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# Virtual Environment Modelling using Simulated Laser Scanners

Hassan M. Qassim
*Technical Engineering College of Mosul*
*Northern Technical University*
Mosul, Iraq
hassanqassim@ntu.edu.iq

Heba Lakany
*Department of Biomedical Engineering*
*University of Strathclyde*
Glasgow, United Kingdom
heba.lakany@strath.ac.uk

***Abstract*— Life quality of people with sever motor disabilities can be improved by developing and inventing new assistive technologies. In this context, it is proposed to develop a semi-autonomous electric wheelchair that has capabilities of navigating through various environments which include different types and sizes of obstacles. This paper describes a methodology to use a range laser scanner mounted on an electric wheelchair to map different environments. The electric wheelchair is simulated in a virtual environment and is developed at the Neurophysiology Laboratory of University of Strathclyde. Mapping the environment is dependent on the information provided by the range laser. An algorithm was developed in MATLAB to record the data received by the range laser and use the data to map the environments and produce a 2D map. The suggested algorithm has been tested using two virtual environments representing rooms with different features. The results showed that range laser scanner can be used on an electric wheelchair platform for efficient mapping of the environment.**

***Keywords*— Electric wheelchair, Range laser scanner, Shared control, Virtual environment, Assistive technologies**

## I. INTRODUCTION

There is around one million wheelchair users in the UK and around two million in the USA. Wheelchairs can be an effective way to move around and alleviate the impact of mobility limitations for many people with severe motor disabilities, allowing them higher level of independence and improved quality of life. The use of wheelchairs has grown in recent years due to a number of factors including the shift in demographics. Recent changes in governments' policies to support wheelchair accessibility in public transport and buildings have had a positive impact on the number of wheelchair users and decreased access barriers they used to face on daily basis when leaving their homes.

Over the last three decades, many researchers have worked and conducted researches to improve the autonomy of the electric powered wheelchair which finally led to the emergence, of what is known as, the smart wheelchair. Smart wheelchairs are basically standard power wheelchairs equipped with different types of sensors and controlled by a computer programme to provide further autonomy activities [1]. These activities are identified according to the user's needs. Some smart wheelchairs are characterised by shared control techniques [2], which are used to reduce the cognitive and physical efforts that required for operating the wheelchair, particularly for obstacle detection, wall following, collision avoidance and environment mapping [1]. Various types of sensors have been integrated to smart wheelchairs to provide different degrees of autonomy. In [3], Simpson has summarised the most popular sensors that are usually used for shared control techniques, those sensors are ultrasonic (sonar) sensors, infrared sensors and laser range finders (LRFs) or the extended version laser scanner sensors [4].

It is necessary that every new assistive system needs to be assessed and evaluated to ensure its suitability to user's needs. Although testing an assistive technology in reality shows the pertinent indications of how the user could adapt to the new system and the modifications are then recorded, real testing is costly, and drawbacks of such testing are usually very specific to each person [5]. Thus, virtual reality represents a technology that can be used to provide a simulated environment which reduces risks and provide the capacity to a wide range and diverse experiments. Therefore, an immersive virtual reality (VR) electric wheelchair simulator has been designed and developed in the Neurophysiology Laboratory at the University of Strathclyde, which provides a safe environment for the user and several maps simulated the real world [2]. More details about the platform will be discussed and explained in the methods section (Section II).

In this work, the objective is to explore and experimentally verify the ability of laser scanner sensors in providing sufficient details about the environment in order to map that environment and eventually augmenting the wheelchair with shared control techniques for the wheelchair such as navigation and obstacle avoidance.

This paper is organized as follows: next Section details the platform used to develop the algorithms. It also includes the methods used in implementing the range laser sensor. Section III covers the results of the proposed methodology through presenting two examples. The results are discussed in Section IV and conclude the paper by Section V.

## II. METHODOLOGY

Urban Search and Rescue Simulator (USARSim) [10] has been used to provide robot simulator at Neurophysiology Laboratory at University of Strathclyde [2], [6]. USARSim is based on a video game engine that provides a wide range of variant simulated sensors that can be used in a smart wheelchair [2]. In addition, USARSim provides unreal editor which allows us to write and implement different elements (such as sensors) to the robot using scripting language similar to C++ and Java. The platform that was used in order to map different virtual environments consists of standard PC, large spherical (dome) screen to provide environment similar to the real one, a projector with a fish-eye lens to project the environment on the screen and a controller pad (joystick or keypad) to control the robot's movement within the virtual environment [6]. Instead of using a robot, a 3D model of an electric wheelchair has been built and added to the environment. The geometries and mass- inertial properties of the wheelchair was developed and implemented in [2].

