LARN: Indoor Navigation for Elderly and Physically Challenged

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Abstract— **Automatic navigation systems have a wide range of applications and are usually implemented in many robotic systems. The area of interest here is an automated powered wheelchair for the elderly and physically challenged individuals, which empower them to navigate inside their homes without having to continuously steer the wheelchair. Such a system dramatically reduces the amount of continuous physical effort the user has to apply. This is achieved by mapping the floor plan of a house into number of square grids, with each grid having a unique address. The Location Aware and Remembering Navigation (LARN) algorithm, which is based on the Dijkstra's shortest path algorithm, calculates the shortest path to a set of predefined locations inside the house. With sufficient hardware to measure the orientation of the wheelchair and distance traversed, LARN can dynamically calculate the shortest path to any of the predefined locations. The greatest advantage of implementing LARN is the fact that the system would require no wireless devices to function. This paper discusses the implementation of the LAN algorithm on MATLAB. Simulation and testing of the algorithm is done in MATLAB 2008 and 2010 in both Intel i3 and i5 processors.**

Keywords- Navigation, LARN, Wheelchair

I. Introduction

Mobility is one of the greatest challenges that elderly and physically challenged people face in their day-to-day life. Powered wheelchairs with various methods of input such as voice, joystick, gesture etc. have proved to be effective in aiding these individuals to a certain extent. However, many of the physically challenged individuals find even these implementations difficult to manipulate. The users are required to put continuous physical effort to navigate the wheelchair inside the house. This becomes very tedious for with high degree of disability such as quadriplegics.

Our system aims at reducing the stress of these individuals who use powered wheelchairs by developing an automatic navigation system that can be incorporated to the existing system. The automatic navigation system is designed for indoor navigation alone. A number of specific locations inside the house to which the user often navigates is identified and stored in the system like the kitchen, living room, bedroom etc. Whenever the user wishes to navigate to these locations, he/ she can press a dedicated push button or give a predefined gesture to indicate the destination to which the wheelchair should move. On receiving the input, the system will automatically take the wheelchair to its destination through the shortest path.

The Location Aware and Remembering Navigation (LARN) algorithm computes the shortest path to the destination regardless of the wheelchair's present location. The algorithm has been developed based on Dijkstra's shortest path algorithm. The algorithm requires the floor plan of the house to be stored in the system. The stored floor plan is divided into a number of square grids of equal size and each grid is assigned a unique address. The locations identified by the user would always correspond to a particular grid. All such grids are mapped and stored in the system. A dedicated push button can be assigned to each of the identified grids.

Apart from the identified grids, one specific grid has to be set as the reset grid. In order for the LARN system to understand where the wheelchair is initially located, the wheelchair has to be manually brought to this grid and a reset button has to be pressed. This is known as resetting the wheelchair system. Once the system is aware of its present location, the automatic navigation can be initiated.

In our implementation, the LARN system is implemented using MATLAB. The sample floor plan of a house was uploaded and the effectiveness of the system for various number locations and gird sizes was measured.

II. Motivation

Before beginning our work, we had a visit to the Center for Rehabilitation at the Amrita Institute of Medical Sciences, Kochi, India. We were able to interact with the doctors and patients and the feedback we received on powered wheelchairs was very positive. It solved various issues of many individuals who had a low degree of disability. However, for patients who were affected by higher degree of disability such as quadriplegia were not able to extensively use these powered wheelchairs for long periods of time. The major reason was that they were not able to provide the continuous physical effort required to guide the wheelchair.

An automated powered wheelchair can solve several problems. Firstly, because it is automated, the user does not have to continuously provide input. This substantially reduces the physical effort to guide the wheelchair and will be quite beneficial for quadriplegics.

Secondly, the system does not use GPS, or any other wireless devices to determine the position of the wheelchair. This way, the system's cost can be reduced without compromising in accuracy. The reduced cost can increase the popularity of this system among individuals who belong to middle class families, especially in developing countries like India.

