Design and implementation of a human following smart 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. The proposed approach aims to grant this freedom to the cart by making sure that it follows the user 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—Automation, Internet of Things, Magnetometer, Message Queuing Telemetry Transport, Radio-frequency Identification, Smart Cart

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 an 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 along with automation 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 direction finding of the robot. The direction finding 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. The proposed application, a human following shopping cart, has a similar aim. To gain an in-depth knowledge of the various direction finding methods that can be used for this application, we studied various research papers [5], [6], [7], [8] that have implemented concepts along similar lines.

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

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

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 direction finding. 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. *Transceivers*

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 direction finding 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 direction finding is 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 direction finding.

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 3-dimensional 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 for each of the vectors $\overrightarrow{UE}$ and $\overrightarrow{CE}$ to find the counter-clockwise angle with respect to the origin in the XY plane. This can be given by the formula:

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

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

A magnetic declination angle m is added to U and C respectively where the 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:

$$\Delta = \mathrm{C} - \mathrm{U} \qquad (3)$$

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:

$$\mathrm{C} = \mathrm{U} \qquad (4)$$

The steering of the cart is then achieved using the algorithm which is elaborated below.

A. *Proposed Algorithm*

The following diagrams represent a 2-dimensional Cartesian coordinate system where, α represents the counter clockwise angle of the user with X-axis and β represents the counter clockwise angle of the cart with X-axis. Angle of bearing of the cart with respect to the user represented by (β - α) is obtained using (3). It is normalized to bring it in the range of [0°, 360°] by performing the following operation:

If $(\beta - \alpha) < 0$, then $(\beta - \alpha) = (\beta - \alpha) + 360°$

If $(\beta - \alpha) \geq 360°$, then $(\beta - \alpha) = (\beta - \alpha) - 360°$

1) *Case 1:*

- North East:
  When $22° \leq (\beta - \alpha) < 68°$, the cart will turn in the North East direction with respect to the user.
- North West:
  When $293° \leq (\beta - \alpha) < 338°$, the cart will turn in the North West direction with respect to the user.

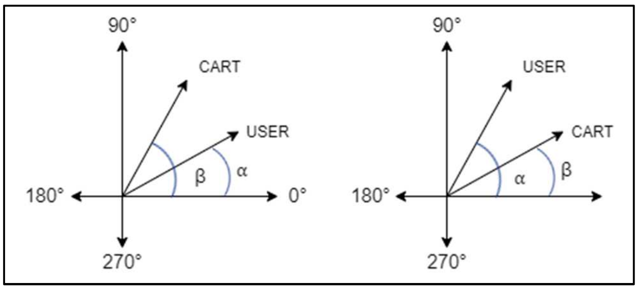

Fig. 2. Steering the cart in the North East direction (left) and the North West direction (right) with respect to the user.

2) Case 2:

- East:
When $68° \leq (\beta - \alpha) < 113°$, the cart will turn in the East direction with respect to the user.
- West:
When $248° \leq (\beta - \alpha) < 293°$, the cart will turn in the West direction with respect to the user.

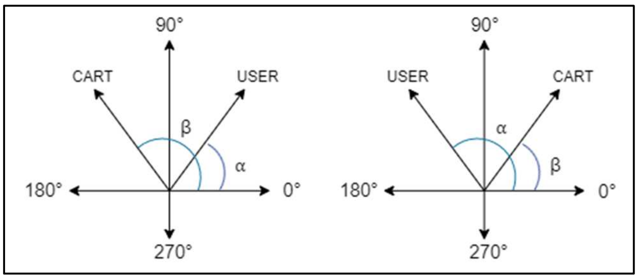

Fig. 3. Steering the cart in the East direction (left) and the West direction (right) with respect to the user.

3) Case 3:

- North:
When $338° \leq (\beta - \alpha) < 360°$ or $0° \leq (\beta - \alpha) < 22°$, the cart will follow the user in his/her direction.

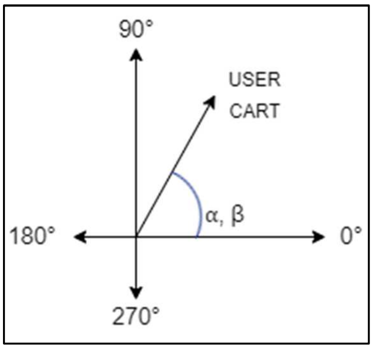

Fig. 4. Steering the cart in the direction of the user.

