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A Framework for Systematic Design and Construction of an Unmanned Small-scale Air-Land-Water Vehicle

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Abstract

In this paper, we present a framework for systematic design and construction of an unmanned small-scale air-land-water vehicle. The systematic design procedure includes design and integration, hardware component selection, as well as experimental evaluation are used to construct a fully functional unmanned small-scale air-land-water vehicle, namely Unmanned Small-scale Air-Land-Water Vehicle (USALWaV). Various component to support maneuver on the ground, flight, and cruising on surface of water feature has been constructed to verify the feasibility and reliability of USALWaV. Double blade axial rotor, propeller set, and pontoon propel the vehicle while fly on-air, move on-land, and float on-water. A control algorithm has also been proposed to allow the USALWaV to travel from its current location to another location specified with changeable channel on Tx Modulator. The results can be followed and used for build a small-scale air-land-water vehicle for research and development purposes.

Keywords: Unmanned Vehicle; Small-scale Vehicle; Systematic Design; Component Selection; Control Design

1 INTRODUCTION

An unmanned vehicle as defined by Association for Unmanned Vehicle Systems International (AUVSI), which might also called as robotic service vehicles, there are in three broad categories: first is unmanned aerial vehicle (UAV's) which is airborne type, secondly is the ground-base vehicle (UGV), and lastly is water-base vehicle which include surface craft (USV's) and underwater vehicle (UUV's) (Bloss R, 2007). All of the unmanned vehicles mentioned have many common purposes. They are use for a number of tasks including military needs, exploration and inspection, search and rescue, surveillance, and vehicle which are controlled by radio control or autonomous as a hobbies purpose.

Many research groups have design and constructed their own small vehicle for their research purposes (Guowei Cai et al., 2008; Mettler, 2003; Spanoudakis et al., 2006; Gavrilets et al., 2000; Dittrich and Johnson, 2002; Zhenyu et al., 2007). The example results about unmanned aerial vehicle has been achieved in many areas of research such as software design and integration (Dong et al., 2007; Velez et al., 2006), identification modeling and characteristic (Mettler, 2003; LaCivita et al., 2002; Shim et al., 2000; Tischler and Remple, 2006), control techniques implementation (Johnson and Kannan, 2005; Sugeno et al., 1995), aerial image processing (Corke, 2004; Lin et al., 2007; Mejias et al., 2006), design of an autonomous amphibious vehicle (AAV) capable of traversing across aquatic and terrestrial environment (Michael and Nokleby, 2008). On other hand, some small-scale unmanned or personal vehicle platforms has been successfully built up and implemented for one or two media operations (i.e. land, air, water, amphibious vehicle, air-land), including the works of (Michael and Nokleby, 2008; Shim et al., 2000; Collar and McPhail, 1995). However, not many researches have been done on unmanned vehicle based on three media operations.

In this paper, we propose a systematic design and followed by construction of an unmanned small-scale vehicle based on three media operations that could be operated on land like a car, fly on air like helicopter and move through the surface of the water like a boat. The methods of the proposed design and construction consist of three main steps: Firstly, the selection of a systematic design environment, where SolidWork was used for building up the virtual layout of the vehicle. Secondly, design specification is proposed. Thirdly, a construction of unmanned Small-scale Air-Land-Water Vehicle (USALWaV) component system is done step-by-step. The results show that the constructed USALWaV was successfully designed to cover a lot of good work when operating in the air, on land, or when moving on the surface of the water. Based on the results, we accumulated experience to make an inventory of all feasible vehicles system and effective design for constructing an unmanned small-scale air-land-water vehicle taking into account all relevant design aspects like minimum complexity and time cost.

2 SYSTEMATIC OF VEHICLE DESIGN

First, to design and construct an unmanned small-scale air-land-water vehicle, the functional and physical requirements should be identified. The specific opportunities in designing process, as well as assumptions and constraints have to be included as well.

2.1 Functional Requirements

The functional requirements consist of:-

a. The vehicle must be capable to vertical short take-off and landing (VSTOL) from the land and/or surface of water.
b. The vehicle must be capable of maneuvering on-air, on-land, and on-surface of water
c. The vehicle must be capable of floating on the surface of water for a certain time.
d. The vehicle must be adaptable, upgradeable, and reliable to a variety of equipments that will be attached in the future for surveillance and monitoring purposes.
e. The vehicle should be simple to operate.
f. The vehicle should be easy to manufacture, assemble, and maintain.

2.2 Physical Requirements

The physical requirements consist of:-

a. The vehicle must be able to carry a payload of up to 20 g when in-air operation, while up to 50 g on-water traverses.
b. The vehicle must be able to withstand from stall condition.
c. The vehicle must be able to operate for a minimum of 15 minute in the field under normal operating conditions.
d. The vehicle must be able to withstand and operate in a wide variety of environmental conditions including raining, temperatures from 0˚C-36˚C.