III. RELATED WORKS

Several techniques exist at present that are used for identifying the location of a subject and to track its movement. Some involve the use of wireless transmitters and receiver whereas the rest make use of sensor reading to identify the current position with in an environment.

The most common as well as basic approach used for indoor localization is estimating certain signal parameters. These parameters include time-of-arrival (TOA), angle-of-arrival (AOA) or Received-Signal-Strength (RSS). [1] Then in a second step, the collection of estimated parameters is used to determine an estimate of the emitter's location. However, the systems based on AOA need multiple antennas or a scannable antenna that are usually costly.

In the previous method, each of the receiver or antenna would individually calculate the position of the transmitter. This value need not be accurate. Another approach involves the estimation of transmitter location by combining the reading of multiple sensors. Here an indoor space is divided into grids. The grids are represented in the sensor readings as vectors. The grid in which the transmitter exits is assigned a positive integer. The rest are assigned zeros. [2] Readings of all sensors together form a matrix. This matrix would give the position of the transmitter after certain mathematical operations.

Another technique involves use of RFID tags and detecting or reading the RFID tags using multiple detectors. In this method also, a particular area is divided into several grids. Each grid corresponds to the coverage area of a single RFID reader. Square grid network presents the solution of placement pattern of RFID readers, hence optimal number of required readers and guaranteed coverage can be achieved. [3] The proposed diffusion algorithm makes use of distance information between the reader and the tag to estimate the RFID tag position. In this approach an accuracy improvement of up to 65 percent was achieved than the other existed algorithms.

An entirely different approach exists, that makes use of radio propagation modeling for tracking the motion of a mobile terminal within an indoor environment. In addition to radio propagation modeling, Kalman filtering is used that is extensively used in navigation and control of vehicles. The use of Kalman filter reduces the error by reducing the sampling time. With this technique, an error less than 2.2 meters was achieved in location estimation. [4] The Kalman filter, also known as linear quadratic estimation (LQE), is an algorithm that uses a series of measurements observed over time, containing noise (random variations) and other inaccuracies, and produces estimates of unknown variables that tend to be more precise than those based on a single measurement alone. A radio propagation model, also known as the Radio Wave Propagation Model or the Radio Frequency Propagation Model, is an empirical mathematical formulation for the characterization of radio wave propagation as a function of frequency, distance and other conditions. A single model is usually developed to predict the behavior of propagation for all similar links under similar constraints.

IV. SYSTEM ARCHITECTURE

Effective functioning of the LARN system requires a significant number of hardware devices to function synchronously. The system will be divided into five modules viz. LARN module, Microcontroller module, Obstacle Detection module, Digital Compass module and Rotation Encoder module. The LARN module will contain the floor plan of the house and will be responsible for executing the LARN algorithm and determine the shortest path when the user requests for it. The LARN module hardware will comprise of a microprocessor and supporting hardware to communicate with the microcontroller module. Figure 1 shows the block diagram of the various hardware components.

The Microcontroller module will function as the heart of the system. It communicates with all the other modules and makes decisions regarding the motion of the wheelchair. Once the shortest path is calculated by the LARN module sends the path to the microcontroller. On receiving the path it gives signals to control the motors of the wheelchair. It continuously communicates with the Obstacle Detection module, Rotation Encoder module and Digital Compass module once the wheelchair is in motion.

