Indoor Navigation System using Optical Mouse Sensor and Smartphone

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***Abstract*—In this paper, we propose a low cost indoor positioning system that uses an ADNS-2610 optical flow sensor from an old Compaq PS/2 optical mouse. We built a prototype for a navigational kit around the proposed indoor positioning system. The navigational path is determined by collecting displacement data from the optical flow sensor and composing the same with the rotational data from the inbuilt magnetometer of an Android based smart phone. The user's position is then updated on a map accordingly. The collected displacement data is initially sent to an Arduino microprocessor, which in turn sends this data to a Bluetooth module for onward transmission to the Android based smart phone. The proposed system has wide applicability not only in accurate positioning but in accurate odometry**

***Index Terms*— indoor positioning, optical mouse, Android, Arduino, Bluetooth.**

I. INTRODUCTION

Positioning is a critical requirement for determining the path from current location to a particular destination. Without the knowledge of current position, a person will never be able to move out of an unknown location. A lot of research has been done in outdoor positioning systems. Reliable outdoor positioning systems with desired levels of accuracy have been developed using GPS (Global Positioning System). GPS provides a decent accuracy of about 5-10m which suffices for macro level positioning and outdoor navigation. Unfortunately, GPS does not work for indoor localization and cannot provide micro level accuracies desired for indoor navigations. There are a number of indoor environments where a person will need navigational assistance. For example, GPS is ineffective for a tour of Grand Canyon or Mammoth caves. There are many other indoor environments such as large construction sites, big malls, museums, heritage sites, where a person needs navigational assistances. Particularly, for visually impaired people, availability of a low cost, highly accurate indoor navigation will be a boon. So, the importance of a low cost indoor positioning system cannot be overemphasized.

Our study of existing indoor positioning systems reveals that most systems have either very low accuracy or very high setup costs. Among the most popular ones, the Wi-Fi based positioning systems use techniques like triangulation, deterministic and probabilistic fingerprinting. In triangulation based positioning systems, Wi-Fi signal strengths are recorded from multiple access points in an indoor environment, and based upon signal strength measurements a person's current position is predicted as described in [1]. Among the three Wi-Fi based techniques, probabilistic fingerprinting provides the best accuracy, which is about 5m. However, it requires extensive calibration and expects the environment to be access-point rich. RADAR [2] represents another RF measurement based system for locating and tracking users inside a building. It operates by recording and processing signals strengths at different base stations which provide overlapping coverage at areas of interest. The reported accuracy of RADAR is about 2-3m. The positioning scheme based on magnetic fingerprinting [3] technique can provide an accuracy up to 1m. It uses the geo-magnetic disturbance signatures of steel structure and furniture in a building. Based upon the previously recorded data, it tries to predict current position. However, it requires high setup cost for placing an array of e-compasses throughout the indoor environment. The setup may become also become unusable, if the positions of magnetic items are changed in the building. The other known positioning system includes Active Badge system [4], [5]. The badge is worn by a person. It sends IR signals at regular intervals to sensors placed at known positions throughout the building which are the sent to the central location manager software. However scalability is a problem due to limited range of IR sensors, and also has high infrastructural costs.

Apart from existing technological approaches mentioned above, optical indoor positioning systems have also been tried out [6]. Optical indoor positioning system provides good accuracies, but the major difficulties in successful implementation and use of such systems have been high cost of camera and/or setup. Two key components in optical odmetry are an optical mouse sensor and a magneto-inductive compass. Optical odometry sensors have been used for self localization in robots [7]. Optical mouse sensor consists of a unit which repeatedly takes pictures and processes them. The picture taking unit then computes the amount of displacement by using some image processing to distinguish between two successive frames. It requires a sufficiently high frame rate of the camera, good optical characteristics for crisp and sharp images. Though, the system requires very low setup cost and provides quite good accuracy, has certain drawbacks. For example, it cannot work on smooth surfaces. Furthermore, the system cannot function at high speeds.

Our idea is to extend the optical mouse sensor based approach as outlined in [8] in a way that it overcomes the aforementioned limitations, and at the same time can be used to give real time navigational instructions in conjunction with an Android based smart phone.