B. Proposed Modules

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:

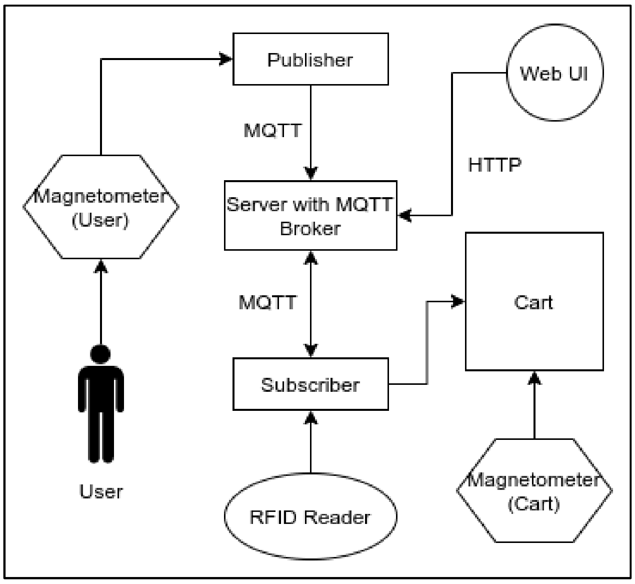

Fig. 5. Architecture of the proposed methodology.

1) 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.

Secondly, the server 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 (present on the cart) and placed in the cart.

2) 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).

3) 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.