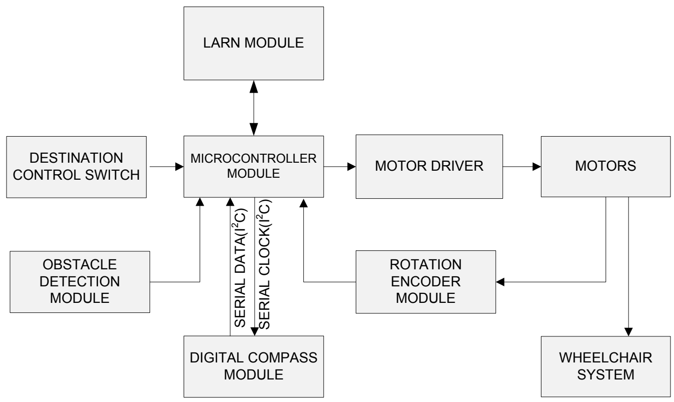

Figure 1. System block diagram

The Obstacle Detection module constantly monitors if an obstacle is present in the path of motion of the wheelchair. It uses ultrasonic sensors to determine the distance of solid objects that are present before the wheelchair. If the distance goes below a threshold value, then the module gives necessary signals to the Microcontroller to halt the motion of the wheelchair.

The microcontroller monitors the distance traversed by the wheelchair with the help of the Rotation Encoder module. This module has hardware attached to the motors of the wheelchair which can count the number of rotations of the motor. The inputs from the Encoder help the microcontroller track the

