Use of LIDAR for Obstacle Avoidance by an Autonomous Aerial Vehicle

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ABSTRACT

In this paper we describe our work on developing an efficient and computationally light algorithm, tested on an aerial vehicle (quadrotor), to plan an efficient path around obstacles. The *growth* algorithm we have developed is capable of functioning in an absolutely unknown environment, where it is not possible to define the end points. Based on a minimum *safe distance*, dependent on the quadrotor's kinematics, and the minimum clearance width required the optimum path around obstacle/s is found. The algorithm performs particularly well when tackling multiple obstacles.

INTRODUCTION

Autonomous aerial vehicles that fly in unknown environments are required to be capable of obstacle detection and path planning to navigate a path free of obstacles. The quadrotor is equipped with LIDAR, an exteroceptive sensor, which is the input device for reading the environment

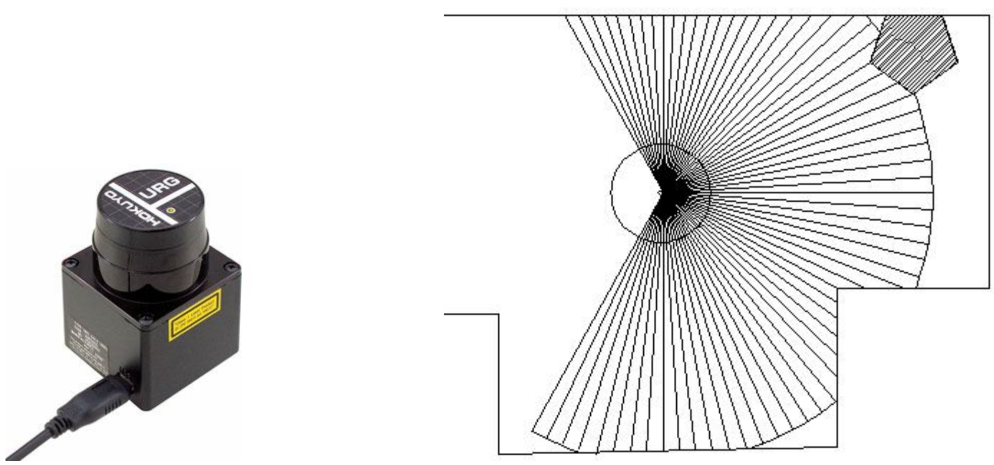

Figure 1: The HOKUYO URG04LX-UG01 LIDAR with 240 degree scanning range

The advantage of using LIDAR is the high precision and resolution it provides in distances measured. This feature is tapped to make a detailed study of the environment for various possible angular resolutions depending on the LIDAR used. We have used the *HOKUYO URG04LX-UG01* which has a scanning range of 5600 mm and an angular resolution of 0.36 degree; these specifications proved to be sufficient for indoor environments.

Interpreting the Environment

Any indoor environment can be studied in different 2D planes parallel to the floor. In any one particular horizontal plane, an approximation of stationary obstacles holds well as compared to more unpredictable outdoor areas. Our entire algorithm has been implemented on a single plane and can be used for ground vehicles as well.

Every time the environment is scanned, the array of distances of the 240 degree span can be mapped onto their respective angles leading to the polar coordinates (r, ϕ) of the surroundings. With raw readings, the world can only be perceived to be a set of points that could be obstacles, noisy values or simply points that are not of interest. To interpret this set of numbers, we define an *obstacle* as a single point or an abstract collection of points that hinder/s the intended path of travel. “Noise” is defined to be a point beyond the scanning distance of the LIDAR, it could also be a value returned off of a speck of dust, etc.

