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IOT BASED SOIL MONITORING AND AUTOMATIC IRRIGATION SYSTEM IN THE RURAL AREA OF BANGLADESH

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Keywords: IOT, WSN, automatic control, automation in agriculture, arduino, NodeMCU, ESP8266

Abstract: To serve the humanity nowadays technology is playing a wonderful role and a man's basic and primary need is food indeed. It can be said that about more than 85% of people of Bangladesh are directly, indirectly depended on agriculture. Proper irrigation by water pump cannot be maintained due to frequent power outages, unavailability of grid lines in remote areas and scarcity/cost of fuel to run pumps. To make the sustainable irrigation system and field monitoring system for getting better crops growth as well as best production, this IOT based Automatic irrigation system is proposed. In this system IOT and WSN are used to control and monitor the irrigation system. IOT is used to obtain stored data monitoring and real time monitoring of various contents of soil. WSN is used to make a fully wireless system to make a user-friendly system to cultivate and irrigate water properly to the field. Different kinds of sensors are used. This report presents a fully automated drip irrigation system which is controlled and monitored by using "Thinkspeak Cloud Server". Temperature and the humidity content of the soil are frequently monitored. The system informs user about any abnormal conditions like less moisture content and temperature rise, even concentration of water by sending notifications through the wireless module.

1 Introduction

It is widely known that the resources of water are decreasing all over the world. On the other hand, rapid urbanization, population growth, industries and agriculture expansion increase the demand for fresh water. In the agriculture-based countries including Bangladesh, for irrigation purpose water is used more than any other purpose, and the production rate can be decreased if any kind of hampering happened in water supply. The improvement of water usage efficiency without decreasing yield can be done by maintaining water management strategies & up-to-date technologies. It has become crying need for the agro-based countries to take more efficient technology in the field of agriculture to create better management of water resources. Digital Bangladesh concept that has led to tremendous growth in digital information storage, retrieval and communication. Now a day the concept of Internet of Things (IOT) has made human life more comfortable. Everyone is referring this system of inter-related computing devices, objects, things, animals, people, etc. Without human involvement the system is able sharing information over a network. The idea of IoT has been blooming since decades [1-7]. For water savings function it has been proved that Wireless sensor network (WSN) system is very much helpful for irrigation management. WSN is the system which is a mesh of network of sensor nodes which have connected each other, and the nodes directly collect data from the environment and provide real time data to the firm which is very much helpful for the farmers. Both as a data collection device and as a decision-making tool for real time monitoring this system can be used. The farmers are aware of water shortage or over watering may damage the yield. They need to understand when and how much amount of water is needed for specific crops. Most farmers have little knowledge of their farm, and they are unaware of the methods of improving their productivity of agricultural practices. All these conflicts make it necessary to think of resolving support systems for agriculture. In order to overcome this problem, IoT based Wireless Sensor Network (WSN) for agriculture monitoring controls are applied. The internet/any kind of information sharing communication without cable connection between computers and other electronic devices can be done by

Wireless Sensor Network (WSN) technology [8-15]. A tremendous achievement has been found in agriculture environment with the help of Sensor Network System. It is said that in the 21st century, the most important technology is the WSN. WSN is a full package of a number of low-power, low-cost, multipurpose sensor nodes for a short and long-distance wireless communication. Different network topologies and multichip communication is allowed by WSN. The effort and the complication can be cut down by WSN for monitoring environment. As a result of it the cost of water and labour can be reduced. Temperature, humidity, and soil moisture percentage and many more measurements can be remote by this technology. It seems that wireless outcomes are much better than the wired-based systems. Within this framework, IOT based wireless sensor network is a promising technology for irrigation management and soil monitoring by using soil conditions and actual weather on the basis of temperature and humidity of the area. A network of small devices which collect and process real time information from the fields in which they are deployed. The use of this technique makes the irrigation system & soil monitoring system independent of human intervention in terms of precise quantification, location and time of irrigation, and thus the establishment of an automatic irrigation system and soil monitoring system that is known as the smart irrigation and soil monitoring system for this reason. The purpose is to present several efficient irrigation systems and soil monitoring systems using IoT based wireless sensor networks, which can improve water use efficiency and also gives the correct condition of the soil by determining the timing of irrigation in an era of increasingly limited and costly water supplies. The second section can deal with the irrigation strategy that can be followed by an overview of smart irrigation by using wireless sensor networks. The artificial implementation of water in the field is known as irrigation. Irrigation comes in many forms. Many kind of efficient water supplying technology is replacing rapidly the old ones and applying it to the soil. Depending on how water is distributed throughout the field there are many different types of irrigation systems,

In this report a system has been developed to solve the problem of real time monitoring and stored data monitoring to investigate the soil condition at any time to take decision what types of crops should be grown and what should be done with the soil to get better and best production of the crops and also makes the whole system wirelessly automatic control over mobile phone which can reduce the cost of the labour as well the effort of a farmer.

Objectives

1. To develop an IOT based automatic irrigation system having a low-cost equipment.
2. To monitor moisture contents at different conditions
3. To improve the system by using Mobile Phone App
4. To improve the system by using WSN (Wireless Sensor Network)

Scope and Limitations

The scope of this project is:

1. Monitoring of soil moisture content.
2. Automatic Control system.
3. Real time monitoring of soil
4. Mobile based control system.
5. IOT Based platform.

Limitations of this project is

1. The system can only be used via internet connection.
2. The system can be used with the help of batteries on the field where AC current is not available.

2 Methodology - system overview

Figure 1 shows our proposed system. Our proposed system consists of 3 Nodes. Node 1 Consist of Arduino+Soil Sensor+NRF24L01 Module. Node 2 is consist of Arduino+NRF24L01+DHT11 Sensor+ESP8266 WiFi Module. Node 3 is consist of NodeMCU and Relay Module.

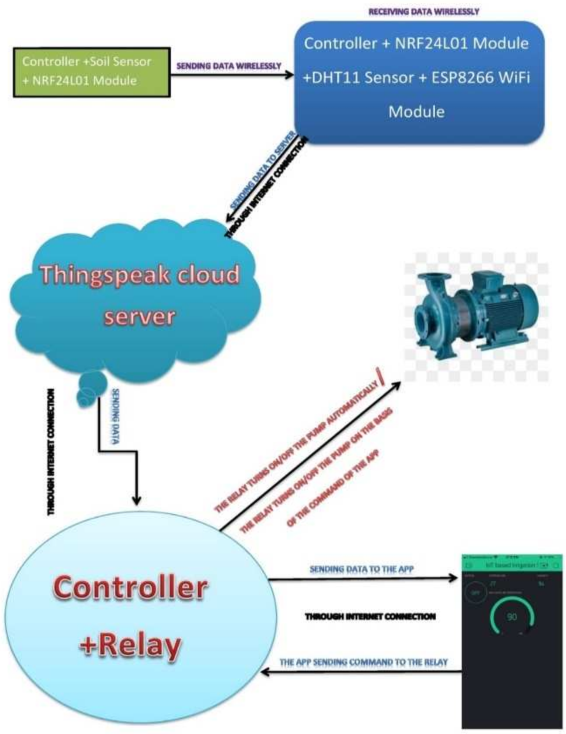

Figure 1 Proposed model

Figure 2 shows our working system. This diagram indicates how our 3 nodes are interconnected with each node.

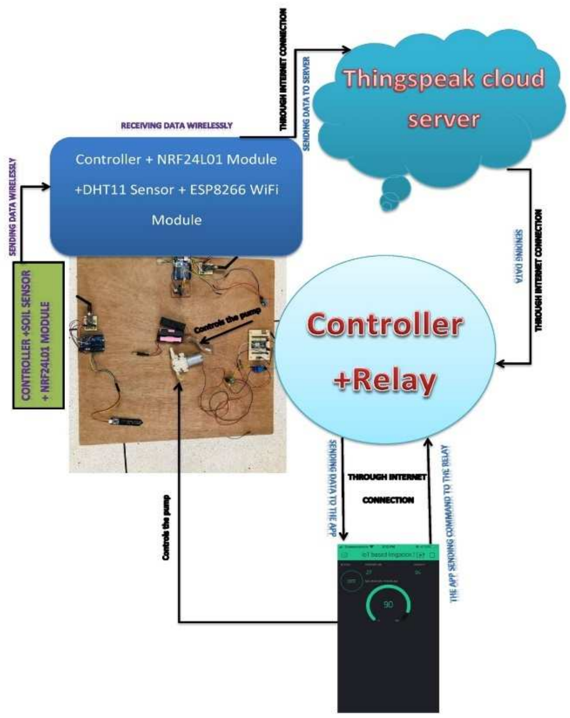

Figure 2 Working System

So, on the basis of our proposed system & working system, according to figure 1, figure 2 we can see that there are 3 nodes in our system. In Node 1, capacitive soil moisture sensor. Arduino Uno & nRF24L01 module are mounted with each other. Arduino Uno collects the soil moisture data and sending data wirelessly in Node 2. In Node 2 Arduino Uno, nRF24L01, DHT11 Sensor, ESP8266 Wi-Fi module is mounted with each other. The Node 2 receives data from Node 1 and collects the temperature and humidity data from DHT11 and sending all the data in Thingspeak cloud server with the help of internet connection. Where all the data get stored for lifetime and it can be monitored at any time, and we termed it as stored data monitoring. The Node 3 which is mounted with NodeMcu and relay module collects the data from the Thingspeak server and send wirelessly via Internet connection to a mobile app named Blynk which can be monitored in real time and the fact is called real time monitoring. The mounted relay can turn on or turn of the pump automatically as it is programmed. The pump can also be turned on or off by using the mobile app (Figure 3).