II. OVERVIEW

For an indoor positioning system, the important factors that need to be taken into account are the displacement and the direction of facing. The user of a navigational system may simultaneously move and change his/her orientation. As a result, an indoor positioning system needs to be accurate in both the measurements. Moreover, such a system needs to be infrastructure independent. The dependence on an infrastructure not only makes the system expensive but also less adaptive for use. This is one of the most significant drawbacks of the current sensor-networks based positioning systems ([2], [4], [5]). An optical mouse is cheap, reliable, easily available, and at the same time extremely precise in tracking movements and converting it to pointer movements on a laptop or desktop. Taking all the factors into account, an optical mouse seemed to be an ideal solution for calculating the displacement. For determination of orientation, the magnetometer of the smart phone can be used. The magnetometer measures the orientation of phone with respect to Earth's magnetic field. For the purpose of the navigation, we only need find the orientation relative to the initial orientation, or just the angle of rotation. There is no need for knowing the geographic north or south. However, three limitations associated with a normal optical mouse sensor need to be handled before we can use it for the purpose of navigation. These are:

(i) A typical optical mouse needs to be kept in contact with the surface (less than 2-3 mm away) on which it moves, to function properly and accurately.

(ii) Moreover, the displacement data recorded by an optical mouse vary over the type of surface [8]. For instance, an optical mouse sensor has inherently different behaviors over paper, rough surface, smooth surface, shiny surface, etc. This issue needs to be dealt with if the system is to be made reliable and usable. In fact, it was one of the major drawbacks in previous work in using optical mouse for displacement purposes [8].

(iii) Another issue associated with an optical mouse sensor is that of speed. Typically, an optical mouse sensor functions properly up to a speed limit of about 1-2 m/s. Since pedestrian speeds may reach up to 2-3 m/s (on a higher side), this problem has to be taken care of.

We made a few modifications in the way the optical mouse sensor should be used in order to handle above limitations. We devised a trolley-like assembly as shown in Fig 1. The optical sensor faces a tire which rotates as the user moves. We record and process the movements accordingly. This way, the first issue is taken care of, as we are able to make the assembly in such a manner that the separation between the mouse sensor and the tire is 2-3mm as per specification demanded by the optical mouse. The second issue is resolved by fixing the type of surface type (which is the tire's side surface). So, our navigational kit becomes independent of the surface on which optical mouse sensor is moved. The third issue is resolved by keeping the sensor close to the axis. Even if the tire rotates at an outer velocity of about 2 to 3 m/s, the surface in-front of the optical sensor would be moving at a speed less than 1 m/s (since the angular velocity for the whole tire is the same). A top level view of the navigational kit is shown in Fig 1 where an optical flow sensor faces the wheel.

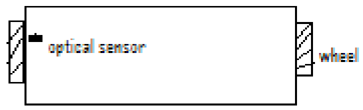

Fig.1. Top View of the proposed trolley-design

III. TECHNICAL SPECIFICATIONS

The summary of overall idea on which the prototype was build is as follows:

(i) Collect the displacement data from the optical flow sensor of a mouse,

(ii) Send the displacement data to a microprocessor,

(iii) The microprocessor in turn sends the data to a Bluetooth module which transmits the data wirelessly to the Android based smart phone

(iv) The smart phone combines the displacement data with its inbuilt magnetometer's rotation data and updates the user's position accordingly.

A brief flowchart of the complete system is shown in Fig 2.

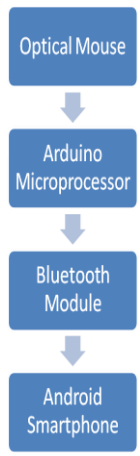

Fig 2. Displacement-data flow

A. Prototype Description

The prototype of the system was built using an ADNS-2610 optical mouse sensor which was taken from an old Compaq PS/2 optical mouse. The pin descriptions for the ADNS-2610 as taken from its data sheet are shown in Fig 3.

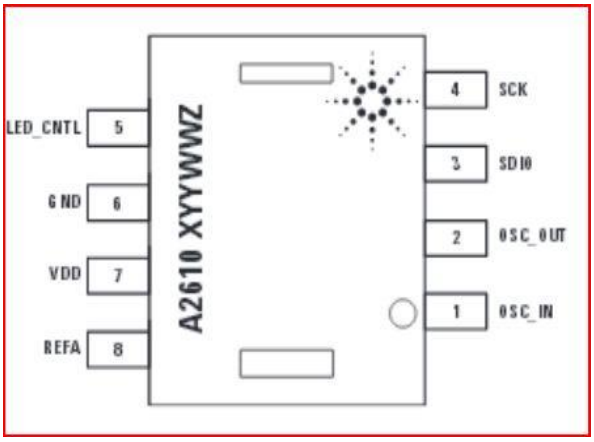

Fig. 3. ADNS -2610 Optical Sensor Pin Specifications

The pins that are relevant for the use of finding displacement are SCK (clock), VDD (power), GND (ground) and SDIO (data). The ADNS-2610 needs a DC power supply of 5 volts. The optical mouse pins were connected to their respective pins in the Arduino Uno microprocessor. The Arduino Uno is a microcontroller board based on the ATmega328 microprocessor. It has 14 digital IO pins, some pins for analog inputs, and has support for USB connection to computer, has a power jack and a reset button. The top view of Arduino Uno is shown in Fig 4. It is the most commonly used microcontroller for prototyping. The Arduino microprocessor reads the displacement data from the registers of the optical sensor at a baud rate of 38400 and sends the data to HC-05 Bluetooth module at a baud rate of 9600 of every 128th displacement data. The data between the HC-05 Bluetooth module and the Android phone is sent over an RFCOMM socket connection.

