is q R nd the constant-coefficient **A** and **B** matrices are:

$$\mathbf{A} = \begin{pmatrix}-k_2 & k_2\\ k_2 & -(k_2+k_3)\end{pmatrix} \text{ and } \mathbf{B} = \begin{pmatrix}1\\ 0\end{pmatrix}$$

$\dot{X}(t) = AX(t) + Bu(t)$
$Y(t) = CX(t) + Du(t)$
Where A is the System Matrix
B is the Input matrix
C is the output matrix
D is the Direct transmission matrix
Given that:
$A = \begin{pmatrix} -K1 & K2 \\ K2 & -K2+K3 \end{pmatrix}$ and $B = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$
Then assuming:
$C = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$ and $D = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$
Also, we assume that the constants K1, K2, and K3 have non-zero values

Controllability

To test for controllability of the system, we first form the controllability equation:
Ctrb = (B|AB)
$AB = \begin{pmatrix} -K1 & K2 \\ K2 & -K2+K3 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \begin{pmatrix} -K1 \\ K2 \end{pmatrix}$
$Ctrb = \begin{pmatrix} 1 & -K1 \\ 0 & K2 \end{pmatrix}$
Next we find the rank of the controllability matrix by first taking the determinant
$\det(Ctrb) = \begin{vmatrix} 1 & -K1 \\ 0 & K2 \end{vmatrix} = K2$
Since the controllability matrix is non-singular, we conclude that the system is controllable.

Observability

To test for observability of the system, we first form the observability equation:
$Obsv = (C^T | A^T C^T)$
$C^T = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$; $A^T = \begin{pmatrix} -K1 & K2 \\ K2 & -K2+K3 \end{pmatrix}$
$A^T C^T = \begin{pmatrix} -K1 & K2 \\ K2 & -K2+K3 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = \begin{pmatrix} -K1 & K2 \\ K2 & -K2+K3 \end{pmatrix}$
$Obsv = (C^T | A^T C^T) = \begin{pmatrix} 1 & 0 & -K1 & K2 \\ 0 & 1 & K2 & -K2+K3 \end{pmatrix}$
Finding the rank of the above matrix by taking determinants of sections of 2x2 matrices that make up the entire observability matrix, we discover that the matrix has a rank of 2. Hence we conclude that the system is OBSERVABLE.

CONCLUSION

The concept of irrigation dates back several thousand years where irrigation had to be done manually and involved a lot of work in order to achieve good results. However, in modern times, the world is moving towards automation in almost every aspect of life and it is only imperative that irrigation too (which when done efficiently improves agriculture which in turn improves the quality and quantity of food which is very essential for living and directly affects the lives of all and sundry) should be automated. The system of irrigation used in this project if implemented on a large scale shall indeed revolutionize the agricultural industry, changing the status quo, reducing wastage and increasing ultimately efficiency.
A miniaturized model of the Arduino – based Automatic Plant Watering System has been designed and tested successfully here. The system is designed to function automatically and devoid of human intervention. The soil moisture sensor measures the amount of moisture present in the surrounding soil. If the moisture level is found to be below the desired level, the moisture sensor sends a signal to the Arduino board which triggers the electronic valve to turn ON (open) and supply water to crops. When the desired moisture level is reached, the system halts voluntarily and the electronic valve is turned OFF (closed). In previous researches, similar systems were implemented using PIC microcontroller which uses RISC, making the program unnecessarily long and difficult to debug in case of errors. Also, the Arduino microcontroller makes both the circuitry and the programming simpler since it is already embedded with several libraries thereby reducing the number of lines of code required. LED's are used in this work to indicate moisture range. Despite the fact that the system is designed to operate autonomously, the farmer or gardener may want to have an idea of the level of water present in the soil. These indicators help to take care of that. Some similar systems designed in the past such as those that use Bluetooth module, SMS system and Wireless sensory network had to be monitored from time to time by the user, but the system used in this research work is completely autonomous.

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