Design of a Blimp Based Unmanned Aerial Vehicle for Surveillance

Muhammad Tayyab [1], Umar Farooq [2], Zafar Ali [3] ,Muhammad Imran [4], Faisal Shahzad [5]
Department of Electrical Engineering, University of the Punjab
Quaid-e-Azam Campus Lahore-54590, Pakistan
[1] tayyabmalik_pu@yahoo.com, [2] engr.umarfarooq@yahoo.com,[3] azafar46@yahoo.com,
[4]m09_427@yahoo.com,[5]faisalshahzad29@gmail.com

***Abstract*— This paper describes the design and development of Blimp Based Air Vehicle with the ability to perform vertical take-off and landing that can serve the purpose of surveillance in an area dangerous for humans. The design uses vectored thrusting to propel the blimp. Software is developed for visualizing the mechanical design of the blimp given its design parameters. The blimp is then developed by utilizing Polyurethane as fabric and helium gas is used for lifting the blimp. Brushless DC motors are used to generate thrust for lifting the blimp and servo motor is used to shift the motion axis of blimp by rotating the assembly of gondola carrying the propellers. A wireless camera is mounted for the purpose of surveillance and control. The video data is received at the base station where it is recorded and afterwards analyzed for the presence of certain object. The control signals for the motors are generated and transmitted by an AT89C52 microcontroller through a 6-channel transmitter. The receiver present on the blimp decodes these signals and controls the motors accordingly.**

Keywords: Blimp, Gondola, Fins, Wireless Camera, AT89C52 Microcontroller, Base Station

I. INTRODUCTION

Blimps have recently attracted great research interest as a platform to reach dangerous or difficulty-to-access environment in applications such as disaster exploration, rescue, security surveillance in public events, climate monitoring, service for planet exploration, mobile monitoring guard and anti-terror attack. It can also be used in Sports competitions for monitoring purpose and advertisement.

Compared to other flying vehicles, blimps have the advantage that they operate at relatively low speed. They do not need to move with high speed in order to keep their altitude, and additionally are not highly sensitive to control errors. As it moves vertically up/down so there is no need of runway and heavy engines hence the fuel cost is reduced. It relies on low density gas inside the envelope to balance its own weight. With this feature, blimp could conduct a continuous aerial operation with very low energy consumption unlike say helicopters.

Blimps are cheaper to procure and reduce the risk of pilot’s life. In case of air accidents or crash landing, the on board equipment is retrievable. So the blimps accidents are not fatal with the use of helium because it will lose its lift when the envelope is punctured or control is failed and start descending gradually. No larger area is required to launch or land the blimp.

Blimp is commonly classified into three types [1], Non Rigid, Semi Rigid, and Rigid. The first two types have polyurethane envelopes dependent upon internal gas or air pressure for maintenance of shape. The rigid type has a structural framework of girders and wires over which a fabric cover is tightly drawn and maintained in shape independently of the gas pressure. Non Rigid and Semi Rigid types are called pressure airships while rigid type as pressureless. The metalclad airship, designed by aircraft development corporation, is unique in being both a pressure and a rigid airship, since it depends upon internal pressure to maintain its thin metal skin in tension and to avoid collapse in flight, while at the same time it is rigid in that it has a structural hull of practically invariable shape, which cannot be deflated and folded like a fabric envelope. The framework of the hull is covered by an envelope or outer cover of cloth, drawn smooth and tight, in order to minimize resistance, and made as nearly impervious as practical to moisture, heat and light of the sun.

We represent the implementation of non rigid Blimp Based UAV for Surveillance in which we use Polyurethane envelope dependent upon internal gas pressure for maintenance of shape. The goal of the paper is to design, construct and test a blimp that would achieve the following objectives:

- To design and build a blimp.
- To implement a complete manual and automatic system for blimp. In manual mode, we use GUI (Graphical user interface)

to control the motion of blimp while in automatic mode, the blimp navigates according to predefined trajectory.

- To have the ability to capture video and transmit it to the ground station.

This paper is organized as follows. The theoretical and software design of envelope is discussed in section II. The lifting gas comparison, selection and atmospheric effects are discussed in section III. The detailed design of blimp including construction of gondola, tail fins construction and surveillance system is described in section IV. The manual and automatic control of blimp is discussed in section V. Finally, in section VI, pre flight procedures and operations are discussed.