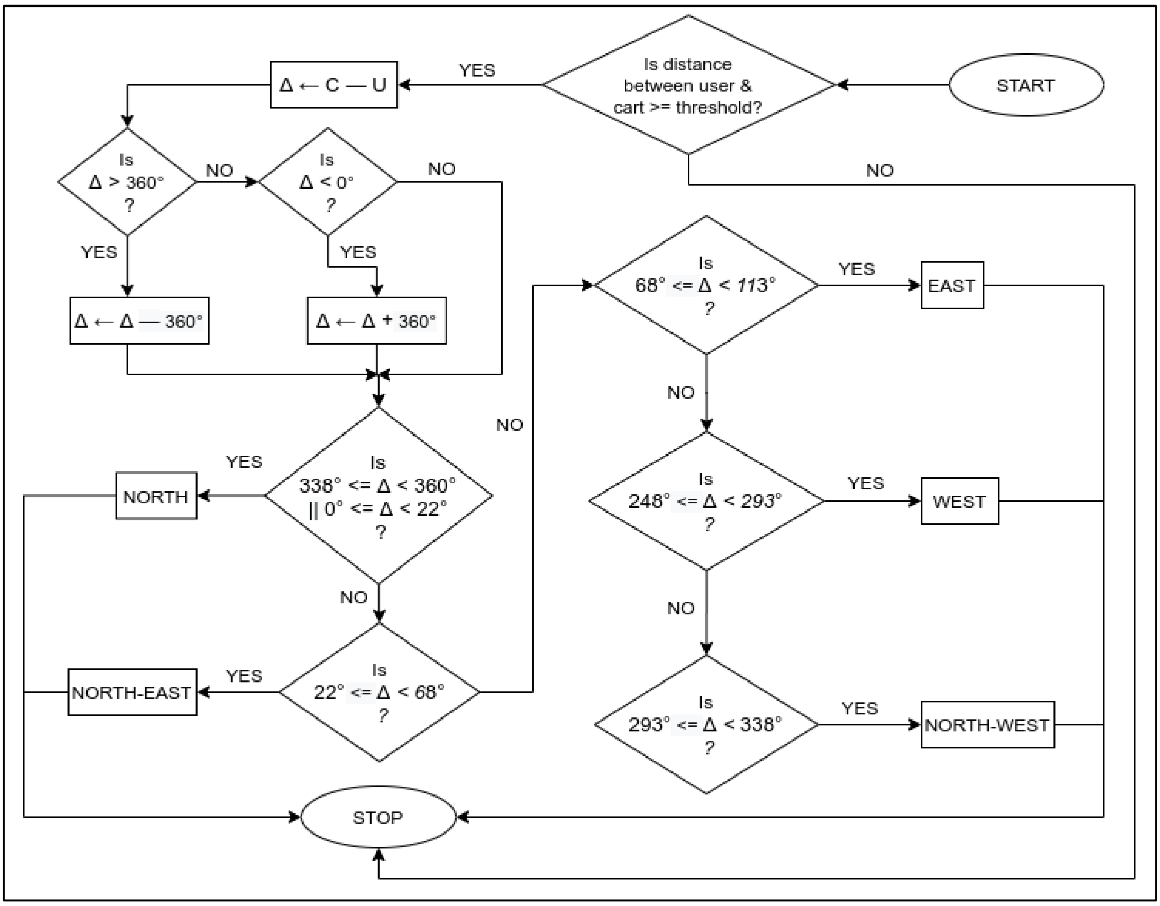

Fig. 6. The proposed algorithm for steering the cart

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 into the inventory table in the database for that particular user. As a result of this, the Web UI is updated in real time reflecting that change for that user session.

C. *Work Flow of the System*

The complete work 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 using (3) and mapped to corresponding directions of either West, North-West, North, North-East or East using the algorithm demonstrated in Fig. 6.
7. The cart is then steered according to the direction obtained in Step 6.
8. Go to Step 2.

IV. IMPLEMENTATION

The proposed implementation for the proposed methodology is explained as follows:

A. *Server Module*

The server module was implemented 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.

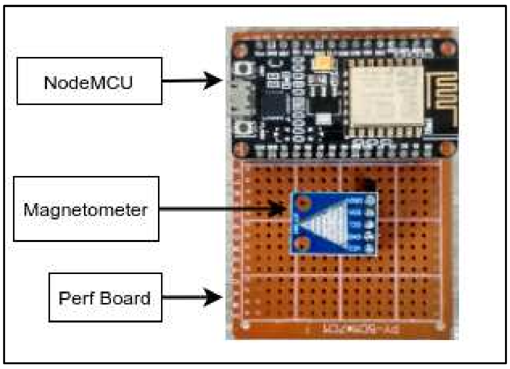

Fig. 7. Prototype of the User module consisting of NodeMCU interfaced with HMC5883L magnetometer sensor.

B. User Module

The user module was implemented 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. 7.

TABLE I. USER MODULE COMPONENTS & SPECIFICATIONS

Name	Quantity	Specifications
NodeMCU ESP8266 12E	1	It is a low-cost open source LUA based IoT firmware with a 802.11b/g/n HT40 WiFi transceiver. It has 128 kB RAM and 4 MB of Flash memory sufficient for large strings and JSON/XML data.
HMC5883L Magnetometer sensor	1	It is a triple-axis magnetometer sensor designed to measure both the direction and the magnitude of Earth's magnetic fields ranging from 10-6 T to 0.0008 T [17].

C. Cart Module

The cart module was implemented 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. 8.

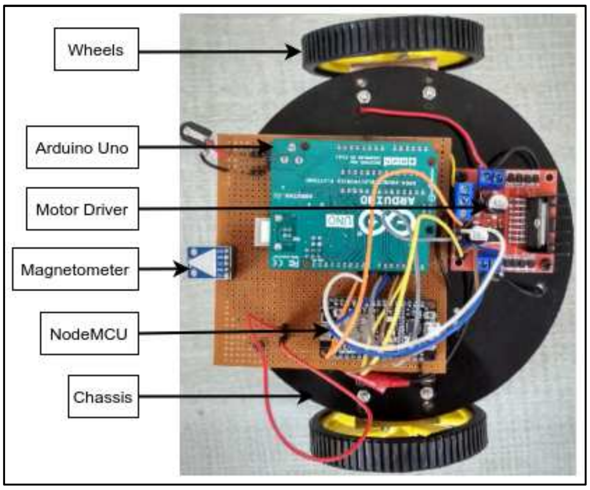

Fig. 8. Prototype of cart module consisting of Arduino Uno interfaced with DC motors and NodeMCU.

