Human Following Smart Shopping Cart

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***Abstract*— In today's era, people look for ways to minimize effort in quotidian tasks like shopping. Shopping carts are meant to aid the customers to carry huge loads. However, with some modifications, we can revolutionize the way we use them. We propose a human following smart shopping cart to provide a hassle-free, cost-effective shopping experience for the users in supermarkets and marts. Many attempts have been made to fulfil this task, but what these methods lacked was the freedom of movement of the cart to move in any direction according to the user. Our approach aims to grant this freedom to the cart by making sure that it follows the shopper even if he/she is not walking in a straight line. As an adjunct to this, a web user interface for keeping a track of the products in the cart will enhance the shopping experience for the users.**

Keywords—Smart Cart, Internet of Things, Automation, Magnetometer, RFID, MQTT

I. Introduction

In the realm of shopping, shopping carts were introduced in the late 1930s. Before shopping carts, the customers would go into stores and marts and would wait in queues at a long counter, where the clerks would show them the wares. This system required skilled clerks who would know all the goods in the stores, which increased the cost for the store owners [1]. Eventually, retailers started putting more products out on display so that the customers could help themselves; thus eliminating the need for clerks. Now this posed another problem: how would the customers carry all the products? A bag over the shoulder would solve the problem only to a certain extent since their carrying capacity was low. It was in 1937 when entrepreneur and inventor from Oklahoma City, Sylvan N. Goldman, came up with an idea of a shopping cart on which two shopping baskets could be suspended [2]. He named it 'Folding Basket Carrier'. Since then there have been modifications in the design of the cart.

Over the past few decades, shopping in today's world has become an increasingly interactive experience for shoppers. Despite the presence of E-commerce, people tend to buy many products only in supermarkets and malls for the sake of their own satisfaction. However, shopping carts in major stores have undergone a little change since their inception. We have carts that have a single basket with better weight distribution so that the physical act of moving with a cart can be eased to a certain extent. But certain people of the society still find it cumbersome to push and pull the cart, especially while carrying heavy loads.

As the leading edge of the continuing technological revolution, automation has had an enormous impact on production, communication and scientific investigation. Automation is the technology by which a process or procedure is performed with minimal human assistance. It is the use of various control systems for operating equipment such as machinery, processes in factories, switching on telephone networks, steering and stabilization of ships, aircraft and vehicles with minimal or reduced human intervention. In control complexity, it can range from simple on-off control to multi-variable high-level algorithms.

With the advent of affordable computer chips and with the presence of Wireless Sensor Networks (WSNs), we can incorporate the Internet of Things (IoT) in every possible field [3]. Today we have various types of sensors that are readily available. By selecting the right sensor according to our needs, we can enable the devices to communicate with humans in real-time thereby adding a layer of 'digital intelligence' [4]. The burgeoning field of IoT has made the concept proposed by this paper implementable with cost effective and dependable means.

II. Related Work

When we speak about human following robots, the cardinal issue that needs to be taken care of is the navigation of the robot. The navigation should be such that the robot follows the designated subject only and it should not deviate from its path. Technological advancements have engendered many methods which aim to tackle this issue with maximum possible accuracy. Our application, a human following shopping cart, has a similar aim. To gain an in-depth knowledge of the various navigation methods that can be used for our application, we studied various research papers [5], [6], [7], [8] that have implemented something along similar lines.

Fig. 1. In this 1960 photo, Sylvan N. Goldman shows a more refined model similar to the carts used today.

On scrutinizing these papers thoroughly, we outlined various methods that were proposed by them. Some of the most common and popular methods of navigation included the use of following sensors or devices:

A. Infrared (IR) sensors

The working principle of Infrared (IR) sensors is that an IR light-emitting diode (LED) emits light in the range of Infrared-frequency and a photodiode acts as the IR Receiver as it conducts when light falls on it [9]. This property makes it useful for IR detection which is one of the most common methods which can be used for the purpose of navigation. However, one major disadvantage of IR sensors is that it works along the line of sight. This means that it will work if the user or the subject is perfectly aligned along the direction of the sensor. A small deviation would render it useless and will force the user to keep the line of sight steady throughout thereby restricting his/her movement.