II. ENVELOPE DESIGN

It is very important to minimize the weight of the envelope in order to minimize the required lift. The surface area of the envelope's material is used to determine the total weight of the envelope. It means that any shape having the smallest surface area while providing the same volume of helium would be considered as the best optimal shape for the envelope. The surface area to volume ratio is then calculated by using a constant volume and the geometric formulae for each shape.

A. Estimation of Payload

It is difficult to calculate the actual overall weight of the blimp. An estimation of payload is important as it will determine the volume of lifting gas. It will also affect the performance of the blimp. To account for the weight of the envelope material, an estimate of 100% of the total weight of components is added. Another 10% is added for the improvements and additions to the blimp. The weight estimation of payload is given in Table 1.

TABLE I
WEIGHT ESTIMATION OF PAYLOAD

Components	**Weight(g)**
2 x EMAX Motors	172
1 x EMAX Motor	45
2 x 10*5 propellers	30
1 x 8*4 propeller	10
2 x Motor holders	30
HITEC Servo	50
4 channels Receiver	23
2* Battery (LIPO 11.1V)	400
1* Battery (LIPO 3 cell)	100
2*Speed Controller, Wires, Switch	150
Back speed control	120
Wireless Video Camera	50
Energizer 9V battery	40
Driver Gear	30
Carbon Fibre Rod with Pinion Gear	50
Tail Fins (Empennage Stabilizers)	100
Gondola (Balsa wood)	100
Total	1500

Total Estimated Weight = 1500+100% (1500)+10%(1500) = 3150g

B. Design Parameters of Blimp

The helium lifting force is 1.02 kg/m^3 [2]. For the total estimated weight, the required volume is 3.0 m^3 .To calculate the length and maximum diameter of envelope we use (1). The coefficient values for (1) are given below,

$Volume = 3.0\ m^3$

$Length\ to\ Diameter\ ratio\ or\ Slenderness\ ratio = F = 2$

$Prismatic\ coefficient = C_v = 0.65$

$Stern\ Radius = 0.1$

$Bow\ Radius = 0.5$

$Point\ of\ maximum\ thickness = 0.4$

1) *Derivation Of Length and Diameter from Volume*

The formulas for calculating the length, diameter and surface area are given as [3],

$$Volume = V = \frac{C_v * L * \pi}{4} * D^2 \tag{1}$$

Since,

$$F = \frac{L}{D} \tag{2}$$

So,

$$Volume = V = \frac{C_v * F * \pi}{4} * D^3 \tag{3}$$

From (3),

$$D^3 = \frac{4 * V}{C_v * F * \pi} \tag{4}$$

Putting the values, we have

$$D^3 = 2.938m \tag{5}$$

So maximum diameter is,

$$D = 1.432m = 4.70\ feet \tag{6}$$

Now the length will be

$$L = F * D = 9.40\ feet \tag{7}$$

Surface coefficient C$_s$ is calculated using $C_v = 0.65$ and graph in Fig. 1 to be

$$C_s = 3.42 \tag{8}$$

$$Surface\ Area = S = C_s * \sqrt{V * L}\ ,\ S = 10m^2 \tag{9}$$

$$Circumference = 3.14 * D = 14.76\ feet \tag{10}$$

2) *Centre of Buoyancy and Centre of Mass*

To determine the centre of buoyancy, the centroid of the shape of the envelope must be determined. The volume of air displaced is exactly the volume occupied by the shape of the envelope. By finding the centroid of the envelope shape, it is equivalent of finding the centre of buoyancy. Figure 2 illustrates the measurement of centre of buoyancy. The length of envelope is divided into two sections. The front section shown in Fig. 3 is described by ellipse formula and the rear section shown in Fig. 4 by modified ellipse.

