A THEORETICAL DESIGN OF A COMBINED AIR AND GROUND UNMANNED VEHICLE FOR SEARCH AND FOLLOW A DISASTER

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Abstract

The combination between unmanned ground vehicle and unmanned Ariel vehicle has become a matter of discussion lately in the field of robotics. This paper proposes a theoretical design of an unmanned vehicle with dimensions of (370 X 367 X 318 mm) which can fly as aerial vehicle and move on the ground, so it is considered unmanned ground vehicle as well. Subsequently, hybrid design is appropriate for following disaster robot because of the harsh environment. This investigation comprises literature review on some previous works in this regards along with the conception of the vehicle is argued in details with 3 D drawings. Furthermore, some calculations of the drag, lift forces and power consumption are performed. Finally, MATLAB plots are extracted to give an indication of the displacement response of the automobile in both X-Y axes.

Keywords:

Following a disaster robot, air and ground unmanned vehicle, quad-rotor with ground vehicle.

1. INTRODUCTION and literature review

Unmanned vehicle can be divided according to the nature of the movement into either aerial or ground drive that are UAV and UGV. UAV denotes to the Unmanned Aerial Vehicle and UGV refers to the Unmanned Ground Vehicle. The structure of this literature review includes three debates. Firstly, it focuses on UAVs types in addition to the each for each kind such as fixed wing, helicopter and quad rotor. Secondly, list main kinds of UGVs. Finally, limp on the recent developments of cooperation or combination between the two systems to generate UAGV.

Dr. Richardson, in his lecture, states that can be classified airplanes by the operating philosophies. They are fixed wing such as (conventional plane), helicopters and quad-rotors which are under rotor aircraft category [1]. The features of a fixed-wing aircraft are flying with higher speed compared with rotary, in addition, the fuel consumption is quite less than the second division which is rotary UAV. However, unmanned jets are appropriate for fixed point monitoring some places especially following disasters because of dangerous environment [2]. The designed control system of a flight in this style faces difficulties such as nonlinearity dynamics as well as complexity in terms of structure.

On the other hand, rotor aerial vehicles particularly quad-rotors are better in hovering than fixed-wing [2]. Quad-rotor robot involves of four rotors located in a symmetric manner, so they form the X-shape. It also has the possibility of vertical landing and take-off in small places. Nevertheless, in designing the controller there are several consideration should be taken. For instance, time delay, actuator degradation in the system and external disturbances but it is low-cost design and attractive to people and military [3]. Helicopter is much more complex to develop in a short time; therefore, it will be dropped in this work.

The second part of the subject is UGV. In the other words, it is land based automobile that has a set of sensors mounted on it. These sensing devices are used to collect the information of the surrounding environment. Unmanned ground car can be divided into two classes: autonomous and remote operated. The first class discusses the vehicle from automatic perspective, so UGVs can sense, plane and make some decision without any interface with the human. Conversely, remote functioned, requires external control to achieve the final decision. To illustrate, in natural tragedies remotely control is favored rather than those driven by intelligent algorithm because the harsh location after bombing, for example, may affect the procedure of the decision making. To conclude, selecting criteria of UGV depends extremely on the application [4].

With to the cooperation between UAV and UGV, many researches have been conducted in this concept. MacArthur, D and Crane, C. [5] have done a research on applying a passive unmanned aerial system in UGVs. In the past two decades, a number of nations have begun to spy on other countries because of security issues. From this point of view, UAV was the best choice to survey applications and satisfied the required reconnaissance. Moreover, perception capabilities for UAV compared with UGV are much better. Eventually, the author [5] investigates UGV/UAV collaboration to perform the task.

The demonstration was a design of UGV platform to state estimation using helicopter principles for Geo-positioning.

Air to ground attack vehicle and air-land to water vehicle are argued in [6], [7] respectively. With respect to the former, the purpose behind the air –to- ground motor vehicle, as mentioned in [6], is anti-radar, real time occurrence, Repel fire and pounce on the enemy. The scheme is combination manned airplane and unmanned one. The manned function is to access wealth info from UCAV such as battlefield situation assessment, decision maker and coordination targets. The study suggests that the vital role of the interaction or tasks allocations between human and automatic control system is an essential feature to reach a successful system strategy.

