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Experimental Performance of Mobile Robotic System by Involving IoT Technique

Ravi Kant Jain
CSIR-Central Mechanical Engineering Research Institute, Durgapur 713 209, West Bengal, India

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In this paper, a concept for the mobile robotic system by using enabling IoT technique is described and architecture for enabling the mobile robotic system using web application is also discussed. The mobile robotic system is controlled through web-based applications and the air quality of the environment is also measured. A node Micro Controller Unit (node MCU) for wireless communications is used which is interacted with robots and their microcontroller. This node MCU uploads the data to the cloud network system. The robot can be remotely controlled using web applications and data are sent and stored in the cloud successfully. By demonstrating the robotic system capabilities, it is revealed that web-based applications can be used for controlling and monitoring the robotic system, and data can be stored which can be accessed from anywhere through mobile android applications. Thus, this gives an affordable solution for accessing/monitoring the pipelines/tunnels of coal mines, oil pipelines, etc. where the exploitation of the human being is very difficult. The use of the IoT cloud also facilitates storing data which leads to a new generation of the robotic system.

Keywords: Cloud platform, Sensor integration, Web-based application, Wireless communications

Introduction

Nowadays, mobile robot technology has been used commercially in medical, industrial, agriculture, military, defence, and domestic applications, etc.[1] Using mobile robots, the different space missions have been explored in various ranges like a lunar robot, Hubble space telescope robot, mars express robot, autonomous pop-up flat-folding explorer robot, etc. where major advantages of mobile robotic systems are that the sensor integration and computer vision technologies can be used to find the environment of space using array matrix system. This provides monitoring of the space in actual/real-time. This kind of technology can also be used in different industrial applications where monitoring of remote locations is required. In the past, Dr. William Grey Walter from Bristol, UK has built the first mobile robotic system in 1948. Further, the first industrial robot of UNIMATE was commenced by the General Motors factory, New Jersey in 1961.[(2)] The researchers have been continuously providing efforts in these kinds of mobile robotic systems. The primary function of the mobile robotic system is to allow movement along with their payloads and carry out the multifunctional tasks through an onboard system. In industries, mobile robotic systems have been used mostly in warehouses and distribution centers, medicine, surgery, security, personal assistance, etc. Internet-of-Thing (IoT) is an advanced Information Communication Technology (ICT) that interconnects different computing devices. By providing a network or pathway system, the digital/mechanical machines transfer the data with the Human-to-Machine Interface (HMI) or Human-to-Computer Interaction (HCI). These kinds of IoT devices can be used for general to specific tasks in robotic systems where the wired robots cannot perform unforeseen conditions. The cooperation of the IoT and robotic systems creates a new paradigm named the Internet of Robotic Things (IoRT).[3] In this concept, smart/intelligent devices can connect to each other's and allow to control the robot and monitor the surrounding remotely where the use of local and distributed intelligence decides the particular step/action and afterward manipulate/control objects in the real world remotely. This kind of IoRT concept shows the vision of mobile robotic systems as a new method for performing autonomous tasks. In this context, the major objective of this paper is to design a web application for mobile robotics using IoT platforms that reduce human involvement in controlling the excess gas in the different inaccessible areas of industry like pipelines/tunnels, etc. This also

Author for Correspondence
E-mail: rkjain@cmeri.res.in; jainravikant@gmail.com

minimizes the cost of labour by providing a robotic system. This can be controlled and accessed through android/mobile phones anywhere. This paper focuses on the following major points as under

a) Development of a mobile robotic system
b) Design a control architecture for web-based applications toward real-time controlling and monitoring applications
c) Experimental performance to find the air quantity and quality in the environment during the operation of the robotic system
d) Monitoring and storing data in the cloud for establishing their analytics

Literature Survey on IoT Based Technology for Robotic Applications

In the recent past, some researchers have attempted IoT-related activities in the control of robotic systems and Graphical User Interface (GUI) applications. Griecoa *et al.*[4] have addressed the technological interventions, their applications, and challenges in the IoT-enabled systems in the robotics area. Butkar *et al.*[5] have attempted a pick & place robotic arm with a soft gripper that is remotely operated using any smartphone whereas Khoje *et al.*[6] have focused on controlling the wheels of the robot that is integrated through smartphones where a Bluetooth module is used for data communication purposes. Turcu *et al.*[7] have presented the integration of robots with the IoT where the potential of IoT and robotics-related technologies are discussed. Simon[8] has presented the concepts of IoT from the autonomous mobile robot's point of view where the properties of barcodes, QR codes, RFID, active sensors, and IPv6, objects are fitted for readability and traceability of the system. Dutta *et al.*[9] have addressed the technological aspect of security which can be enhanced using IoT-aided robotics where the networked robots can perform the tasks in complex environments. Fathima *et al.*[10] have implemented a methodology for the integration of Cloud and IoT with the robotic system. This method can be used for the communication of various types of robotic systems. He *et al.*[11] have developed a cloud-based application and its corresponding cloud driver for connecting the robot and the cloud where a cloud-based real-time control system provides better multi-robot collision avoidance. Surekha *et al.*[12] have focused on the localization of an autonomous mobile robot for refinery inspection using IoT where wi-fi devices are used for communicating with the robot and an algorithm is developed and tested to minimize the number of wi-fi access points and their locations in any given environment.

