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An Open-Path Obstacle Avoidance Algorithm Using Scanning Laser Range Data

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14. ABSTRACT

The Open-Path Area algorithm described searches a region scanned by a laser range finder for the most open path that will allow a robot of a specified width to move the furthest distance. Range data are mapped into an array space in which the column indices are the beam numbers and the rows are the range values divided into an arbitrary number of bins. The path to be searched is also mapped into this framework. The open-path search algorithm checks each beam index as a potential direction and finds the range bin index at which the path is obstructed. The path areas associated with these indices are calculated only once and stored in a look-up table. The beam index that returns the maximum open path area determines the direction the robot should move. The response of the robot is a fluid motion around obstacles in its path.

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1. Introduction

A Light Detection and Ranging (LIDAR) laser scanner provides 2D range information in a horizontal plane ahead of the scanner. It can detect obstructions within the field of view of the scanner. Such data are useful in allowing a robot to avoid obstacles in its path. The objective of the Open-Path Area algorithm described in this report is to search the region scanned by the range finder for the most open path that will allow a robot of a specified width to move the furthest distance. If the identified path is to the side, the robot should turn in that direction until the path is directly ahead. Then it will move forward.

2. The Obstacle Array

Figure 1 shows a sample set of range data from a scanning LIDAR in a Cartesian coordinate system. The LIDAR is located at the bottom center. In this case, ranges are obtained every half degree. Index zero is to the right; index 180 points directly ahead; and index 360 is to the left.

To search for an open path, it is helpful to map the range data to an array where the column indices are the beam numbers and the rows are the range values divided into an arbitrary number of bins. This "Obstacle Array" is shown in figure 2. The path to be searched must also be mapped into this space.

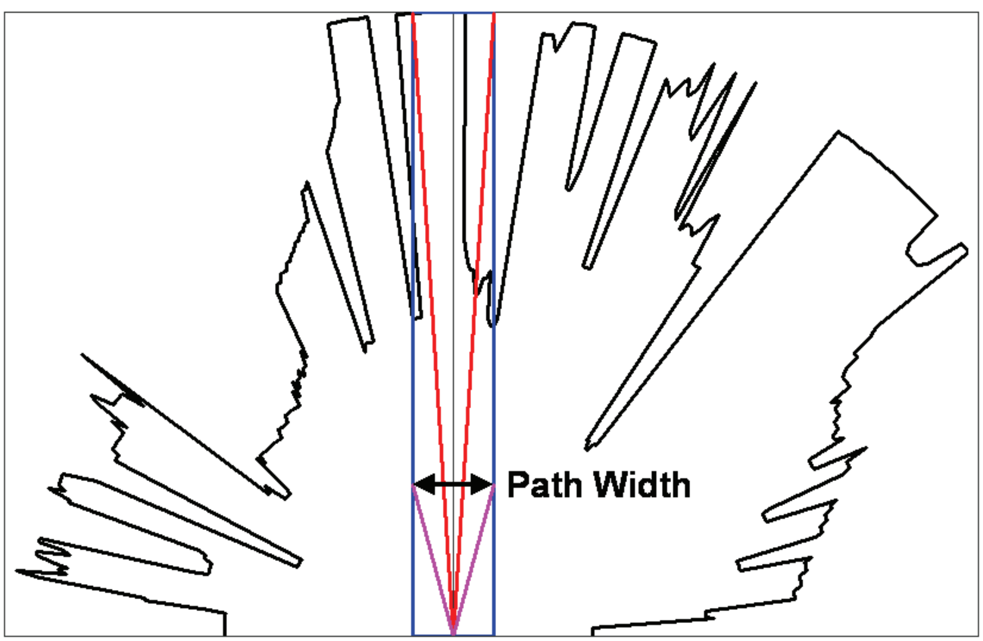

Figure 1. Scanning range data, cartesian coordinates.

