

CANAL FOLLOWING USING AR DRONE IN SIMULATION ENVIRONMENT

Ali Ahmad, Ahmad Aneeqe Khalid
Department of Electrical Engineering
SBA School of Science & Engineering, LUMS, Pakistan
{14060006, 14060019}@lums.edu.pk

Contents

Abstract	2
Related Work	2
Our Approach.....	3
Experiments & Analysis	11
Future Work & Conclusion.....	12
References	12

ABSTRACT

Robots are becoming a part of agriculture field in different ways over all the world. Different agricultural work is now being done by robots due to the simple nature of work like spraying, fruit picking or harvesting. Mostly these sort of works are carried out by ground robots which perform their tasks by moving on pre-defined tracks within the plant fields. Different sensors are used for getting the environment data & then the robot is allowed to move on the calculated trajectories without disturbing the plant. In this particular simulation project, we have discussed a flying robot which is guided over an empty canal. Such robot can be used for various purposes in actual environment for acquiring canal data like silting etc.

In this project, Gazebo [1] & ROS [2] have been used for simulation. The main challenge is to navigate quad copter over the center of the canal. Laser scanner has been used for taking the scan of the canal & then a trajectory has been created by taking the center of canal as guidance point. The parts of the project are discussed in detail below.

RELATED WORK

A lot of work has been done on agricultural robotics over all the world for different purposes. Mostly ground robots are used in the fields for different tasks. A similar work has been done by German researchers [3] by guiding a tractor in the field for autonomously collecting the windrow.

OUR APPROACH

The whole project has been implemented in Gazebo & ROS. A step by step explanation of all the parts is given below.

1. Canal Model:

First of all a canal is designed. Due to non-availability of custom object making tools in gazebo, a canal was first designed in “Google Sketch up” & then the mesh was imported in gazebo after downscaling. A simple mesh is not treated as an object in gazebo so collisions were added to make it a rigid object. Figure 1 shows a top view of canal in gazebo.

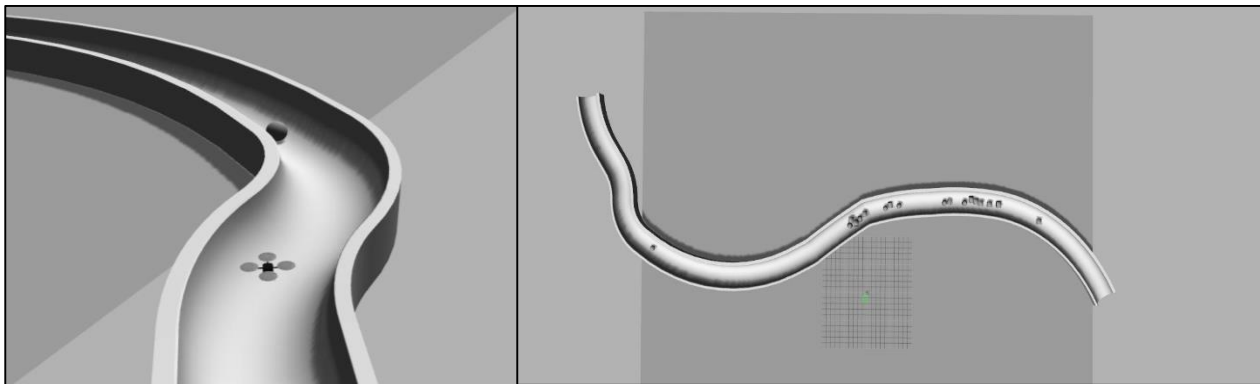


Figure 1: Side & Top View of Canal in Gazebo

2. Quad copter model & Laser scanner

Gazebo is a powerful simulation tool which can be used along with ROS (Robot Operating System). A basic Quad copter model “Hector Quad rotor” is used in this project. ROS is used for generating the guidance commands to quad copter.

“Hokoyo” laser scanner is attached to the bottom of the quad rotor for taking the scan of the canal. Figure 2 shows the quad copter & the laser scanner mounting position. The laser scanner is tilted at an angle of 30 degrees from the base.