According to [7,] the unmanned vehicles are subdivided into three main categories. UAV's and UGV's which are discussed above while USV's belongs to the name of unmanned surface vehicles or UUV's which states the abbreviation of underwater vehicles. In this reference, the writer proposes a conceptual design for a vehicle that could be operated on land or functioned as an airplane and move like a boat on the surface. The design of it requires mechanical system plan and selection of electrical components. After that, testing this multifunctional unmanned automobile should be available. Finally, the construction is under name of, (USALWaV), unmanned small-scale and air-land- water. The implementation is done successfully by solid works as well as a real model involves helicopter controlled by radio control (RC) [7].

Due to the concentration of the production of unmanned vehicles for the military purposes that lead to reduce the focusing on civil application. There is a fact which states that the percentage of UAV manufacturing for civilian purposes is 3 percent of total market for aerial unmanned vehicles. However, new areas are found in terms of civilian uses such as following disaster robots, forest firing emergencies, climate change discoveries, path-following and traffic monitoring so they can bring less risk to people [8]. To illustrate, unmanned airships have unique benefits in low-speed and low elevation applications which make them easy to communicate in crises management [9].

2. RECENT DEVELOPMENTS IN COLLABORATION UAV WITH UGV

2.1 Autonomous UAV lands on moving UGV

Fig 1 UAV landing [10]

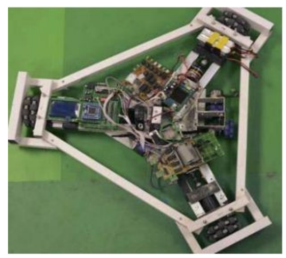


Fig 2 ground vehicle [10]

The quad rotor platform consists of UAV landing on a table that moving by three Omni wheels. A single on board camera has been employed to achieve the target as shown in figure 1, 2. The practical purpose behind this accomplishment is to realize autonomous UAV landing on UGV and takeoff based on vision system. PID controller implements the closed loop control [1].

2.2 Surveying operations UAV/UGV [11]

As a result of frequent wars have proliferated in recent frequent mine, which in turn has caused great harm to humanity. Autonomous UGV is the best solution for this issue from two perspectives. First one, it can protect the teleoperator by isolating him in a safe place. The second one, unmanned ground vehicle can access to narrow places.

However, in difficult environment the telecommunication between the robot and the operator may be lost, so quad copter will assist UGV to achieve the goal and expand the field of view.

The principle of operating is the vehicle tracks the centroid of the helicopter based on artificial vision [11].

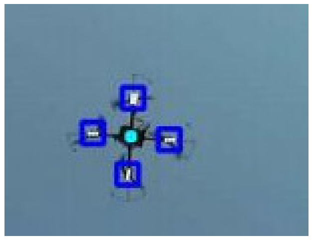


Figure 3 quad copter [11]

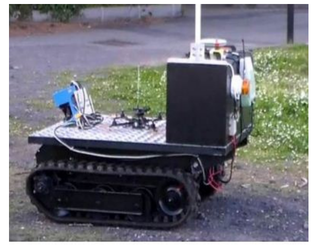


Figure 4 adopted UGV [11]

3. SYSTEM DESIGN

A.Initial perception of design (Objectives of this paper)

UGV and UAV have been an object of research recently. However, the search process in a hybrid system that combines the good features of both types has become arguably subject during the past decade. From this engineering point of view, the designing approach for the vehicle in this paper aims to initialize a theoretical design for a car that most of what distinguishes it from other peers is portability of aviation.

The system is not ideal or perfect project. Because of eliminating a several parameters throughout the calculation processes and modeling by using MATLAB software. A case in point, it is considered that the net weight represented by the mass is point mass, so it doesn't matter about the shape of the vehicle. In addition, the size of the UAGV is quiet big compared with the other works but this is the challenging could be achieved. Accordingly, there is no need to determine the centroid of the profile. Conversely, the final design is almost symmetric which helps to satisfy the condition of the quad rotor to fly in straight level. Therefore; the previous speech focuses on the limitation of this paper.

