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3D Object Modeling Using Data Fusion from Laser Sensor on Quadrotor

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Abstract. Environmental modeling of a robot which is needed for robot navigation and path planning is in the form of planar or 2D modeling. Several previous researchers have used laser sensor to model 2D obstacles because it has data accuracy for navigation. It is in a planar shape and implemented in quadrotor thus the obstacle modeling formed is in 2D. The problem in a 2D environment is that the path planning and navigation of the robot requires a considerable time because the robot stops at loca minima and attempts to find other paths in the dimension. The problem can be solved by using combined data taken from the laser sensor. The combination of the data uses several algorithms such as graph theory and vector field histogram algorithms. Therefore, this paper presents the combination of the algorithms to model a 3D environment. By using this model, the quadrotor is able to avoid loca minima.

INTRODUCTION

The laser sensor is a sensor that has a very far distance of sensor range and not affected by sunlight interference. Many researchers have used laser sensor as a laser for wheeled robot navigation such as Morales et al. [1]. The laser sensor which they used can detect obstacles as far as 2 meters. By using the sensor, they made a path tracking with pure pursuit algorithm. Other researchers such as Dekan & Vitko [2] also used a laser sensor to navigate a wheeled robot. By using it, they made an environment mapping for the robot. Laser sensor was used by Lingemann et al. [3] for wheeled robot localization.

Several other researchers combined laser sensor with some other sensors to optimize localization. The Researchers such as Gu et al. [4] combined laser sensor with an inertial sensor. The laser sensor was combined with odometry sensor as conducted by Yoshida et al [5]. The other researchers such as Kirsch & Rohrig [6] with research entitled "Position tracking using sensor fusion of a wireless network and a laser range finder" used fusion sensor to combine wireless network with a laser sensor. The combination was used for tracking the position of the robot. With the merger the position of the robot could be determined.

Besides being used for navigation on wheeled robots, laser sensor was studied to create an obstacle in the form of 3D modeling. Some researchers who examined the environment and obstacles modeling in 3D are Mohottala et al. [7]. They used laser sensors in combination with camera sensor for pattern recognition. They used graph algorithms to form a 3D object shape. Other researchers such as Bok et al. [8] experienced a problem in the merger between the laser sensors with camera sensors. The problem that exists for the data collection process was not the same, thus a synchronization algorithm is needed. Gruyer et al. [9] conducted research by combining a laser sensor with a camera. In a study entitled "Vehicle detection and tracking by collaborative fusion between laser scanner and camera", they performed tracking and vehicle detection by using a collaboration of the two sensors. Another researcher for modeling 3D objects is Solea et al. [10]. They modeled an obstacle and environment into a 3D object. To model an obstacle into 3D, they used a laser and servo motors. The motor would move the laser sensor up and

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down so that the planar data would be obtained every movement of the servo. The data was then combined to make its 3D object.

This paper presents the algorithm of graph theory with vector field histogram to form a 3D object from the sensor. The sensor used in this paper is laser sensor which is mounted in a quadrotor. In addition, graph algorithms to model a 3D environment with a data fusion of laser sensor were used.

QUADROTOR MODELING

Robot model presented in this paper is a model of flying robots with rotary wing type. Rotary wing type is a type of robot that can perform VTOL and hover. Hover is a position of a UAV that is stable at a high altitude. Research on hover has been much conducted by researchers such as Shin et al. [11]. They conducted research by using a ducted fan to hover at particular altitudes. Other researchers such as Sandino et al. [12] used a helicopter to hover.

In this paper, a quadrotor model is used which was first studied by Pounds et al. [13] that created a dynamic and kinematic model for quadrotor that could lift weights of 4kg. The model of the quadrotor is shown in Fig 1.

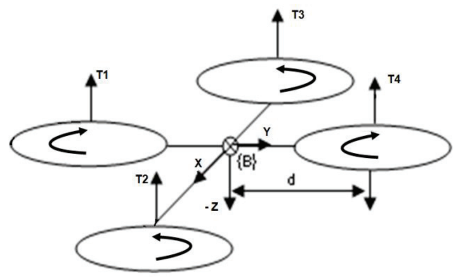


FIGURE 1. Quadrotor Modeling

In Fig. 1, the quadrotor has 4 rotors which are mounted on each arm. The speed of each rotor is denoted as ωi and vector thrust as Ti. When the motor rotates, it generates a 12-state denoted as x, y, z, $\dot{x}$, $\dot{y}$, $\dot{z}$, ϕ, θ, ψ, $\dot{\phi}$, $\dot{\theta}$, and $\dot{\psi}$. Each rotor speed equation is as follows

$$T_i = b\omega_i^2 \quad i = 1,2,3,4 \tag{1}$$

Each rotor torque equation is as follows:

$$Q_i = k\omega_i^2 \tag{2}$$

To control Quadrotor while it is navigating, roll and pitch torques are controlled. The input of roll torque is an angle difference of ω1 and ω2 as shown in equation 1. With the difference in angle, there is a speed difference of two facing rotors.