Kamburugamuve *et al.*[13] have developed an algorithm based on cloud computing for implementing the Simultaneous Localization And Mapping (SLAM) towards mobile robots to enhance the accuracy of the resulting map when the robot performs onboard computer tasks. Dhayalini *et al.*[14] have implemented a Raspberry pi control system in a mobile robot for military applications where a webpage is developed for controlling the movement of the robot. This mobile robot can be controlled using IoT for suitable applications in the military. Mahesh *et al.*[15] have attempted the control the mechanical movements of the robot through a remote system using web applications. A camera is also integrated into the robot for visualization of the environment. Cho *et al.*[16] have proposed a robotic software platform for IoT-based context-aware services where the robot software platform is designed using an ontology agent, robot service execution engine, and context handler. Simoens *et al.*[17] have shown a vision of IoRT which combines pervasive sensors and objects with robotic and autonomous systems. Pandure *et al.*[18] have provided the mechanism of the rover for monitoring/surveying the place by using the self-navigation method. Whereas Lee *et al.*[19] have proposed a Cyber-Physical Autonomous Mobile Robot (CPAMR) framework for IoT infrastructure systems that is capable of human-machine interaction by permitting users to place and handle orders using a cloud platform. Tzafestas[20] has explored a concept of IoT-AI synergy where the concepts of IIoT, IoRT, and Industrial Automation IoT (IAIoT) are summarized and different case studies are presented.

Oltean[21] has focused on a low-cost solution for controlling the mobile robot which is operated by Raspberry Pi and Arduino Uno microcontroller. This kind of mobile robot can be used for 2D mapping, path planning, obstacle avoidance, and navigation features. Singh *et al.*[22] have attempted the implementation of IoT and IIoT protocols for data collection, visualization, and analytics in cyber-physical system control stations, manufacturing machines, and a collaborative robotic system. Skanda *et al.*[23] have attempted an IoT-based camouflage army robot where multi-functional sensors, wireless cameras, and color sensors are used for camouflaging features for defense applications. Durmu *et al.*[24] have attempted the integration of the mobile robot along with greenhouses and then sent this gathered data to the web application or cloud using defining the classified on the web application or cloud. Song *et al.*[25] have described modern network and communication technologies where networking plays a vital role in robots, the system architecture and properties identification, as well as developments in the cloud system and fog robotics, are also explored. Salman *et al.*[26] have emphasized combining autonomous and non-autonomous robot features where the robot can be monitored the environment of a closed room during the entering of unauthorized humans and send an alarm message with push-button in the android mobile application. Faigl *et al.*[27] have addressed the problem of the inspection and path planning of a mobile robot using a sensor placement algorithm where the given workspace is identified. This is based on sensing locations along with the length of the inspection path. Jain *et al.*[28] developed a mobile robotic system that is controlled through an IoT-based system.

Elouerghi *et al.*[29] have attempted the diagnosis of early breast cancer detection which is based on embedded micro-bio heat ultrasensitive sensors This is connected with IoT technology and sends information to a smartphone. Chowdhury *et al.*[30] have proposed an android application for diagnoses of breast cancer in the early stage where the user can easily upload an image and get results aided by the deep learning method. Arslan *et al.*[31] have attempted an abstraction method for assembly tasks with encoding and control of multi-robot systems by using hierarchical clustering. So, the yielding can be done in a precise manner for flexible organizational specifications at selectively multiple resolutions whereas Wong *et al.*[32] have focused on a clustering-based algorithm that can solve spatially constrained robotic manipulation tasks with a sequencing problem. This can be applicable in an airbus shopfloor challenging environment. Dagdeviren *et al.*[33] have proposed a Big Data Analysis Clustering Cloud IoT (BICOT) approach which can be applicable in clustering cloud-based IoT systems using a wireless sensor network. This provides a faster response by selecting appropriate nodes. Ratnaparkh *et al.*[34] have presented a review about sensors and different devices for IoT applications that collects data from agriculture fields. Diwakar *et al.*[35] have reviewed the various types of autonomous remote security systems and mobile surveillance that have been carried out using IoT which helps in security, detection of thrift, etc. Chakraborty *et al.*[36] have developed a framework for securing and selecting IoT cloud platforms using fuzzy set theory and the entropy distance approach which provides a solution toward optimal efficiency with a particular focus on user-specific priorities. The relevant works of literature are summarized along with the advantages and demerits in Table 1.

Based on the state-of-art, it is observed that the IoT-enabled web-based application for mobile robotic systems towards finding the environmental air quantity in assorted applications like narrow pipelines, tunnels, etc. are not investigated till now. Therefore, we have developed a mobile robotic system that is controlled through an IoT-based system. The proposed paper is an extended version of our pervious study.[28] Further, demonstration and data collection from various pipelines are discussed in the proposed paper where an architecture for IoT-based system and controlling process for mobile robot using android/web application are presented and data are stored in the cloud for analytics. As well, the experimental performances are also discussed.