2.3 Opportunities

The specific opportunities in designing process include:

a. Designed so that various types of wheels and pontoon with the same weight can be mounted and experimented with.
b. A mechanism that keeps a vehicle stable at all media operation.

2.4 Assumptions

The assumptions in designing process include:

a. There are no extreme environment, such as hurricanes, blizzards, and waters with strong wave.
b. The operator will be able to control the vehicle in the field through the use of a remote control.
c. The vehicle will be manufactured only in a very small-scale dimension, 500 g of weight, and small quantity (1-2 units).

2.5 Constraints

The constraints in designing process include:

a. The vehicle should be designed with the appropriate computer aided design (CAD), quality components, however, ones that can be purchased for the lowest cost.
b. The complexity of the vehicle should be kept to a minimum.
c. The vehicle should be designed with the waterproofing and anti-vibrating.

Design for manufacturing process and design for assembly an unmanned small-scale air-land-water vehicle were also taken into several stages to support design requirements.

The manufacturing process should be identified as shown in Figure 1. It can be classified into several stages. The first stage concentrates on the design concept of the vehicle. The next stage can be described in two sections; the first section is the development of the mechanical structure. Thus, computer-aided software such as the SolidWorks software is used to draw and animate the vehicle that are proposed and expected. Another section is the development of the vehicle. The final stage is concluded with its testing, appraisal and minor adjustment of the project.

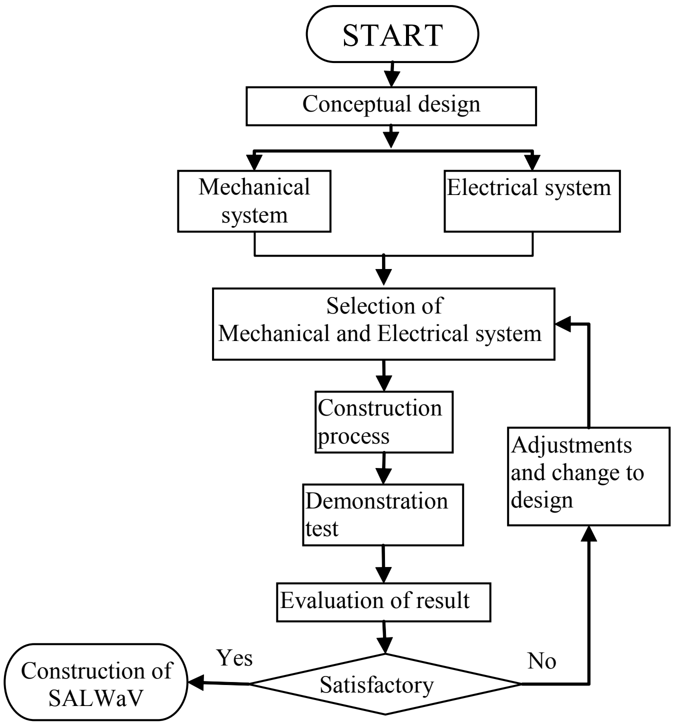


Figure 1 : Flowchart of systematic design and construction of USALWaV

The concept and design procedure in the construction of USALWaV was mainly based on two-dimensional computer-aided-design (2D CAD) and powerful 3D design environment. We develop a powerful design environment using SolidWorks. SolidWorks mechanical design automation is a feature-base, parametric solid modelling design tool which takes advantages:

a. *Easy-to-learn:* A user can be familiar with the necessary commands, options, and menus in a short time through learning and practicing several examples and case studies.

b. *Provides design software to create 3D models and 2D drawings:* In SolidWorks software, the virtual component can be modelled to be identical with the real hardware component, mainly in shape, dimension and visual properties (colour and texture). When the model 3D design is finished, the corresponding 2D views will be generated at the same time for the convenience of mechanical manufacturing.

c. *Physical properties:* The physical properties of each virtual component can be parameterized with necessary physical parameters such as any unit of measure, density, modulus of elasticity, tensile strength, yield strength, heat transfers mode and weight. The centre of gravity (CG) can be either calculated by SolidWorks or arbitrarily specified.

d. *Export and import utility:* Users can export SolidWork documents to a number of formats for use with other application. This utility includes descriptions and instruction for all analysis features and capabilities of the COSMOSWorks and ANSYS software.

e. *Animation function:* For certain components, which can move or rotate, we can emulate their motions by using an animation function.

Practical conversion systems of 2D drawings and 3D models have been developed for low and mid-range commercial CAD systems. For example, SolidWorks is a major mid-range CAD system and it can be used to generate 3D models from 2D drawings arranged in a 3D environment (David and Marie, 2006).