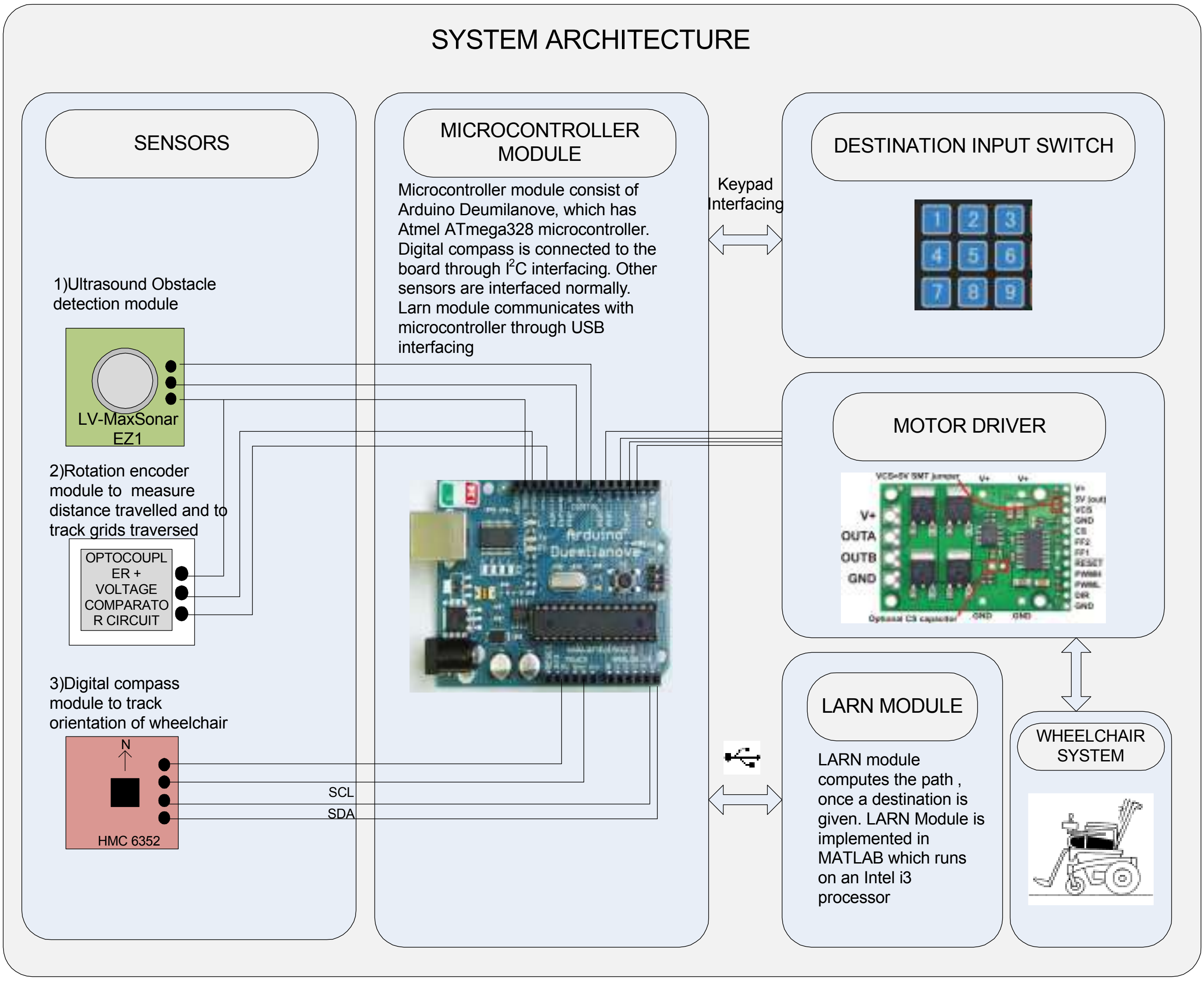

Figure 2. Architectural diagram

location of the wheelchair in grids and ask it to stop when the destination is reached.

The Digital Compass module as mentioned before functions when the wheelchair has to be rotated and oriented in a specific direction. It is directly linked to the microcontroller module. Figure 2 shows the architectural diagram of the LARN system.

V. THE LARN ALGORITHM

The LARN Algorithm is based on Dijkstra's shortest path algorithm and is modified to meet the purpose of automatic navigation. In the LARN system, the cost between subsequent nodes will always be one. The working of the algorithm can be illustrated with the following example.

Figure 2 shows a simple floor plan that is divided into 36 grids, with no obstacles or walls. Each grid is assigned a unique address and grid (2, 3) can be assumed to be the start grid and (4, 6) the destination grid. The grids (2,2), (2,4) and (3,3) can be reached by traversing one grid from the starting grid.

Similarly, grids (2,5), (2,1), (3,2) and (3,4) can be reached by traversing two grids, which makes the total cost to reach these grids 2. Likewise, the algorithm populates the matrix till the cost to reach the destination grid is calculated. Here, we can see that the cost to reach (4,6) is 5, meaning the wheelchair will have to traverse five grids to reach this destination.

We can see from the populated matrix that there are various shortest paths to reach the destination. Figure 2 shows the various possible shortest paths the wheelchair can take to reach the destination. The algorithm picks the path which requires he least number of 90° turns. In this case, there are two paths which require only one 90° rotation. In such cases, the algorithm identifies the initial orientation of the wheelchair and chooses the optimum path.

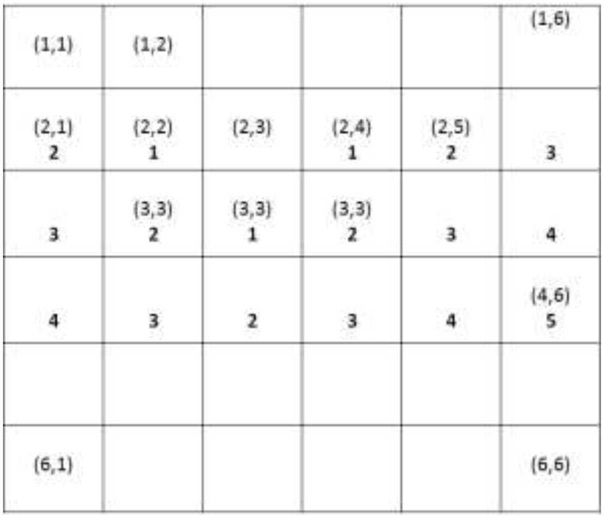

Figure 2. Sample floor plan illustrating the LARN algorithm

Figure 3 shows the various shortest paths that are available for the wheelchair to reach the destination. Of all the paths, there are two which require only one 90° turn to reach the destination and the wheelchair may arbitrarily take any of these two. It is at this juncture that the initial orientation of the wheelchair has to be considered. The heading values of the wheelchair with respect to the grids are given in Figure 2. To move down any column, the wheelchair would have to first orient to 0° and then move forward. Similarly, to move across a row, it will have to orient in 270° and so on.