Moving to the vital aspect of this article that is embodied in graphical design. Solidworks, it had a lion's share in this concern, have been relied upon in the design by up to more than 90 percent. Some 3d drawings that can be imported from [12], especially for already drawn sensors and actuators such as cameras and encoders but all the body is performed by the writer.

B.The system from a detailed perspective

In literature [13], the idea of the following disaster robot that results from combining UGV and UAV features is based on two crucial things. First, the vehicle is in a big size compared with the previous works which is in itself challenging to build vehicle with 37 cm in width. The second aspect is trying to minimize the weight as much as possible to be able lift it by using Carbon Fiber Reinforced Plastics (CFRP) as a chassis material because it is extremely strong and light.

The main components of the theoretical design are the body of the car and 4 brush less DC motors of quad rotor part. The structure of UGV prepared as follow, base, front brick and rear brick. The base supports the sensors (gyroscope, accelerometer and battery) as well as the optical encoders that coupled with the rear wheels while the front and rear sections carry the motors. The front and the rear bricks are not solid there is a space inside them enough to put the PCB cards such as drive circuit of the servo motor with encoder and electrical speed controller for quad rotor (ESC) respectively.

The principle of quad rotor or quad copter working is quite easy in terms of mechanic and electronic as shown in fig7. It is four motors controlled by microcontroller through changing the speed individually per each motor to obtain 6 directions of motions: left - right motion, backward - forward motion and takeoff –landing motion. In general, the connection between the motors are made by X shape, however in this design the motors are fixed on the arms of the frame to contribute to reducing the total weight of the vehicle. M1, M3 are responsible for moving forward and backward respectively whereas M2, M4 move it right and left relative to their rotations where the former rotates in clockwise in contrast with the later which turns in counter clockwise direction [14].

The motors, as shown in (**grey color**) in the figures, of the quad rotor are brushless DC motor which are fast, more efficient, less noise and higher reliability than brushed dc motor [15]. Selecting the combination motor-propeller based on a certain equation. This equation is to calculate thrust per motor that required thrust per each motor is equal to the total weight of the vehicle multiplied by 2 divided by 4 the number of motors. The other factor related to the brushless DC motor when purchasing is the efficiency as much as higher will be better. Regarding the propeller, two things associated with it: pitch and length whenever increasing them it requires more current drawn from the source. Thus, selecting criteria of motor-propeller are essential when establishing the quad rotor [16].

Motors of the moving part are controlled by four transistors with microcontroller by something called H-bridge circuit [17] [18]. The brief concept of H-bridge working is to change the direction of the rotation. On the other hand, speed is controlled by pulse with modulation approach which is done by the microcontroller circuit. For example, when fix the speed of the left motor and decrease the speed on the right the car will turn right and vice versa. Therefore, in this design optical encoders send the feedback signal of the current position for each motor to the control circuit to correct the error.

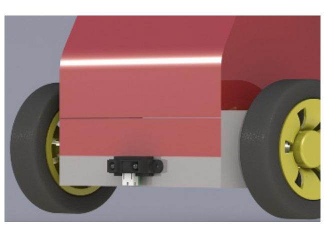


Fig 5 IR sensor (optional)

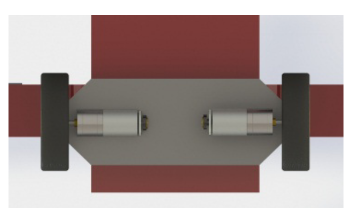


Fig 6 optical encoder motors

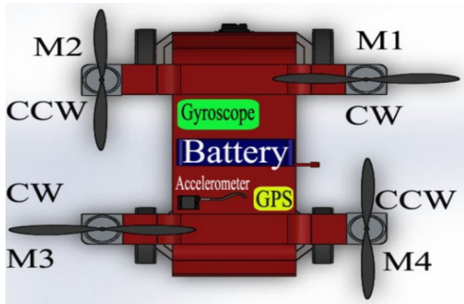


Fig 7: is the top view of the unmanned aerial and ground vehicle.