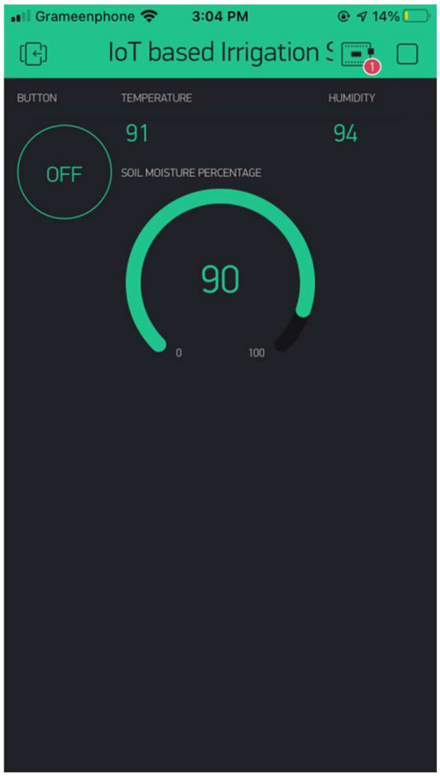

Figure 3 Mobile App (Blynk)

Thingspeak cloud server is an open server where any kind of data is stored by which all the system can be monitored. Figure 4 is showing how the data are plotted in the server and how it is storing all the data for monitoring.

Figure 5 is indicating our system architecture.

Figure 4 Thingspeak Cloud Server

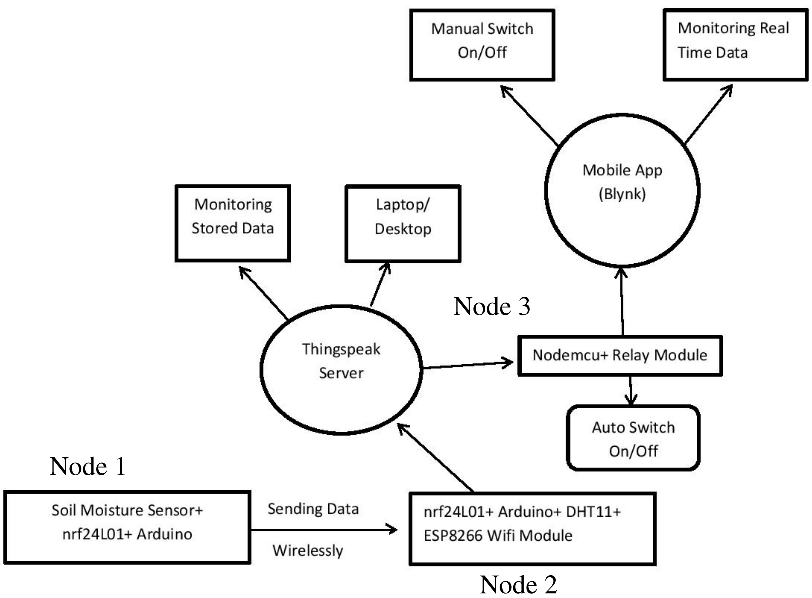

Figure 5 System architecture

Node 1: Node 1 is mounted with Capacitive Soil Moisture Sensor, nRF24L01 & Arduino Uno.
Capacitive Soil Moisture Sensor: The Sensor senses the data from soil.
Arduino Uno: The moisture data of soil is processed by Arduino Uno.
nRF24L01: It's a wireless module. The processed data are sent wirelessly to node 2 by nRF24L01.

Node 2: Node 2 is mounted with Arduino Uno, nRF24L01, DHT11 & ESP8266 Wi-Fi module.
nRF24L01: This module receives the data which is sent by the node 1 and gives it to the arduino.
DHT11: This module collects the data of temperature and humidity and gives it to the arduino.
Ardiuono Uno: It processes all the data.
ESP8266 Wi-Fi module: This module sends all the processed data to the thingspeak server via internet connection.

Node 3: It is mounted with Node MCU & Relay.
Node MCU: It receives the data from Thinkspeak Cloud Server and processes data and send them to the mobile app for real time monitoring and also gives command to the relay module.
Relay Module: This module can turn on or turn off the DC pump by the command of the Nodemcu.

2.1 *Methods and tools used*

Table 1 is showing the specification of our System. Which components we used here and how does it operates.

Table 1 Specification of a system

Item	Specification
Arduino Uno	ATmega328P – 8 bit AVR family microcontroller, Operating Voltage 6-20V, DC Current on I/O Pin – 40ma.
NodeMcu	ESP-8266 32-bit, Operating Voltage- 3.3V, Input Voltage- 4-10V, Flash memory- 4 MB/64 KB
Development Platform	IA-32, x86-64, ARM.
Language Used	Arduino C++
Code development	Arduino Softwere

Table 1 describes the specification of our system. In our system, we use Arduino Uno as our mother controller. We use Arduino C++ as our operating language and Arduino software is used for code development.

2.2 *Experimental setup*

IOT (internet of Things) part: Data are sent from Node 1 to Node 2. Node 2 receives the data & transfers the data to Thingspeak cloud server through internet. These data are received by Node 3 via internet. This is real time data monitoring. WSN (Wireless Sensor Network) Part: Data is sent from node 1 to node 2 wirelessly. NRF4L01 is mounted with it Automatic/Manual Control of the Pump through Mobile App (Blynk): the pump can be turned on or turned off automatically, the pump also can operate manually by using mobile (Figure 6).

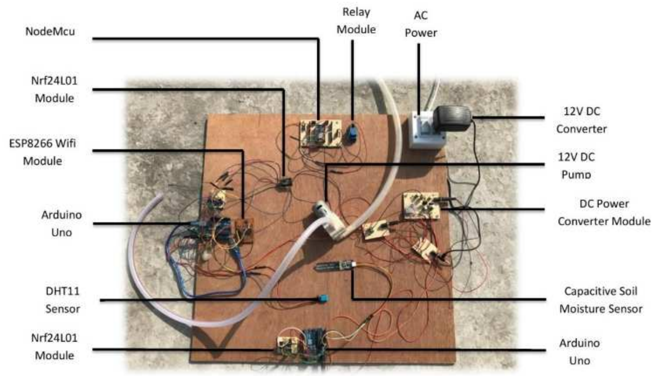

Figure 6 Experimental setup

3 Sensing system

Capacitive soil moisture sensor senses soil moisture data of soil (Figure 7). The sensor is mounted in node 1. In Node 1, there is an Arduino Uno & NRF24L01 module which sends data wirelessly to Node 2.

The Capacitive Soil Moisture Sensor Has Three Pins

1. 5V VCC Pin.
2. GND Pin.

Analog Reading.

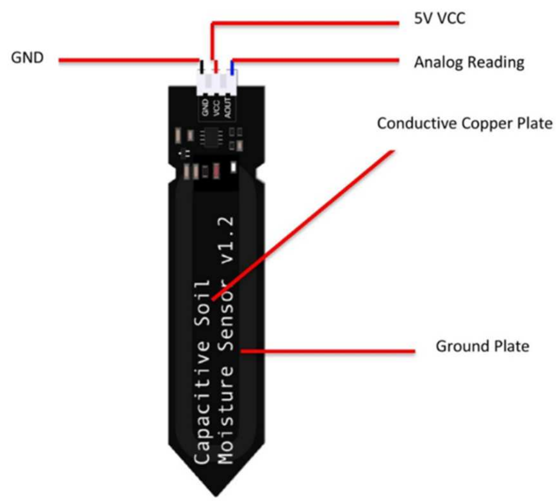

Figure 7 Sensing system Capacitive Soil Moisture Sensor

The 5V Vcc pin of the Sensor in connected with the Arduino from which the Sensor gets power to run the process. The Analog pin of the Sensor is connected with the A1 pin of the Arduino and the GND pin is connected with GND pin. When the Sensor is power up by 5V VCC then the Arduino gets the Sensor value through the pin A1 from the Analog Reading pin of the Sensor.

