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Design and Development of an Obstacle Sensing Umanned Air Vehicle (UAV)

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***Abstract*—Unmanned Air Vehicles (UAV) has become a trend now a day among academia, industries and hobbyists because of its mechanical simplicity. Its application ranges from surveillance to recreational flight and a plenty of research being conducted in regards to design and control. But use of small UAVs is limited because of the lack of collision avoidance technology. A simple approach for obstacle detection and collision avoidance for UAV, using cost efficient ultrasonic sensor, is presented in the paper. In order to study the impact of different design setups, the UAV model is constructed and used for experimentation.**

***Keywords*— Collision avoidance; obstacle detection; ultrasonic sensors;Unmanned Air Vehicle .**

I. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are used for both military and humanitarian missions such as search and rescue, surveillance of disaster stricken areas, and battlefield assessment. Research in this field continues to increase due to the versatility of their potential use. However small UAVs are typically not capable of obstacle or collision avoidance due to the heavy, expensive, and energy consuming nature of the sensors necessary for detection and analysis of obstacles. Lack of this technology on small UAVs makes them vulnerable to incoming objects such as other vehicles as well as stationary obstacles such as walls or buildings and despite so many applications, the use of these small UAVs remained limited to military and restricted airspaces. The collision avoidance approach is divided into two main modules which are obstacle detection and collision avoidance.

A. Obstacle Detection

Navigation of an autonomous UAV in an outdoor environment is possible using GPS data for positioning but in the indoor environment GPS is not operational. Common approach for indoor application is the use of camera systems for obstacle detection, collision avoidance and positioning but this approach has drawbacks like dependency on external camera systems and heavy computational requirements. Moreover, any optical sensor is sensitive to light and a diaphanous environment, therefore smoke, steam and every gas which absorbs light will cause optical sensor systems to fail, whereas ultrasonic sensors are less affected in such situations. Ultrasonic sensors are selected for detection.

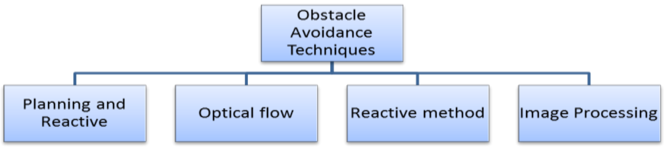


Figure A

B. Collision Avoidance

Function of this module is to differentiate the area around the quad-copter based on the measured distance into three zones in each direction, named as safe, danger and a prohibited zone. Instructions from transmitter are as it is sent to flight controller when flight is in safe zone. Extreme values of signal from transmitter are confined within specified range when flight is in danger zone whereas algorithm overrides the instructions from transmitter, once the flight is entered in prohibited zone, to pull the flight out of prohibited zone.

II. IMPLEMENTATION

The presented concept has been implemented and integrated in the self-developed UAV, specially designed to lift the obstacle sensing system as its pay load. Implementation of the concept was divided into following three phases;

A. Design and development of UAV

B. Development of collision avoidance system

C. Integration of UAV and Obstacle Avoidance System

A. Design and Development of UAV

Multi rotor UAV was selected for the application after trade study given in Table 1.

Table 1

Fixed Wing	Multi rotor
Hovering is NOT available	Hovering available
Can't fly below stall speed	Can fly at low speeds
Not suitable for most application	Suitable for most of applications
Long Endurance	Less Endurance
Less Maneuverability	More Maneuverability

Ranging from helicopter to octa-copter, various multi-rotors are in use but quad-copter is most widely used because of its mechanical simplicity, sufficient stability and maneuverability. X configuration of quad-copter was selected after trade study.

Dimensions of quad-copter physical layout were set according to the size of pay load. Aluminum box beam and wooden square plates were used to build the frame utilizing campus workshop facility for machining and assembly process

(Figure B). Arducopter was chosen as flight controller after the comparison given in Table 2.

Table 2

Flight controller	Cost($)	Weight (gm)	Programming	Assembly
Ardupilot	40	32	Simple	Simple
Lisa-L	99	11	Complex	Complex
Pixhawk	199	38	Simple	Simple
MultiWii PRO	65	16	Complex	Simple

Specifications of the manufactured quad-copter (Figure B) are given in Table 3.