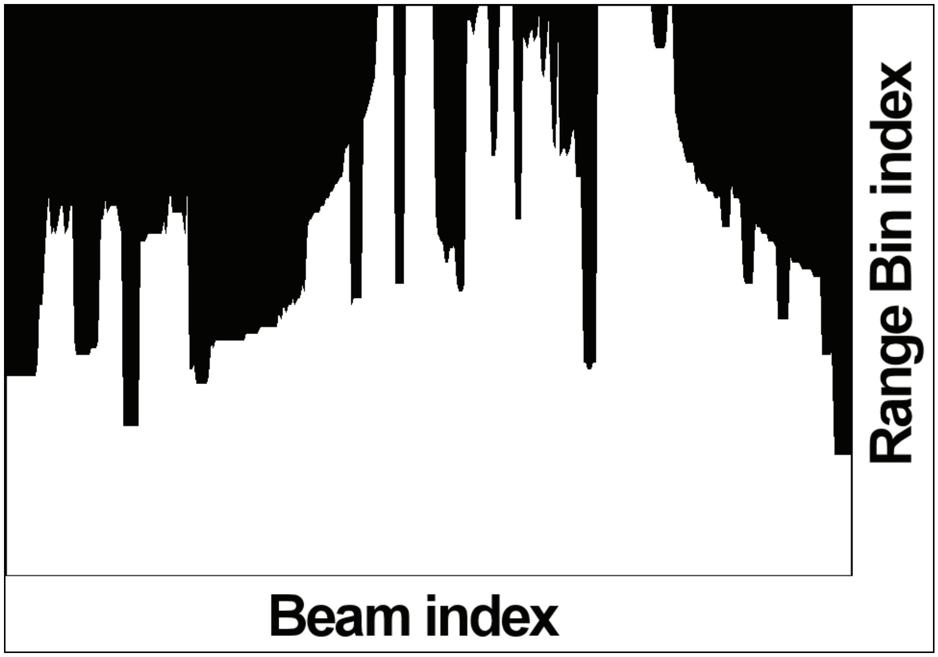

Figure 2. Scanning range data obstacle array.

The width of the path, in terms of beam indices, is a function of the range bin index, figure 3. Figure 1 shows the beams that impinge on the sides of a potential path at two sample ranges. The angle subtended by the left and right beams tapers with range. By geometry, the width of the vehicle in terms of scan angle is:

$$\text{Path Width (angle)} = 2*\text{atan}((\text{Path Width}/2)/\text{Range} \tag{1}$$

Subsets of that shape determine the open area of the path.

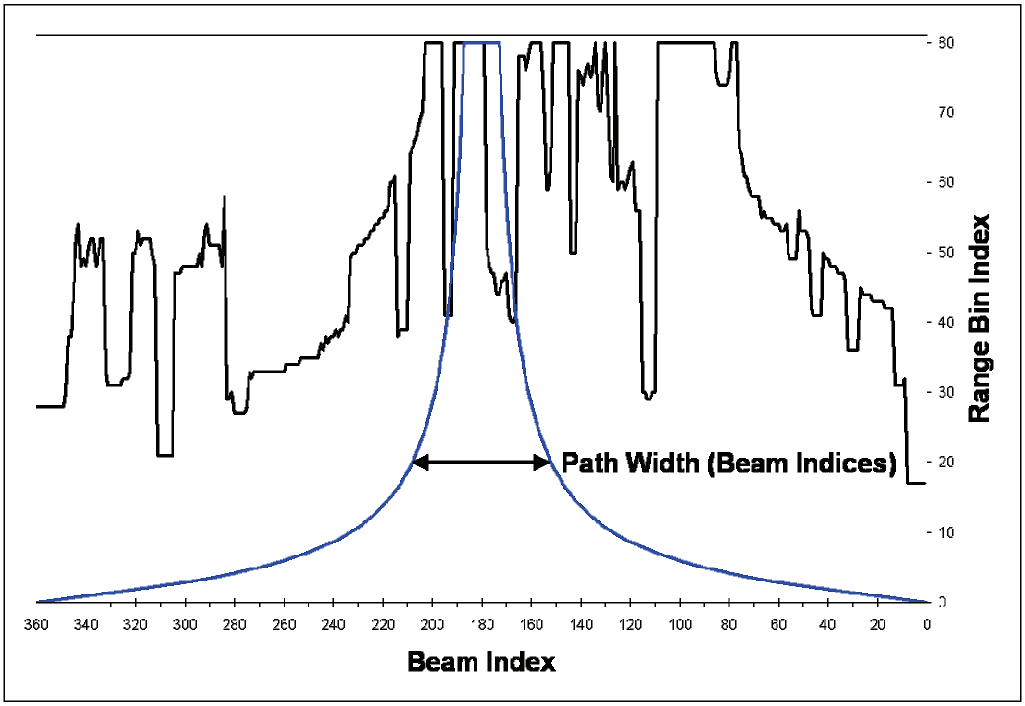

Figure 3. Path width in beam indices.

3. The Open-Path Algorithm

The Open-Path search algorithm checks each Beam Index as a potential direction and finds the Range Bin Index at which the path is obstructed. Figure 4 shows three example potential paths. These same unobstructed paths are shown in Cartesian coordinates in figure 5. The areas for each unobstructed path need to be found.