$$\tau_x = k\left(\omega_4^2 - \omega_2^2\right) \tag{3}$$

Input of pitch torque is

$$\tau_y = k\left(\omega_1^2 - \omega_3^2\right) \tag{4}$$

In this paper, to make Quadrotor hover at a certain height, torque on all motors is needed. Torque equation for a motor is shown in equation 5. Total reaction torque with the z-axis is shown in equation 5.

$$\tau_x = k\left(\omega_1^2 - \omega_3^2 + \omega_2^2 - \omega_4^2\right) \tag{5}$$

LASER SENSOR

Hokuyo laser sensor is a 2D planar laser sensor which has been widely used by researchers for robot navigation as conducted by Zezhong et al. [14]. By using the sensor, robot detects an obstacle located in front of it. Babinec et al. [15] used this sensor to detect obstacles and for robot navigation by using VTH algorithm. Habermann & Garcia [16] used 2D laser for detecting and tracking objects. Kondaxakis et al. [17] used a laser sensor for tracking many targets by using JPDA-IMM algorithm.

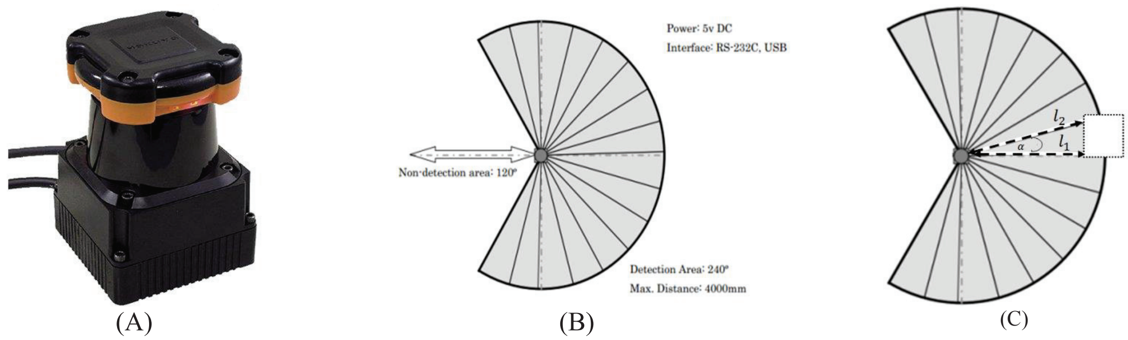


FIGURE 2. Hokuyo laser sensor

This study uses Hokuyo laser sensor UBG-04LX-F01 type as shown in Fig 2(A). This sensor uses light with a wavelength of 785nm. The voltage required is 12 volts and it is connected to the robot by using RS232 or USB connector. Fig 2(B) shows the characteristics of the laser sensor radiation. The farthest obstacle that can be detected by this sensor is 2m, while the nearest is 20mm. Resolution angle of the sensor is 0:36 degrees. In fig 2(C) it can be seen that the data obtained from laser sensors in the form of range data. With these data the objects which are in front of the robot can be modeled. From these data the object can be modeled as:

$$\alpha = \cos^{-1} \frac{l_2}{l_1} \tag{6}$$

Where, data l_1 and l_2 is a range data that makes up the angle α. To determine the width of the obstacle, trigonometry formula is used as follows:

$$l = l_1 \tan \alpha \tag{7}$$

SENSOR FUSION

Sensor fusion is an algorithm combining several data from many sensors or a sensor. Modeling an object as an obstacle can be conducted by using sensor fusion algorithm. The examples of algorithms used for sensor fusion algorithms are fuzzy by Tan et al. [18], graph theory algorithm by Mohottala et al. [7] and Vector algorithm by Babinec et al. [15]. This paper presents the combination of graphs and Vector Field algorithms.

Vector field

Vector field algorithm is the one which uses a basic principle of a vector. Ulrich & Borenstein [19] applied the algorithm to detect obstacles. Behrens et al. [20] used field vector algorithm to create a path for multi-agent navigation. Bresler [21] created optimum visual with vector field algorithms and multi-sensor fusion. Kwon & Chwa [22] made the wheeled robot formation with a vector field algorithm.