Theoretical Considerations

Design Concept for Mobile Robotic System by Enabling IoT Technique

A design concept of the mobile robotic system is proposed which is operated through the IoT technique as shown in Fig. 1. This robot is controlled using a microcontroller and a web-based application or the User Interface (UI) application. The robot control system is developed using a microcontroller (Make: Arduino, Model:YUN). On the body of the robot, an ultrasonic sensor, a gas sensor, a node MCU, and a wi-fi module are mounted with the microcontroller. The four wheels are operated using two servo motors where one motor provides the forward-backward movement for the backside of the wheels of the robot and another motor provides front-rear directional motion for the wheels of the robot. A gas sensor is integrated for identifying and checking the air quality of the environment inside the pipelines/tunnels. An ultrasonic sensor finds the obstacles within the identified path during the motion of the robot. The command control is linked with the microcontroller for taking appropriate decisions. The data has been sent through the wi-fi module which establishes the connection between the robot and the UI application. During the development of the network, a node MCU is used for receiving the data and sending them back to the robot. This node MCU plays an important role in transmitting data in the network. For sending the

Table 1 — Summary of the related state-of-art report along with their advantages and demerits

Authors/ Citations	Objective/Methodology	Advantages	Demerits
Griecoa *et al.*[4]	The IoT-aided robotic systems are discussed and various applications are targeted. The design methodology is also consolidated.	A process flow for the development of IoT-based robotic applications is presented for better utilization of the system.	Distributed and pervasive environments are required for solving such kind of problems with network security.
Khoje *et al.*[6]	A mobile-wheeled robot is connected to a smartphone using Bluetooth which controls the robot wirelessly.	The robot is controlled wirelessly through android smartphones which provides a solution for industrial and other general purposes of the robot.	This kind of robot can be used for a limited range of applications.
Simon[8]	Concepts of the IoT from the autonomous mobile robots aspects are discussed.	The advantages of active sensors, QR codes, RFID, and IPv6 are highlighted when these are fitted with the system. This enhances the readability and traceability of the system.	The fusion of communication and broadcasting is not highlighted.
He *et al.*[11]	Cloud-based applications through suitable cloud drivers are developed and deployed in the cloud environment. This connects the robot and the cloud.	Using such technology, the number of robots can connect which increases the effective utilization of resources. This also helps the online batch production.	A collision avoidance algorithm is implemented in the local environment and information is updated in the cloud.
Kamburugamuve *et al.*[13]	A cloud-based architecture for the computation of real-time robotics is proposed where the SLAM algorithm is implemented for a multi-node cluster in the cloud.	The proposed algorithm enhances the accuracy of the map when robots move freely in the environment.	This method is used for realizing that particle filtering in the cloud is not explicit to SLAM.
Mahesh *et al.*[15]	A mobile robot is developed where a web-based monitoring system is controlled using Raspberry PI Board.	All sensors, switches, and control of motors have been done by a single embedded board, Raspberry Pi which has capabilities of 40 GPIO pins.	A web application is shown in a lab-scale environment.
Pandure *et al.*[18]	A design of a self-navigation rover using IOT is discussed where GPS is mounted on the rover. This helps in marking the position on the map.	This kind of application can use for locating the position of the rover easily and use for monitoring the places and unauthorized persons.	The prototype is tested in a low altitude environment.
Singh *et al.*[22]	IIoT is implemented in cyber-physical system control stations, manufacturing machines, and a collaborative robotic system for visualization and collection of data and analytics in SEPT Learning Factory (LF) at McMaster University, Canada.	LF helps in sending several messages through IoT platforms using IIoT protocols to students for data collection, visualization, and analytics.	SEPT LF has only explored in their university.
Song *et al.*[25]	The importance of networking and communication technology are discussed and how to build networked robotic systems and developments for cloud and fog robotics are presented.	The networked robots enhance their abilities in sensing, perception, planning, decision-making, and action by using limited resources.	The challenge for such technology is real-time communication in multiple robots.
Jain *et al.*[28]	A mobile robotic system is developed and is controlled through an IoT-based system	An IoT-based control system provides remotely operated through wi-fi and an IoT system.	The data are uploaded to the cloud environment.
Elouerghi *et al.*[29]	An attempt on the diagnosis of early breast cancer detection is made which is based on embedded micro bio-heat ultrasensitive sensors This is connected with IoT technology which sends the information via smartphone to the physician/patient.	The data can be seen by a physician/ patient for possible medical monitoring centers.	For younger women, the sensitivity shows unsatisfactory results towards the denser and precise mammary glands.
Chowdhury *et al.*[30]	A web/android application for diagnoses of breast cancer in the early stage is proposed where the user can easily upload an image and get results aided by the deep learning method.	The proposed framework for web applications provides very minimal human intervention because it is integrated with the cloud. Therefore, less load is transferred on the edge devices.	The resolution of the breast thermal image is limited.