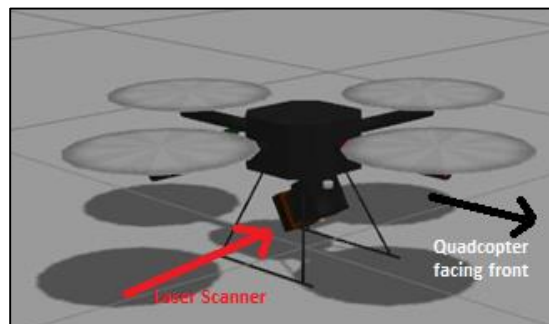


Figure 2: Quad copter & Laser scanner

A clearer picture of how the laser scanner is mounted & how the scans are translated is shown in figure 3 & 4. Hokoyo laser scanner is a 2D laser scanner & outputs data in the form of spherical coordinate system (r, θ) according to the object distance as shown in the figure below. Here “ r ” is the distance of laser ray from the object & “ θ ” is the angle of that particular ray from the center ray in radians. There are total of 1081 rays & they are spread over from -70° to 70° in front of the laser 2D coordinate system. So the angular resolution of laser scanner can be calculated as $(140^\circ/1081) = 0.1295^\circ$.

In our case, we have to calculate the center of canal from the scan data so we have converted this spherical coordinate system to rectangular coordinate system (x, y) for ease in processing of data & calculation of center point. The conversion of a (r, θ) point in (x, y) system is shown in figure 4.

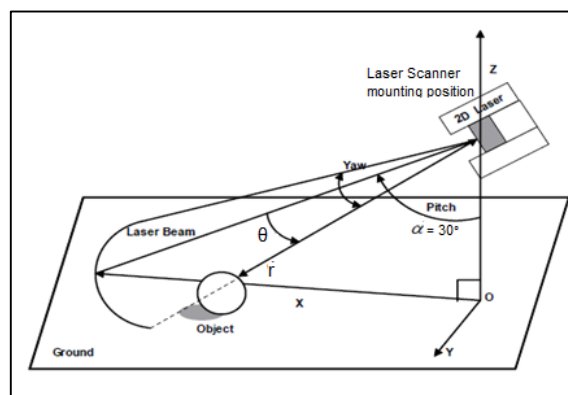


Figure 3: Laser Scanner Position & Resolution

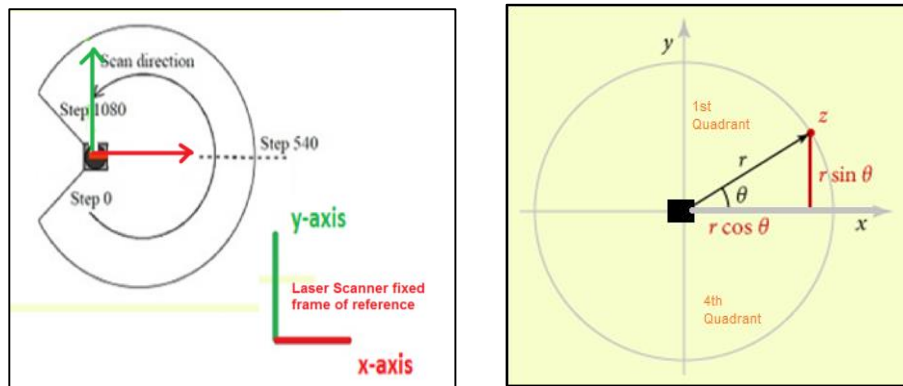


Figure 4: Laser scan direction & conversion from spherical to rectangular system of coordinates

The laser scanner data is acquired from the topic “/scan”. It is converted to desired data afterwards for processing & calculation of center.

3. Flow Chart

The flow chart below explains how the whole process works. We have assumed that initially the quad copter is at some fixed height over the canal & the canal is visible in the scan.

First we take the scan of canal. From the scan we calculate the center point of canal & afterward the guidance command is sent to quad copter over the control topic of quad copter `"/cmd_vel"`. As the quad copter progresses over the canal, the guidance points are taken & a trajectory is made in order to give accurate steering commands to the quad copter. The flow chart in figure 5 explains the process.