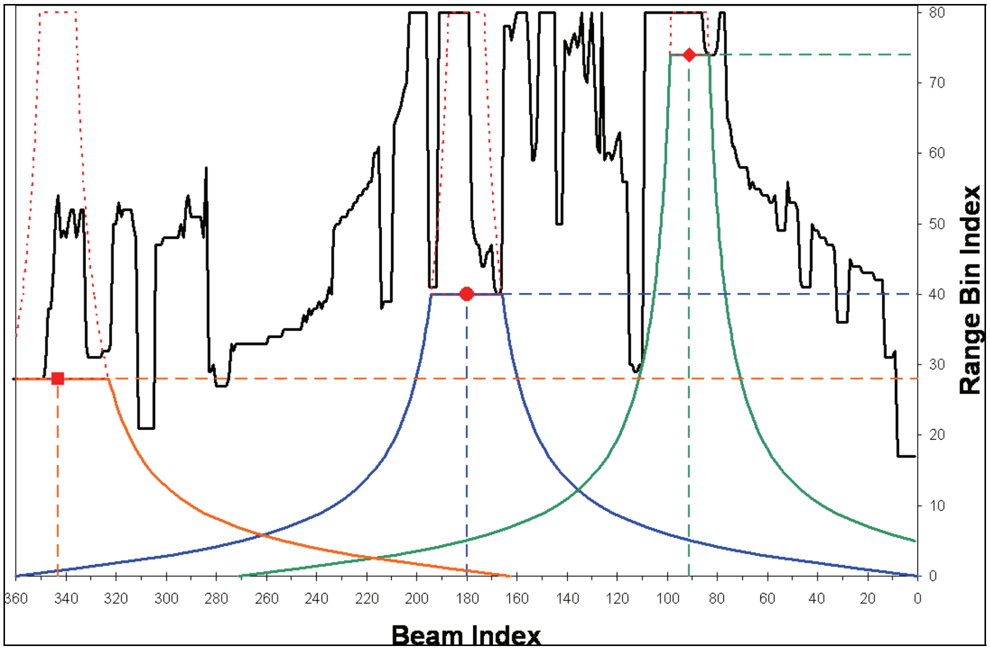

Figure 4. Open paths (obstacle array).

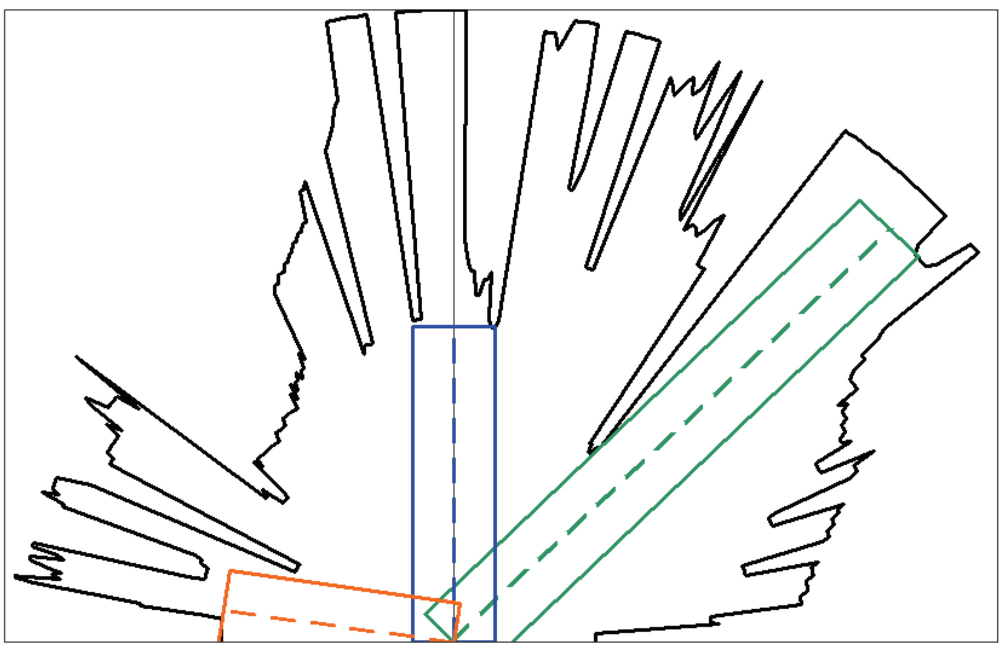

Figure 5. Open paths (cartesian).

The first implementation of the Open-Path algorithm created an actual obstacle array from the LIDAR data by placing a value of one if the element was unobstructed, and a zero if it was blocked. Then, subsets of the path width to be searched at each range bin were methodically extracted and added together until the path width encountered a zero. This gave the area of the unobstructed path. Such an approach was highly inefficient because an obstacle array had to be created each time the range data was updated, and many calculations needed to be performed for every beam index. Figure 6 shows a few steps in the systematic search of the path width. Each element in the array subset is checked to see if it is open (shown in grey) or obstructed (shown in black). Those elements that have been searched are shown in white.