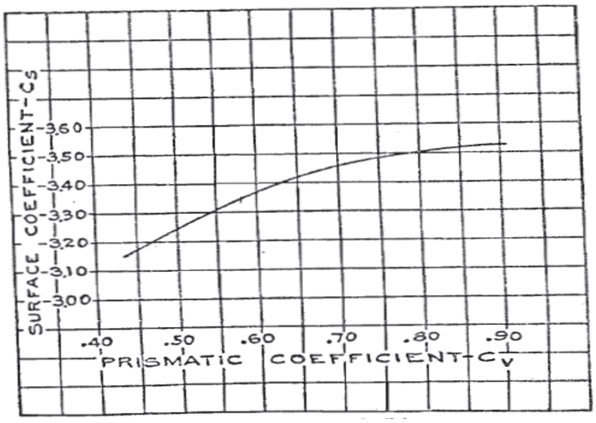


Fig. 1. Surface area coefficient [3]

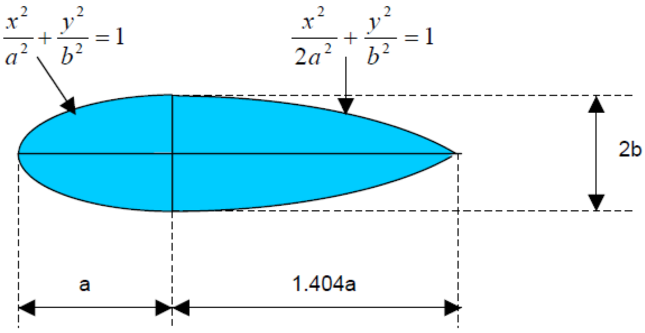


Fig. 2. Illustration of measurement of centre of buoyancy [4]

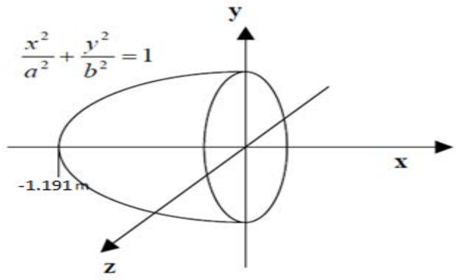


Fig. 3. Front section of envelope.

The formulas for calculating centre of buoyancy are given as [4],

$$V_1 = \int_{-1.191}^{0} x * \pi * r^2 dx \tag{11}$$

Since, $y^2 = r^2$, Putting value of y^2 from ellipse equation in (11), we have

$$V_1 = \int_{-1.191}^{0} \pi * (x - \frac{x^3}{a^2}) * b^2 dx \tag{12}$$

Integrating,

$$V_1 = -0.571m \tag{13}$$

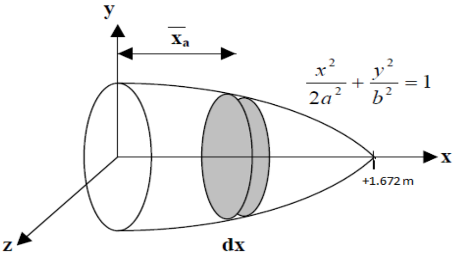


Fig. 4. Rear section of Envelope.

$$dV = \pi * r^2 dx \tag{14}$$

$$V_2 = \int_0^{+1.672} x * \pi * r^2 dx \tag{15}$$

Since, $y^2 = r^2$, Putting y^2 from modified ellipse equation we have,

$$V_2 = \int_0^{+1.672} x * \pi * (1 - \frac{x^2}{2a^2}) * b^2 dx \tag{16}$$

Integrating, we have

$$V_2 = 0.70m \tag{17}$$

For composite body,

$$X = (-0.571 + 0.70) = 0.1373m \tag{18}$$

Thus,

Centre of buoyancy = $C_b = 0.1373 + 1.191 = 1.3283m$ (19)

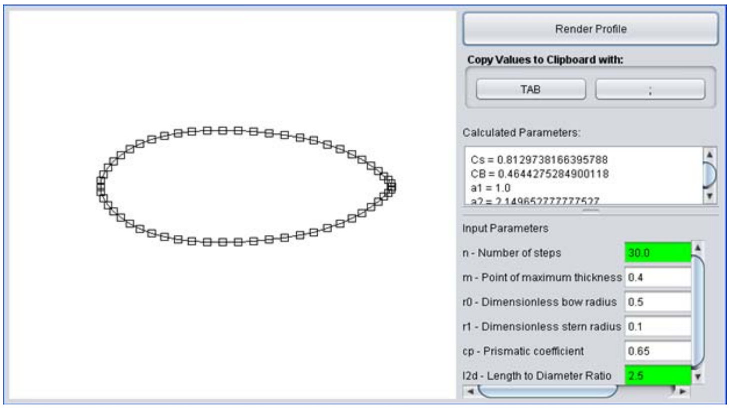
$$C_b = 4.35\, feet \tag{20}$$

The position of the centre of buoyancy is ***1.3283 m*** from the head of the blimp and it lies on the line of revolution. The envelope is made of homogenous material, so the centre of mass will coincide with the centre of buoyancy.