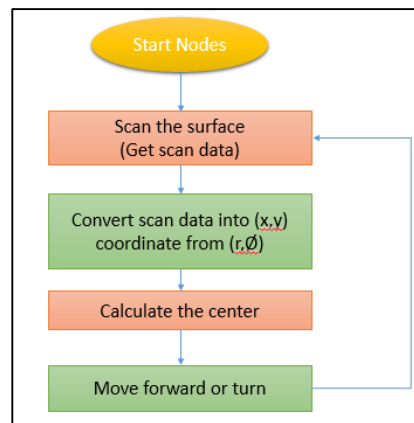


Figure 5: Flow Chart

Scanning Data (Calculation of Canal Center)

For a particular section of canal as shown in figure 6, we get the shape of the canal as shown in figure 7. A typical scan of the canal during simulation is shown in figure 6. In this case, we have assumed a very

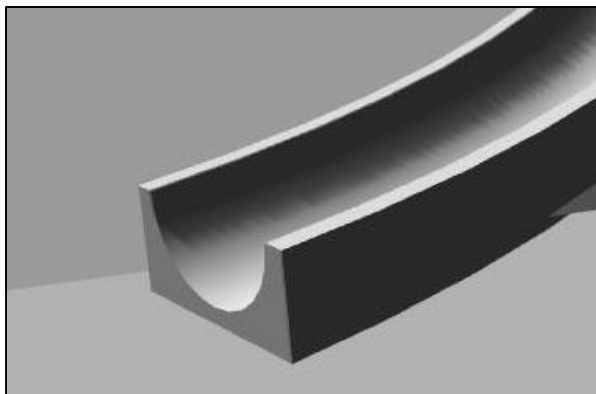


Figure 6: Canal Shape (side view)

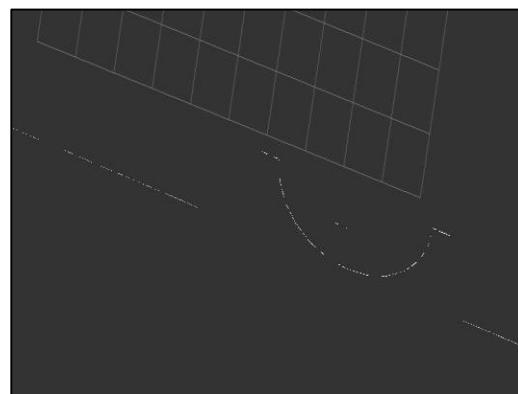


Figure 7: Laser scan of canal shown in figure 6

pure symmetry of canal. In actual the sides are a bit more tilted and unclear. We have used different

shapes of obstacles in canal in order to show the non-symmetry. Different methods can be used to detect the center point.

A. Our Approach

Our program calculates the slope between the successive points of the converted laser scan data. For this scan the slope between the points would change sign from -ve to +ve or vice versa as we move along the whole scan points. For this case, we have used this slope change as the key to finding the

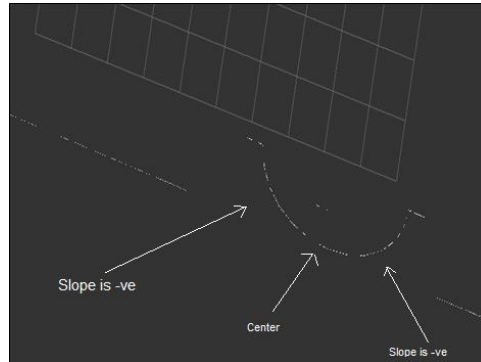


Figure 8: Center calculation method

center of the canal. This concept is shown in figure 8.

Results:

For our case, the slope method works fine. We placed some obstacles in the canal model in order to check the method, the center point deviates a bit depending upon the type of obstacle but it lies within the symmetry of canal. The results of center calculation are shown in figures below. Figure 9(a) shows a camera view of quad copter & a slight curve surface. In figure 9(b), the algorithm has calculated the green points representing the center of the canal. As the quad copter was moving so the previous points are also visible in the scan.