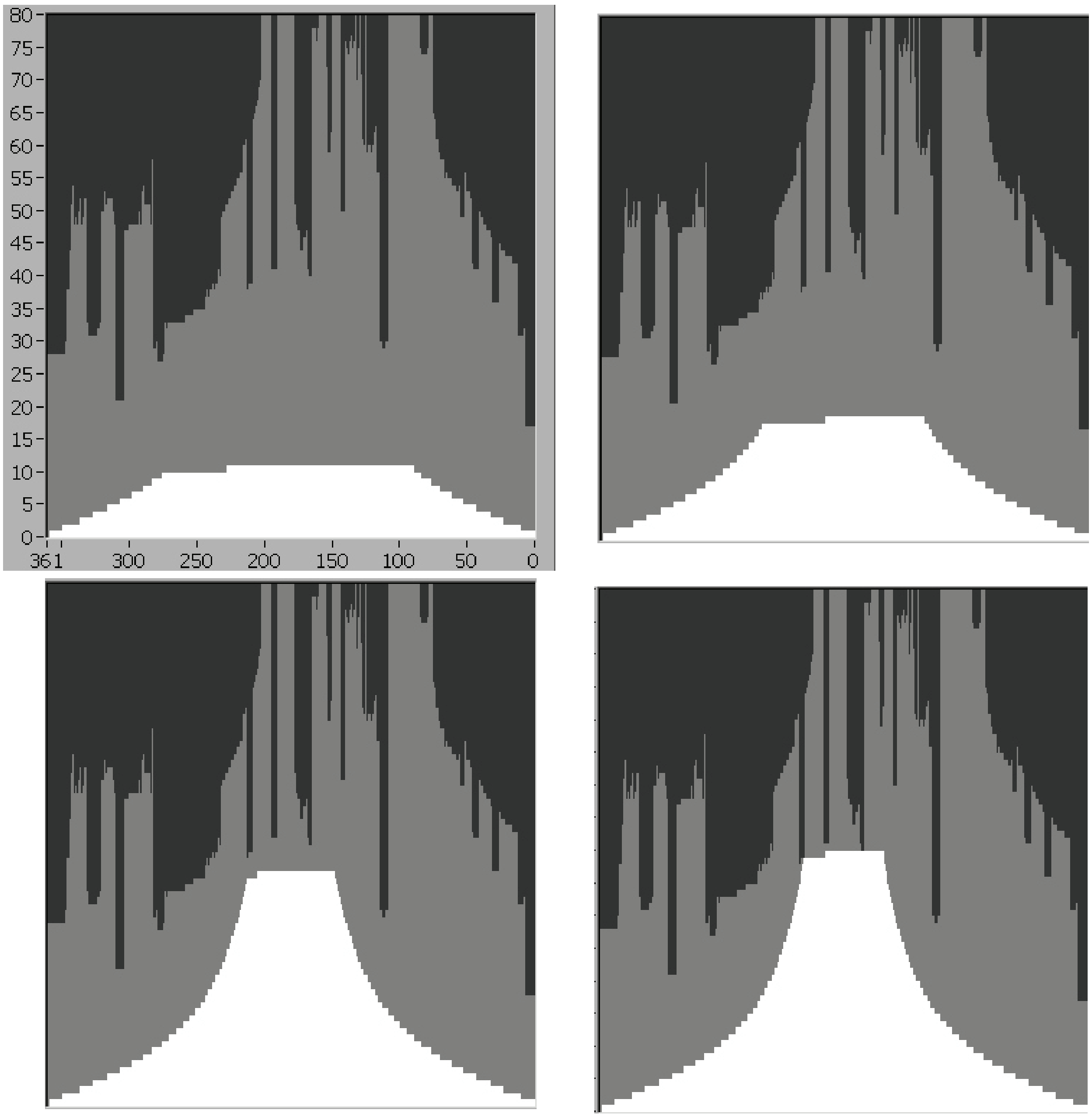

Figure 6. Open path search in obstacle array.

It became apparent that constructing the obstacle array was unnecessary and that the open path areas did not have to be computed at each step. Instead, the range data from the LIDAR could be manipulated directly. The range data consists of a one-dimensional array containing the range values for each beam scan. The index of each range value is the beam index. The range data could be divided into an arbitrary number of range bins.