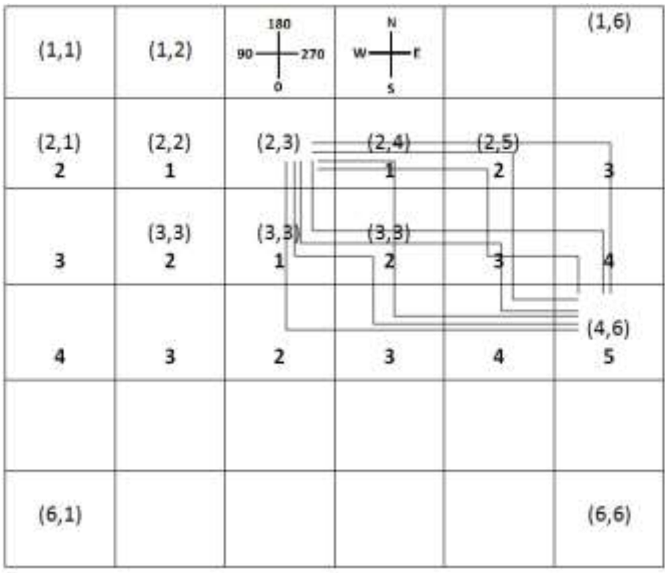

Figure 3. Various shortest paths

The system requires the aid of a digital compass or corresponding hardware to determine the orientation of the wheelchair. The heading values 0°, 90°, 180° and 270° on a digital compass correspond to North, East, South and West respectively.

VI. Implementation and Testing

The LARN algorithm was implemented in MATLAB and was tested with a sample floor plan. One reference grid and two destinations were assigned. The grid dimension of the floor plan is 10 x 10. Figure 4 shows a visual representation of the sample floor plan. The light green area in the map indicates grids with walls or other permanent obstacles through which the wheelchair is prohibited to traverse. The dark green area represents free grids that the algorithm can utilize to calculate the shortest path to the destination. The reference grid on this map is (5,1) and is marked with the yellow circle. Two destination grids, each marked with the red circle represents grids (1,3) and (10,7).

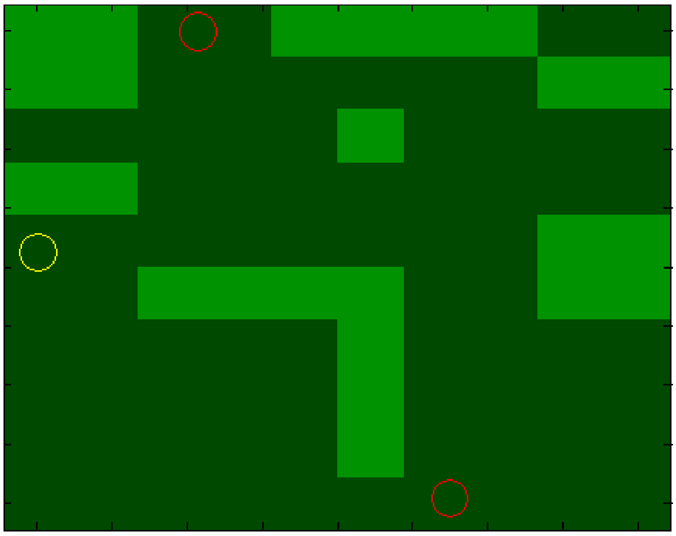

Figure 4. Sample floor plan

The algorithm and the program have the capability to accommodate a greater number of destination grids. In fact, the program can find the path to any grid in the floor plan. However, only two destination grids are assigned in this example for the simplicity of illustration.