TABLE II. CART MODULE COMPONENTS & SPECIFICATIONS

Name	Quantity	Specifications
Arduino Uno	1	It is a low cost open source microcontroller board [18] which operates on a supply of 7 V - 12 V and has a RAM of 2 kB and a Flash memory of 32 kB.
HC-SR04 Ultrasonic Sensor	3	It offers non-contact range detection with high accuracy and stable readings. It operates at an input voltage of 5 V. It has a practical measuring range of 0.02 m – 0.8 m [19] with a resolution of 0.003 m and a measuring angle of 30°.
MFRC522 RFID reader	1	It is a transmission module for contact-less communication with RFID tags (ISO 14443A standard tags) at 13.56 MHz and communication with a microcontroller via Serial Peripheral Interface (SPI) at a maximum data rate of 10 Mbps.
RFID Tag	1 per product	ISO 14443A standard RFID tags
L298N Motor Driver	1	It controls the direction of rotation and speed of motor requiring 5 V - 35 V at up to 2 A per channel. It is controlled with logic signals and has 25 W rated power.
Wheels	2	Diamter of 12 cm
NodeMCU ESP8266 12E	1	Same as mentioned in the Table I.
HMC5883L Magnetometer sensor	1	
Motor	2	100 RPM Johnson DC motor.

The data transfer from the 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.

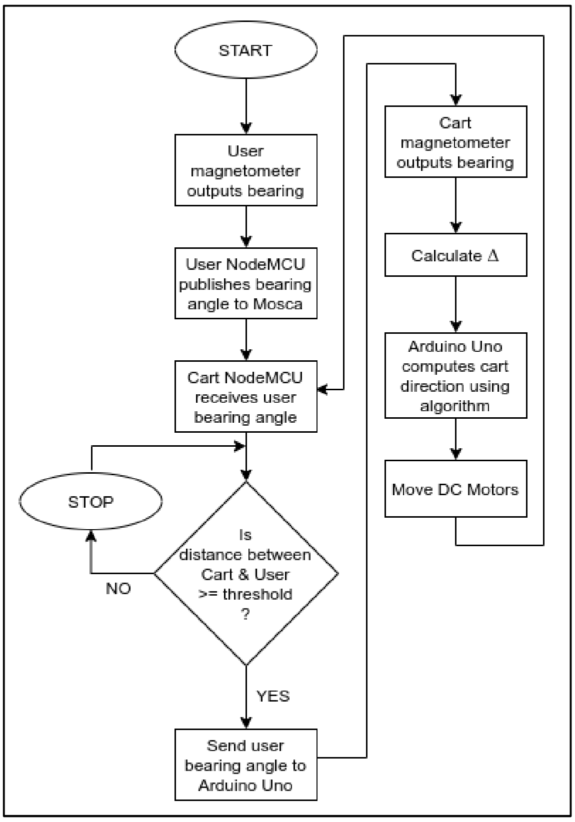

Fig. 9. Flowchart of the proposed implementation.

TABLE III. RECORDED OBSERVATIONS OF 5 TRIALS OF CART MOVEMENT

Expected Output	**Inside Threshold**				**Outside Threshold**					
	Trial 1		***Trial 2***		***Trial 3***		***Trial 4***		***Trial 5***	
	Δ	***Observed Output***	***Δ***	***Observed Output***	***Δ***	***Observed Output***	***Δ***	***Observed Output***	***Δ***	***Observed Output***
WEST	-	-	-	-	288.05	WEST	264.89	WEST	292.74	NORTH WEST
NORTH WEST	-	-	-	-	324.32	NORTH WEST	294.97	NORTH WEST	314.52	NORTH WEST
NORTH	-	-	-	-	357.6	NORTH	339.14	NORTH WEST	11.38	NORTH
NORTH EAST	-	-	-	-	48.99	NORTH EAST	54.44	NORTH EAST	36.70	NORTH EAST
EAST	-	-	-	-	112.89	EAST	78.87	EAST	90.55	EAST
STOP	NULL	STOP	NULL	STOP	-	-	-	-	-	-

V. RESULTS AND DISCUSSION

To implement the proposed mechanism, we conducted 5 trial which showed satisfactory results as demonstrated in Table III. The subject had to entered the cart ID and a password through the user-friendly Web UI from his 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 as demonstrated in Fig. 10.

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.