Figure 7 illustrates how a search for an open path is conducted using the range data directly. The ith Beam Index (0 <= i <= Number of Beams) is the path direction being checked. For the ith Beam Index and the jth Range Bin Index, a subset of the range data is extracted between indices:

$$\{\text{ith Beam Index} - (\text{Path Width}(j)/2)\ ,\ \text{ith Beam Index} + (\text{Path Width}(j)/2)\} \qquad (2)$$

Where Path Width(j) is the width of the path at the jth Range Bin in terms of beam indices (0 <= j <= Number of Range Bins). If the subset to be extracted lies outside the length of the range data array, then the extracted portion of data is cropped on the appropriate side.

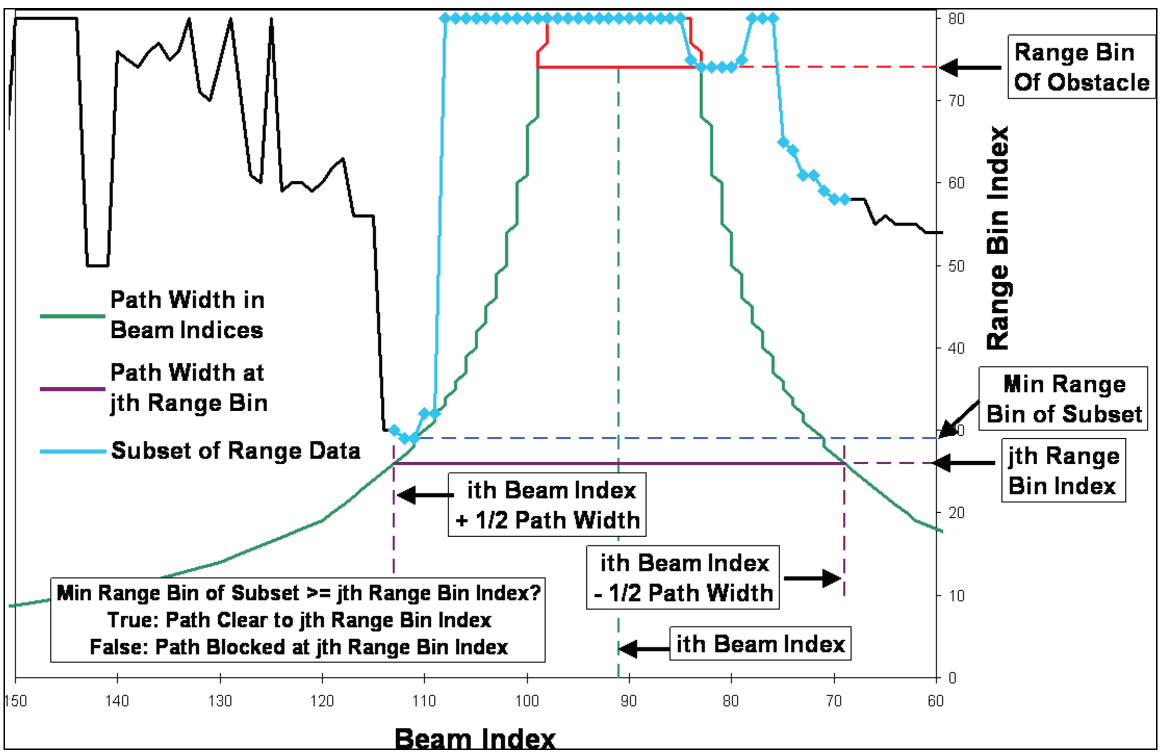

Figure 7. Open path search in range data.

Then, the minimum range bin value of the data subset is found. If that minimum range bin value is greater than or equal to the jth Range Bin Index, then the path is clear to the jth Range Bin Index. The algorithm then moves on to check the next Range Bin Index. When the minimum range bin value is not greater than or equal to the Range Bin Index, then the path is blocked at that Range Bin Index and the path search at the ith Beam Index stops. The resulting two indices, the ith Beam Index and the jth Range Bin Index, at which the path is last open identify a unique subset of the maximum possible open path area of the shape shown in figure 3. Three such examples are shown in figure 4.

The path areas for every Beam Index and Range Bin Index combination only need to be calculated once and stored in a look-up array. Figure 8 is an intensity graph of such an array. The largest possible open area that can be scanned would be directly ahead out to the maximum range. This is the top center portion of the graph. Potential path directions to either side of the center shift a portion of the path out of the scan range so the area is less. Likewise, shorter ranges reduce the area under the curve. The array is symmetrical about the center beam index. The open area for each potential direction is read from the array using the Beam and Range Bin indices obtained from the algorithm. When computing the areas of the open paths included in this array, it is convenient to divide the range bin indices into the same number as half the beam indices. The range bin index obtained from the algorithm is scaled accordingly for the look-up array.