In this work, scanner has been implemented which simulates a laser range scanner sensor on the wheelchair. The laser scanner covers a field of view of 180˚ with a resolution of approximately 1˚ and range of 10 meters [3], [7], [8]. However, it should be noted that increasing the resolution of the laser scanner affects the speed of data processing. It was found that 1˚ resolution offers a good compromise between accuracy of mapping and data processing speed. The working principle of laser scanner is defined as a line emitted from the sensor position along the direction of the sensor. When this line strikes a point in the virtual environment, the distance between the sensor's position and that point is returned as a range value. However, if the line does not strike any point (within its range) the returned range value will be maximum value and refers to the absence of any obstacles in this range. As the field of view of our scanner is 180˚ and the resolution is 1˚, 181 lines or range measurements were expected for each scan. A number of scans may be required according to the number of features or obstacles in the environment [8].

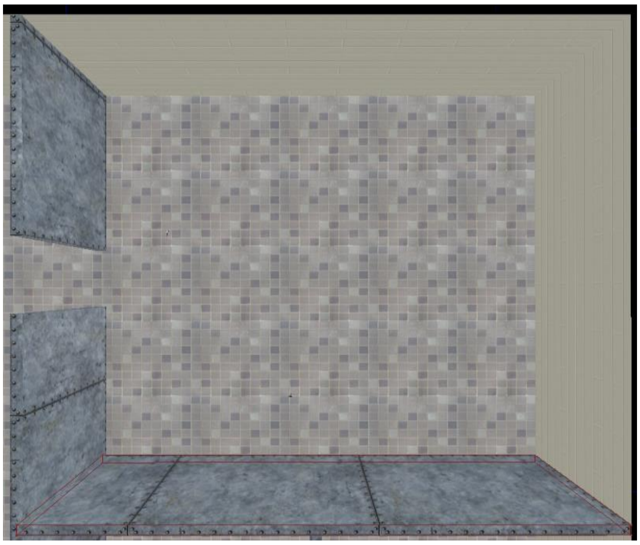

Fig. 1 depicts a top view of the first environment; representing a room with a doorway.

Fig. 2 illustrates a top view of the second environment representing a room with obstacles and a curved wall.

Two virtual environments were developed and implemented to test mapping capabilities of the range laser sensor mounted on the simulated electric wheelchair. The environments included various features required to be mapped in order to determine the ability of the laser scanner in recognizing different features of any environment such as corners, curvatures, doors and the most popular segments walls. Unreal editor was used to create these two environments [9]. Both environments are halls with dimensions of 10x10x3 meters. The first environment is a simple cubic room with four corners and one door is shown in Fig. 1, while the second environment has three corners and one curvature as shown in Fig. 2. In addition, two obstacles were added to the second environment, where both of them are cubes but in different sizes. The large cube has dimensions of 1.5x1.5x1 meters while the small one has dimensions of 0.5x0.5x1 meters. Those two obstacles were added in order to check the ability of the laser scanner to detect and map obstacles and corners from outside rather than inside the corners.

As the wheelchair moves the laser scanner rotates from start point to end point. The start point and the end point of our scanner are 0˚ and 180˚ respectively, where 0˚ refers to direction along the positive horizontal-axis while 180˚ refers to the direction along the negative horizontal-axis. The time between successive scanning can be determined and changed in the unreal engine [10].

Each sensor responds to the variations in the environment and outputs a message, which describes that environment according to the function of the sensor. These messages are provided by Unreal Tournament 2004 (UT2004) [2]. Messages produced by laser scanner were collected. The messages were then used to extract data to create 2D maps of the environment. A program has been developed and implemented in MATLAB for that purpose.

The messages of the range laser scanner are provided in polar coordinates and needed to be transformed to Cartesian coordinates. Each line of the 181 range measurements of the scanner was converted to two coordinate points, first point was over the horizontal-axis and the second point was over the vertical-axis (X and Y points). X and Y points of each line were calculated using the following two formulae

$$X = range * \cos(\beta) \quad (1)$$
$$Y = range * \sin(\beta) \quad (2)$$

The range is the value of the line, and (β) is the angle of the specific line. As 181 lines were achieved, β angle was changed from 0˚ to 180˚. (β) is equal to 0˚ for the line number one while (β) is 180˚ for the line number 181.
In addition, an odometry sensor was used to show the inclination of the wheelchair relative to its starting position while it is moving around the room. The angle of inclination provided by odometry sensor is then used to change the orientation of the laser scanner values and aligned them to the original orientation (hall orientation) using a Jacobian matrix.