B. Transceiver

The functionality of both transmitter and receiver are combined into a single device known as transceiver [10] . An Radio-frequency (RF) transceiver can be connected to the cart while the other one is with the user. The communication between the two along with other sensors can be used to make the cart follow the user. The method may seem plausible but one drawback which serves as a deterrent in the task of human following is that it lacks unique identifiers. This makes it difficult to follow a particular user only. In addition to this, this method will not be reliable to detect the direction for the cart to turn according to the user.

C. Ultrasonic sensors

The ultrasonic transmitter transmits ultrasonic waves which reflect off the surface and are received by the receiver module. This working principle is very useful in tasks such as object or obstacle detection. The drawback of using it for navigation again lies in the fact that it cannot uniquely identify the user. So, it will not prove to be of much help in making the cart follow the designated user.

D. Microsoft Kinect sensor

The Kinect sensor is a combination of three vital hardware components which include: an RGB colour VGA video camera, a depth sensor and a multi-array microphone [11]. This hardware integrated with the software is capable of generating 3D images of the human being and can recognize him/her within its field of vision. This can tackle the issue of uniquely identifying the user and follow him/her accordingly. However, the cost of Kinect sensors available in the markets is more as compared to other sensors. So, the overall cost of implementing this method increases exorbitantly.

One of the most challenging hurdles in implementing these methods of navigation are that of finding the bearing of the cart with respect to the user. Most of the automated carts that have been implemented previously have made use of IR sensors or cameras mounted on the front of the cart to solve this problem. This approach has proved to be effective for simpler scenarios which don't take into account the floor plan consisting of shelves and narrow aisles often seen in a typical supermarket or a mart. Thus, we aim to find a solution to the drawbacks that these proposed theories have and come up with a method which could revolutionize the task of navigation.

III. PROPOSED METHODOLOGY

The proposed methodology is based on the working principle of a magnetic compass [12]. A compass acts as a pointer to "magnetic north". The magnetized needle in a compass aligns itself with the horizontal component of the Earth's magnetic field. This magnetic field exerts a torque on the needle. This causes the north end of the needle to get pulled approximately towards the Earth's north magnetic pole and the south end of the needle towards the Earth's south magnetic pole.

Assuming that unit vectors $\hat{x}, \hat{y}, \hat{z}$ represent the axes of a Cartesian coordinate system, let the user's bearing with respect to Earth's magnetic north be represented by $\overrightarrow{UE}$. Similarly, the cart's bearing with respect to the Earth's magnetic north is represented by $\overrightarrow{CE}$. This implies that if the user and the cart each have a compass, then the compass needles will always point to a common "magnetic north". We consider the $\hat{x}$ and $\hat{y}$ components of each vector to find the counter-clockwise angle with respect to the origin in the XY-plane. This can be given by the formula:

$$\mathrm{U} = \tan^{-1}\left(\frac{\overrightarrow{UE}\,.\,\hat{y}}{\overrightarrow{UE}\,.\,\hat{x}}\right) + m \tag{1}$$

$$\mathrm{C} = \tan^{-1}\left(\frac{\overrightarrow{CE}\,.\,\hat{y}}{\overrightarrow{CE}\,.\,\hat{x}}\right) + m \tag{2}$$

A magnetic declination angle m is added to U and C respectively where magnetic declination angle is defined as the angle on the horizontal plane between magnetic north and true north of Earth. This angle varies depending on position on the Earth's surface and changes over time. To find the angle of bearing of the cart with respect to the user represented by Δ, we use the formula given by:

$$\Delta = \mathrm{C} - \mathrm{U} \tag{3}$$

Here $\Delta, \mathrm{U}, \mathrm{C}$ and m are expressed in degrees. Using (3), we can calculate Δ and try to steer the cart in such a way that Δ becomes zero at every instant in time. On substituting $\Delta = 0$ in (3), we obtain:

$$\mathrm{C} = \mathrm{U} \tag{4}$$

The steering of the cart is then achieved using the algorithm demonstrated in Fig. 2.

The primary objective of this paper is to use the concepts of IoT and Web Development to design an architecture which supports compass based direction finding. The secondary objective of this paper is to provide an interactive and cost-effective shopping experience for the users [13]. To achieve the aforementioned objectives, we propose an architecture design. The proposed architecture is divided into three modules: server, user and cart. Each of these modules are responsible for performing a specific task which is explained as follows:.