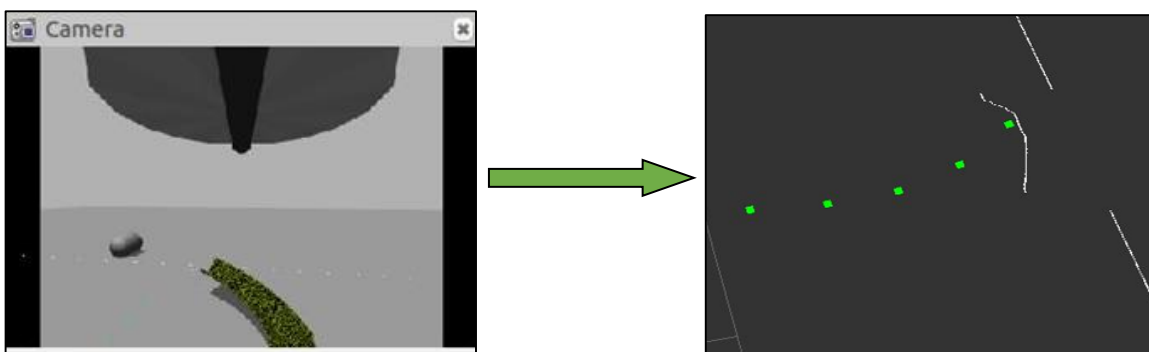


Figure 9a, 9b: Surface scan & calculated center (green)

Similarly, figure 10(a) & 10(b) shows the results of center calculation.

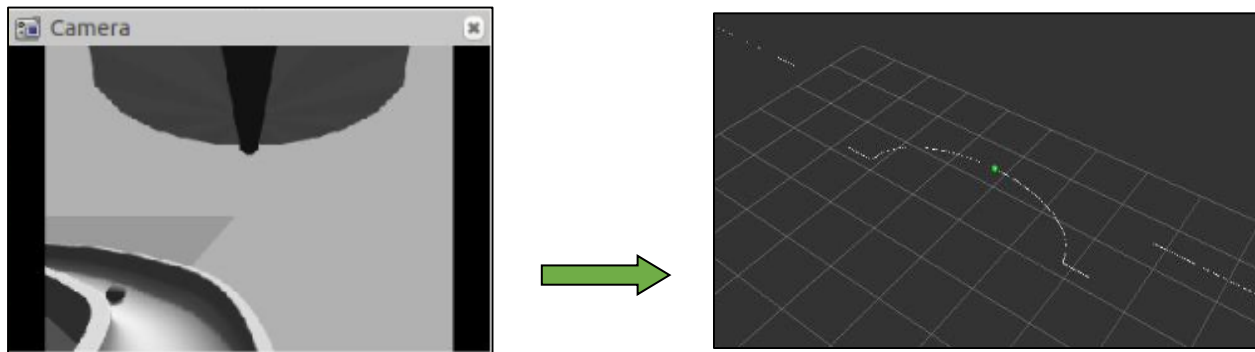


Figure 10a, 10b: (a) Canal visible in front camera. (b) Center calculation results (Calculated center in green)

B. Other Methods

For a real life environment, different other methods can be used to obtain the center of the canal. The scan of the canal can be uneven due to the nature of surface. For uneven surface first of all the actual canal will have to be extracted before applying any algorithm for finding the center. In some cases we can use moving average to the points for getting a curve shape.

On the other hand more complex algorithms can be curve fitting & then extraction of points on the basis of their angle. In a nutshell, any method can be chosen while keeping the actual canal surface or the complexity of algorithm in mind. Some circle & line detection techniques have been discussed in [3].

Navigation of Quad copter

The center point of the canal is the guidance point for our quad copter. After calculating it, quad copter needs to be steered accordingly. As the quad copter moves, the guidance points increase. These points move in the quad copter frame of reference with the movement of quad copter. Due to uncertainty in center calculation algorithm & the varying shape of canal, points are sometimes spaced randomly on left & right. For sending good steering command, these points need to be spaced at some distance in a regular fashion otherwise very close points will results in a continuous varying trajectory & the motion of quad copter will be very oscillatory. To achieve higher speeds & to avoid this type of motion, a smooth trajectory has to be created for navigation. For this purpose, Bezier curves algorithm has been used.

A. Bezier Curves

Bezier curves are most commonly used in computer graphics in estimating shapes from give set of points. The curve is defined by a set of control points P_0 to P_n where “n” is the order of the curve. The general formula for the Bezier curve is described in equation below.

$$B(t) = \sum_{i=0}^n \binom{n}{i} (1-t)^{n-i} t^i P_i \quad (0 < t < 1)$$

For a simple two point curve, it is simply the linear interpolation of a straight line between two points. For example, a curve for 6-points can be evaluated by using above equation & substituting n=5. Bezier curve for points 2 to 6 is shown in figure 11 below.