## III. RESULTS

The results were produced using mentioned methodology while scanning two different rooms, are presented in this section.
The first environment is a simple hall of (10x10x3) meters. As we are dealing with 2D range scanner, it was expected to get a 2D map of (10x10) meters. The first environment was built as an empty cubic room comprising of four corners and one door. After all the messages were read, a 2D map was extracted from the laser data and drawn and is shown in Fig. 3. Messages from three scans were used in order to draw these maps and the angle between each chosen scan and the successive one was approximately (80˚-120˚). As shown in Fig. 3, the four corners are clearly shown and there is a gap and a cone on the left side of the drawn square. This gap represents the door in the real map.
The second environment simulated a room that consisted of three corners while the fourth corner was replaced by a concave curvature. The room included two different sized cubes placed against or near to one of its straight walls. The second map was produced using the collected laser scanner sensor's messages and the developed MATLAB program. The resulting map is shown in Fig. 4. similar to the first map, three scans with different angles have been used to draw the second map. As shown in Fig. 4, the bending on the upper right corner and the corners on the left side of the map are clearly shown. One can observe that the bottom right corner is partially hidden by an obstacle (the large cube). In addition, the two curved forms on the bottom side of the Fig. 4 represent the large and the small cubes in the virtual environment and both of them have been drawn in these forms according to the wheelchair and range scanner position. Further discussion of this result will be detailed in Section IV.
One can also observe some discontinuities appearing on the bottom edge of the map in Fig 3 and left hand side edge of that in Fig 4.

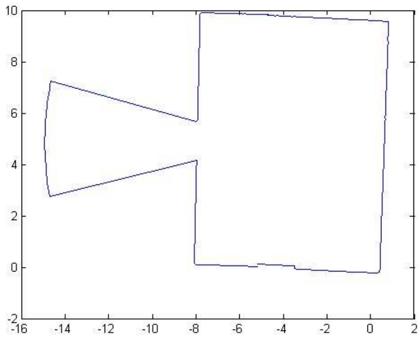


Fig. 3 depicts how the range laser scanner scans or "sees" the first environment, which represents a room with a doorway

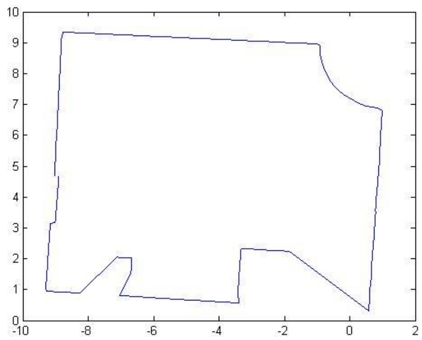


Fig. 4 depicts how the range laser scanner scans or "sees" the second environment, which represents a room with obstacles and a curved wall.

## IV. DISCUSSION

Many scans have been performed in order to scan the two halls. The values of three of these scans for each map have been selected (for different angles) and read by the implemented MATLAB program. As the field of view of our scanner is 180˚ degrees, two scans were enough to map these two environments. However, one additional scan was added to correct any gaps that could appear between the essential two scans. As can be seen in Fig. 3 the door is represented by a form similar to a cone. This is because of the laser scanner sees the door as a hole in the wall, therefore the lines of the scanner extend until is blocked by a further object outside the room. Consequently, as the range of laser scanner is 10 meters, the lines of laser scanner extended through the door for approximately 10 meters. As the laser scanner cannot "see", detect or scan behind walls and obstacles, Fig. 4 depicts two curvatures representing the two cubes that have been mapped according to what laser scanner has detected, i.e., only the frontal profiles of the cubes have been mapped [4].
Another issue that should be noted is the dimensions of the both environments. The two rooms have dimensions of

(10x10x3) meters and as we are using 2D laser scanner, it was expected to get (10x10) meters maps for both halls. It is shown in Fig. 3 and Fig. 4, however, both maps produced are less than (10x10) meters by few centimeters. This is attributed to the walls' thickness, where both halls have been built with wall thickness of (20) centimeters. So, each dimension should be less than 10 meters by 0.4 meter and this explains the resulting dimensions in the maps.

Figures 3 and 4 show that both maps are slightly inclined to the right and do not start from (0, 0) point. This is because of the original orientation of the wheelchair was chosen slightly inclined and thus has a specific starting point. Therefore, all the values of laser scanner were analyzed to points at X and Y axes and matched to the original axes after a simple calculation have been done to these values according to start position of the wheelchair and the original orientation [11].