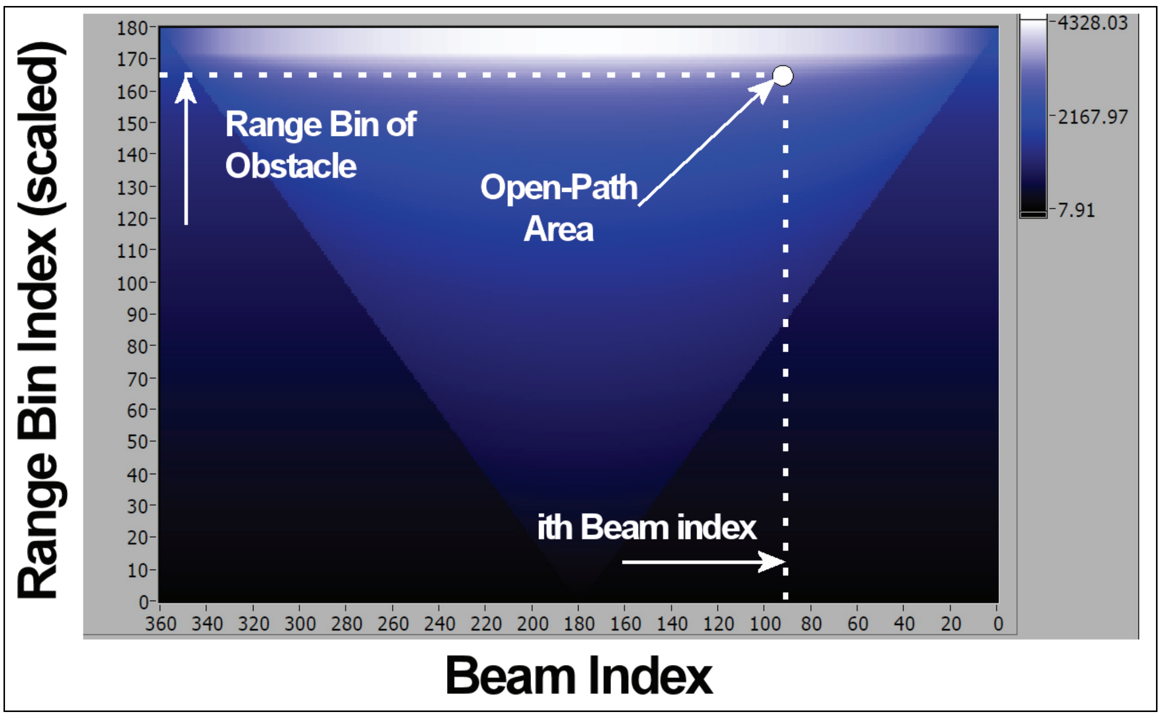

Figure 8. Open path areas look-up array (intensity graph).

Figure 9 shows the encountered Range Bin Indices and resulting open path areas for each Beam Index. The Beam Index that returns the maximum open path area determines the direction the robot should turn toward. The turning rate is proportional to the angle from the forward direction to the most open path. Greater angles will cause the robot to turn faster. When the open path is oriented closer to directly ahead, the robot will turn slower. The Forward speed of the robot is proportional to the size of the open area when the most open path is “directly ahead.” Angles to either side within some reasonable amount would qualify as directly ahead. When that area is below a set threshold, the robot will reverse and turn slightly so it can search for a new path.