Table 3

Quad-copter Specifications	
Arm length (motor to motor distance)	450mm
Weight	1290gm
Maximum Available Thrust	2800gm
Estimated Maximum Flight Time	15 min
Flight controller	Arducopter

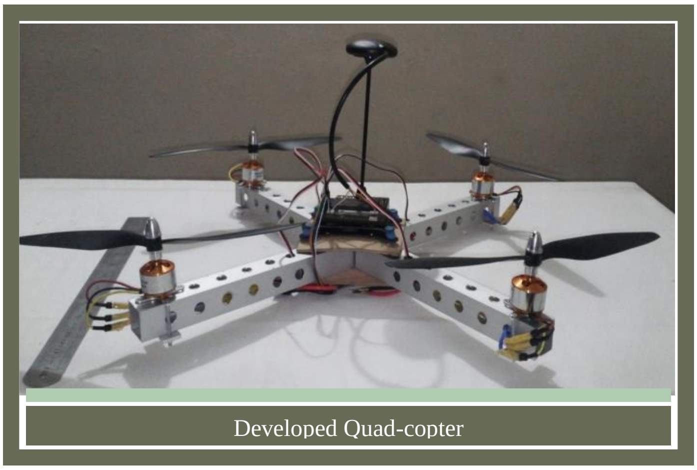


Figure B

Sensor	Range (m)	Mass (gm)	Price($)	Energy Consumption (mA)
Max Sonar-EZ0	0 - 1	4.3	30	2
SICK Lidar	0 - 10	1200	4,000	470
Xbox Connect	0 - 2	5606	99	5
HC-SR04	0 - 4.5	8.8	2	15

Four HC-SR04 sonar sensors were mounted on the frame to produce a quad-copter capable of determining distances to objects left, right, forward, and rear of the vehicle (Figure D).

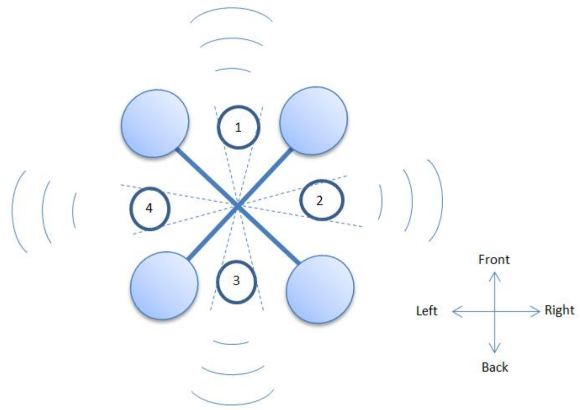
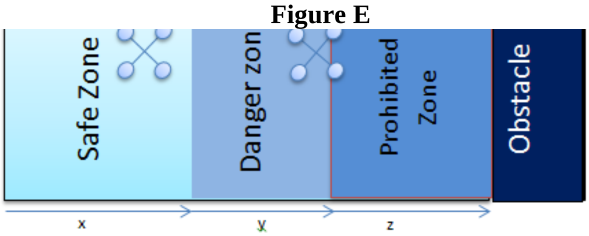


Figure D

C. Integration of UAV and Obstacle Avoidance System

Arduino Mega 2560 board is used for data processing. Instructions in the form of PPM signal from transmitter are fed into arduino mega 2560 which uses sensors feedback to generate and send appropriate PWM signal to the arducopter (Figure C & E). Coding is done in arduino language, which is merely a set of C/C++ functions.