4 Circuit diagrams

Node 1 is mounted with capacitive soil moisture sensor, Arduino Uno & NRF24L01 wifi module (Figure 8). There are 3 pins in capacitive soil moisture sensor which are directly connected with Arduino Uno. The pins of NRF24L01 are connected with Arduino Uno. So, the pins are connected to each other like this.

NRF24L01	Arduino Uno
Pin CE	Pin 7
Pin CSN	Pin 8
Pin SCK	Pin 13
Pin MISO	Pin 12
Pin MOSI	Pin 11
Pin VCC	Pin 3.3V
Pin GND	Pin GND
Soil Moisture Sensor	Arduino Uno
Pin VCC	Pin 5V
Pin GND	Pin GND
Pin Analog Reading	Pin A1

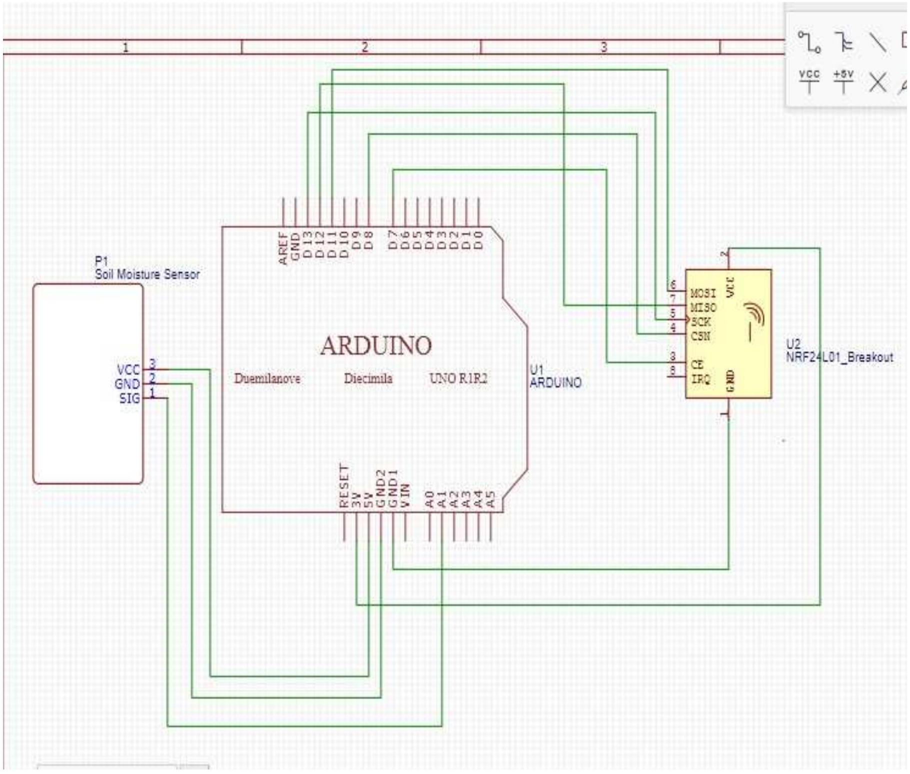

Figure 8 Circuit diagram of Node 1(Arduino+ nrf24L01+ Soil Moisture Sensor)

Node 2 (Figure 9) is mounted with DHT11 sensor, Arduino Uno, NRF24L01 wifi module and ESP8266Wifi Module. So, the pins are connected to each other like this.

NRF24L01	Arduino UNO
Pin CE	Pin 7
Pin CSN	Pin 8
Pin SCK	Pin 13
Pin MISO	Pin 12
Pin MOSI	Pin 11
Pin VCC	Pin 3.3V
Pin GND	Pin GND

DHT11 Sensor	Arduino UNO
Pin VCC	Pin 5V
Pin GND	Pin GND
Pin DATA	Pin 4
ESP8266 WiFi Module	Arduino UNO
Pin RXD	Pin 3
Pin TXD	Pin 2
Pin VCC	Pin 3.3V
Pin GND	Pin GND
Pin CH_PD	Pin 3.3V

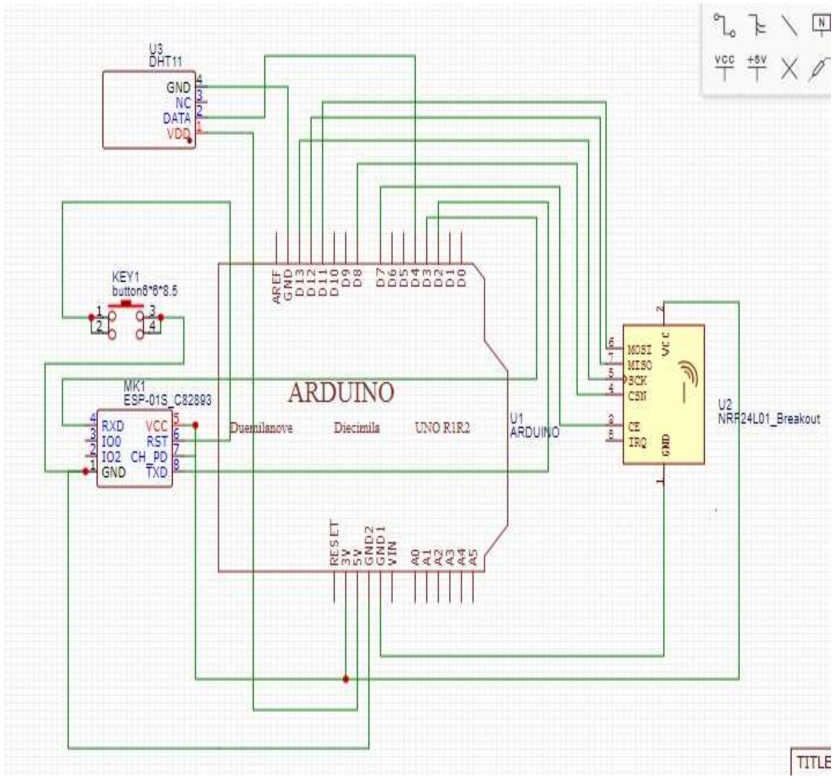

Figure 9 Circuit Diagram of Node 2(NRF24L01+ Arduino Uno+ DHT11+ ESP8266)

Node 3 (Figure 10) is mounted with NodeMCU and Relay module. So, the pins are connected to each other like this.

Relay Module	NodeMCU
Pin EN	Pin D8
Pin VCC	Pin Vin
Pin GND	Pin GND

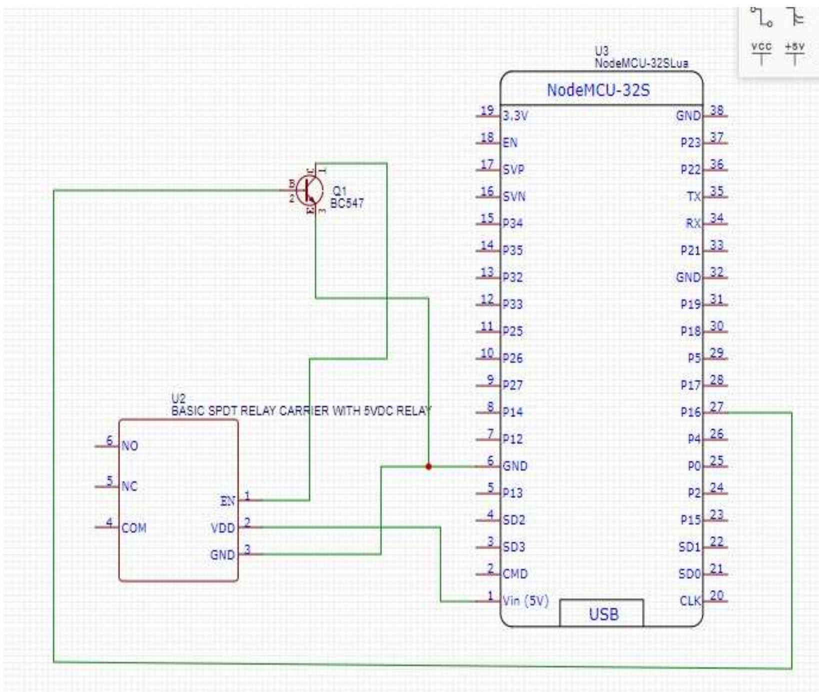

Figure 10 Circuit Diagram of Node 3(Nodemcu+ Relay Module)