Although the laser scanner gives accurate readings for the distance between its position and the hit point, there is still some error in these readings and this can be seen at the bottom side of Fig. 3 and in the left side of Fig. 4, as well as the small variations along the walls in both maps. One of the reasons that causes these errors is the values of field of view and the resolution angle of the laser scanner. The resolution angle is defined as the angle between successive lines of laser scanner. The field of view and the resolution values have to be measured in terms of π and this is implemented in the programming file of the game engine [10]. The field of view was represented as 3.14 (=π) which is approximately equal to 180˚, while the resolution was written as 0.0174 which is less than 1˚. As the messages are sent in polar coordinates and were transformed to Cartesian coordinates, this transformation caused a slight error in the resulting map. These errors are reflected in the gaps that can clearly be noticed when we zoom into the map and observe the discontinuities in the lines representing the walls.

Although the π values and transformations could cause errors, the major error comes from the sensors that have been used. Firstly, there is noise represented by a random number that is added to data before it is sent back and this leads to producing wrong data according to the value of the noise. This property is integrated in the game engine [10]. Secondly, the odometry sensor which has been used to show how much the wheelchair is inclined or rotated relative to start position. Odometry sensor uses the wheel's diameter, the separation between left and right wheels and Wheels' spin angle to measure the position of the wheelchair. The sensor's errors come from inaccurate measurement of wheel's diameter and inter-wheel separation measurement [10].

As the lines of the laser scanner have a maximum range (10 meters), the distance between the end points of these lines will be greater than any other point over those lines. So, the closer the object or the obstacle, the more lines that hit it and ultimately it is represented by that number of points. Thus, the probability of missing mapping small objects increases at further distances relative to the range of the laser scanner sensor. In order to calculate the smallest object that can be seen by the laser scanner at its maximum range (10 meters), the distance between the end points of the two successive laser's lines at a maximum value needs to be calculated. As we already have the length of the two successive lines and the angle between them, the cosine rule for the isosceles triangle has been applied to measure the unknown side of the triangle

$$C^2 = A^2 + B^2 - 2AB\cos(\alpha) \tag{3}$$

Where A, B represent the length of two successive lines of laser scanner and are equal to 10 meters, and (α) is equal to 1˚. Therefore (C) is equal to (0.1743) meters or (17.43) centimeters and any object with width less than approximately 17.5 centimeters cannot be seen by the laser scanner when the range is at its maximum value. However, the resolution of the laser scanner can be increased to (0.5) to get (361) lines from the laser scanner and mapping small objects, where increasing the resolution means increasing the numbers of lines that are emitted by the laser scanner and eventually more lines hit the object [8]. However, this has an impact on the time to process the data and hence producing the 2D maps.

The experiments were conducted for an indoor environment, where the start position is known or can be easily estimated. The start position has been identified when the maps were built and the game engine sends a message identifying where the start position was during on-going scanning. However, for an environment with unknown start position, the location of the wheelchair can be taken as the reference point and mapping is continued according to this identified point [12].

Various sensors such as sonar (ultrasonic), infrared and stereo cameras sensors are currently available and can be used for indoor environment mapping. Most of these sensors, however, have their own limitations [13]. Sonar and IR sensors limitations have been summarized and discussed by [3].

Firstly, the sound wave of the sonar sensors has to be almost perpendicular to the detected object to be captured by the sonar sensor when it is reflected back. This phenomenon often arises when the object is almost smooth or light absorbent. Furthermore, the "cross-talk" property affects the function of the sonar sensor. The IR sensor is similar to a sonar sensor but light is emitted instead of sound waves. However, light cannot be reflected by light absorbent or dark objects and thus these kinds of objects are difficult to detect by IR sensors. Moreover, IR sensors detect objects only within distances of 0.1m to 1.5m [13].

Finally, although stereo cameras are good for environmental detection, they still have their own limitation in comparison to laser scanners. For example, stereo cameras are able to determine distances only within 2m to 10m, and they need adequate lighting to recognize the environment. In addition, they do not perform well in environments with transparent or metallic surfaces [14], [15]. Another disadvantage is stereo cameras provide field of view of around 40˚ to 50˚ [16], in comparison to the 180˚ field of view provided by laser scanner [3], [8]. Despite the fact the 2D laser scanner is relatively expensive and requires high power [3], it is very efficient for indoor environment mapping. As each type of sensor has specific characteristics and limitations, researchers have found that is beneficial to use and fuse data from different sensors for indoor mapping [14].

## V. Conclusion and Future Work

In conclusion, a simulated 2D laser scanner has been used to map virtual environment and it was shown that the laser scanner has the ability to map different features of any environment such as walls, corners and curvatures. Consequently, laser scanner can be integrated to powered wheelchair for mapping and navigation purposes. Further work could include building a more complex room such as a room with tables, chairs and desks which simulates a real room in order to evaluate the ability of laser scanner in mapping different objects and features. Furthermore, a 3D laser scanner can be used in further work for 3D environments' mapping and this would be very beneficial to identify the height of the objects in the environment which gives more realistic mapping.

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