Figure E



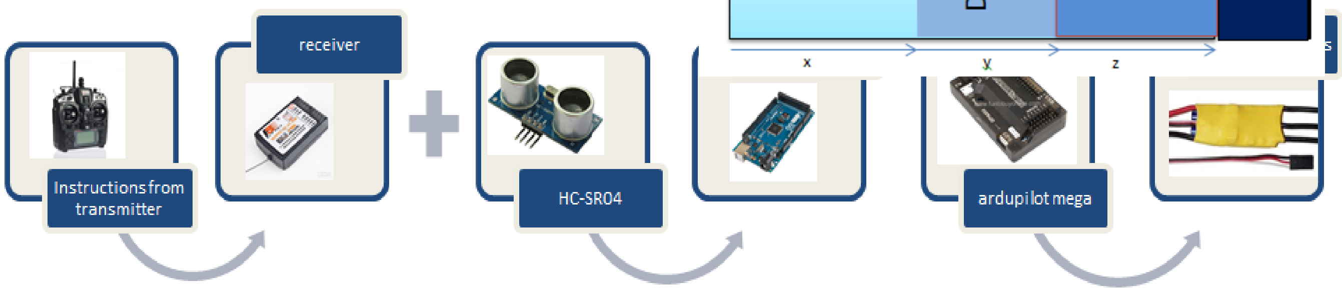


Figure C

Figure F

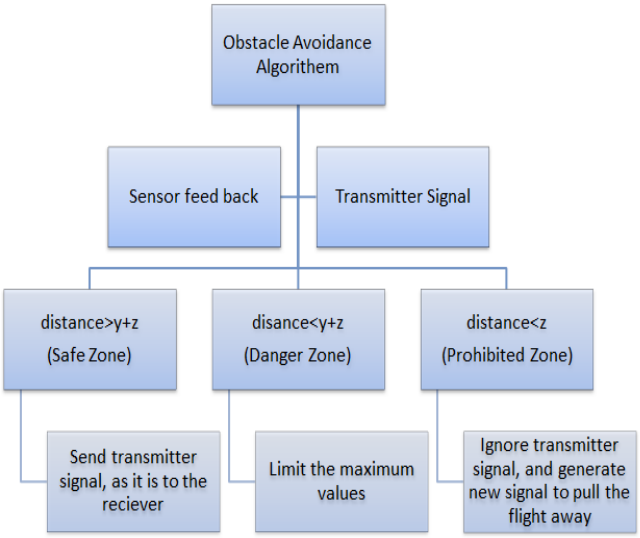


Figure G

III. EQUATIONS

Rigid body approximation on free body diagrams gives relationship between each engine's (motor) thrust, quad-copter pitch and roll angles, and the quad-copter accelerations are determined as given below:

$$a_x = \frac{T_3 \sin\theta + T_4 \sin\theta + T_3 \cos\psi + T_4 \cos\psi}{m} \qquad (1)$$

$$a_y = \frac{T_1 \sin\phi + T_2 \sin\phi + T_3 \sin\psi + T_4 \sin\psi}{m} \qquad (2)$$

$$a_z = \frac{T_3 \cos\theta + T_4 \cos\theta + T_1 \cos\phi + T_2 \cos\phi}{m} \qquad (3)$$

Attitude angles are determined by the IMU to find accelerations and the thrust is determined through lookup tables, generated through the bench testing of motors. Dynamic equations for rigid body aircraft provide forces in body axis system as given by the following equations:

$$X - mg\sin(\theta) = m(\dot{u} + qw - rv) \qquad (4)$$

$$Y + mg\cos(\theta)\sin(\Phi) = m(\dot{v} + ru - pw) \qquad (5)$$

$$Z + mg\cos(\theta)\sin(\Phi) = m(\dot{w} + pv - qu) \qquad (6)$$

Applying small angle approximations and dividing these equations with mass gives relationship for measured accelerations, actual acceleration and velocity as following:

$$\dot{u} = a_x - qw + rv - g\theta \qquad (7)$$

$$\dot{v} = a_y - ru + pw + g\Phi \qquad (8)$$

$$\dot{w} = a_z - pv + qu - g\theta_0\theta \qquad (9)$$

Measured accelerations in addition to the calculated accelerations can be used to determine the quad-copter's velocity. This velocity is then integrated to determine actual position of the quad-copter.