5 Controlling system design

5.1 Algorithms and flow chart

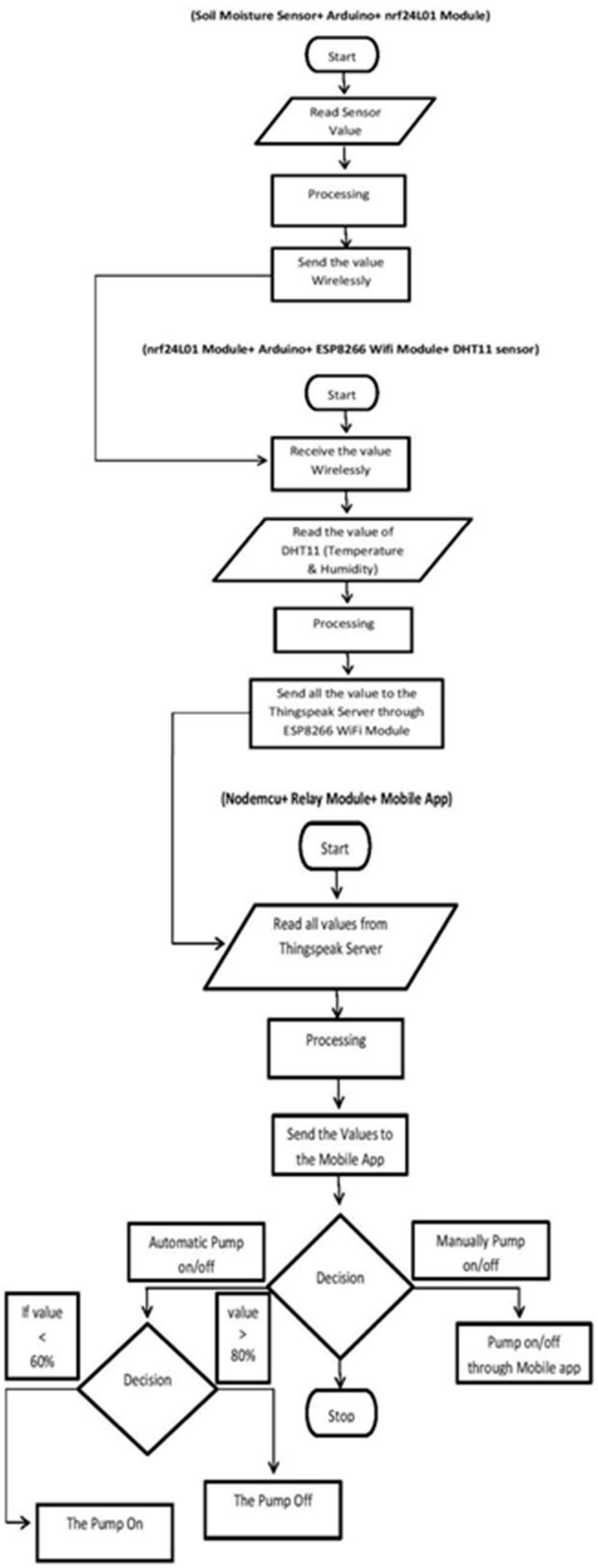

Figure 11 Flow chart of the system

Algorithm:

(Soil Moisture Sensor+ Arduino+ nrf24L01 Module)

Step 1.Start
Step 2.Read the value of the Soil Moisture Sensor
Step 3.Processes the Value on Arduino
Step 4.Send the Value Through nrf24L01 Wirelessly

(nrf24L01 Module+ Arduino+ ESP8266 Wifi Module+ DHT11 sensor)

Step 1.Start
Step 2.Receive the value Through nrf24L01 Module from the soil moisture Sensor node
Step 3.Read the values of Temperature and Humidity from the DHT11 Sensor
Step 4.Processes the values on Arduino
Step 5.Send all Values to the Thingspeak Server Through ESP8266 Wifi Module

(Nodemcu+ Relay Module+ Mobile App)

Step 1.Start
Step 2.Read the values From the Thingspeak Server Through Nodemcu
Step 3.Processes the values on Nodemcu
Step 4.Send the values on Mobile App (Blynk)
Step 5.Taking Decision to turn the motor automatically on/off or manually on/off.
Step 6.If The value of soil moisture is less than 60% the pump will automatically be turned on
Step 7.If the value of soil moisture is greater than 80% the pump will automatically be turned off
Step 8.The pump can be turned on/off through mobile app (Blynk) between the value 61% to 79%
Step 9.Stop

Flow Chart (Figure 11):

5.2 Working Principle of controlling System

Three major parts are involved here:

1. IOT (internet of Things) part: Data are sent from node 1 to Node 2. Node 2 receives the data & transfers the data to Thingspeak cloud server through internet. These data are received by node 3 via internet. This is real time data monitoring.
2. WSN (Wireless Sensor Network) Part: Data is sent from node 1 to node 2 wirelessly.nRF4L01 is mounted with it.
3. Automatic/Manual Control of the Pump through Mobile App (Blynk): The pump can be turned on or turned off automatically. The pump also can operate manually by using mobile.

5.3 Working Principle of controlling System

Node 1 is mounted with 1 unit Arduino Uno, 1-unit nrf24L01 & 1-unit capacitive soil moisture sensor. Total cost 850 tk (Table 2).

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Table 2 Cost estimation for Node 1

Sl. No	Item Name	Specification	No. of Unit	Unit Cost (TK)	Total Cost (TK)
1	Arduino UNO	ATMEGA-328	1	350	
2	Nrf24L01	single chip 2.4GHz	1	200	850
3	Capacitive Soil Moisture Sensor	PH2.54-3P	1	300	

Node 2 is mounted with 1 unit Arduino Uno, 1-unit nrf24L01, 1-unit DHT11 & 1 unit ESP8266 Wifi module. Total cost 900 tk (Table 3).

Table 3 Cost estimation for Node 2

Sl. No	Item Name	Specification	No. of Unit	Unit Cost (TK)	Total Cost (TK)
1	Arduino UNO	ATMEGA-328	1	350	
2	Nrf24L01	Single Chip 2.4GHz	1	200	900
3	DHT11 Sensor	150	1	150	
4	ESP8266 Wifi Module	32-bit microcontroller with IEEE 802.11 b/g/n WiFi	1	200	

Node 3 is mounted with 1-unit Nodemcu & 1-unit Relay module. Total cost 500 tk (Table 4).

Table 4 Cost estimation for Node 3

Sl. No	Item Name	Specification	No. of Unit	Unit Cost (TK)	Total Cost (TK)
1	NodeMcu	ESP-8266 32-bit	1	400	
2	Relay Module	5V switch	1	100	500

6 Results and discussion, experimental data

We have collected over 5000 data stored in the Thingspeak server which was collected in the indoor and outdoor situation at the format of excel (Figure 12).

From the above data we come to an point on some different issues like when the values of humidity, temperature, soil moisture got changed. So on the basis of this we have made some data tables which has been given bellow.

Some Specific values of Temperature, Humidity & Soil Moisture Percentage from the 5000 data have been given bellow (Table 5):

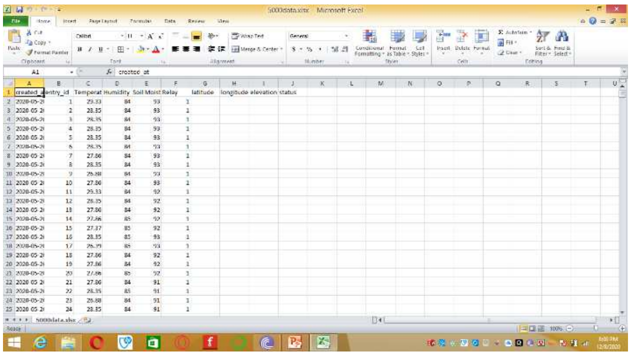

Figure 12 Collected data

Table 5 Some specific values of temperature, humidity, and soil moisture percentage

Date and Time	Temperature	Humidity	Soil Moisture Percentage
2020-05-23 04:45:00	26.88	84	88
2020-05-23 05:00:00	26.88	85	89
2020-05-23 05:15:00	28.35	85	89
2020-05-23 05:30:00	28.35	85	89
2020-05-23 05:45:00	28.84	85	89
2020-05-23 06:00:00	27.86	85	89
2020-05-23 06:15:00	27.37	86	90
2020-05-23 06:30:00	27.86	86	90
2020-05-23 06:45:00	26.88	86	90
2020-05-23 07:00:00	28.35	85	89
2020-05-23 07:15:00	27.37	83	89

On the basis of the over 5000 data (Figure 13, Figure 14) which was collected both on indoor and outdoor sides, we found that the values of the humidity and the soil moisture was decreasing.

So from all the data we get that the humidity and the soil moisture percentage was increased in the morning of 5AM-7AM. That is mean the humidity and the soil moisture percentage always increase in the morning.