C. Software Design of Envelope

We generate 2-D pattern of envelope using Airship world profile generator software as shown in Fig. 5. From this pattern we calculate different points of diameter along the length of envelope. Blimp envelope shapes are described by five parameters [5] as:

- Slenderness ratio
- Prismatic coefficient
- Location of maximum thickness
- Bow radius
- Stern radius



Cs = 0.8129738166395788
CB = 0.4644275284900118
a1 = 1.0
a2 = 2.149652777777527

n - Number of steps 30.0
m - Point of maximum thickness 0.4
r0 - Dimensionless bow radius 0.5
r1 - Dimensionless stern radius 0.1
cp - Prismatic coefficient 0.65
l2d - Length to Diameter Ratio 2.5

Fig. 5. Snapshot of software

D. *Material for Gas Envelope*

Usually PVC, Polyurethane, three-ply rubberized cotton cloth, Dacron fabric, Polyurethane coated nylon cloth and Mylar film are used for envelope. Dacron fabric envelope is coated with aluminized paint for protection from sunlight. Polyurethane is selected for gas envelope because it has the following features [6],

- Low helium permeability (4 % loss per day)
- More durable
- Good weatherability
- More flexible which allow 10% expansion.
- The hole does not propagate in polyurethane.
- RF heat sealable.
- Excellent hydrolytic stability.

III. LIFTING GAS

The effective upward acting buoyancy force due to the lifting gas can be expressed as a function of density of the lifting gas, density of the air and the volume of the envelope. Using second law of motion:

$$F = mg \tag{21}$$

As,

$$m = \rho V \tag{22}$$

So,

$$F_{lift} = (\rho_{air} - \rho_{liftinggas}) * g * V \tag{23}$$

Where,

$F_{lift} = Lifting\,Force(N)$

$\rho_{air} = Density\,of\,air(kg/m^3)$

$\rho_{liftinggas} = Density\,of\,lifting\,gas(kg/m^3)$

$V = Volume\ of\ the\ Envelope\ \left(m^3\right)$

Four different alternative lifting gases can be used for the blimps: hydrogen, helium, methane and ammonia. A comparison of the lifting force among all the above four lifting gases is shown in Fig. 6. For ease of comparison with the mass of components used, the unit of lifting force (Newton) was converted into grams.

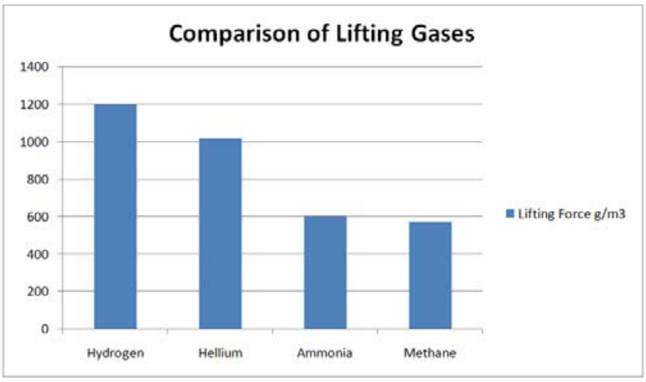


Fig. 6. Comparison of theoretical lifting force of lighter than air gases.

Figure 6 shows that, at least a volume of about 5m^3 of ammonia or methane would be needed to lift a weight of 3kg. A total volume of approximately 3m^3 would be needed if we use hydrogen or helium as a lifting gas because hydrogen and helium provide almost double the lifting force per unit volume in comparison with ammonia or methane. Hydrogen is not a right choice and it could not be used as a lifting gas due to its extreme flammability. Hence by considering above all the four choices, it is concluded that helium is the only suitable choice which can be used as a best lifting gas for the blimp.