M1, M2, M3and M4 are the quad motors. CC and CCW abbreviations are clock wise and counter clock wise directions. The green box shows the gyroscope position

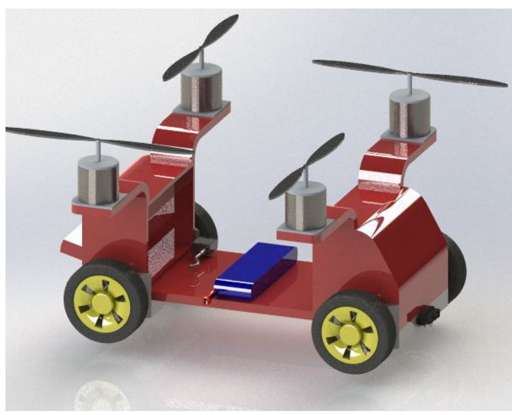


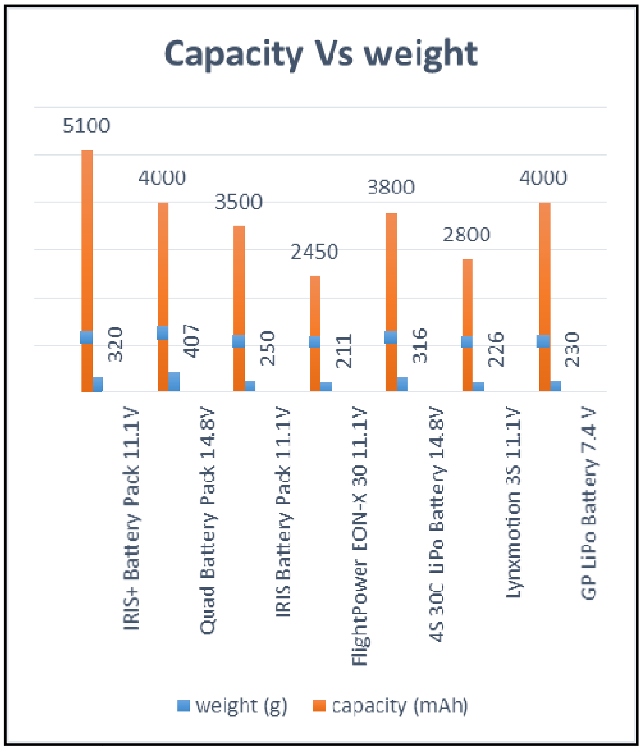
Fig 8: the isometric view of the vehicle. The blue color device represents the battery, while the quad rotor motors represented by grey. The propeller in the view is smaller than actual size.

The weight of the vehicle is estimated between 1.9-2.2 Kg, this is include the total weight of the body and its components on account that the carbon fiber plastic is quite lighter and stronger than aluminum, although its price is higher.

The sensors are important elements to respond to a particular physical change and give an electrical signal as a voltage to give feedback to the controllers. Accelerometer shown in black in fig 7 measures the acceleration force whether it is static such as gravity for the body in the rest manner or dynamic force due to vibration [19]. In the hovering of the quad rotor as well as landing and take-off, this sensor is quite useful to observe the acceleration value of the vehicle because after analyzing the amount of the acceleration it can be calculate the angle of tilt . The green rectangle shown in fig 7 represents the gyroscope position that is a device to maintain the orientation of the vehicle through conservation of angular momentum [20].

The battery, (as shown in blue in fig 7), selection criteria relies mainly on three factors: the capacity of the battery that measured by electric charge unit which is commonly seen in ampere-hour (Ah) or mille ampere- hour (mAh), the weight is essential for thrust calculations because it is added to the overall mass and finally, the voltage provided by this DC source. After research, the findings are presented in the table 1 the 4S 30C L Lithium-Polymer Battery 14.8V, for the quad rotor, has been selected.