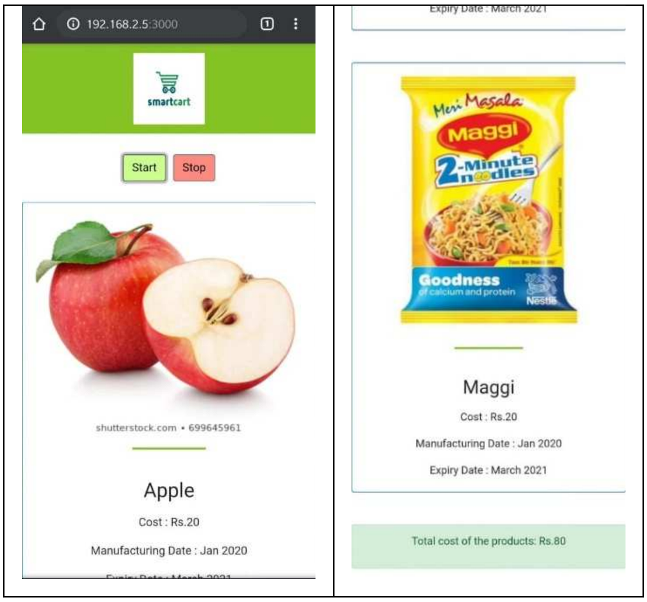

Fig. 10. The Web User Interface showing real time inventory and product details.

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 term in (1) needs to be adjusted according to the magnetic declination angle in that region.

VI. BENEFITS AND 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. Other advantages complementing the main aim are explained as follows:

A. *Freedom of movement and unique identification*

The proposed mechanism allows the cart more freedom of movement regardless of the floor plan or arrangements of shelves in stores or supermarkets. One such scenario is when the user abruptly turns left/right at the end of the shelf with the cart still behind him. In this scenario, the cart will also move in the user's direction (left/right) without colliding with the shelf using the aforementioned algorithm. The problem of uniquely identifying each user cart pair has been addressed in this approach by mapping user wearables with the carts using private channels on the MQTT broker.

B. *Use case for a specific demographic*

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.

C. *Contactless shopping*

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 after playground equipment and armrests on public transportation on the list of nastiest public items to touch, 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.

D. Economical and interactive shopping

Impulse spending is a big problem that affects many people. A 2014 survey by Creditcard.com found that 75% of Americans had made an impulse buy. A study conducted by Nielsen last year found that impulsivity caused 52% of people in Thailand, 48% of people in India and 44% of people in China to buy something they didn't need [21]. The Web UI interface integrated with the smart cart will keep the user conscious about the costs of his/her inventory. If the user has a specific budget in mind, then he/she can shop accordingly without going over that budget. The user won't have to look for the details on the product. All the product details will be reflected on the Web UI as soon as the product is scanned on the RFID reader.

E. Use of RFID tags over barcodes

RFID tags have numerous advantages over barcodes. Firstly, RFID tags do not have to be in line of sight with the scanner and work over much greater distances as compared to the barcodes. Secondly, RFID tags are read as well as write devices which enables them to carry large and detailed data of the product whereas the barcodes have no read or write capabilities and contain only manufacturer information of the product. RFID tags can contain information such as the cost, manufacturing data, expiry date, etc. [22].

VII. FUTURE SCOPE

In recent times, cloud computing has proved to be one of the promising fields as a new technological stack. Integration of existing systems, both hardware and software, with cloud has led to improved efficiencies and cost effectiveness [23]. The field of robotics too can make use of the benefits of cloud computing by designing architectures based on cloud. The scope of the idea proposed in this paper can be extended further by integrating it with the cloud. Integration can be done by deploying the centralized Node.js server on the cloud through cloud computing platforms such as Amazon Web Services (AWS), Google Cloud Platform (GCP), Microsoft Azure, etc. which can ensure seamless transfer of data as well as efficient horizontal and vertical scaling. This can be achieved in two ways depending on factors like budget, staffing, etc. Either the stores can have their individual private clouds where the servers can be deployed, or the collective chains/franchise of the stores or supermarkets can have their shared cloud-based architectures with elastic compute and storage policies. Further study in this domain will surely prove to be of utmost help for achieving better performance and scalability along with low latency.

VIII. CONCLUSION

The authors were successful in implementing the proposed design and the prototype of the human following smart cart. The concept of steering the cart based on the bearing of the cart with respect to the user using two magnetometers showed promising results. Thus, the need of IR sensors or cameras was eliminated, 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 the proposed system which need to be solved by the research community to make this system more reliable and efficient.

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