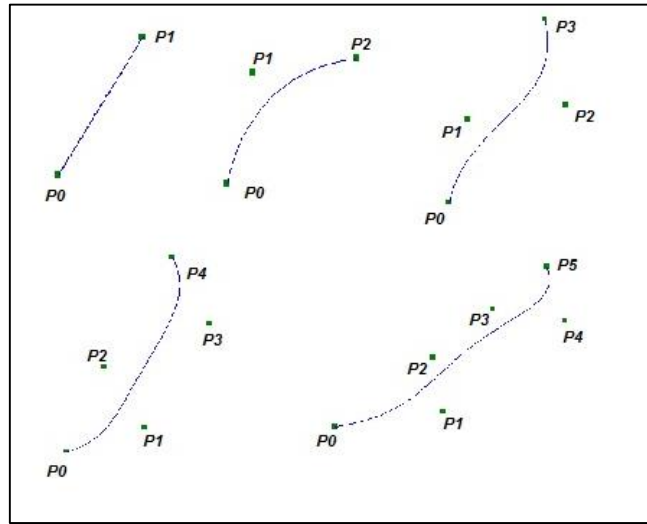


Figure 11: Different Bezier Curves, from 2 points to 6 points curve

While keeping in mind the calculation complexity, we have used 6 point Bezier curve in order to get a smooth trajectory. Different trajectory results are shown in figures (12, 13 & 14) below.

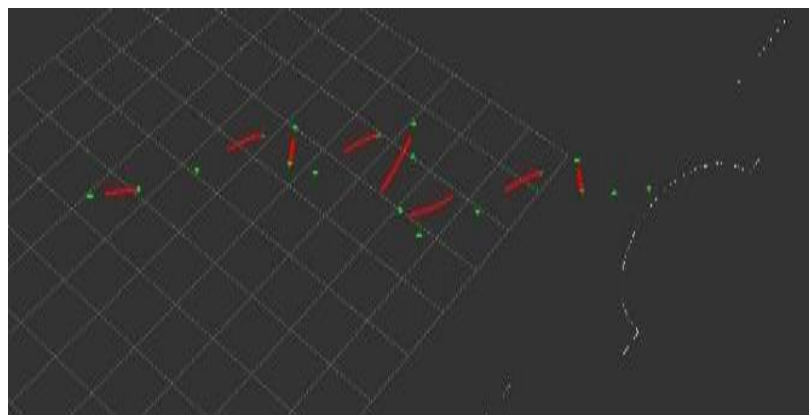


Figure 12: 3-point Bezier curve (Green points are guidance points & red are Bezier Points)



Figure 13: 6-point Bezier curve (Green points are guidance points & red are Bezier Points)

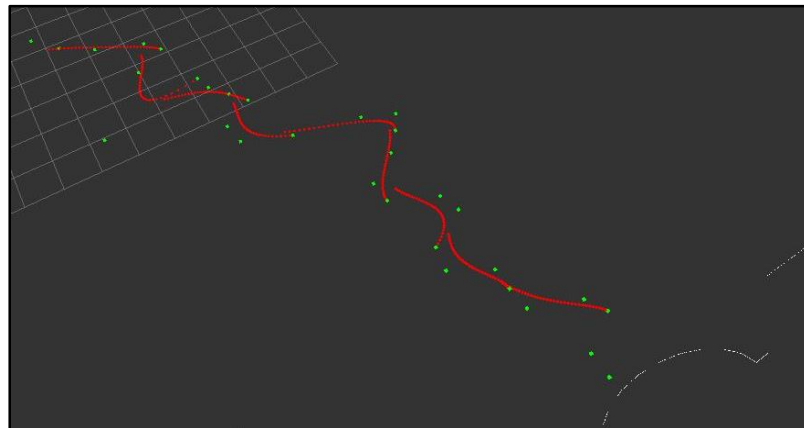


Figure 14: 4-point Bezier curve (Green points are guidance points & red are Bezier Points)

B. Control Algorithms

○ Proportional Control

We this project, we have assumed that the quad copter is moving at a fixed height over the canal. The main goal is to move the quad copter linearly & then generate the angular motion (Yaw) commands according to the position of center point in the laser scan data. In this technique, once laser scan data is generated in rectangular coordinates (figure 4) in the laser frame, the controller generates linear

velocity & yaw velocity command according to the x, y coordinate of the center point. The control equation is described below.

$$\text{Linear velocity (forward)} = Kp \cdot \sqrt{x^2 + y^2}$$

$$\text{Angular velocity (Lateral)} = Kp \cdot \tan^{-1}\left(\frac{y}{x}\right)$$

Where x & y are the coordinated of the laser fixed frame of reference (figure 4) & Kp is the gain. Although this method worked, but this was very basic control without any bound on the velocity. So, a better method is also discussed below.