(*Contd.*)

Table 1 — Summary of the related state-of-art report along with their advantages and demerits

Authors/ Citations	Objective/Methodology	Advantages	Demerits
Arslan *et al.*[31]	An abstraction clustering method has been introduced towards assembling task encoding and controlling the multi-robot to reduce hierarchical clustering etc. So, yielding can be done in a precise manner for flexible organizational specifications at selectively multiple resolutions.	The advantages of hierarchical clustering are to compute correct and efficient navigational paths by coordinated multi-robot motion.	This method is only used for non-trivial clustering applications.
Wong *et al.*[32]	A clustering algorithm is developed to solve the spatially constrained robotic task of sequencing problems. This can be applicable in an airbus shopfloor challenging environment.	The major advantages such clustering-based algorithms are that they can be applicable for various tasks such as surface profiling, drilling, free-form, screw fastening, surface inspection, etc.	This algorithm is applied to a common industrial robot (KUKA KR 6 R900). if this will apply to other robots then precision is an important factor.
Dagdeviren *et al.*[33]	A BICOT big data analysis clustering approach is proposed which can be applicable in clustering cloud-based IoT systems using wireless sensor networks.	This method provides a faster response by selecting appropriate nodes.	When the number of nodes in the wireless network system will increase, it will be little in process/control from the cloud.
Ratnaparkh *et al.*[34]	A review of sensors and different devices for IoT applications is discussed which collects the data for desired information. In agriculture applications, the NPK sensor is used to measure the soil moisture content and detect diseases, etc.	IoT method is applied in smart/precision agriculture where the data can be utilized for making the benchmark of the applications.	IoT application in agriculture, challenges, advantages, and disadvantages are summarized based on the review paper.
Diwakar *et al.*[35]	Autonomous remote security and mobile surveillance system using IoT have been presented which helps towards the development of full-proof security and in other important aspects of lives.	The multiple devices can connect using the internet and provides command instructions remotely as per necessity which is a reliable high-level security solution and the working principle is also simple and easy to implement.	The possibilities and capabilities of IoT devices are discussed.
Chakraborty *et al.*[36]	A framework using fuzzy set theory and entropy distance approach is proposed for the development of an IoT-based cloud platform.	This method is attempted to find the optimal efficiency with a user-specific requirement. This creates a distinctive solution for user-specific demands and also provides market trends.	The different case studies are not discussed where security and privacy are major criteria.

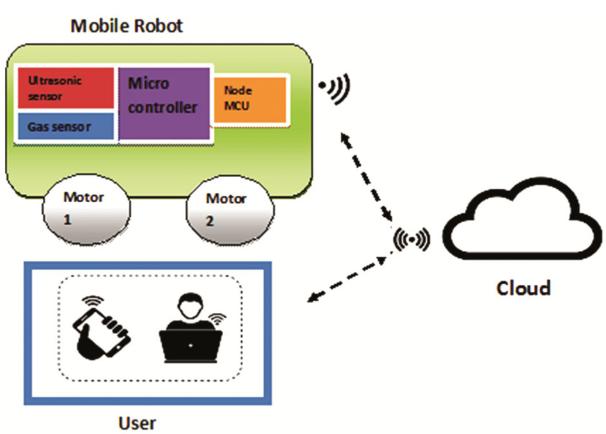

Fig. 1 — Design concept for the mobile robotic system using enabling IoT technique

data in the cloud, a think speak cloud is utilized. This provides bridging between the UI application and the robot where all sensor data are stored. The graphical representation is designed for analyzing sensors mainly gas data and developed the analytics for particular applications like sensing and monitoring data of pipelines etc. This data is automatically updated in the cloud during the operation of the robot where UI applications allow and instruct the robot for operation. Here, we have designed a UI application using the pop button for the particular operation of the robot and visualization of the sensor data accordingly. Through this UI application, the data are sent to the cloud for storing and analyzing purposes.

System Architecture for Enabling the Mobile Robotic System using Web Application

A system architecture for mobile robot control is designed which consists of three layers i.e. Hardware end or robot end, server or Internet end, and Application end or user-end as shown in Fig. 2. During the designing of the first layer, all sensors and actuators are linked to the microcontroller using a power supply at the hardware end or robot end, that

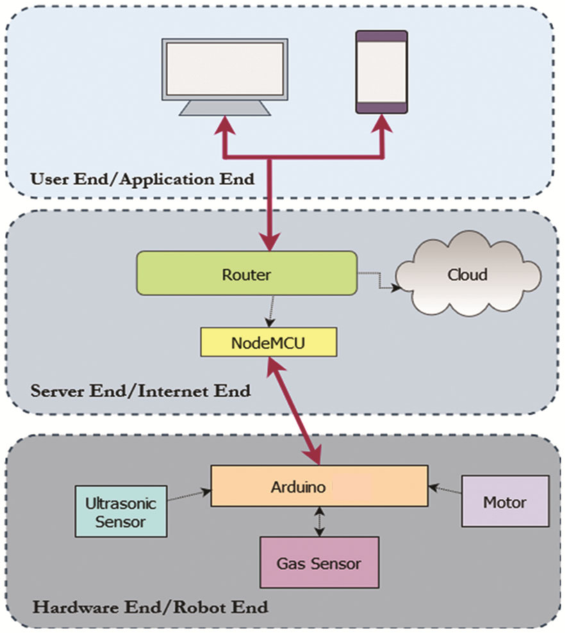

Fig. 2 — Design of the system architecture for IoT enabled/control the mobile robotic system