A. Server Module

The server module consists of a centralized server which facilitates the communication between the user and the cart [14]. Firstly, the server acts as a publisher/subscriber broker between the user module and the cart module using the Message Queueing Telemetry Transport (MQTT) protocol [15]. MQTT is an open OASIS and ISO standard lightweight, publish-subscribe network protocol that transports messages between devices such as small sensors and mobile devices. It is optimized for high-latency or unreliable networks.

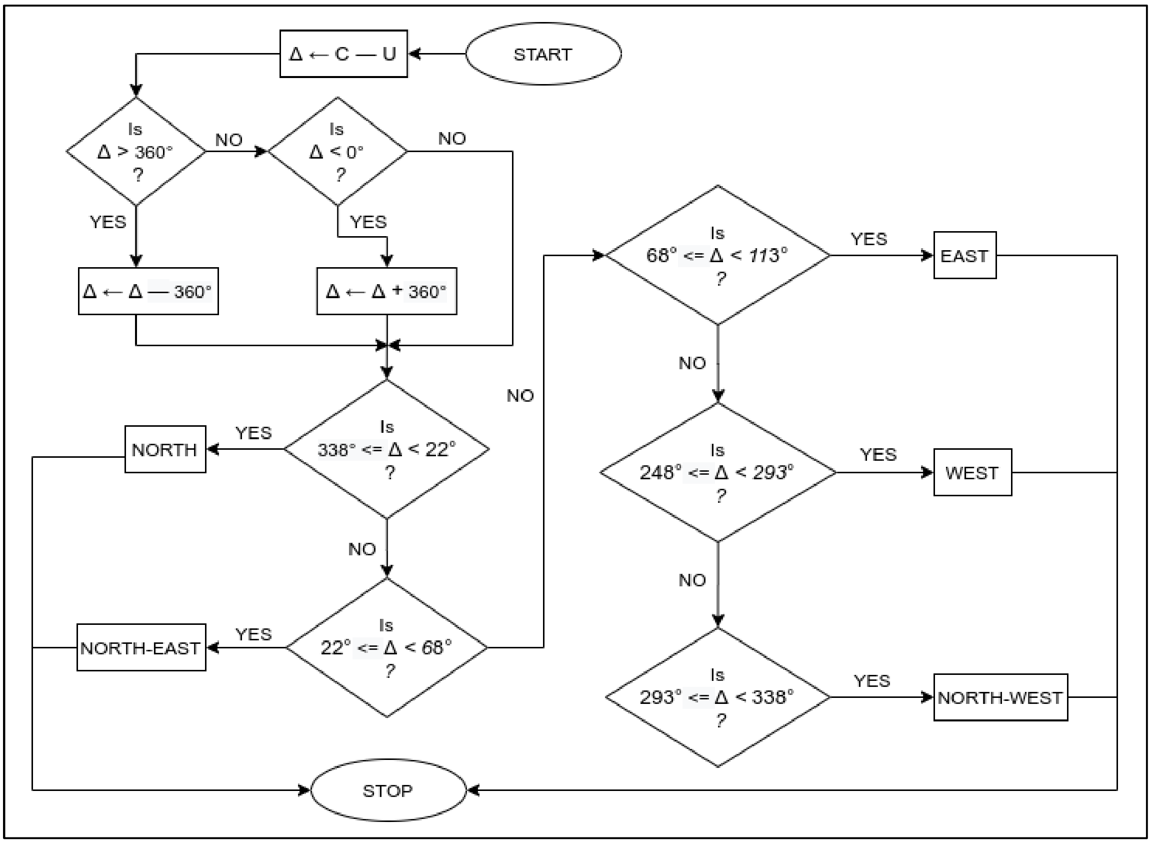

Fig. 2. Our algorithm for obtaining the directions for steering the cart.

Secondly, it exposes a Representational State Transfer (REST) Application Programming Interface (API) endpoint which is used by the Web User Interface (UI). The Web UI provides the user with product details such as price, expiry date, capacity, nutritional information, etc. for each product that he/she has scanned on the Radio-frequency Identification (RFID) reader and placed in the cart.

B. *User Module*

The user module consists of a publisher interfaced with a triple-axis magnetometer which outputs the user bearing. The user bearing is then published on the centralized server on a private channel unique to each cart. This whole setup can be mounted on a wearable which can be given to the user to track his/her bearing. The angle of the user's bearing in the XY-plane is then calculated using (1).