Table 1: This table shows the distribution of capacities and weights for each type of battery, taking into account the value of voltages corresponding to each type.



C. The Analysis and calculations part

It is better to study the motion for each UGV and UAV separately. This is because the direction of the UGV along X direction while the quad rotor goes along X-Y direction so the modeling for it a bit harder than the former.

1.Motion of UGV

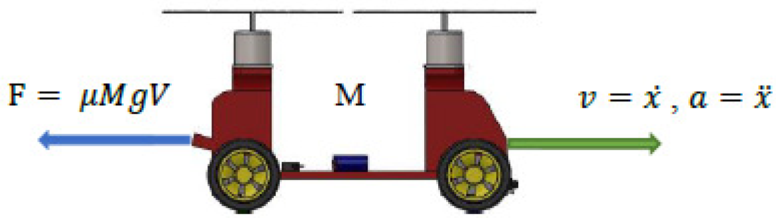


Figure 9: side view of the vehicle

One of the linear motion equation in terms of velocity can be written:

$v_{final} = v_{initial} + a \times \Delta t$ .... (1)
$v_{initial} = 0\ , v_{final} = 1\ \left(\frac{m}{s}\right) ...given$

On one hand, the car starts from rest so the initial speed is zero. On the other hand, the newton second law can be applied on UGV during its motion with an acceleration (a) in$(\frac{m}{s^2})$.

$\sum F_x = Ma$ .... (2).
$M = 2.1$: Mass of the vehicle in (Kg).

Time from the battery = $capacity\ /\ discharge\ rate$ ... (3)

$$\Delta t = 2800\ mAh \times \frac{10^{-3}}{30\ A} = 0.0933\ hours \times 3600 = 336s$$

That means the maximum time to operate the UGV≈ $6\ min$. Substitute time value in (1):

$1 = 0 + a \times 336, \quad a = 0.00297\ (\frac{m}{s^2})$.
$F - F_f = 2.1(Kg) \times 0.003 \left(\frac{m}{s^2}\right)$