○ **Stanley Based Control**

The quad-rotor has four independent degree of freedom (DOF) and for this reason for lateral control angular yaw motion is being used as control parameter. The height of the aerial robot is taken independent of other motion parameter.

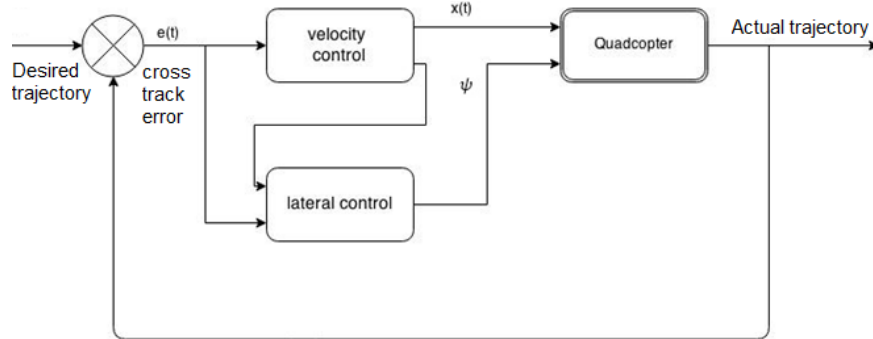


Figure 15: Stanley based control diagram

The scan parameters are same as discussed above. The appropriate control sequence is done in two steps. The linear (forward) control & the yaw (lateral) control guide the copter linearly & along the turns respectively. A general control diagram of Stanley control is shown in figure 15.

● **Velocity Control**

The linear velocity is dependent upon the error (e) between the reference and current robot trajectory. The basic control law we have used for linear velocity is given by equation below [4].

$$\dot{x} = v - \left| \tan^{-1} \frac{ky}{x} \right|$$

Where v & y are maximum allowable velocity and cross-track error. \dot{x} represents the actual velocity of quad copter. 'k' is the gain factor & we have taken it to be 1 for this case. The velocity control law ensures that safe upper bound is observed.

- **Lateral Control**

In order to generate yaw motion Stanley's [4] steering control is implemented, although the original control is for acker-man drive but due the fact that both system are related if the z axis motion (height of quad copter) is taken as constant. The steering control takes input form the velocity control and the current cross-track error and generates the appropriate yaw velocity. The yaw velocity can be calculated from the equation below [4].

$$\psi = \frac{-ky}{\sqrt{1 + \left(\frac{ky}{\dot{x}}\right)^2}}$$

EXPERIMENTS & ANALYSIS

At initial stage, before making a canal model, we also tested our method by placing back to back cylinders in Gazebo. This is illustrated in figure 16, 17 & 18.

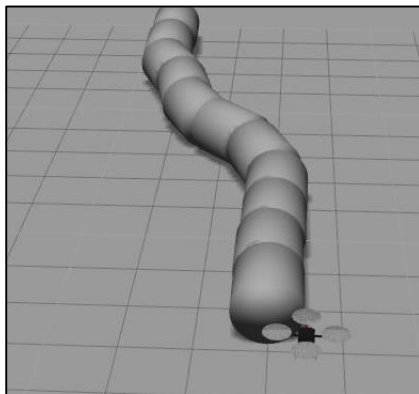


Figure 16: Cylinders placed in Gazebo

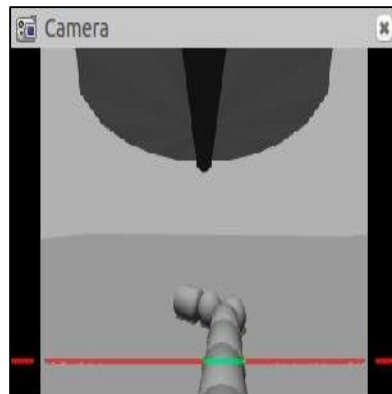


Figure 17: Front view of quad copter
(Laser scan in red & green line)

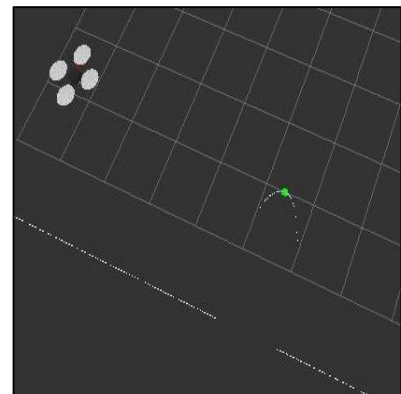


Figure 17: Center calculation (Green point)

Similarly, after canal model was created we tested the whole algorithm on the canal. First the proportional control was done. It resulted in very oscillatory trajectory. Over a whole simulation, the trajectory which quad copter followed is given in figure 19 below.