In this paper, the laser sensor is read by robot operating System (ROS). Laser sensor data is processed by the ROS generating a distance value. By using vector algorithms, the value of the distance will be modeled into a 2D obstacle. 2D vector field algorithm equation is as follows:

$$\overline{V} = \left\{ \overline{V_1}, \overline{V_2}, \cdots, \overline{V_n} \right\} \tag{8}$$

where $\overline{V}$ is a 2D vector field. $\overline{V_1}$ is the value of each vector in 2D space. The value of this field vector is in the form of obstacle distance to the robot. The following is vector field equation:

$$\overline{V_1} = \sqrt{\left(X_R - X_O\right)^2 + \left(Y_R - Y_O\right)^2} \tag{9}$$

where x_R, y_R is the point of the robot position and x_O, y_o is the point of the obstacle position. Angle formed by vector fields uses the following equation:

$$\alpha = \tan^{-1} \frac{\left(X_R - X_O\right)}{\left(Y_R - Y_O\right)} \tag{10}$$

By using equations 9 and 10, it can be seen the point of the robot obstacle with the following equation:

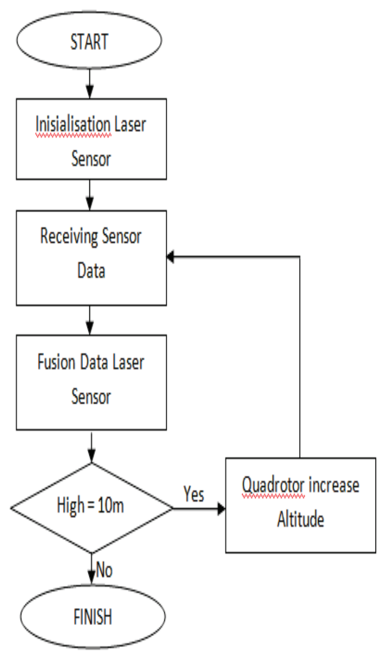
$$X_O = X_R \sin^{-1} \alpha$$

$$Y_O = Y_R \cos^{-1} \alpha \tag{11}$$

From many points of obstacles, objects in two dimensions will be modeled by using graph theory.

```
function Dijkstra(Graph, source):
      for each vertex v in Graph:
          dist[v] := infinity ;
          previous[v] := undefined ;
      end for

      dist[source] := 0 ;
      Q := the set of all nodes in Graph ;

     while Q is not empty:
         u := vertex in Q with smallest distance in dist[] ;
         remove u from Q ;

         if dist[u] = infinity:
             break ;
         end if

         for each neighbor v of u:

             alt := dist[u] + dist_between(u, v) ;
             if alt < dist[v]:
                 dist[v] := alt ;
                 previous[v] := u ;
                 decrease-key v in Q;
             end if

         end for
     end while
  return dist;
```

(A)



(B)

FIGURE 3. 3D model algorithm

Graph theory

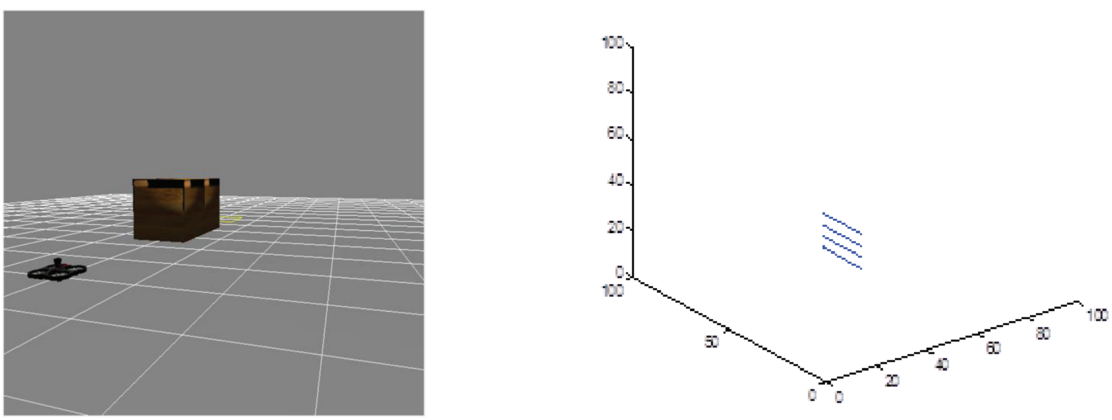
Graph theory is a theory that is used by some researchers to search the shortest path [23]. Graph theory has been developed to be applied in several path planning. This theory can also be implemented to analyze a laser sensor and multi-sensors. Yu & LaValle [24] used graph theory to optimize multi-robot path planning. Grigoryan & Harutyunyan [25] conducted research to find the shortest path. A search for the shortest path they have conducted used graph knodel algorithms. Yang & Sun [26] processed multi-sensor robot data underwater by using graph theory. They combined graph theory with fuzzy. Mohottala et al. [7] conducted research by using laser sensors and cameras. For object recognition in the form of cars, they used graph algorithms. Graph G consists of a non-empty set of an element called the point (E), and a path between points is called the side or line (V). A graph G is denoted as G = (V, E). The graph used in this paper is a weighted and undirected graph. The weight of the graph is an object point obtained from equation 12. Figure 4 is an obstacle distance point obtained from equation 12. In this figure it is seen that the distance point of E1 and E2 will be equal to the distance point of E2 and E3. Distance from all points is obtained by calculating equation 8. Furthermore, it is connected to a line by using Diksjark algorithms as shown in Fig. 3(A).