The design parameterization conducted at both part and assembly levels. At part level, design parameterization implies creating solid features and relating dimensions among or across solid features. For example, as shown in Figure 2, the part is created using dimensions standard methods and references to other geometry in the assembly. At assembly level, design parameterization involves placement constraints and relating dimensions across parts.

Figure 2 : USALWaV and virtual counterpart

3 PROPOSED USALWaV DESIGN SPECIFICATIONS

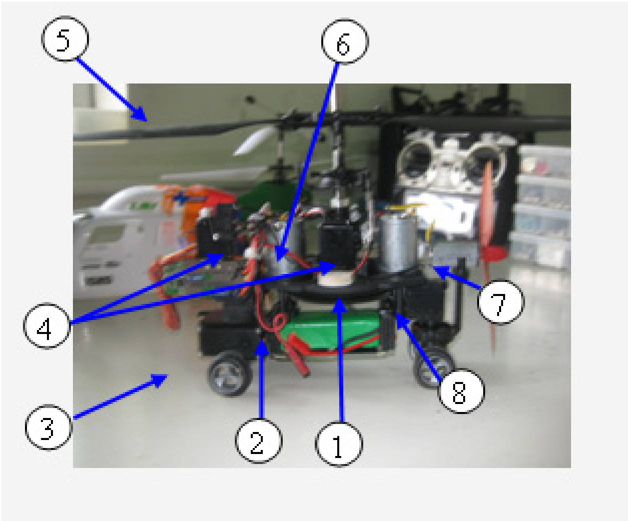
Mechanism and electrical system proposed of the vehicle are presented at Table 1. These values also correspond to the Lama coaxial RC helicopter model E 020, 2.4 GHz, regarding range, weight, and speed. Base on this vehicle we modified by a set of propeller and pontoon.

Table 1 : Specification of a USALWaV

Full length of vehicle	270 mm
Height	280 mm
Full Width	180 mm
Main rotor diameter	460 mm
Propeller diameter	254 mm
Weight	0.500 kg
Motor	370 motor x 2
Maximum operating time	~15 min

3.1 Main Frame

The USALWaV frame or chassis consists of two parts as shown in Figure 3, the main frame and the skid set. This is the most important element of the vehicle design, since it dictates the vehicle's shape and it must withstand loads applied during flight, take-off, cruising, and landing. Especially for the skid set, it could be used for supporting pontoon during on surface of water operation.



1	Main frame
2	LiPo-Battery
3	Tire and suspension
4	Motor 2 x 370
5	Main rotor
6	Transmission system
7	Propeller
8	Rudder
9	Pontoon
10	Fuselage

Figure 3 : USALWaV proposed components

3.2 Transmission System

The transmission system is placed at the centre and back of the main frame for flight and surface manoeuvre. It transfers power needed from the power motor to the main rotor and propeller with a constant gear ratio. Meanwhile, the transmission system during ground operation we use four servos (6g, 41g) and completed it with pair of gears.

3.3 Main Rotor

The main rotor, placed exactly above the transmission system, consists of two rotating blades with a diameter of 460 mm respectively which increased the capability to lift and lighten the vehicle weight during flight. The two blades are made from top quality plastic material and widely used by such vehicle manufacturers, as resulted by the market survey on RC helicopter.

3.4 Propeller

The propeller is placed behind the body frame; a rotating shaft needed to transfers the movement to it. It has also two rotating blades made from plastic material with a diameter of 115 mm. Prouty (1990) presented the diameter depends on the main rotor diameter needed to produce the necessary propulsion in flight configuration that will prevent the vehicle rotation around its vertical axis.

3.5 Motor

Two motors are used for it electrical system, placed vertically beside the main shaft of the vehicle, based on main frame with anti-vibration mounts. The main frame is to set in a way to allow accommodate several electric type motors with different horsepower depending on applications. In this study we use two carbons brushed motor type 370.

3.6 Battery

Recent advancements in battery technology are making electric flying device more feasible in terms of operating time. Lithium Polymer (LiPo) batteries are able to provide the high current required for high performance aerobatics while still remain light. Typical operation times are 4-15 minutes depending on the flying style and battery capacity. In this research we used 11.1 V, 800mAh Lithium-polymer battery.

3.7 Center of Gravity (CG)

The centre of gravity position of the USALWaV is very important during flight and floating operation. Type of propulsion used is an important factor in defining the best C.G. position. In the proposed design refer to Prouty (1990), the ideal placement is exactly on the axis of rotation of the main rotor. In this way, the frame remains horizontal during hovering; controlling and manoeuvring the vehicle becomes easier.