C. *Cart Module*

The cart module consists of a subscriber interfaced with the cart. The cart also has a triple-axis magnetometer which outputs the cart bearing. The angle of the cart's bearing in the XY-plane is then calculated using (2). The subscriber obtains the angle of the user bearing from the private channel for that cart on the centralized server. It then relays the angle to the cart via serial communication. This determines the direction and speed of motors to steer the cart such that Δ becomes zero. The cart is mounted with three ultrasonic sensors, each on the front, left and right side of cart chassis to prevent collisions with the surroundings and the user.

The subscriber on the cart module is also interfaced with an RFID reader which consists of an antenna, transceiver and decoder, to send periodic signals to inquire about any tag in vicinity [16]. When the user picks up an item from the shelf of the supermarket, he/she has to scan the item RFID tag on the reader. This is relayed by the subscriber to the MQTT broker which will save this change in the database. As a result of this, the Web UI is updated in real time reflecting that change for that user session.

The complete flow of the system is explained in a sequence of steps as follows:

1. The user is given a wearable mounted with the User module which publishes the angle of user bearing on the centralized server at a regular interval of 1.25 s.

2. The subscriber on the cart module receives the angle of user bearing from the centralized server and relays it to the cart via serial communication.

3. The ultrasonic sensors mounted on the cart are used to obtain the distance between the cart and the user as well as the distance between the cart and its surroundings.

4. If this distance is less than or equal to a pre-specified threshold, then the cart stops to prevent a collision with the user or its surroundings (shelves in a supermarket).

5. Else, the magnetometer on the cart module outputs the angle of cart bearing.

6. Δ is calculated and mapped to corresponding directions of either West, North-West, North, North-East or East using the algorithm in Fig. 2.

7. The cart is then steered according to the direction obtained in Step 6.

8. Goto Step 2.

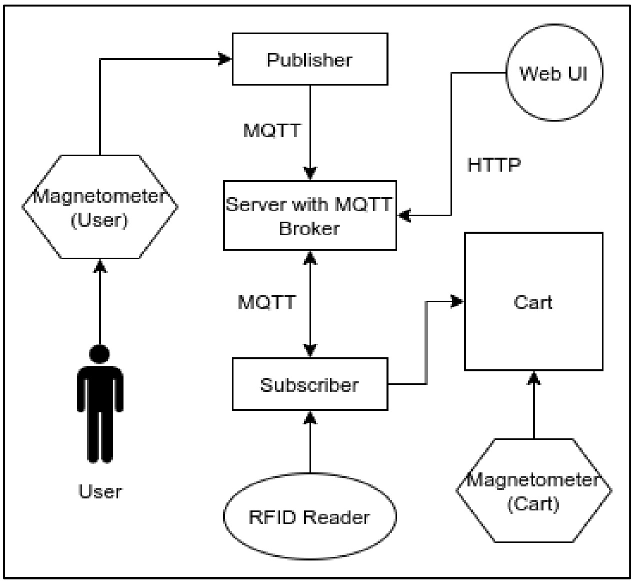

Fig. 3. Architecture of the proposed methodology.

IV. IMPLEMENTATION

Our implementation for the proposed methodology is explained as follows:

A. Server Module

We implemented the server module using a Node.js server with a Mosca MQTT broker and the Web UI was made using the React frontend library.

- The Mosca broker has an in-built message queue for synchronizing the messages between the publisher and subscriber pairs on their respective private channels.
- The Web UI is thoughtfully designed to be interactive, mobile responsive and user friendly to provide ease of use for the shopper.

B. User Module

We implemented the user module using a NodeMCU ESP8266 interfaced with a HMC5883L magnetometer sensor. The NodeMCU microcontroller acts as a publisher. The user module prototype is demonstrated in Fig. 4.

Fig. 4. Prototype of the User module consisting of NodeMCU ESP8266 interfaced with HMC5883L magnetometer sensor.