3-DIMENSIONAL MODEL

By using a laser sensor and combining VFH algorithm with graph theory, 2 Dimensional obstacle models is obtained. With 2D obstacle, many researchers could conduct wheeled robot navigation. This paper uses a UAV type robot which works in a 3D environment. The algorithm used to create a 3D obstacle of laser fusion of sensor data is shown in Figure 7. The figure shows that quadrotor takes the plannar data of laser sensors at several heights. The quadrotor will rise by 5 cm to retrieve the data plannar of laser sensor. Having obtained the data from the laser sensor, the data is processed into a 3D model by using algorithms shown in Fig. 3(B).

RESULTS AND DISCUSSION

This paper carried out experiments by using ROS. In ROS there are gazebo programs that serve to simulate a robot. In this simulation Hokuyo laser sensor mounted on a quadrotor is used. There are two simulations carried out in this paper using one square-shaped and 3 square-shaped obstacles.

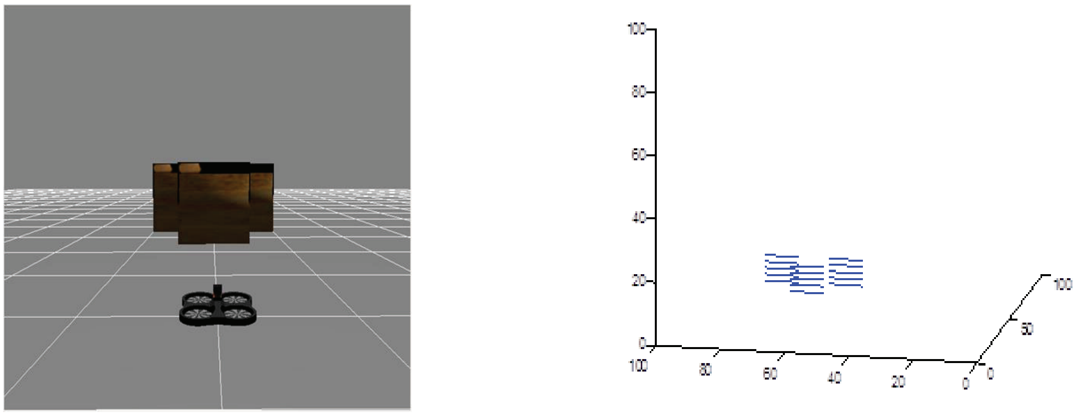


(A) (B)

FIGURE 4. Simulation Quadrotor with an obstacle

The first experiment carried out in this paper is to detect an obstacle object by using laser sensor. The sensor is mounted above quadrotor as shown in Fig. 5(A). The object which will be detected by the sensor is in a square shape by using VFH algorithm. Then it is modeled in 2D by using graph algorithms. By using the 3-D Model Shape algorithm, a model as shown in fig 5(B) is created.

Fig. 5(B) shows a graph of simulation as the results of 3D modeling of an obstacle. It is seen in the figure wall-shaped obstacles with a height of 1 meter and length of 1 meter. Such obstacle model cannot be in the form of square-shape obstacle as the original one because the laser will scan it in the form of planar, consequently it is not known whether the object is a triangular or square.



(A) (B)

FIGURE 5. Simulation Quadrotor with three obstacles

The second experiment uses 3 square-shaped obstacles. An obstacle is placed at position point (60; 60).Then two other obstacles placed behind the first one at position point (60; 60), and (60; 70) as shown in Fig. 5(A). This experiment also uses quadrotor mounted in a laser sensor. Obstacles saw in Fig. 5(A) are created in a 3D model. The shape of obstacle objects is seen in Fig. 5(B).

Figure 5(B) shows the characterize Fig. 5(A) is a graph of simulation as the results of 3D modeling of obstacle objects. It is seen in the figure three wall shaped obstacles with a height of 1 meter and length of 1 meter. The wall is indented with a width of 1 meter. The obstacles are square, but they seem wall shaped to the robot because the laser will scan it in the form of planar, consequently it is not known whether the object is triangular or square.

CONCLUSION

In robot navigation, an obstacle modeling is necessary for the robot to be able to avoid obstacles. In UAV robot modeling in 3 dimensions is required for navigation. This modeling uses VFH and graph theory. By using the combination of the two algorithms, it is obtained a 3D model of obstacles.

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