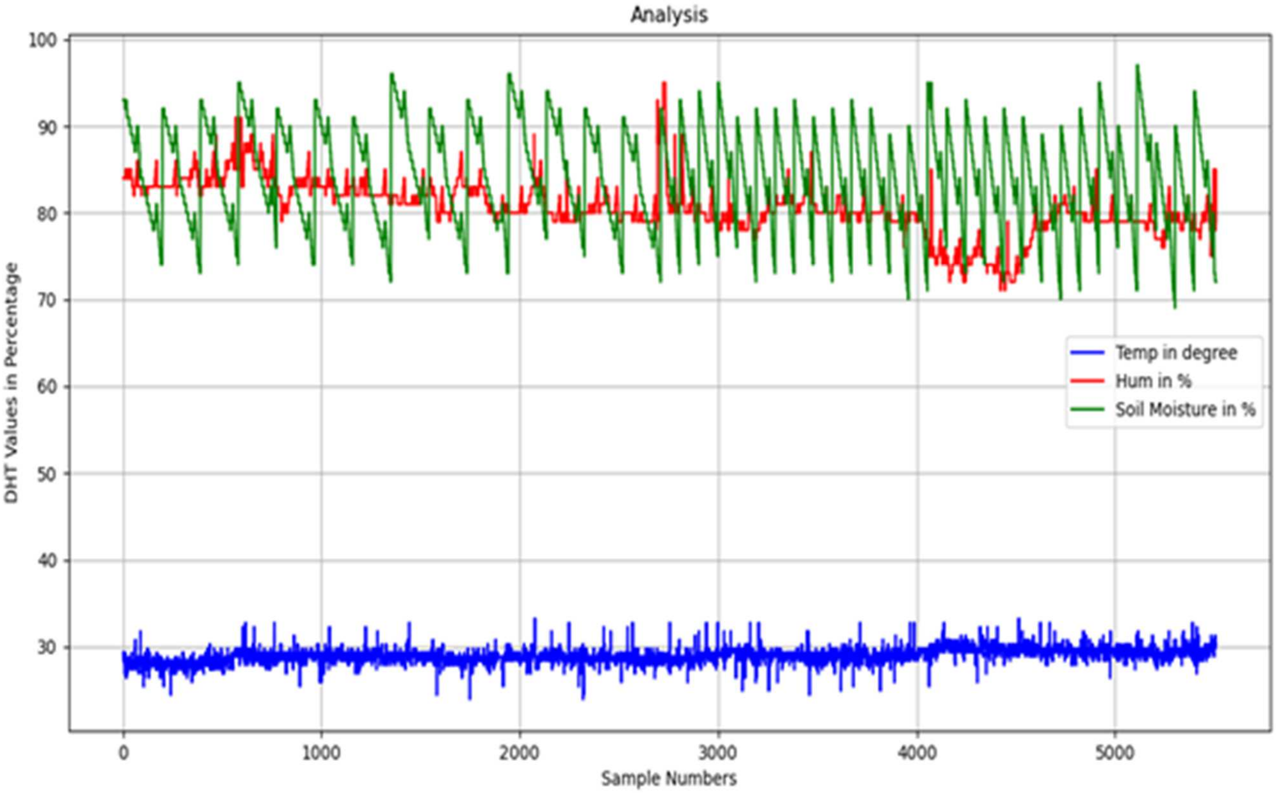

Figure 13 Graph of the indoor and outdoor position on the basis of over 5000 data

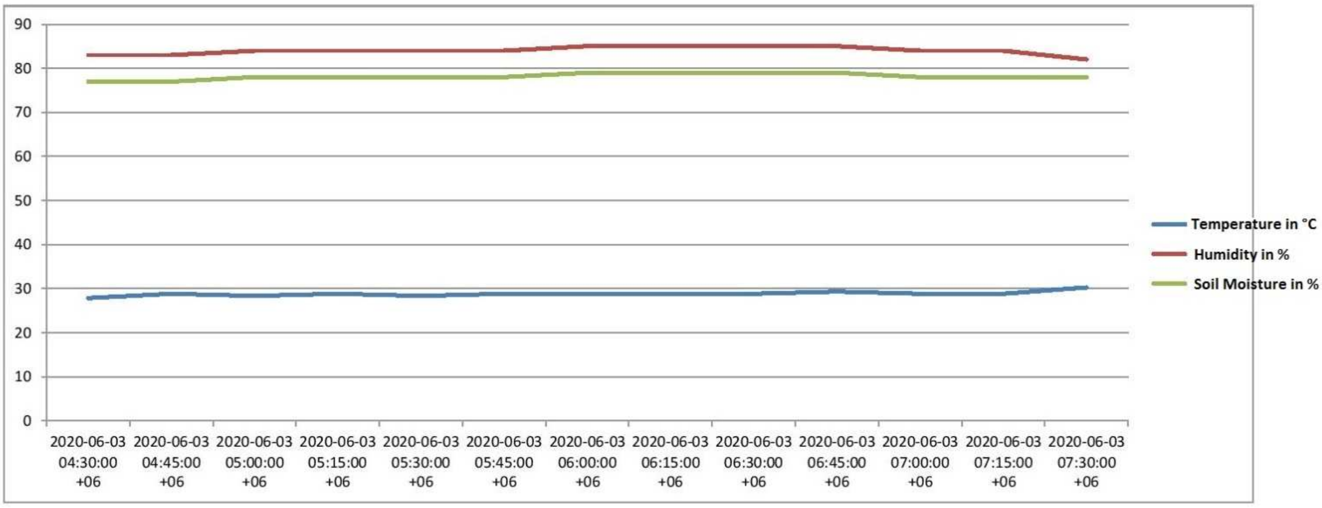

Figure 14 Represents the graphical view of the values

After determining the boundaries of a given area, a soil moisture sampling plan should be developed. The initial sampling should be performed in a small grid; however, it is important to maintain a minimum of twenty sampling points per acre for a good soil moisture characterization, covering the entire area [16], Subsequent soil moisture sampling can be conducted using a grid-based system.

During the time of our experiment we had faced some difficulties collecting data. The moisture content was suddenly fluctuated with the drastic change of outdoor and indoor temperature. For this scenario, there some error happened at the time of taking our moisture content. But after doing some calibration We could successfully complete our experiment.

7 Conclusions and future recommendations

The main achievement of our thesis is to build a system of real time monitoring and stored data monitoring of the soil condition during irrigation. As ours have an agriculturally based economy we have to be fully focused on maximum productivity. So, water wastage and soil monitoring during irrigation has to be done at a satisfactory rate so that maximum production can be ensured. The main objective of our thesis is to design a fully automated drip irrigation system and real time soil monitoring, stored data monitoring using IOT & WSN. The system provides an efficient monitoring of moisture, humidity and temperature content of soil. The data collected by the system can be used for further analysis purpose.

This project can be extended in future studies in order to improve the system in various aspects such as

This project can be used vastly in the rural areas of Bangladesh if Bangladesh agricultural ministry gives quality emphasize on this project. Then it would be made possible for the agricultural officers to monitor the farms without going to the lands. For this the farmers will be so much benefitted & at the same time production rate can be increased.

Online based warning system was not able to generate an alarm warning for insects. But it is very much needed thing to detect the insects for further decision making for the betterment of crop growth and another thing can be added in this research project and it is detection and distinguish the depredating insect sounds from other environmental sounds. For recognizing deficiencies, pests, diseases, and other detrimental agents in the vineyards an image processing method that can be added to the system.

Luminosity is a key factor of brightness analysis for estimating light radiation on plants can be applied for determining the sugar concentration, controlling the amount of sunlight received by the vines, and determining the optimum time for harvesting more accurately and timely. By utilizing luminosity sensors it can be measured that how much light radiation are falling to the crops or how it should be planted for better growth.

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EXPERIMENTAL VISION SYSTEM SETUP BASED ON THE SERIAL CONFIGURATION INTERFACE

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Keywords: data transfer, automation, communication, camera system
Abstract: Successful SME companies see indisputable advantages in implementing and image processing of vision systems. The proposed technical solution described in this article points to the need for deploying the advanced functions of vision systems to achieve the relevant computing power in the form of CCD cameras. It is expected to be used in a real-life automated consisting of, among others, a standard industrial robot. Here the starting point of the manufacturing process is the automatic selection and detection of arbitrarily oriented objects. In addition to the above, the article aims to point out the current progress in this area and draw attention to comparative methods within advanced camera systems. The resulting topics will gradually introduce us to the field of advanced image processing, where the use of functions such as object reconstruction or property estimation is assumed.

1 Introduction

Vision systems are, in general, systems that use a camera and various image analysing software to extract useful information from an image. These systems are flexible, highly adaptive, and can be used for a broad range of tasks like tracking moving objects [1], vibration, displacement and strain analysis [2], object position and orientation detection in manufacturing [3], etc.

Advantages that come from the implementation of vision systems in automated workplaces together with their impact cannot be disputed. This article is aimed at obtaining some chosen object characteristic, mainly the 3D coordinate information, using a vision system. The proposed solution (based on RS232C communication interface) can be considered as a relevant starting point to picture capturing, advanced sensing and object data processing followed by data processing with the help of a powerful pc workstation [4].

Verified technical solution – an experimental stand equipped with CCD cameras designed for easy implementation into a real manufacturing workplace that is containing a SCARA robotic arm. Its potential purpose is the automated selection and recognition of objects that arrive from oriented vibratory trays. Beside this, reliable automation of manufacturing processes can be reached by interconnection with an advanced control level (ERP, MAS etc...) [5]. Besides the experimental data obtained by using this stand, students, teachers and potential cooperating companies can acquire higher levels of skill and experience in the field of vision systems. TCP / IP communication protocol will be implemented during future research.