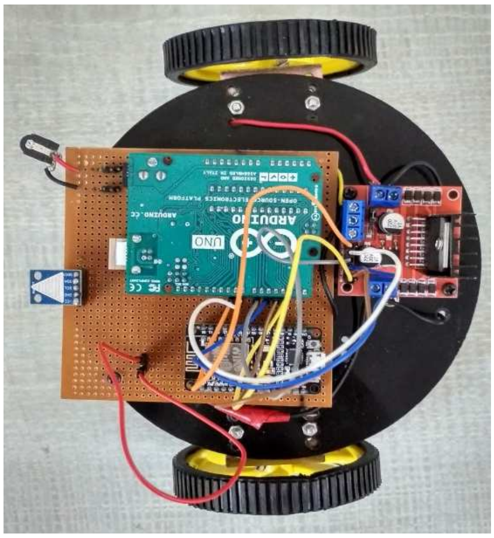

Fig. 5. Prototype of cart module consisting of Arduino Uno interfaced with DC motors and NodeMCU ESP8266.

- NodeMCU is a low-cost open source LUA based IoT firmware developed for the ESP8266 WiFi chip. It has 128 kB RAM and 4 MB of Flash memory which is sufficient for large strings that make up Web pages and JSON/XML data. The ESP8266 chip integrates 802.11b/g/n HT40 WiFi transceiver, which enables it to connect to a WiFi network and set up a network of its own, allowing other devices to connect directly to it.
- HMC5883L is a surface-mount, multi-chip, triple-axis magnetometer sensor designed for low-field magnetic sensing, compassing and magnetometry. It is designed to measure both the direction and the magnitude of Earth's magnetic fields ranging from 10^{-6} T to 0.0008 T. It contains a 12-bit ADC that enables 1° to 2° compass heading accuracy [17] . The I2C serial bus of the instrument allows for an easy interface.

C. Cart Module

We implemented the cart module using a NodeMCU ESP8266 interfaced with an Arduino Uno. The Arduino Uno is connected to two direct current (DC) motors and a HMC5883L magnetometer sensor. The NodeMCU microcontroller acts as a subscriber and is interfaced with an MFRC522 RFID reader. The cart is also mounted with three HC-SR04 Ultrasonic sensors on the front, right and left side of the main chassis. . The cart module prototype is demonstrated in Fig. 5.

- Arduino Uno is an open-source microcontroller board based on the ATmega328P [18]. It allows the user to provide extensive functionality which is of utmost importance using Arduino IDE. It is a low-cost device which operates on a supply of 7 V - 12 V. It has RAM of 2 kB and a flash memory of 32 kB.
- HC-SR04 Ultrasonic sensors offer excellent non-contact range detection with high accuracy and stable readings in an easy-to-use package. It operates at an input voltage of 5 V. It has a theoretical measuring range distance of 0.02 m – 4.5 m and practical measuring range of 0.02 m – 0.8 m [19] with a resolution of 0.003 m and a measuring angle of 30°.

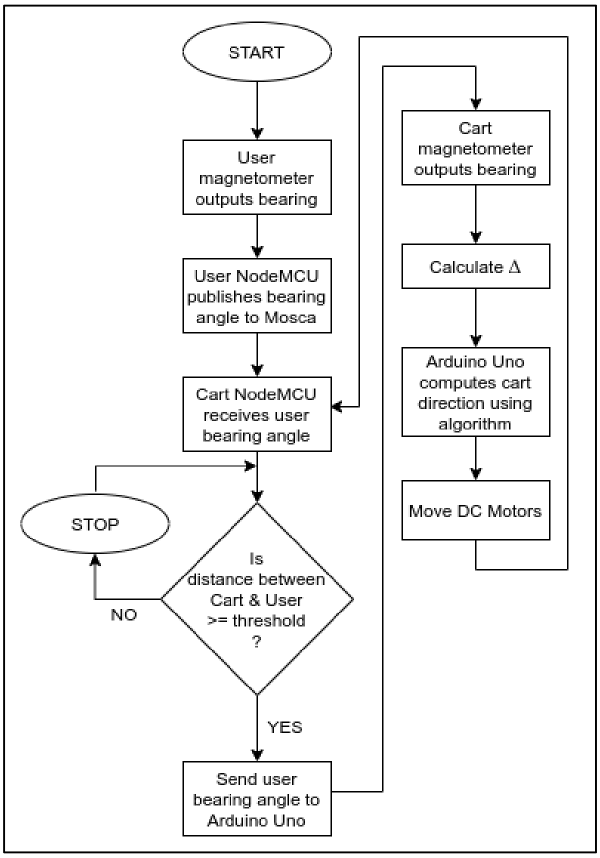

Fig. 6. Flowchart of our implementation.