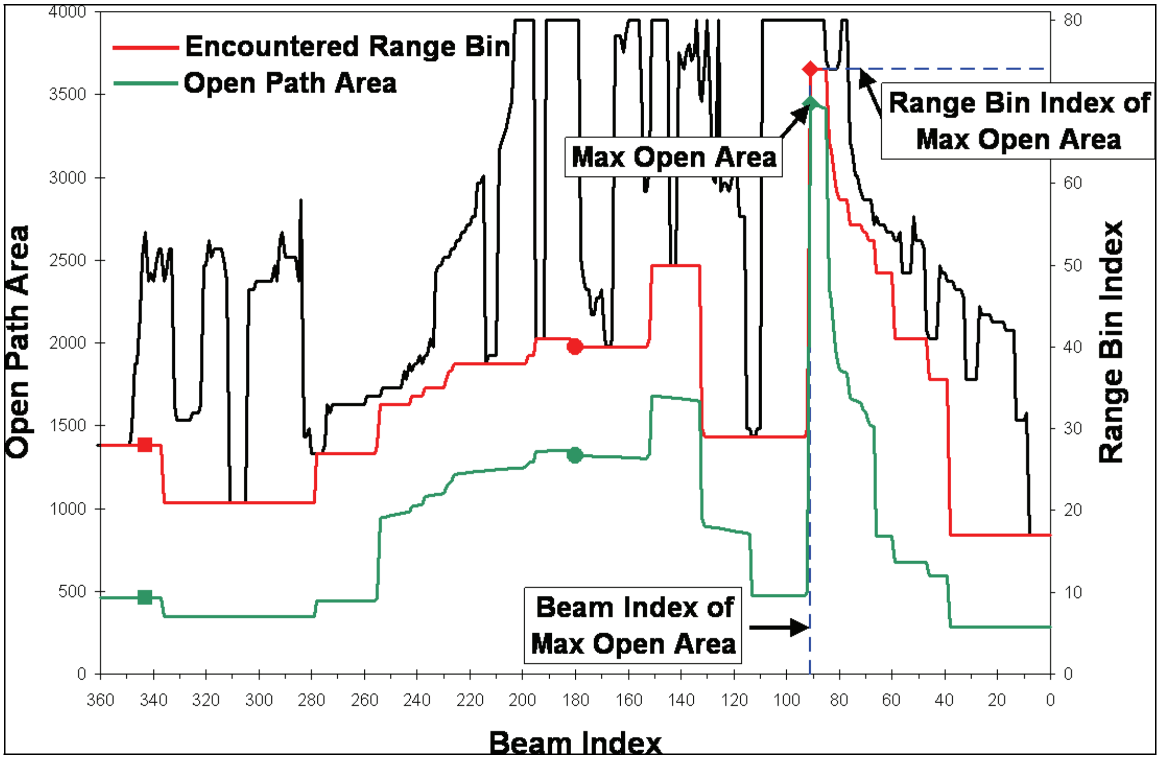

Figure 9. Encountered range bins and open path areas.

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4. Results and Conclusions

Figure 10 shows the path taken by a virtual robot under the control of the algorithm. The robot responds to the virtual range data from the obstacles by turning in place towards, and then moving in the direction of, the most open path that will accommodate the width of the robot. Figure 11 is another example of paths found through a cluttered room. The robot starts at several arbitrary locations and orientations. The first fan of laser range data is shown in red. The paths eventually find the door, but the robot is not seeking nor is it attracted to the door. It has no knowledge of its location. The robot only responds to the door's presence when it is in the LIDAR's field of view. It moves toward it because it presents as a more open path.

The algorithm is not designed to seek out an exit. Rather, the robot simply wanders along the most open path. This does not guarantee that a doorway will be found, as shown in figure 12, where the robot starts in a large empty room with a small doorway just wide enough for the robot to go through. The path the robot takes approaches the door on several loops but does not pass through it. Since finding an exit or entrance may be a desirable capability, a means to do so would have to be found.

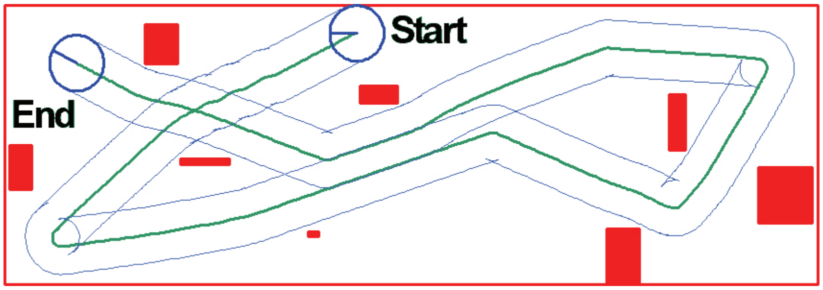

Figure 10. Path found through obstacles.