furnishes the data communications among them where a double-channel relay is integrated for appropriate activation during on/off switching of the robotic system. Further, a Node MCU ESP8266 is used for communicating the data on the internet/server end using the open-source think-speak platform. The wireless communications are sent using installing a router. Whenever the UI generates or receives data as a result of interacting with the user it is the request for the application to generate a set of data to be transmitted over the network and to be received by the microcontroller. The set of data will later trigger operation for the robot. Using web application, the data are cleared after certain error from micro controller and distances are covered by robot accordingly. The data required for visualization is sent from the cloud storage that receives data from the microcontroller, mainly the gas detection and air quality data. Therefore, the application simultaneously receives and sends data throughout the entire operation of the robot. The set of data from the application is transmitted over the network through the router or any other physical pathway to the Node MCU, the wi-fi module, and then to the microcontroller.

A router or any access point for establishing the network between the application and the robotic system acts as a bridge or main gateway for connecting the robotic system, the application, and the cloud storage. The data from the robot mainly gas detection and gas quality data is stored in the cloud and simultaneously sent to the application to enable real-time visualizations via router also the data is transferred between the application and the robot without requiring it to go through the cloud storage and also passes through the router or the access point. In the second phase, the Server End mainly focuses on the functionality of the router that makes the module work globally. Node MCU is responsible for processing all the data which is to be sent and received by the microcontroller. Serial communication is used between the wi-fi module and the microcontroller. The third phase Hardware End is where the microcontroller operates the robot as per the data sent from the user end. Whenever received data is processed by the wi-fi module and sent to the microcontroller, the microcontroller again processes the data to generate instructions for various components connected with it, or for performing any other such logical or physical activity. The microcontroller is also used for collecting all the necessary data from the sensors and sending the data to the Node MCU and then to the User End application through the cloud storage or directly through a logical pathway. This web-based application can be utilized for controlling and monitoring the system where the motions of the mobile robotic system are directed through web-based applications using mobile/android phones and environmental air quality is also visualized using this web-based application.

Proposed Methodology for Development of Web Application towards Controlling the Mobile Robotic System using IoT Platform

The proposed methodology for developing the web application for controlling the mobile robotic system using the IoT platform is shown in Fig. 3. At first, the robot motors and sensors (gas and ultrasonic sensors) are connected to the microcontroller which is installed on the robot. These are enabled automatically by getting commands from the microcontroller when it is in the 'On/Off' condition. For obtaining the command, a UI web application is designed where the communication between the microcontroller and the web application is created for transmitting the data where an identical IP address is set. Using IP protocol, the command data is sent to the robot which is connected through a wireless communication process. When the UI web application and the robot are connected, the wireless communication will

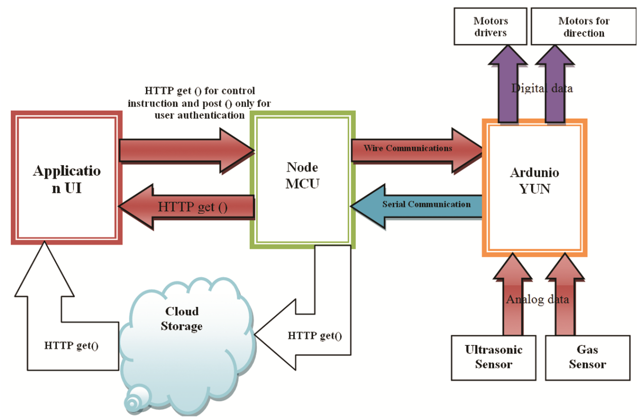

Fig. 3 — Data process diagram for IoT based mobile robot

follow the instructions using routers. For operating the overall functionality of the robot, a cloud platform is used where the connection between the UI application and the robot is established.

When the web-based applications and the Arduino have to interact or communicate with each other, Node MCU acts as a bridge between them by processing all the data to send and receive the data. Further, it also allows for storage of the data in the cloud. The applications have two cases for sending data to the Node MCU. The first case is when user authentication is being carried out, the user login data is sent to the Node MCU through the network for validation using the Hyper Text Transfer Protocol (HTTP) Post method to ensure security. In the second case whenever the user interacts on the given application UI i.e. has a control operation to be performed, the application responds by sending a set of data to the Node MCU using HTTP Get method. In particular, the set of data will be sent by the application for a particular control request. The application also receives data simultaneously from the Node MCU about user validation, distance covered by the robot, and certain errors. Node MCU sends data to the application using the HTTP Get method. When the Node MCU receives data from the application for the Arduino a wired communication is followed wherein SDA (Serial Data) wiring for data transfer and SCL (Serial Clock) wiring for the synchronized clock are used, to send data to the Arduino. Node MCU also receives data from the Arduino following serial communication wherein only one bit of data at a time in sequential order is transmitted as shown in Fig. 4. Using the pop button, the robot can get the forward-backward and left-right motion by the user using a mobile/android phone. The motion and sensor