Apart from the above-mentioned properties, it is the aim of our experiments to apply comparative methods in combination with vision systems. [6]. Future research will be focused on processing of an object and determination of its properties via sensing from different angles and sides. As a next step, the captured information can be processed by dedicated software.

2 Communication

Data transfer between the robotic arm and the vision system is realized via RS232C communication channel. A both way communication with the use of serial channel during the process is assumed. [7]. The configuration process is followed by a cold start-up of the control system of the robotic arm.

Serial interface must be configured in respect to the operating system in a way suitable for transmission with the use of CREAD / CWRITE command, see Table 1, 2, and 3. Serial communication can be usually configured through CREAD / CWRITE according to the followed figure, see figure 1.

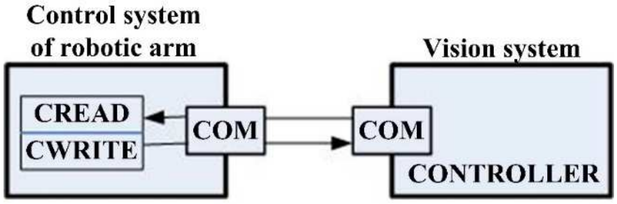

Figure 1 Setup of vision system

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Table 1. Configuration of serial interface

1.	[COM3]	
2.	BAUD = 9600	;110, 150, 300, 600, 1200, 2400, 4800, 9600, 19200, 38400, 57600
3.	CHAR_LEN = 8	;7, 8
4.	STOP_BIT = 1	;1, 2
5.	PARITY = 2	;EVEN = 2, ODD = 1, NONE = 0
6.	PROC = 1	;3964R = 1, SRVT = 2, WTC = 3, XON/XOFF = 4

Table 2. Configuration of transmit protocol 3964R that is used for the data transfer

1.	[3964R]	
2.	CHAR_TIMEOUT = 500	;msec, max. interval between two symbols
3.	QUITT_TIMEOUT = 500	;msec, max. waiting time at control system of robotic arm – to symbol DLE
4.	TRANS_TIMEOUT = 500	;msec,
5.	MAX_TX_BUFFER =2	;1..5, max. value of cache output
6.	MAX_RX_BUFFER = 10	;1..20, max. value of cache input
7.	SIZE_RX_BUFFER = 1..2048	;dimension of receiving memory input (in bytes)
8.	PROTOCOL_PRIOR = 1	; HIGH = 1, LOW = 0, priority

Table 3. An example of successful communication between both systems (vision system and control system of robotic arm)

1.	DEFDAT SEND
2.	;DECLARATION
3.	INT HANDLE
4.	DECL STATE_T SW_T, SC_T
5.	DECL MODUS_T, MW_T
6.	ENDDAT
7.	DEF SEND ()
8.	;INITIALIZATION
9.	MW_T = #SYNC
10.	;INSTRUCTION
11.	OPEN_P()
12.	WRITE()
13.	CLOSE_P()
14.	END

3 Experimental testing - Setup

Main aim of the experiment on the vision system OMRON F150-3 is to experimentally verify its declared properties, in-build functions and fields of use, especially the task of determining chosen object characteristic. Through this system it is possible to determine an observed object position in a working envelope, followed by the determination of coordinates of the centre of gravity (x, y, z), as one of the goals, in this paper [8]. The control system of the robotic arm uses this information to determine the next motion of the arm.

The core of the introduced solution is the task of estimating the position of the centre of gravity of an object in 3D space. By using step sequencing together with the help of two CCD camera systems precise methodological verification of measurements were reached. As key parameters of the vision systems (OMRON F150-3) are considered resolution (512x484), field of view (in our case = 0 because were not used additional source of light) and focus (35mm).

Through the use of auxiliary light sources in this technical solution it is possible to sense an object with minimum rectangular envelope cross section of 50x50mm from a distance up to 76mm. Experimental setup of the measuring stand requires the implementation of complex control, input - output and communication peripherals, mainly: control system for postprocessing, CCD camera systems with 35mmm lens, console, monitor and corresponding cables. The CCD cameras are directly fixed to an aluminium frame of modular construction, see figure 2.

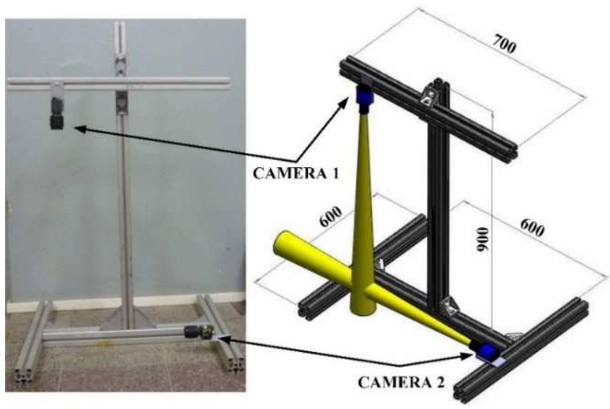

Figure 2 Realized technical solution – measurement experimental stand with CCD cameras

The outlined technical solution utilizes two CCD cameras mounted as seen in Figure 2 in order to be able to capture all object data coordinates [9]. This way, we try to avoid camera placement, which would not yield enough „ z" coordinate axis data (shape, depth, high of the sensing object).

With respect to this requirement, the CCD cameras have been mounted in a coplanar fashion with the axis of the lenses perpendicular to one another and pointing towards the same point. The vertical CCD camera system is determining the object parameters in „x“ and „y“ axis. Coordinate „z“, as the third supplementary axis, will be evaluated with the help of the horizontal camera system.

3.1 Necessary steps for acquiring the coordinates of the scanned object

The purpose of the following steps is to describe and present all necessary activities and functions needed for successful measurement. Firstly, both CCD camera systems need to undergo initial calibration, as is described in figure 3. This step contains several sub-activities, for example vision system start-up followed by CCD camera system registration and specification of additional light sources [10].

After these sub-activities it is necessary to set up and specify a processing mode type that is required for the next processing. Depending on the current lighting conditions the exposition time of the CCD camera needs to be adjusted.

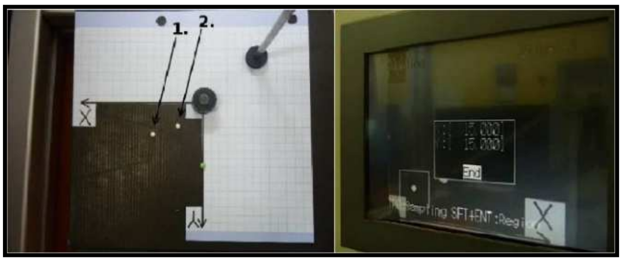

Figure 3 Initial calibration of CCD cameras

With the help of an accurate digital measurement instrument, the coordinates for the first calibration point were determined as [x = 25mm, y = 10mm, z=15mm] and for the second calibration point as [x = 30mm, y=15mm, z=15mm]. Two calibration points are sufficient for calibration because the magnification scale in axes „x“ and „y“ is the same. An additional step of CCD camera system setup is object presence detection (if it is in the working envelope for both CCD cameras), see figure 4.

Density averaging function (that is included in the vision system) was used on the measurement area. Basically, this function compares the two pictures brightness and evaluates them based on their grey scale [11].

Following this, an overall brightness average is determined with the measurement (firstly for the empty area, second for the area with sensed object).

Figure 4 Detection of scanned object presence

The result of the verification process of the sensed object, in regard to the relevant lighting conditions, is the evaluation of the overall pixel density. The average density value of measured area was 74.451. In order the measurement to be correct it is necessary to set colour black/white colour threshold bounding conditions.

The next step is the identification of coordinate axes „x“ and „y“ for the sensing object by using the gravity and area function. Following this the area of the sensed object is calculated as is viewed from the top. Sensed object is represented by white pixels and the remaining area is black, see figure 5.

Figure 5 Determination of “x” and “y” coordinates

Next step consists of determining the parameters tied to the „z“ axis like the shape, depth and high of the sensed object, see figure 6. A sub-activity of this step consists of post-processing applied to the captured picture from vision system in a way that the edge position function was successfully applied to the sensed object. This function is characterized by the ability to detect the edges of the sensing object, provided there is sufficient contrast between the object and the environment. By applying this process, we can evaluate (in the appropriate direction) edges of the sensed object with respect to the simultaneously used functions “light to dark” (if is the sensed object is dark and the background is bright) or “dark to light” (if is the sensed object is bright and background is dark).

Figure 6 Determination of "z" coordinate

The last step consists of the determination of coordinates of the centre of gravity of the sensed object, which we determine by a simple mathematical operation [x, y, z/2] – because the centre of gravity is determined at the middle of the object. Information that was obtained by this principle is then transferred into the computer via RS232C serial interface for advanced processing (coordinates transformation from external coordinate system to the coordinates of robotic arm control system).