A. *Atmospheric Effects*

There are three main atmospheric factors which affect the lifting capacity of the blimp.

- Temperature
- Altitude
- Air density

Any altitude effects were considered negligible due to the low ceiling height. Air density effects were also deemed negligible because air was assumed to be an ideal gas. Hence, the effect of atmospheric temperature on the lifting gas density can be calculated using Ideal gas law:

$$\rho_{liftinggas} = \frac{P*M}{R*T} \tag{24}$$

Where,

$P = atmospheric\ pressure\ (Pa)$

$M = Molar\ mass\ of\ air\ (kg/kmol)$

$R = Specific\ Gas\ Constant\ (N\ m\ kg-1kmol-1)$

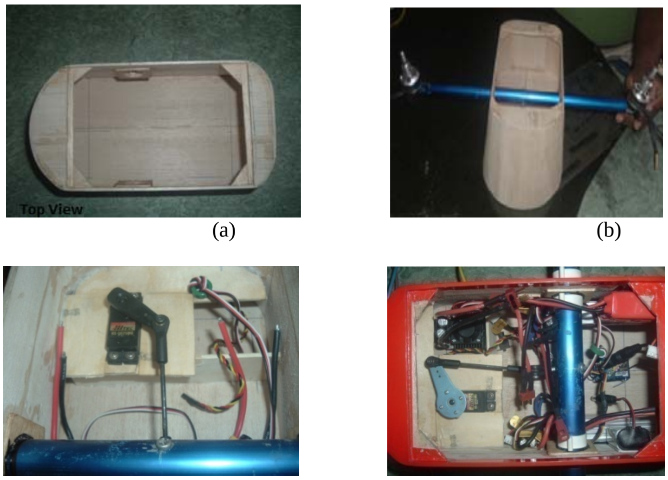
$T = Temperature\ (K)$

From (24), it is clear that by increasing the temperature, the lifting force of gas will decrease. For indoor experiments, the temperature would generally be between 15 and 25º C. For outdoor flight, the maximum operating temperature for the blimp is considered to be 35º C. At higher temperatures above 35º C, the Blimp is unable to fly due to insufficient helium lifting force.

IV. DETAILED DESIGN OF BLIMP

A. *Construction of Gondola*

The gondola, shown in Fig. 7(a), is made of balsa wood of 3mm thickness. To reduce the air drag, the shape of gondola must be streamlined. To reduce the skin friction drag, the sharp corners and rough surfaces should be avoided. A motor attachment mechanism is required to connect the motors to the axles as shown in Fig. 7(b). To achieve this, a small aluminium plate is welded to the axel rod. The plate had two small holes for the support of motor. The motors are attached to the plate with small screws. We connected the servo motor with axel rod using servo arm as shown in Fig. 7(c). The final inside view of gondola is shown in Fig. 7(d). The circuit diagram of console is shown in Fig. 8.



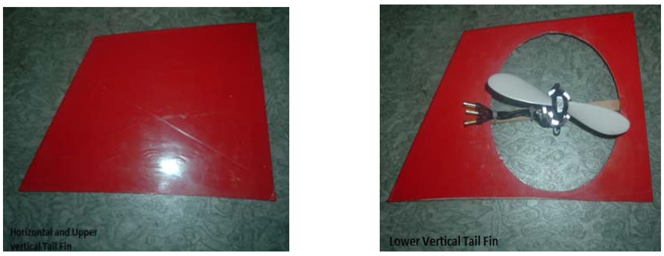
(a) (b)

(c) (d)

Fig. 7. Different stages in Gondola design (a) Top view of Gondola (b) Mounting the motors (c) Attaching the servo (d) Inner view of Gondola

B. *Tail Fins Construction*

The four fins are attached on the tail of blimp. They are made of balsa wood of 3mm thickness. We attached the fins, shown in Fig. 8(a), in cross configuration. For controlling the yaw motion of blimp, we installed a propeller motor on the lower vertical tail fin as shown in Fig. 8(b). The tail fins are not required to generate pitching moment so control surfaces (rudder, elevators) should not be installed. Also the control surfaces are ineffective for slow speed applications.