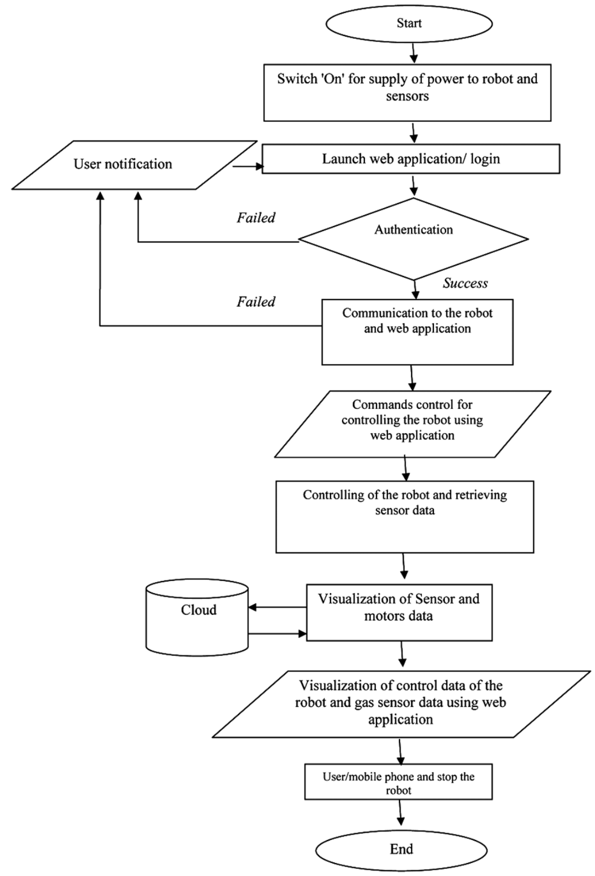

Fig. 4 — Flow chart for controlling the mobile robot via web-based applications

data will be uploaded to the cloud using the Think speak cloud platform. After getting the command, the robot can reach a particular location and it will collect the air quality of the environment. After acquiring the sensor data, the robotic system will allow for returning to the said location. The user presses the stop button for ending the process so that the robot can be stopped. Thereafter, the log-out button will be pressed to quit the web application.

Results and Discussion

Development of Prototype and Experimental Work

For proof-of-concept, a small mobile robot prototype is developed. A four-wheel-based robotic system is developed where the four wheels mechanism is derived through the two motors. One motor is used for connecting the front wheel mechanism and another motor is used for the backside two wheels. The motion of wheels is controlled using a microcontroller. For computing the air quality, a gas sensor is interfaced with the microcontroller and the robot. For providing wireless communication between

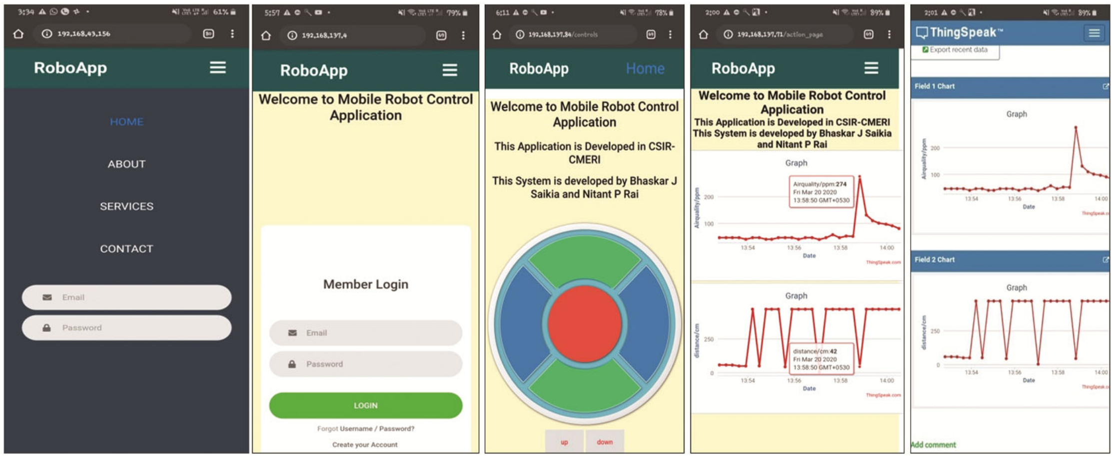

Fig. 5 —Development of Android app and visualization of data

the microcontroller and web application, a node MCU is also interfaced with a microcontroller, and a Wi-Fi module is also integrated for wireless communication using node MCU. For providing the proper amount of power to the robotic system and microcontroller, a customize power supply is used which can provide the voltage range of 5–12 VDC. For controlling the motion of the robotic system, a web-based application is designed that interfaced with a cloud platform for controlling the data through mobile/android phones from anywhere. To develop web applications, a web-server is created where Node MCU communicates between mobile robots and mobile phones through wi-fi. An IP address for the Node MCU is first assigned to set up the connections and then the web application provides all the necessary user interfaces through codes. Further, the URL browser will automatically run through the user interface. The login page will first open to provide the authentication by the user, then the designed web application will open to operate and control the robot as shown in Fig. 5. Further, a visualizations window will open to monitor the robot location and analysis the gas conditions in the pipelines, tunnels, etc.