Where;

a_x	= actual forward acceleration (ft/sec^2)
a_y	= actual side acceleration (ft/sec^2)
a_z	= actual vertical acceleration (ft/sec^2)
g	= acceleration due to gravity (ft/sec^2)
m	= quadrotor mass (slug)
p	= roll rate (rad/sec)
q	= pitch rate (rad/sec)
r	= yaw rate (rad/sec)
T	= engine thrust (lb)
u	= forward velocity (ft/sec)
v	= side velocity (ft/sec)
w	= vertical velocity (ft/sec)
$\dot{u}$	= measured forward acceleration (ft/sec^2)
$\dot{v}$	= measured side acceleration (ft/sec^2)
$\dot{w}$	= measured vertical acceleration (ft/sec^2)
X	= longitudinal force (lb)
Y	= side force (lb)
Z	= vertical force (lb)

IV. EVALUATION

Testing of the HC-SR04 sensors with arduino mega 2560 was done for the calibration, so that they gave accurate distance to the obstacles they detect. Both individually and simultaneously, sonar data taken from each of the four sensors mounted on the vehicle was compared to actual distances from the sensors.

Several static tests were performed (while keeping the quad copter static) using different types of obstacle to find out detection capabilities and reliability of the developed algorithm by observing the output signal from arduino mega. Output signal from arduino mega was fed into arducopter observed on Mission Planner, which is GUI firmware for arducopter (Figure H).

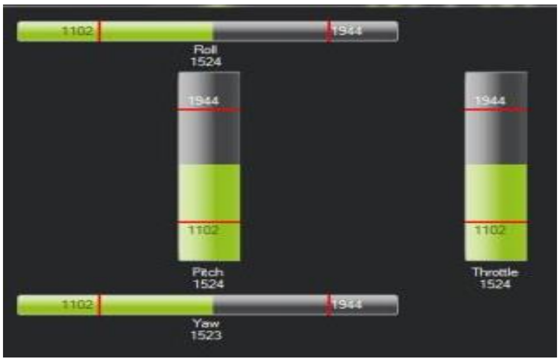


Figure H

Initial flight test was designed taking into account the safety of quad-copter for testing the stated algorithm. For this particular test, range of prohibited zone was kept 1 meter while range of danger zone was 2 meter from the obstacle. Quad-copter was set to hovering flight, 2 feet above the ground. A rectangular wooden sheet of 2ft x 2ft was used as obstacle and moved near the quad-copter.

A. *Results*

When obstacle was moved towards front side of quad-copter up to the distance of 0.6 m from quad-copter, obstacle was detected with about a time delay of half second and quad-copter pitched up and moved away in somewhat following fashion (Figure I).

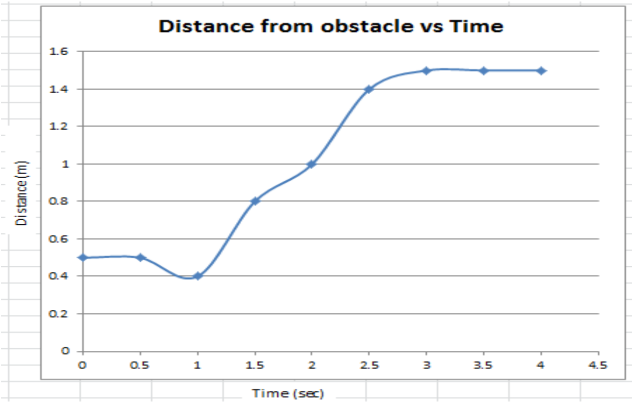


Figure I

Ultrasonic sensors can measure only the distance up to 300cm efficiently. System can detect flat or straight surfaces well, but problematic surfaces are not detected with the required reliability.

B. *Conclusion & Future Work*

The result of evaluation process shows, that the system is operational and capable of avoiding obstacles from four directions to autonomously perform function of collision avoidance. Ultrasonic sensor is helpful in detection of smoky environments and autonomous flight is possible under such conditions.

Multiple arrangements of sensors are required to be tested to find the optimal arrangement and number of sensors for accurate measurement. Measuring angle of the sensor is 15 degrees therefore more than one sensor for single direction is required to get reliable obstacle detection. Combination of optical and sonar sensors is recommended for further research.

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