$F_f = friction\ force\ , \mu = friction\ coefficient$

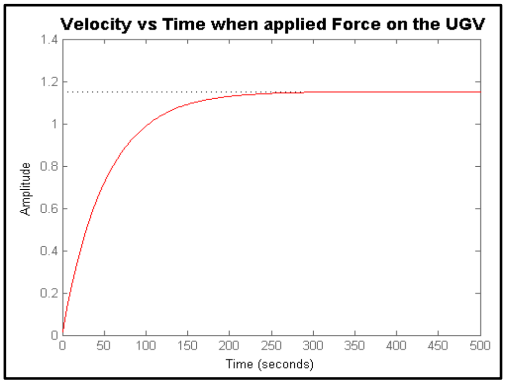
$assuming\ it = 0.002\frac{s}{m}$

$F = 0.0063\ (N) + \mu MgV\ (N)$= *0.04745 N*

$M\ddot{x} = \sum F_x = F - \mu Mg\dot{x}$
$F = M\ddot{x} + \mu Mg\dot{x}$

$$F(s) = M \times S^2 + \mu \times M \times g \times S$$

1.1 MATLAB plots to show response in time and frequency domain.



Step input response of the ground vehicle

2. Rotorcraft drag and lift forces:

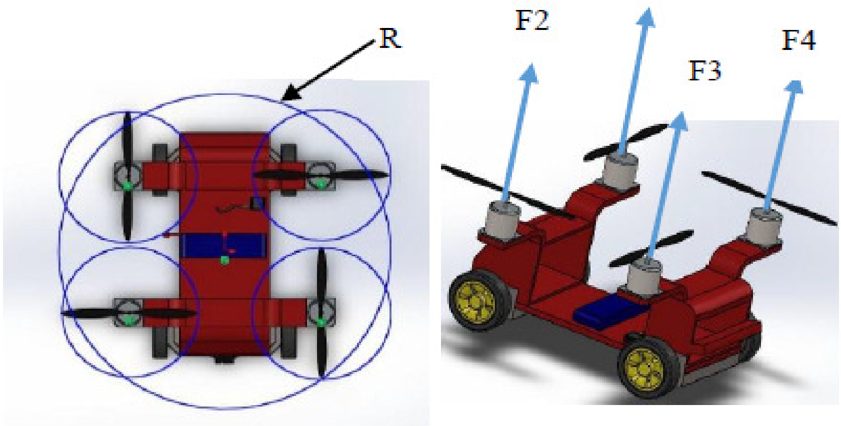


Figure 10 : rotor disk

Table 4: some given and calculated parameters

Parameter	Value	Parameter	Value
ρ (density of air)	1.22 kg/m^3	R(radius of rotor disc)	27 cm
ω rotation speed (rad/s)	≈ 1361	Drag force ≈ total thrust of motors – weight of the	(5-2.1) g= 29.43 N

		vehicle	
A_d (area of the rotor disc)	$\pi R^2 = 0.2293\ m^2$	Thrust per motor	1250 g

The precise control of quad-rotor is quite long so we simplify the derivation by using just the two below equations for rotorcraft in general:

$T = C_T.\rho.A_d.(\omega.R)^2 \ldots..(1)\ Thrust\ force$
$Q = C_Q.\rho.A_d.(\omega.R)^2.R \ldots \ldots.(2) rotor\ torque$

From (1) it can extract the thrust value of torque coefficient (C_T).

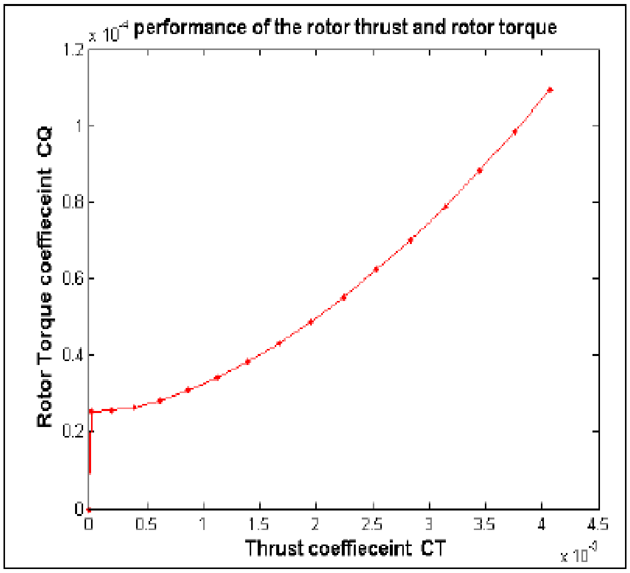
$$5Kg \times 9.81(\frac{m}{s^2}) = C_T \times 1.22 \times 0.2293 \times (1361 \times 0.27)^2$$

$$C_T = \frac{5 \times 9.81}{1.22\text{kg}/m^3 \times 0.2293 \times (1361 \times 0.27)^2} \approx 0.0013$$

$$D = C_d.\frac{1}{2} \times \rho.V^2.A, \qquad C_d = \ 0.00158\ Drag\ coefficeint$$

Assume $C_d \approx\ C_Q\ this\ leads\ to\ Q = 16\ N.m$

To see the performance of the vehicle as a one rotor, let's use this MATLAB plot:



The curve gives an indication that the relation between the thrust and the torque coefficient is almost linear.

4. CONCLUSION

This paper has revealed a theoretical design of an unmanned aerial and ground vehicle. In terms of the hardware, several sensors and actuators has successfully fused with this mobile robot. However, the software programming and control implementation has limited to just use simple m-files in MATALB to display the response of the applied forces on the vehicle as well as the performance of the rotor. The prototype might be need more optimization in terms of shape. The analysis states the feasibility of the vehicle to fly and move but practically it is required to study the effects of the air flow forces. The aim behind this works is to employ the mechatronics engineering science to build successful scheme and could use this system in harsh environment such as disaster area.

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