To develop the Android mobile app, the Thinkspeak^{TM} platform is used where this IoT cloud platform provides the services and permission to store and visualize the data. Further, the data in the cloud using web service can also be analyzed. Thus, the data can be stored in a faster manner using the cloud and the webpage is opened within a second. Using the ThingSpeak^{TM} cloud platform, the robotic system is controlled and their motors accelerations data can be displayed and air quality sensor data are also visualized (Fig. 5). To analyze the experimental performance, the successive steps for the movement of the robot are shown in Fig. 6. The following experiments/trials have been carried out in three different conditions: Case-I normal air, Case-II environmental smoke condition, and Case-III inside air condition of the tunnel pipelines. Each condition has 10 trials for data collection. The gas sensor MQ-135 starts retrieving data as soon as the gas sensor is turned on. When the robot moves in the given environment, the gas sensor data varies and can be visualized from in the ThingsSpeak channel retrieved and placed on the application.

In the first case (Case-I), the robot is tested along with a smoke sensor in a normal air environment with normal air. The experimental data of different trials (three trials) are collected through the Think speak cloud platform. The different trials are conducted for data analysis as plotted as shown in Fig. 7. The data is analyzed in MATLAB software. After analyzing all the ten sets of data for the case of normal air the 4th-degree pattern is obtained with the polynomial equation as given below;

$$y = 0.00021x^4 + 0.012x^3 + 0.18x^3 + 0.77x + 43 \ldots (1)$$

where, y is air quality and x is a set of data.

All the trials have an air quality range between 40 to 55 ppm where the behavior of air quality is obtained as the pattern of the 4th-degree polynomial.

In Case-II, the robot is tested along with gas sensors in the smoke environment. The experimental data (three trials) are obtained through the Thinkspeak^{TM} cloud platform**.** In this case, some flame gases are present in the smoke where the quality of the air remains poor. The smoke can be found at certain locations along the pathway of the

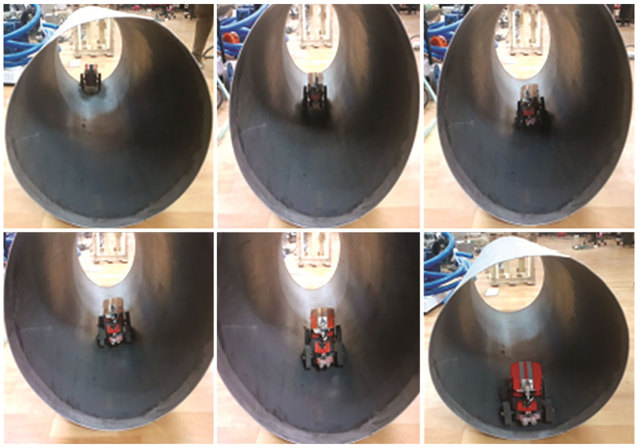

Fig. 6 — Successive pictures of mobile robots traveling inside tunnel pipelines

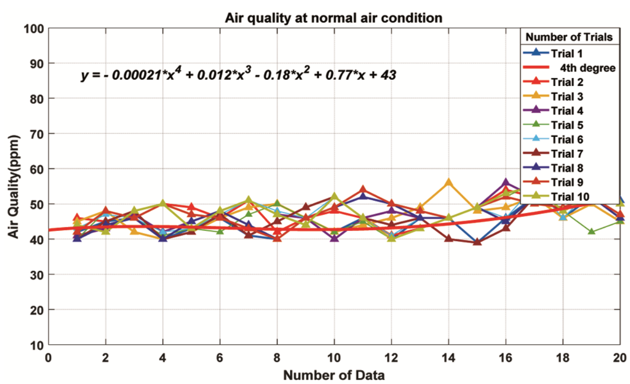

Fig. 7 — Analysis of several trials performed by mobile robot along with air sensor at normal air condition using MATLAB.

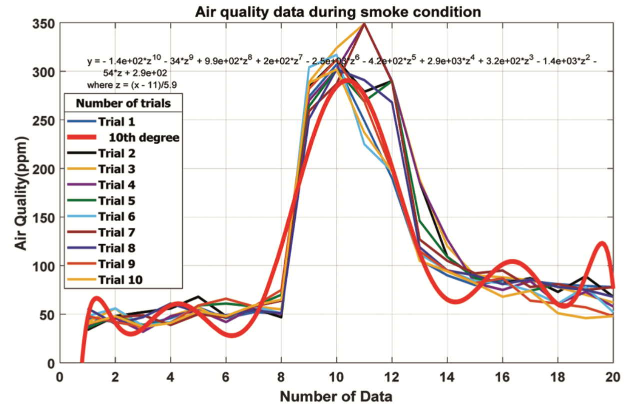

Fig. 8 — Analysis of several trials performed by mobile robot along with air sensor at smoke condition using MATLAB