***Obstacle* Detection**

In any particular state, *obstacle* points could be present anywhere in the environment, but it is important to ignore those points that would not hinder the motion of the quadrotor along its intended path. However, if these *obstacle*s are present directly in the path of the vehicle, they are classified as a threat. The process of detecting a threat involves studying a certain degree-span of readings directly in front of the vehicle which are calculated based on a *safe-distance* and the minimum clearance required for the quadrotor to pass safely. This is elaborated in the figure below:

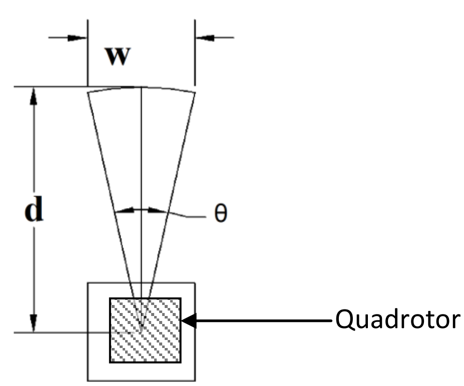

Figure 2: Obstacle Scanning Range

If **θ** is the range to be studied, **w** is the clearance width and **d** is the *safe-distance*, then:

$\boldsymbol{\cos(\theta/2) = d / g}$ *where* $\boldsymbol{g = d^2 + w^2/4}$

We determined this range of readings to be 16 degrees based on our quadrotor's width and *a safe-distance* of 2m.

Obstacle **Growth Algorithm**

Once an *obstacle* is detected, every point in the entire scanning range is considered to be a *point obstacle* and is "grown" by the half the clearance width of the vehicle **w/2**. This allows for the vehicle to be considered to be a point object since its dimensions are superimposed on the entire environment.

Growth is simulated by drawing a circle of radius **w/2** around every point and shortening all LIDAR range readings such that no part of any of the line segments fall within any circle. This process can be described as shown below:

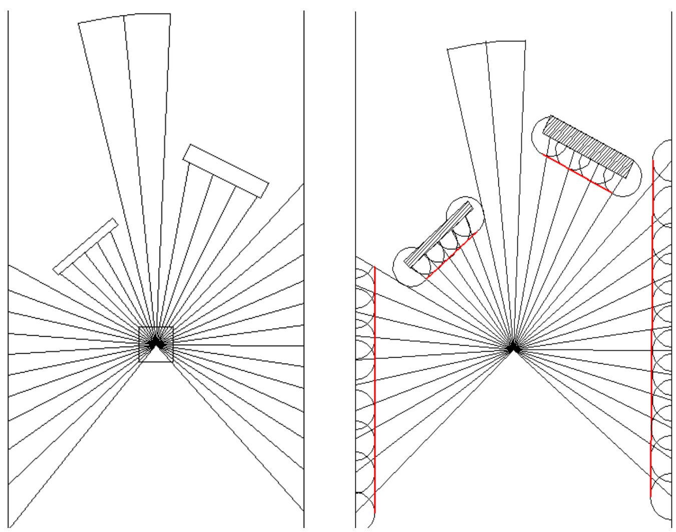

*Figure 3: Obstacle detection and corresponding growth by **w/2***

Figure 3 shows range readings in the actual environment and then in the new "grown" environment (shown in red) in which the vehicle is considered to be a point object.

When a LIDAR ray intersects a circle, we reduce the distance to the intersection point which gives the shortest length. This is computed as follows:

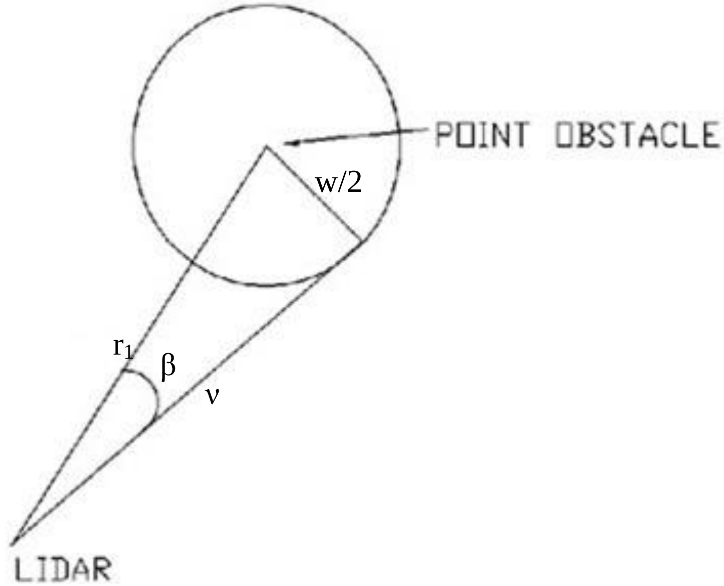

Figure 4a: Growth and related parameters

$\beta = \cos^{-1}\left(\frac{y}{r_1}\right)$ and $\nu = \sqrt{r_1^2 - R^2}$

where **r_1** is the range reading from LIDAR

β is the angle between the circles' tangent and the corresponding LIDAR ray **r_1**