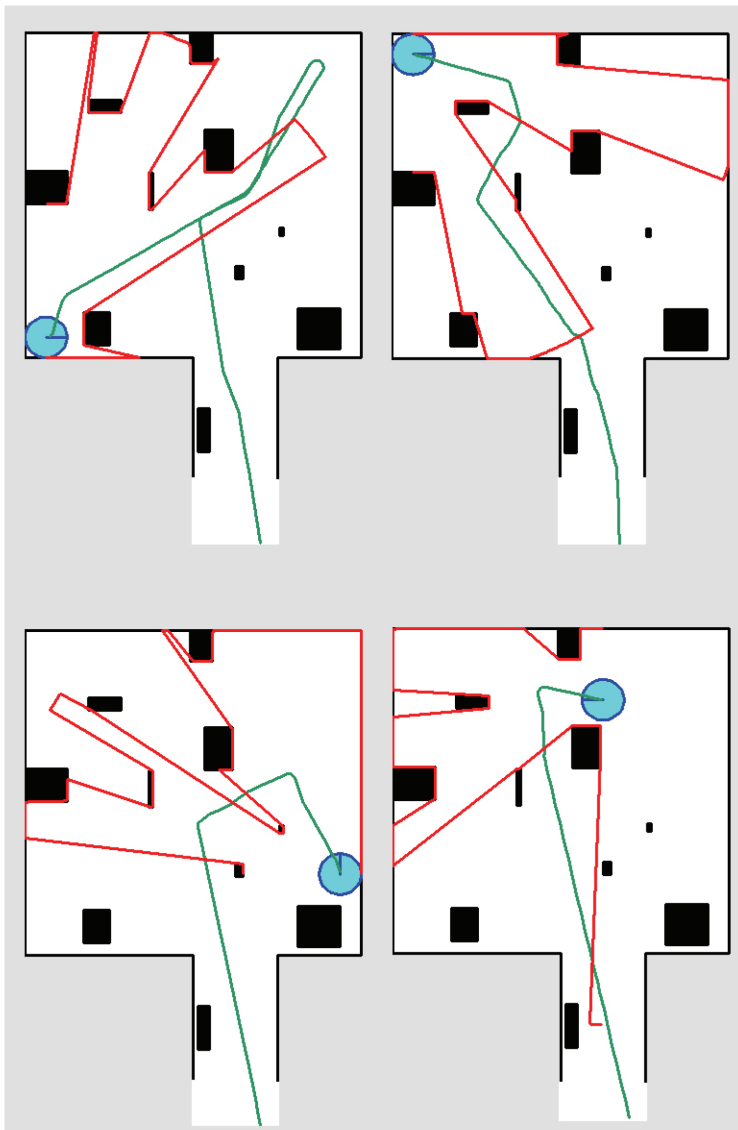

Figure 11. Paths found through cluttered room.

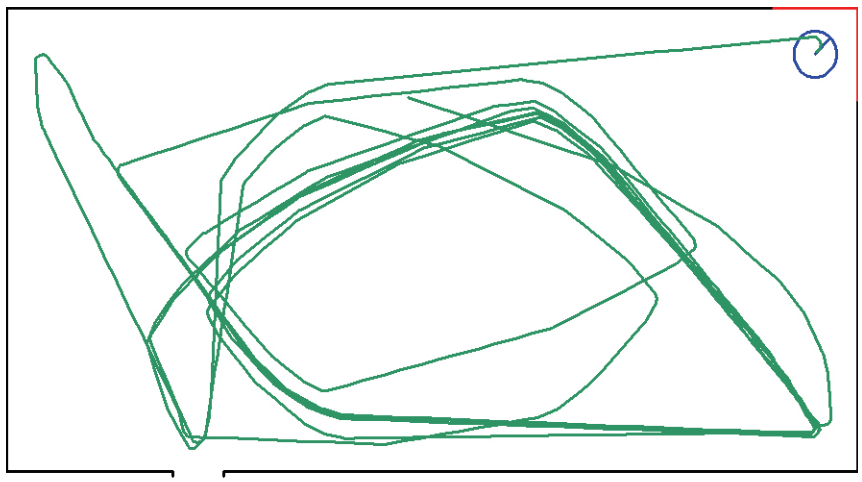

Figure 12. Path through a large empty room with a small door.

5. Conclusions

The algorithm developed proved to be a rather robust obstacle avoidance technique. The algorithm was implemented on a skid-steer Segway Robotic Mobility Platform (RMP), as shown in figure 13. The RMP seemed almost intuitively to search out a clear path. For example, it would weave its way between traffic cones placed in random order in front of it. Also, starting in a closed area surrounded by cones, one cone was arbitrarily removed to create an opening just wide enough for the RMP to pass through. The RMP would move around within the area until the opening came within view. Then it would line itself up to the opening and exit the area. It was found that the dynamic motion of the robot precluded an exact repeat of a change in direction. This proved to be an asset as it ensured a bit of randomness to the robot's path; the robot did not get locked into a repeating pattern and eventually "saw" the opening. The robot would also center itself while going down a hallway.

The Open-Path Obstacle Avoidance Algorithm described in this report results in a fluid robot motion that reacts to and naturally avoids obstacles in its path. The laser range data are quickly manipulated to identify the direction of the path that is least obstructed. The algorithm returns direction and range indices that are used in a lookup table containing the open area of the path. These areas need only be computed once and stored. The algorithm could be coupled to other algorithms that look for doorways or other features. A robot need not be directed to go in the direction of the most open area. The method shown to determine if a path is open enough for a robot to fit could also simply be used to check if goal points of a desired path are unobstructed.

Figure 13. Skid-steer Segway Robotic Mobilty Platform.

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