(a) (b)

Fig. 8. Tail fins construction (a) Horizontal and upper vertical tail fins (b) Lower vertical tail fin

C. *Surveillance System*

A wireless video camera is installed in gondola for surveillance. The video transmitter is within the camera casing as shown in Fig. 9 (a). The wireless video receiver is attached to the DANY video management system to receive audio video (AV) output on laptop as shown in Fig. 9(b).

(a) (b)

Fig. 9. (a) Wireless video camera (b) Setup for real time video.

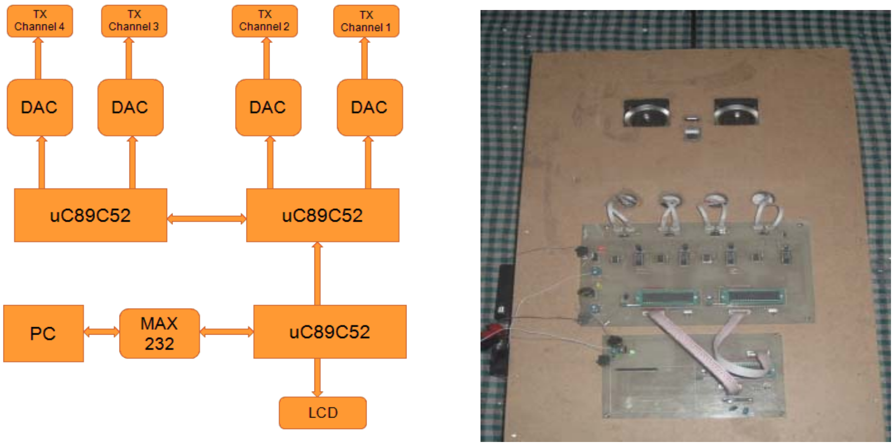
V. BASE STATION

There are two controls at the base station.

- Manual Control
- Automatic Control

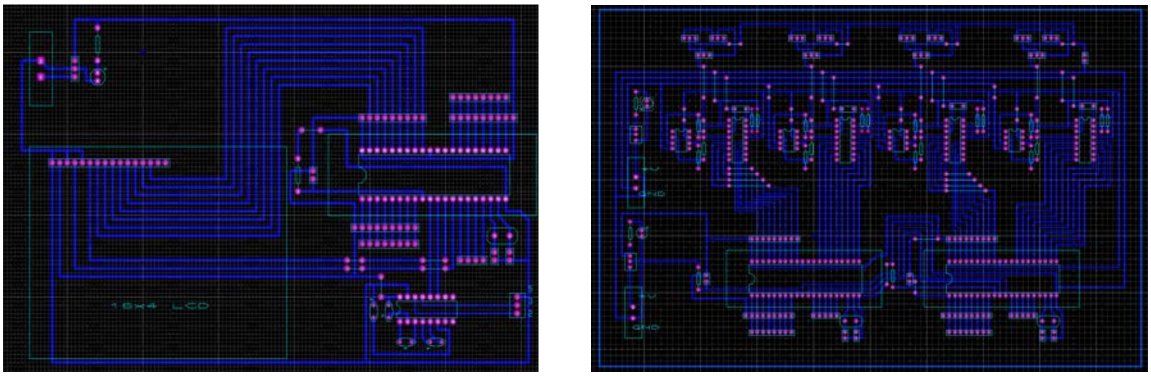
In manual mode of operation, motion of the blimp is controlled using the buttons in Graphical User Interface which is developed in MATLAB. The buttons vary the digital value associated with particular movement. These digital values are then transmitted serially to a main microcontroller. The main microcontroller decodes the values for the channels, displays them on 16x4 LCD and passed these values to two sub-microcontrollers where these values are converted into analog voltages using DAC0808 digital to analog converters. The analog voltages are then fed to the transmitter section for motion of the blimp. Table 2 summarizes the voltage ranges of various channels.