ν is the length of the tangent

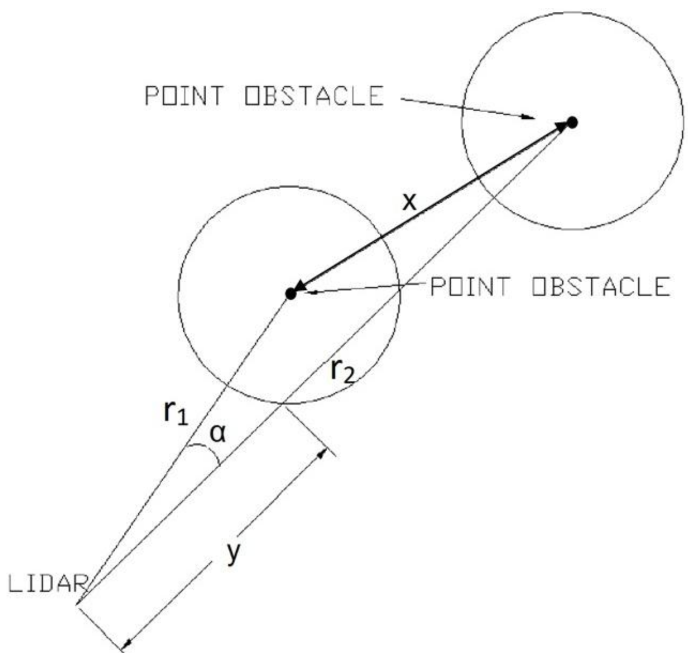

Figure 4b: Growth and related parameters

$\alpha = \cos^{-1}((r_1^2 + r_2^2 - x^2) / 2r_1r_2))$

where $x = \sqrt{r_1^2 + r_2^2 - 2\, r_1\, r_2 \cos(\phi 2 - \phi 1)}$ *and* $\mathbf{y} = r_2 \cos(\phi 2 - \phi 1) \pm \sqrt{r_2^2 \cos^2(\phi 2 - \phi 1) - r_2^2 + R^2}$

ϕ as defined earlier

Of its two possibilities **y** is selected to be such that it is less than $\mathbf{r_1}$.

Path Planning

Although the optimum path is to be selected within the 120 degree span ahead of the vehicle, it is necessary to study the entire scanning range of 240 degrees to ensure that no *obstacle*'s growth circle is entering the 120 degree zone marked. If an *obstacle* outside the zone does, indeed, cause a growth circle to enter into the zone it shall be considered as any other circle and the line segments within the 120 degree zone shall be reduced accordingly before the algorithm proceeds to find the optimum path. The rays to "infinity" are considered as noise and are ignored in the *obstacle growth* procedure.

After performing the growth algorithm we now calculate the possible paths through which the quadrotor can avoid the *obstacle* efficiently. We select the longest free straight line along which the point robot can traverse. This could, though, have a negative effect if the deviation of the line from the intended path is not considered. Hence, rather than simply choosing the longest line we choose a line based on a *priority factor* with proportionality relation as given below:

Priority factor $\propto$ *(1 / Deviation) * Length of path*

Deviation is the angle of deviation from the present line of motion,

Length of path is the length of each possible path of traversal (considering the growth of the environment)

Once the best path is chosen, the quadrotor yaws in the said direction and begins traversing the intended path.

This entire procedure is run every 0.5 seconds and hence leads to a smooth trajectory being assumed around the *obstacle/s*

Conclusions

In this method we obtain an efficient way by which autonomous vehicles can plan paths around *obstacle*s and avoid threats ahead of them. The *priority factor* is a key step which weighs the "benefits" against the "cost" of a particular path and appropriately makes the best choice. For aerial vehicles, the stability of the vehicle is a very important factor in the performance of the algorithm since frequent oscillations could lead to misinterpretation of the environment. The algorithm can be implemented on ground vehicles without any changes.

References

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