Relevant information is sent directly to the control system of the robotic arm. We can state that the lighting conditions (light uniformity) and vertical camera system distance from the sensed object have majority influence on the results.

4 Conclusion

Existing classical approaches and techniques for determination of some necessary sensing object characteristic do not meet relevant needs of the automotive engineering industry and end customer needs. 3D vision sensors, as the main representative of vision systems, are an important key device for the automated assembly workplaces in order to enlargement its peripheral abilities and possibilities in the sense of industry 4.0 concept.

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BRISTLED PIPE ROBOT WITH ADJUSTABLE BRISTLES

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Keywords: pipe robot, locomotion, bristle, pipe
Abstract: The bristled pipe robot moving in the pipe on the principle of friction difference is intended for locomotion in the pipe using the friction difference between the bristles and the pipe's inner wall. The robot consists of an electromagnetic linear actuator, on the frame of which the rear bristle block is attached and on its extension rod, the front bristle block is placed. The bristle blocks contain three bristle carriers and clamps. The bristles are the contact elements between the robot and the pipe's inner wall. The geometry of the bristles can be adjusted using the adjusting elements. The bristles are mounted on the robot so that the span of their free ends is greater than the inner diameter of the pipe, thus creating the desired normal and frictional force between the pipe wall and the bristle ends. The bristles are mounted at a mounting angle concerning the robot axis, thus creating a difference in friction between the pipe wall and the bristles as they move back and forth, resulting in a forward movement of the robot.

1 Introduction

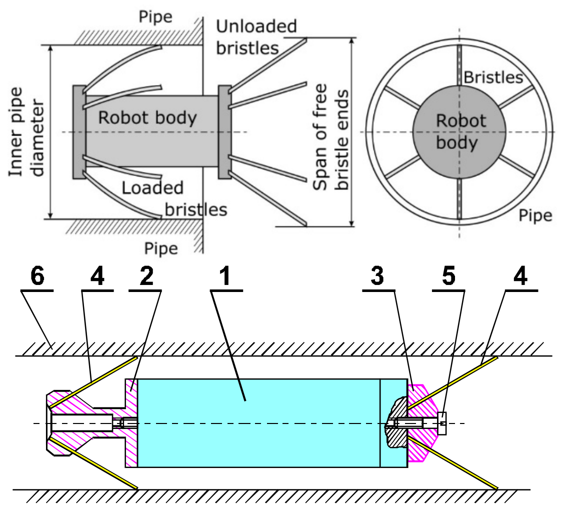
If we imagine a vehicle moving on a solid surface, most of us imagine a kind of "monster" with wheels. However, it is not just the wheels that move the world, and in some situations, the wheels cannot cope, and what we often see on snowy and icy roads will happen. Therefore, unconventional types of contact elements between the moving means and the surface are increasingly used. The vast majority of them are inspired by biological patterns. All we need is a look at the fascinating movement of a spider, caterpillar or cockroach, etc.

Pipe robot move in the pipeline, and their task is mostly inspection work, repair of the pipeline or installation of cables in the pipeline, or other special tasks. With the decreasing inner diameter of the pipe, wheel slippage becomes a serious problem, especially in the case of dirty pipes.

Instead of wheels, it is possible to use, e.g. bristles. Then we are talking about a bristled in-pipe robot (fig. 1). This article deals with the application of bristles in the role of supporting elements for pipe robot. Bristles are bending springs that are embedded at one end. Bristles are often used in common practice, e.g. for sealing the bearing spaces of rotating parts, which are exposed to extreme conditions (high pressure and temperature, the presence of aggressive substances, etc.) [1-21].

2 Robot motion analysis

In the case of the solved in-pipe robot, the bristles are mounted on two modules around the circumference while they are positioned diagonally (obliquely) with respect to the axis of the robot and the pipe. A suitable actuator is to achieve a cyclic change in the distance between these bristle modules and, due to the existence of a friction difference between the bristle and the inner pipe wall as the bristle moves back and forth, the entire robot moves. The choice of the use of diagonal bristles (fig. 1) results from the experience in solving pipe robot within the solved research tasks. The problem is to design the bristles so that the movement of the robot is as efficient as possible.



1 - actuator; 2 - front bristle block; 3 - rear bristle block; 4 - bristles; 5 - screw for fixing the bristle block; 6 - pipe

Figure 1 The principle of locomotion of a pipe robot

To derive the mean speed of the V_S robot, it is possible to use the extended Hamiltonian principle for steady oscillation of the actuator. A representation of Hamilton's principle is that the robot moves to minimize the overall work done by the robot. This work includes W_{IW} work done on the inner wall of the pipeline and external W_E work. If we assume that the actuator will perform harmonic movements, then the speed of movement of the bristle end in the direction of the robot's movement is approximately described by (1), (2):

$$v_1 = v_s + v_b(\omega)\cos(\omega t) \tag{1}$$

$$v_2 = v_s - v_b(\omega)\cos(\omega t) \tag{2}$$

Where:

ω - angular velocity of the actuator,

v_S - steady speed actuator.

The speeds v_1 and v_2 represent the bristle ends of the front and rear bristle blocks.

The total work done by robot W is determined by (3):

$$W = W_E + W_{IW} \tag{3}$$

Where the work done by the front bristle block on the inner wall of the robot is (4):

$$W_{IW1} = \int_{-\frac{T}{4}}^{t_1} N_0\mu_2 v_1 dt - \int_{t_1}^{t_2} N_0\mu_1 v_1 dt + \int_{t_2}^{\frac{T}{4}} N_0\mu_2 v_1 dt \tag{4}$$

And the work done by the robot's rear bristle block on the inner wall is (5):

$$W_{IW2} = \int_{-\frac{T}{4}}^{\frac{T}{4}} N_0\mu_2 v_2 dt \tag{5}$$

The external work of the robot is defined by the relationship (6):

$$W_E = \frac{F \cdot v_s T}{2} \tag{6}$$

Where F is the traction force that can be derived from this relationship.

The steady speed of the robot can then be derived in the form of (7):

$$v_s = \frac{\pi\left[2(\mu_1 - \mu_2) - \frac{F}{N_0}\right]}{4(\mu_1 + \mu_2)} \cdot v_b \tag{7}$$

The pipe robot is designed for movement inside the pipeline for the purpose of inspection or repair of damaged pipeline or for the purpose of transporting cables or other equipment inside the pipeline. Existing solutions usually use the wheeled principle of movement in the pipeline, but this principle of motion is ineffective if the inner wall of the pipeline is covered with dirt and deposits. The subject of this work is a robot that allows movement in the pipeline by means of bristles, which are contact elements with the wall of the pipeline and allow movement even along the dirty wall of the pipeline.

3 The principle of the robot's function

The robot is designed to move inside the pipeline. The contact elements of the robot are three bristles placed evenly around the perimeter of the robot in two blocks - front and rear block. The bristles are attached to the robot so that the span of their free ends is larger than the inner diameter of the pipe, and thus when the robot is inserted into the pipe, the bristles are deformed and a normal contact force and frictional force is created between the robot and the inner wall of the pipe (fig. 1). The bristles are held at a mounting angle with respect to the axis of the

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robot, so that when the bristles move, there is a difference in frictional force. This means that the friction force between the bristle and the pipe wall is less when moving in the direction of the bristle bevel than when moving in the direction against the bristle bevel (fig. 1, 2).

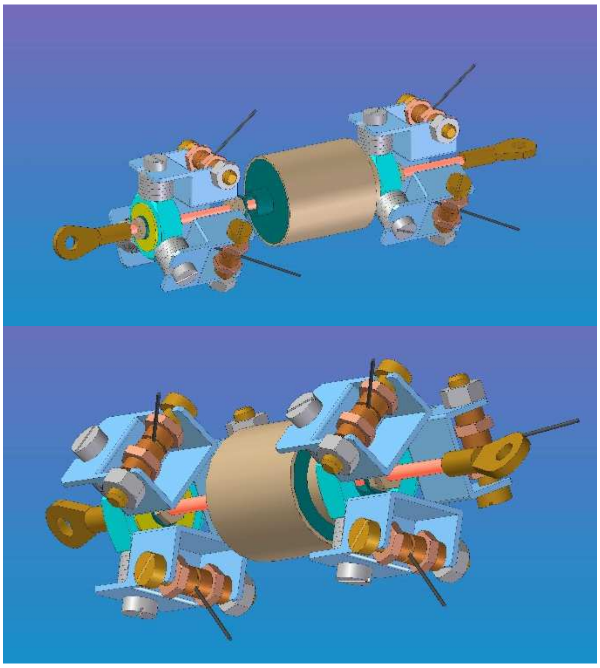

Figure 2 Pipe robot arrangement with adjustable bristles

The rear bristle block is attached to the frame of the linear electromagnetic actuator coil. The front bristle block is attached to the extension rod of the linear electromagnetic actuator. Activation of the linear electromagnetic actuator cyclically extends and retracts the extension rod, thus creating a change in the relative position of the front and rear bristle blocks. The difference in the frictional force of the bristles will cause the robot to move forward (fig. 2).