In automatic mode, a set of digital values are stored in an array corresponding to motion of blimp in specified trajectory. The MATLAB program fetches the values from the array and transfers them in a serial fashion to microcontroller section where the corresponding analog voltages are generated and passed onto transmitter section. The block diagram of the base station module is shown in Fig. 10(a) while the designed circuit is shown in Fig. 10(b). The PCB layout of main microcontroller section is shown in Fig. 11 (a) while PCB layout for sub-microcontrollers section is shown in Fig. 11(b). The GUI for the blimp is shown in Fig. 12. The block diagram of image acquisition and processing for the blimp to achieve required height and track a target (implemented in MATLAB) is shown in Fig.13.



(a) (b)

Fig. 10. (a) Block diagram of base station (b) Hardware for base station



(a) (b)

Fig. 11. Circuit design (a) PCB layout for main microcontroller section (b) PCB layout for sub-microcontrollers section

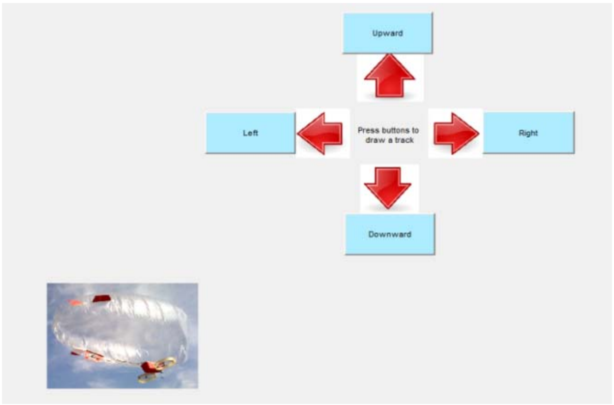


Fig. 12. Blimp GUI

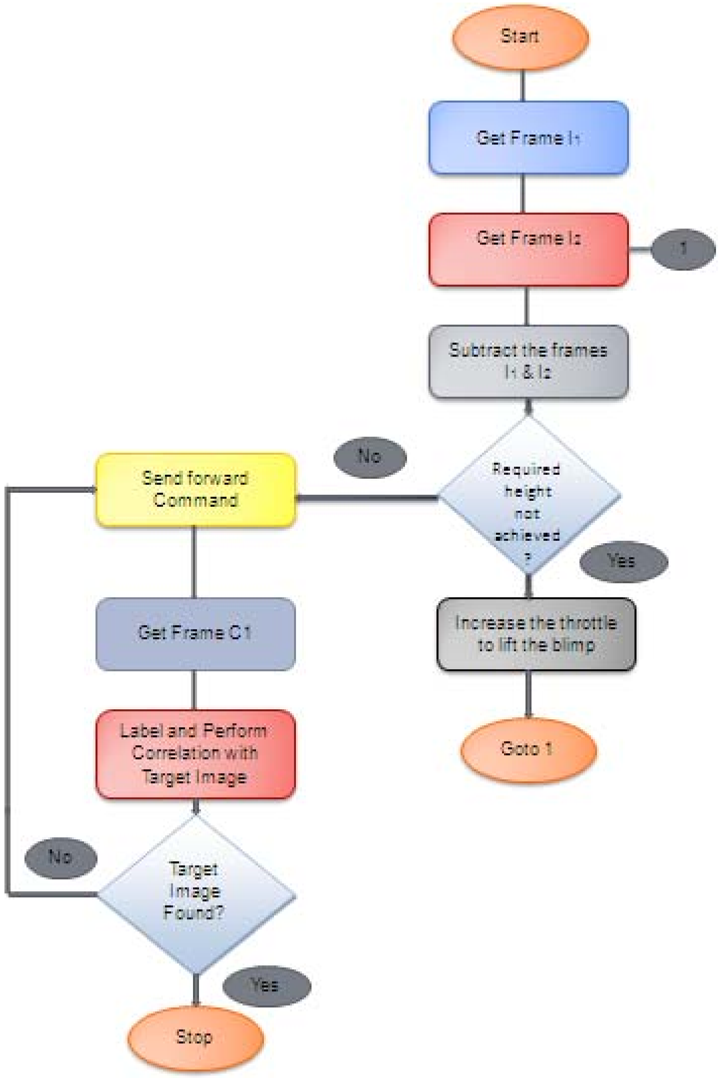


Fig. 13. Image acquisition and processing flowchart for blimp

TABLE II
CHANNEL VOLTAGES FOR TRANSMITTER SECTION

Channel No.	Value	Calculated voltage at P0	Calculated voltage at P2	Measured voltage at P0	Measured voltage at P2	Channel
1	165	1.933	1.933	3.11	3.07	Extra(upper)
	100	1.172	1.172	1.9	1.88	Extra(lower)
2	162	1.898	1.898	3.05	3.00	Servo(down)
	103	1.207	1.207	1.95	1.94	Servo(lower)
3	185	2.167	2.167	3.47	3.47	Pitch(upper)
	110	1.289	1.289	2.23	2.23	Pitch(lower)
4	155	1.816	1.816	2.95	2.91	Yaw(leftmost)
	100	1.172	1.172	1.9	1.88	Yaw(Rightmost)

VI. PRE-FLIGHT PROCEDURE AND OPERATIONS

It is necessary to prepare and test the main blimp components before flight testing in order to ensure that they would operate correctly during the flight tests. The envelope is inflated with helium and then gondola is attached to the envelope, to make the blimp only 100 grams overweight. A summary of each test is shown below.

A. Gondola Component Tests

- Connect all electronic components.
- Using the RC unit, test the servo and rotation of the rod.
- Test the operation of front motors and back motor separately.
- Test the operation of all motors simultaneously.

B. Envelope Inflation

- Turn on the valve of the cylinder and start filling the helium gas into the envelope.
- Stop filling the helium gas into the envelope when all the wrinkles in the envelope have been disappeared.

C. Attaching Gondola

Connect the gondola to the inflated envelope using the Velcro strips, ensuring that the gondola is firmly attached. The final shape of blimp during flight is shown in Fig. 14.

Fig. 14. Final shape of blimp during flight

VII. CONCLUSIONS