Fig. 4. Arduino Uno Microprocessor

The TX pin of the Arduino Uno was connected to the RX pin of Bluetooth module, and the RX pin of the Arduino Uno was connected to TX pin of Bluetooth module. A circuit diagram for the connection is shown in Fig. 5.

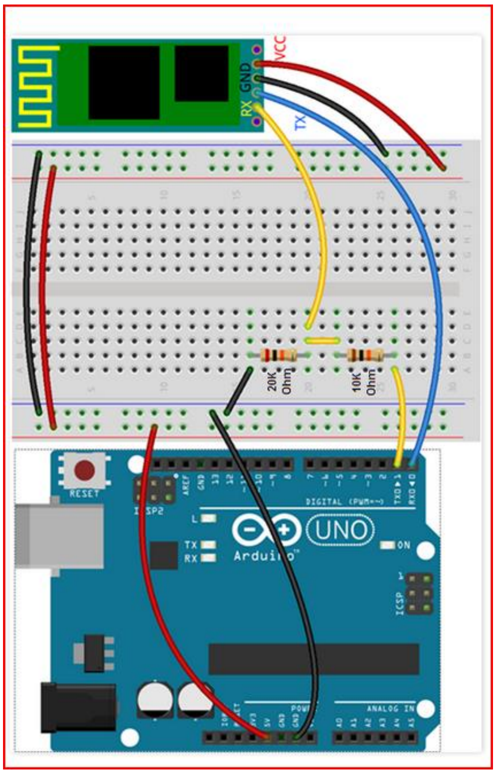

Fig 5. Circuit diagram of Arduino Uno with HC-05 Bluetooth Module connection

A prototype of the navigational kit is given in Fig 6.The Android phone we used was Samsung Galaxy Grand Quattro I8552. The data received on the phone is parsed to get the relevant data in proper format. Then this data is combined with magnetometer data and interpreted as movement of the user's position pointer appropriately on a map. The Android phone has a multi-threaded application component on it which receives data via Bluetooth, parses it and updates user's location on the map. All the threads work in a synchronized manner to show the user's current location.

B. Orientation Measurement and Position Update

Most Android smart phones come with a built-in magnetometer which can report orientation of the phone in terms of azimuth, pitch and roll as shown in the figure below. For finding the orientation of user in the *x-y* plane (parallel to the ground), the azimuthal angular movement has to be taken into account. The range of azimuthal angle extends from +180 degrees to -180 degrees. After -180 degrees, the azimuthal value wraps around to +180 degrees and vice versa.

As soon as the user opens the map view of the application, the initial azimuthal angle is recorded as *initialCompassAngle*. The user then has to input their initial facing direction in terms of top/bottom/right/left/top-right/top-left/bottom-right/bottom-left with respect to the map. This input is then recorded as

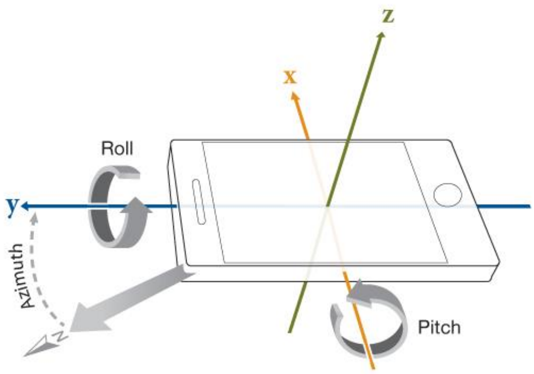

Fig. 6. Orientation Axes in Android Smartphone

initialFacingAngle which equals (45 degrees * chosenDirection). Next, whenever the orientation of user changes, the currentFacingAngle is computed as follows:

currentFacingAngle = (currentCompassAngle
- initialCompassAngle
+ initialFacingAngle) modulo 360;

After computing the *currentFacingAngle*, the orientation of the user on the map is then used to update the displacement in the direction of *currentFacingAngle*. The coordinate system of the smartphone is shown in the figure 7.