- The RFID tag is made of a wireless transducer, an encapsulating material and an antenna.
- MFRC522 RFID reader is a highly integrated transmission module for contact-less communication with RFID tags (ISO 14443A standard tags) at 13.56 MHz. The reader can communicate with a microcontroller over a 4-pin Serial Peripheral Interface (SPI) with a maximum data rate of 10 Mbps.
- L298N motor driver is also interfaced with Arduino Uno to control the direction of rotation and speed of the two DC motors. It drives a motor requiring 5 V - 35 V at up to 2 A per channel. It has a high voltage and current full-bridge driver with 2 H-bridges used to drive inductive loads like DC and Stepper Motors. It is controlled with logic signals and has 25 W rated power.

The specifications for HMC5883L and NodeMCU ESP8266 are the same as that mentioned for the User module. The data transfer from NodeMCU to Arduino Uno in the Cart module takes place via serial communication. Serial communication is a form of I/O in which the bits of a byte being transferred appear one after the other in a timed sequence on a single wire.

V. RESULTS AND DISCUSSION

To implement our proposed mechanism, we conducted a trial which showed satisfactory results. The subject had to enter the cart ID and a password to uniquely identify the cart for himself. This was done through the user friendly Web UI from the user's phone. After this, the cart followed the user wherever he went and stopped when the user stopped depending upon the threshold distance between the cart and the user. When the user scanned the RFID tag on the product before putting it into the cart , he could see the details of that product on his phone in real time which included the manufacturing date, the expiry date, cost of the product, etc. On adding multiple products, the user could see the total cost of all the products present in the cart at the bottom of the screen of his phone.

Some limitations of the proposed design must be noted. A magnetometer is highly influenced by its environment. It gives rise to magnetic bias of two types: hard iron bias and soft iron bias. Hard iron bias is a result of material which is magnetized inside the device and soft iron bias is a result of synergy between variation of the Earth's magnetic field and material inside the magnetometer. These biases can cause the magnetometer output readings to fluctuate when the users bring their cell phones closer to the wearable. The low voltage and low current flow in the circuit on the wearable sets up a magnetic field of its own which may disturb the magnetometer chip. The presence of external magnetic fields due to different products having permanent magnets in them can also affect the readings (e.g. magnet in the speaker of a phone).Other electronic items like laptops, batteries also cause soft iron interference. Different places on Earth have different magnetic declination angles. Hence the m term in (1) needs to be adjusted according to the magnetic declination angle in that region.

VI. SOCIAL IMPACT

Every product that is built aims at making the lives of people easier. In order to measure the success of the product, it is necessary to analyse what impact it will have on people and what section of society will benefit from it. The main idea behind designing and building an automated human following cart is to obliterate the manual labour involved in pushing and pulling the cart. It will serve to be of great use to the women who are pregnant or who are carrying their infants with them. Apart from them, it will also benefit the elderly people who might find it difficult to push the cart due to reduced muscular strength caused due to old age. It will also benefit the owners of supermarkets, stores and marts as they will be able to provide better customer service, thereby increasing their clientele.

A study conducted by the University of Arizona in 2007 found human saliva, mucus, urine, faecal matter, blood and juices from raw meat on the handles and child seats of 36 grocery carts in San Francisco, Chicago, Tucson, and Tampa [20]. Carts ranked third on the list of nastiest public items to touch, with only playground equipment and armrests on public transportation producing more germ-laden results. Thus a human following cart which has no physical interaction with the user can help in reducing the risk of spreading germs through contact and can prevent health and sanitation violations.

VII. CONCLUSION

We were successful in implementing the proposed design and the prototype of the human following smart cart. It followed the designated user as expected. The concept of steering the cart based on the bearing of the cart with respect to the user using two magnetometers showed positive results. Thus, we eliminated the need of IR sensors or cameras, which would require the users to align themselves along the line of sight of those sensors or cameras. The RFID reader read the tag and displayed correct information about the product on the mobile phone of the user via the interactive Web UI in real time. This paper also outlines the limitations of our system which need to be solved by the research community to make this system more reliable and efficient.

ACKNOWLEDGMENT

The authors are thankful to Dr. Narendra Shekokar, former Head of Department of Computer Engineering and Professor, Dwarkadas J. Sanghvi College of Engineering, Mumbai, India for providing necessary resources and infrastructure to conduct this project work and for his encouragement.

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