After the weight estimation, parameters of the blimp like surface area, volume, length and maximum diameter are calculated. A blimp envelope is designed using high frequency heat sealing machines. Flight tests carried out during the course of the project have shown that the designed blimp is capable of performing the manoeuvres. The designed blimp has the VTOL (Vertical Take-Off and Landing) capability.

Our final blimp is capable of lifting a payload of approximately 3kg .The cruise speed achieved is 0.8 m/s; for longer indoor testing area the speed could have been greater. Based on the field tests, it is observed that blimp can be operated continuously for half an hour.

The blimp is able to perform surveillance task around build-up areas. A continuous video stream is successfully captured and transmitted by the installed camera system .Received video is recorded at base station. By using more expensive camera setup, the image quality and transmission range can be improved. The performance of blimp is suitable for slow speed operation because slow speed is required for better surveillance. The range of camera restricts the height, so the achieved height is 100 meter.

We have also achieved the objective of automatic control of Blimp. The control circuitry is designed using MAX 232 level translator, AT89C52 microcontrollers, DAC0808 digital to analogue converters (DAC) and LM741 as current to voltage converter. We have controlled the blimp manually as well as automatically using MATLAB Graphical User Interface (GUI).

The blimp has advantages in terms of operational cost in comparison to fixed and rotary wing aircrafts. Blimps are not prone to fatal crashes as that experienced by other aircrafts.

VII. FUTURE WORK

The blimp is capable of performing surveillance for different purposes. Especially it is designed for low altitude operations. The currently designed size of blimp has difficulty in countering weather conditions. A smaller disturbance can have the effect of unbalancing the blimp. To overcome the problem, more powerful motors are required. This will cause an increase in net static weight; thus to meet the demand the net static lift must also be increased, hence the overall process will result in an increase in blimp volume. Along with powerful actuators, a gyro stabilizing mechanism can be designed and installed into the system for controlling the blimp in severe weather conditions. The surveillance system can be enhanced to track a given object.

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REFERENCES

[1] Charles P. Burgess, Airship Design, Chapter 1: The Types of Airships, 1927
[2] Available [online]: http://sites.google.com/site/airshipwiki/the-team
[3] Charles P. Burgess, Airship Design, Chapter 3: Volumes, Areas and Linear Dimensions, 1927
[4] NG Kay Boon, Mini Airship Patrol Craft, National University of Singapore, 2004.
[5] Available [online]: http://www.airshipworld.com
[6] Available [online]: http://www.rlhudson.com/O-Ring%20Book/selecting-material15.html