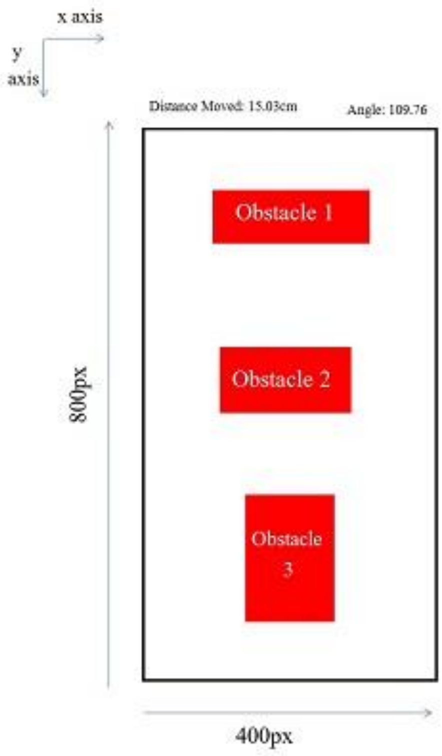

Fig 7: Smartphone coordinate system with sample map

The new coordinate position of the user on the map is computed by taking into account the displacement in the *currentFacingAngle* direction. The displacement that is received from the optical mouse is scaled appropriately by a factor of centimeters to pixels according to the formula below:

newX = oldX
*+ (displacement * (cmToPixelFactor)*
** (calibrationFactor)*
** (Math.sin(Math.toRadians(currentFacingAngle)))*

newY = oldY
*+ (displacement * (cmToPixelFactor)*
** (calibrationFactor)*
** (Math.sin(Math.toRadians(currentFacingAngle)) * (-1))*

The (-1) appearing in the computation above, takes into account the fact that the coordinate system of Android phone has *Y* axis growing opposite in direction to the conventional *Y* axis. The *cmToPixelFactor* is computed from the screen size and screen resolution. For the prototype, the Android phone that was used had a resolution 480 x 800 pixels and the diagonal length was 4.7 inches. Hence, for the prototype, the factor turned out to be:

cmToPixelFactor = PixelWidth / ScreenWidth (in cm)

cmToPixelFactor (prototype) = 480 / 6.14

The calibration factor was found upon calibration, and it turned out to be 90 for our prototype for the optical sensor being placed at 1 cm from the axle and the wheel radius being around 4cm.

C. Path Finding and Navigational Assistance – The A-star Algorithm

For finding the path of movement from the current position of user to a selected target position, we used the A-star path finding algorithm [10]. As A-star traverses the graph, it follows a path of the lowest expected total cost or distance, keeping a sorted priority queue of alternate path segments along the way. The A-star path finding algorithm takes a map (a two dimensional array of pixel values) with information about obstacles encoded in it and gives the shortest path around the obstacles. The algorithm converts the problem into a graph traversal problem and is known for its performance and accuracy. A-star is an extension of Dijkstra's algorithm [11] and achieves better performance by use of heuristics. In our implementation, we use the Manhattan distance heuristic [12].

IV. APPLICATIONS

Indoor Positioning cum Navigation system using optical mouse can be used in various locations like tracking shopping carts inside a store, tracking cabs in a city, indoor navigational support for visually impaired person, helping in indoor movements in shopping malls, museums, airports construction sites, tracking movement of trolleys in warehouses. The device can be attached with a shopping cart so as track the places where the customers spend most of the time around a shopping mall. The device gives an accuracy of around 95% which makes it very efficient to track the path of the customer. So, the information can be used to improve customer's experience in a modern shopping mall. The system is very small and lightweight and does not need infrastructure like sensor network. So, it is easily deployable, reducing the installation cost appreciably. Additionally, detailed maps could even help the user in locating items to a very high granularity.

V. RESULTS

With our prototype of the system, we were able to get on an average error less than 2% in terms of distance moved. This is significantly better than the existing systems including the ones which have very high setup costs. The error can be further reduced in practice by recalibration at landmark points on the map using QR codes. The prototype cost was less than 40 U.S. Dollars making it easily deployable for mass usage. However, there still lies scope of improvement in terms of direction determination.

VI. FURTHER WORK

The direction determination can be improved by use of two optical mice instead of one. This would eliminate the use of magnetometer and hence would give excellent accuracies while keeping the cost minimal. This system can be further extended to include text to speech and speech to text features to give navigational instructions to visually impaired people. If needed, we can have the gears along with the wheels so as to make the system robust for higher speeds.

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