The essence of the robot is that the friction difference between the bristles and the inner wall of the pipe is used to create a movement of the robot in the pipe.

The advantage of this piping robot solution is that it allows movement even in piping that is dirty and contains deposits.

Another advantage is that the robot allows to adjust the geometry of the bristles - the length of the bristle attachment, the mounting angle of the bristles and the distance of the bristle attachment from the axis of the robot. By optimally adjusting the geometry of the bristles, it is possible to achieve that the return movement of the bristles is minimal and thus it is possible to achieve the phenomenon of self-locking of the return movement of the robot, thus increasing the efficiency of the robot movement in the pipeline (fig. 3).

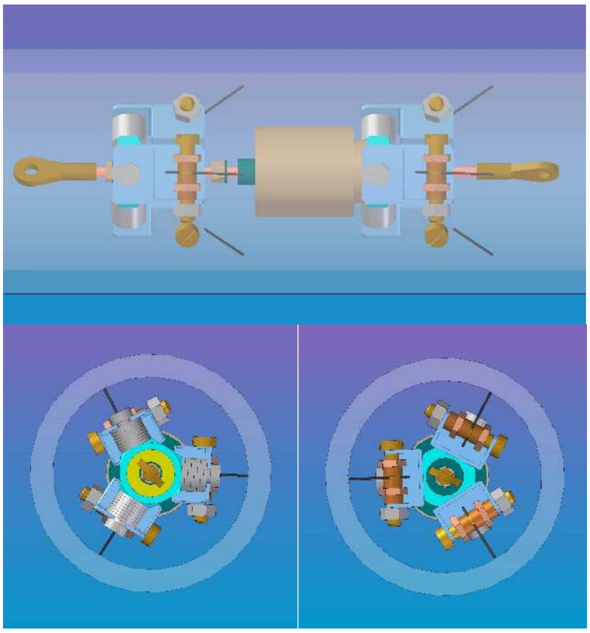

Figure 3 Pipe robot in the pipeline

4 Realisation of a pipeline robot

The robot comprises an electromagnetic linear actuator (1) for creating a linear reciprocating motion (fig. 4). A rear bristle block (3) is attached to the frame of the linear electromagnetic actuator (1).

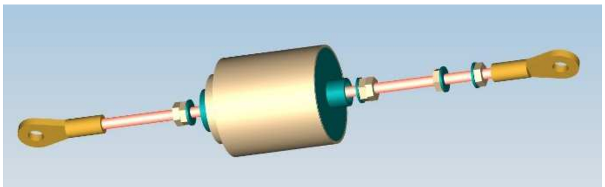

Figure 4 Electromagnetic linear actuator

The front bristle block (2) is attached to the extension rod (9) of the electromagnetic linear actuator (1) (fig. 5). The front bristle block (2) and the rear bristle block (3) are identical.

The bristle block (2, 3) comprises three bristle carriers (4), in which bristle clamps (6) with inserted bristles (5) are inserted. The bristle clamp (6) allows you to adjust the length of the free end of the bristle (5) and the mounting angle of the bristle (5). The carriers (4) are fastened with screws (7) for fastening the bristle carrier to the bristle block (2, 3) (fig. 6, 7).

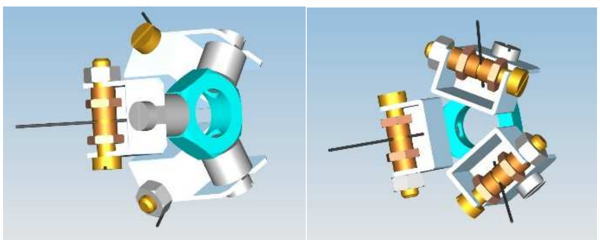

Figure 5 Bristle block

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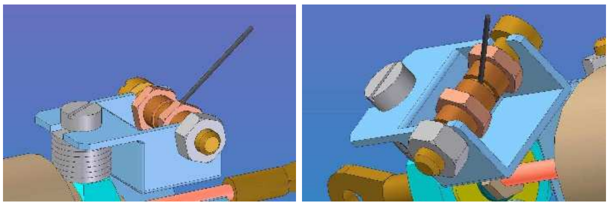
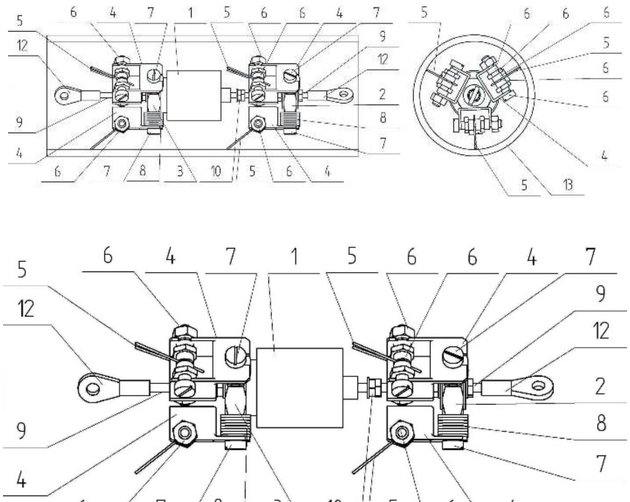


Figure 6 Bristle geometry adjustment mechanism



1 - Electromagnetic linear actuator; 2 - Front bristle block; 3 - Rear bristle block; 4 - Bristle carrier; 5 - Bristles; 6 - Bristle clamp; 7 - Screw for attaching the bristle carrier to the bristle block; 8 - Spacers for adjusting the distance of the bristle from the robot axis; 9 - Linear actuator extension rod; 10 - Actuator stroke adjustment nut; 11 - Nuts for securing the front bristle block to the actuator extension rod; 12 - Actuator hanging eye; 13 - Piping

Figure 7 Pipe robot components

Under each bristle carrier (4), spacers (8) are inserted to adjust the distance of the bristle (5) from the axis of the robot. To adjust the stroke of the linear electromagnetic actuator (1), nuts (10) for adjusting the stroke of the actuator are arranged on the extension rod (9) of the actuator. The front bristle block (2) is attached to the extension rod (9) of the linear electromagnetic actuator by means of nuts (11) for holding the front block. The robot moves in the pipe (13) by cyclically changing the stroke of the actuator, using the difference of friction between the bristles (5) and the wall of the pipe (13). On the extension rod (9) of the electromagnetic linear actuator (1), suspension eyes (12) are attached for attaching the guide wire (fig. 7, 8).

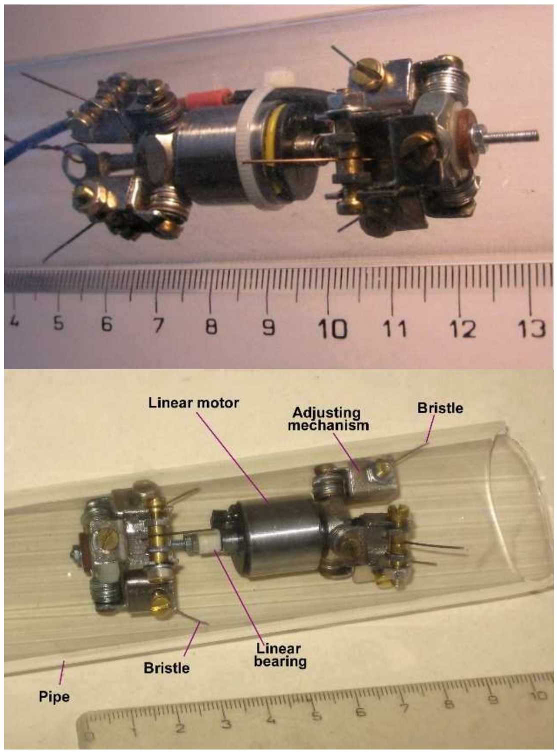


Figure 8 Pipe robot prototype

The overall dimensions of the prototype (fig. 8) are 25 mm in diameter and 80 mm in length. The robot was tested for pipes with an inner diameter of 35 mm. In this pipeline, the robot reached a maximum speed of 50 mm / min. But this is still the subject of further research in the future to find the optimal geometry to achieve the maximum speed and traction of the robot.

5 Conclusion

The application of bristles in the role of supporting elements for a pipe robot brings with it a number of advantages in the form of elimination of slippage on the contaminated inner surface of the pipe and better adaptation due to geometric deviations in the size and shape of the pipe. Their application is especially important for pipes with a small inner diameter (less than 25 mm). This work was focused on the design of a mechatronic system for a specified purpose, and other works are known from practice, where a similar methodology is followed [22-33].

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