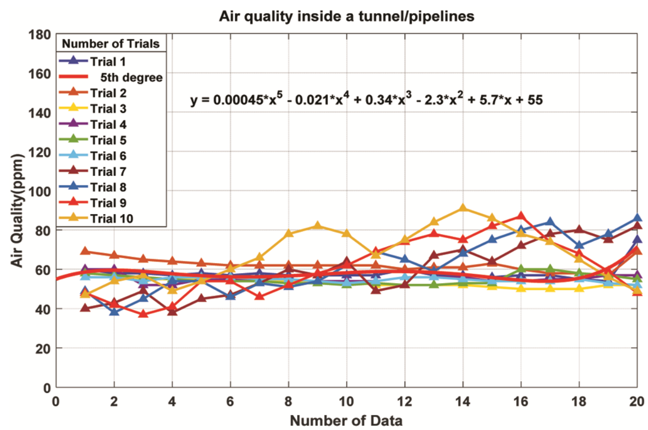

Fig. 9 — Analysis of several trials performed by mobile robot along with air sensor at tunnel/pipeline using MATLAB

robot. When the robot moves closer to the smoke the air quality varies from normal to poor. Therefore, the detection of the gas sensor is analyzed to observe the working of the gas sensor efficiently. In this case (Case-II), the same number of trials are conducted and plotted using MATLAB software as shown in Fig. 8. The analysis shows that the behavior of a gas under smoke conditions has acquired with 10^{th} degree polynomial equation as given below;

$$y = 2.7e^{-06}x^{10} + 0.00028x^{9} - 0.012x^{8} + 0.3x^{7} - 4.6x^{6} + 43x^{5} + 2.6e^{02}x^{4} + 9.4e + 02x^{3} - 2e^{03}x^{2} + 2.1e^{03}x + 8.1e^{02} \quad \ldots (2)$$

Here, y is air quality and x is a set of data.

In this case, all 10 trials maintain curve formation between the range 50 to 350 ppm when the number of data is between 8 to 14 that following the behavior pattern of the 10^{th} degree polynomial equation.

In Case-III, the robot travels inside the tunnel pipelines where the working environment may be varied. During testing, the empty pipelines have taken. In this case (Case-III), the data conducted in the different trials are acquired and plotted using MATLAB software as shown in Fig. 9. The analysis reveals that the behavior of a gas under tunnels/pipelines has been found with the 5^{th}-degree polynomial equation as given below;

$$y = 0.00045x^{5} - 0.021x^{4} + 0.34x^{3} - 2.3x^{2} + 5.7x + 55 \quad \ldots (3)$$

where, y is air quality and x is a set of data.

Here, all the 10 trials also continue curve formation between the range 57 to 92 ppm and the pattern of the 5^{th}-degree polynomial equation**.**

After the demonstration and different trials, it has been envisaged that the mobile robot is operated and controlled using web-based applications. Air equality will be varied according to conditions and places. This can be monitored through web applications and the data can be stored in the cloud. The most important advantages of such systems are that the robotic system can be controlled through mobile/ android phones which can be accessed from anywhere using a wireless communication system. The performance of the developed IoT and node MCU-based wireless mobile robot control system is compared with wireless robotic control using RF module[37,38] and STM32F103ZET6 chip-based vehicle control system[39], it shows the faster repose, integrated wi-fi supported and low power energy consumption. This shows an IoT and node MCU-based wireless mobile robot control system is much more effective for wireless autonomous robotic systems. This also reduces human involvement and monitors the environment situation remotely by deploying the robotic system. Thus, the IoRT concept is applied in the mobile robotic system which shows the potential of the new generation of mobile robots for operating autonomously.

Significance and Major Contribution of this Research Work

The significance and major contribution of this research work are summarized below;

i. Remotely monitoring of mobile robotic system pipeline inspection, tunnels, narrow spaces, etc. is developed where access of humans is not possible.
ii. A web-based application is designed and developed for monitoring, inspection, and controlling the robotic system remotely and the data is also stored for assessment of the pipeline inspection, tunnels, etc.
iii. A novel concept of web-based applications using android applications is attempted where the IoT concept is applied for controlling the robotic system remotely. Therefore, this provides the solution for a new generation of the mobile robotic system which is wirelessly controlled through an android mobile phone from anywhere.

Conclusions

A mobile robotic system is developed and operated using computer-controlled systems. This provides the autonomous remotely operated solution for various applications. For furnishing such features, a web/Android application is developed using an IoT platform that provides the functionality of a robotic system, controls of sensors and actuators, and visualization capability using wireless camera controls where all controls have been carried out using the IoT platform. The web/android-based applications execute the commands and transmit the data to the controller inside the robot using NodeMCU and wi-fi modules. These are installed inside the robot and the robot is controlled through IoT web-based applications and mobile apps data are stored in the cloud and data on air quantity are collected under different conditions such as tunnels/pipelines etc. Thus, the IoT cloud computing platform provides the facility to store data for analytics purposes which provides the new concept to carry out the robotic autonomous tasks. This is a novelty of the paper.

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