3.8 Electronics Equipment

The electronic systems placed on the vehicle consist of a gyro and a remote/ autonomous control module. Depending on the mission and application such equipment may be modified. Electrically powered models utilize mechanical or electronic speed control units to adjust the amount of power delivered to the electric motor.

The power delivered is proportional to the amount of throttle called for by the transmitter, the more we pull or push the joystick, the faster it goes. Based on the design criteria, basic concept for USALWaV must be compiled with satisfactory condition motion on different media operation as shown in Table 2.

Table 2 : Design criteria for different media operation

Components	Sufficient condition		
	on air	on land	on water
Main rotor	Active	Inactive	Inactive
Propeller	Inactive	Active	Active
Tyre	Inactive	Active	Inactive
Pontoon	Inactive	Inactive	Active

3.9 Payload

Payload, in most of cases, corresponds to ability in assuming or completing a mission. Thus it is of importance for such a vehicle to carry as much as possible payload, as also to host it on the fuselage in a way that especially electronic equipment can function without being interfered by vibrations.

The 20 g of payload positioned close to vehicle centre of gravity. This placement provides the flexibility required, so that multiple kinds of equipment can be used easily. This includes light camera, and any kinds of additional electronic devices required for specialized missions. For all these, a special mount functioning as an isolation mechanism will be developed. The base must isolate vibrations interfering with electronics. This can be addressed only after ground and flight tests are conducted and vibration measurements are available.

4 SYSTEMATIC CONSTRUCTION AND INTEGRATION OF VEHICLE SYSTEM

Based on the proposed vehicle design specification in section 3, we now proceed to carry out a systematic construction and integration of those components for a small-scale air-land-water vehicle. The construction procedure consists of three parts: (1) flight layout design: (2) landing condition: and lastly (3) design on surface of water operation.

4.1 Flight layout design

On the air, vehicle designed as gyro system. Vehicle lift means comprising a coaxial-rotating rotor, and effective horizontal stabilizer and rudder, as shown in Figure 4.

Figure 4 : The basic formation design of the vehicle when flight manoeuvre

4.2 Landing condition

The front wheel is connected rotatably to body shell and connected steerably to a control servo and serves as front landing gear in flight configuration. This manoeuvre design is shown in Figure 5.

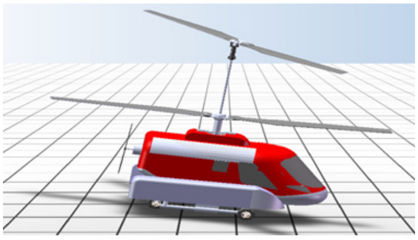


Figure 5 : The basic shape design of the vehicle when manoeuvring on the land

On ground, the main rotor, pontoon and propeller are inactive until vehicle is ready to fly.

4.3 Design on surface of water operation

The real components layout on the water surface manoeuvre purpose as shown in Figure 6, vehicle move by pontoon, outboard propeller or thrust propeller and controlled by rudder provides swift as turning control assemblies on back bottom of vehicle.

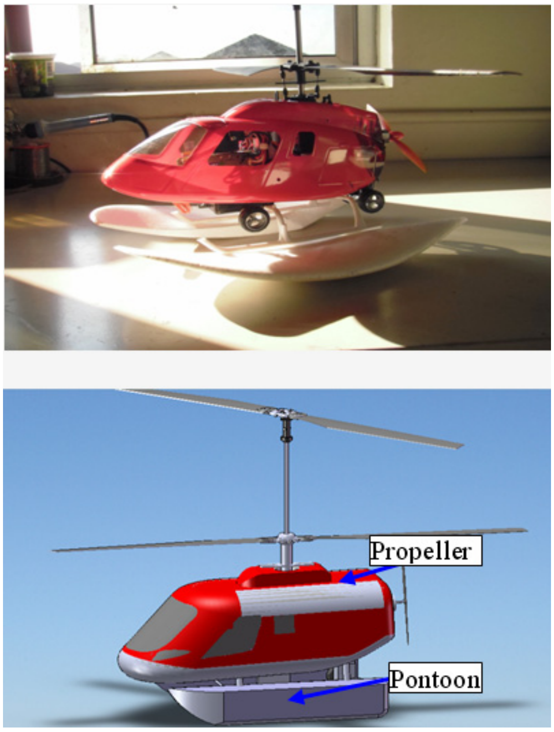


Figure 6 : Real components layout of vehicle on water operation and virtual counterpart

4.4 Design control system

The manual control system, which is normally a radio-controlled joystick, always comes with the RC helicopter 4 channels and developed to 6 channels for used to control the small vehicle by the pilot in manual air, land, and water tests. The switch control system whose working principle is shown in Figure 7.