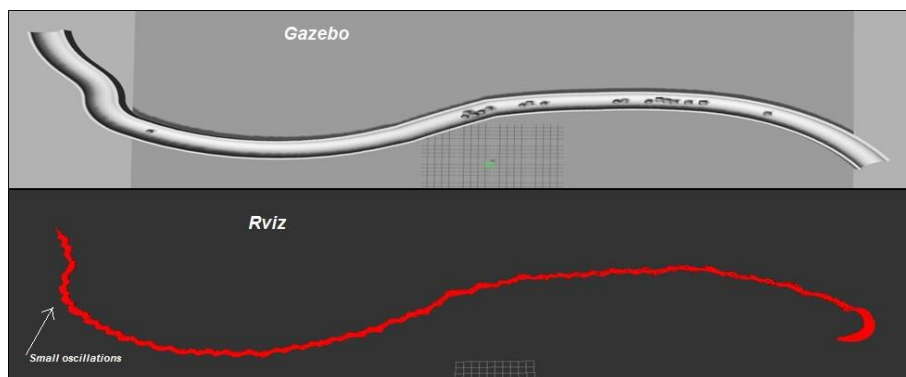


Figure 8: Complete trajectory followed by quad copter (Red line was formed by quad copter motion), small oscillations visible along whole track due to 'P' control.

After testing the Stanley control method, the same trajectory was improved & the oscillations were improved. The results are shown in figure 20.

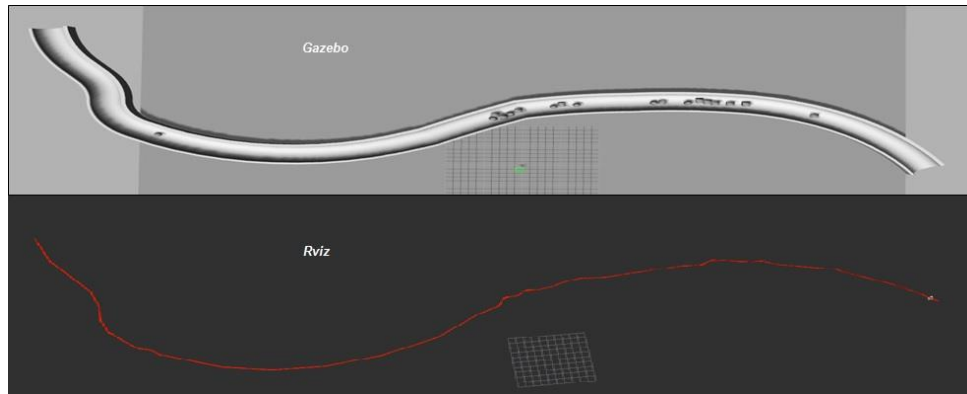


Figure 20: Same trajectory followed by quad copter as in fig 19 (Red line was formed by quad copter motion).
More smooth motion less oscillations

FUTURE WORK & CONCLUSION

After doing all the simulations, the main objective of navigating the quad copter was achieved successfully. Stanley type control gave better result than the proportional control. The environment was almost very ideal so by testing on real environment data & changing the algorithm accordingly can enable us to implement this on real quad copter. Similarly, the Bezier curve algorithm can also be improved accordingly to achieve desired speeds on the quad copter in real environment.

REFERENCES

- [1] <http://gazebosim.org/>
- [2] <http://www.ros.org/>
- [3] Fleischmann, Patrick, Tobias Föhst, and Karsten Berns. "Trajectory Planning and Lateral Control for Agricultural Guidance Applications."
- [4] Thrun, Sebastian, et al. "Stanley: The robot that won the DARPA Grand Challenge." *Journal of field Robotics* 23.9 (2006): 661-692.