Figure 4 only provides a visual representation of the floor plan. Figure 5 on the other hand, shows the matrix representation of the same floor plan. Each grid has a specific values assigned to it. The value -2 represents grids which have permanent obstacles or walls, to which the wheelchair cannot traverse and the ones marked with -1 represents those grids which can be traversed.

-2	-2	-1	-1	-2	-2	-2	-2	-1	-1
-2	-2	-1	-1	-1	-1	-1	-1	-2	-2
-1	-1	-1	-1	-1	-2	-1	-1	-1	-1
-2	-2	-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-2	-2
-1	-1	-2	-2	-2	-2	-1	-1	-2	-2
-1	-1	-1	-1	-1	-2	-1	-1	-1	-1
-1	-1	-1	-1	-1	-2	-1	-1	-1	-1
-1	-1	-1	-1	-1	-2	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Figure 5. Matrix representation of the grids

The result of the algorithm is illustrated in figure 5. The destination given in this test was (1,3) and the wheelchair was initially at the reference grid (5,1). We can see that grid (5,1) has been assigned the value 0 and the two adjacent grids are marked 1. Likewise, the floor plan is populated till the destination is found. In this case, to reach the destination, the wheelchair is required to traverse 6 grids. The algorithm can actually run till it finds the cost to each and every grid in the floor plan from the start location. However, for computational and processing efficiency, the algorithm terminates once the destination is obtained. In figure 6, the grids assigned -1 were not explored by the algorithm since the destination was found out with a lesser number of steps. Figure 7 visually illustrates the path which the wheelchair takes to reach the destination.

-2	-2	6	-1	-2	-2	-2	-2	-1	-1
-2	-2	5	6	-1	-1	-1	-1	-2	-2
6	5	4	5	6	-2	-1	-1	-1	-1
-2	-2	3	4	5	6	-1	-1	-1	-1
0	1	2	3	4	5	6	-1	-2	-2
1	2	-2	-2	-2	-2	-1	-1	-2	-2
2	3	4	5	6	-2	-1	-1	-1	-1
3	4	5	6	-1	-2	-1	-1	-1	-1
4	5	6	-1	-1	-2	-1	-1	-1	-1
5	6	-1	-1	-1	-1	-1	-1	-1	-1

Figure 6. Result of LARN algorithm.

The MATLAB program developed to implement the LARN algorithm was tested in two different hardware environments, and with different versions of MATLAB software for computation delay. For both cases, the floor plan dimensions in terms of the total number of grids were varied to test the performance of the algorithm. The test results are in Table 1.

From the above table it can be seen that as the output computation times increase as the size of the floor plan increases. For most cases of indoor navigation the floor size of 100 X 100 grids will be more than sufficient as the grid size of about 1.5 square meters means that the floor area for 10,000 grids will be 15,000 square meters.

Figure 7. Visual representation of the path to grid (1,3)

Floor dimensions	*T_c (Intel i3 microprocessor and Matlab 2008)*	*T_c (Intel i5 microprocessor and Matlab 2010)*
20 X 20	0.0030 s	0.0016 s
40 X 40	0.0075 s	0.0041 s
75 X 75	0.0191 s	0.0137 s
100 X 100	0.0307 s	0.0233 s
120 X 120	0.1114 s	0.0294 s
200 X 200	0.1346 s	0.0808 s
2000 X 2000	27.9941 s	19.1904 s

Table 1. Output computation times of LARN implementation of Matlab

VII. Conclusion

The LARN Algorithm is able to provide the shortest path possible to reach the destination for an automated powered wheelchair in a very short period of time. This can be allow cost implementation for other similar systems which require automatic navigation. The cost reduction achieved can help the vast number of disabled individuals in developing nations such as India.

VIII. Acknowledgment

We wish to thank Almighty God who gave us the opportunity to successfully complete this venture. The authors wish to thank Amrita Vishwa Vidyapeetham and the Humanitarian Technology Lab for aiding us in this endeavour. The authors also acknowledge the support from IEEE Foundation, NJ, USA.

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