AUTONOMOUS SOLAR POWERED UAV

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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ABSTRACT

In current time and age Unmanned Vehicles are promising future enabling man to achieve what previously were dangerous and impossible tasks. But to do so, Unmanned Vehicle controller required training which still limited the task on hand due to the range and data loss.

Here we are working on optimized Unmanned Aerial Vehicle design that requires minimum input from the controller to complete the tasks. Our UAV have on board cameras, flight controller, GPS, sensors and Computer System. It has direct connection with the Ground Controller and has virtually unlimited range.

UAV can:

- Taxi autonomously.
- Take off and Land automatically without any assistance from Human.
- Visually detect multiple objects.
- Navigate automatically.
- Complete robotic tasks such as vehicle following, terrain 3D mapping, reconnaissance and Surveillance.
- It can also be used as low altitude satellite as it has the capability to remain in air for hours because of Solar Cells.

UAV will also have on board solar cells which will increase flight time of the UAV.

ACKNOWLEDGMENTS

We are hugely thankful to our supervisor Dr. Yasar Ayaz for their help during the process of making of this project and all of its intricacies.

Lect. Hamza Asif Nizami, our Head of Department Dr. Emad-ud-din as well as our Principal Dr. Shahid Ikram-ul-lah Butt are also be thanked who gave us the golden opportunity to do this wonderful project on the topic of *AUTONOMOUS SOLAR POWERED UAV*.

We would also like to thanks many of our fellow students who also helped us in doing a lot of research. Along the process we came to know about so many new things and found new and interesting interconnection among various fields of engineering with our own.

ORIGINALITY REPORT

3

ORIGINALITY REPORT

7%	4%	5%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Aayush Gupta, Daniel Bessonov, Patrick Li. "A decision-theoretic approach to detection-based target search with a UAV", 2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2017 Publication	1%
2	Chethan Chithapuram, Yogananda V. Jeppu, Ch. Aswani Kumar. "Artificial Intelligence guidance for Unmanned Aerial Vehicles in three dimensional space", 2014 International Conference on Contemporary Computing and Informatics (IC3I), 2014 Publication	1%
3	www.ijcai.org Internet Source	1%
4	Cristian Ramirez-Atencia, Victor Rodriguez-Fernandez, Antonio Gonzalez-Pardo, David Camacho. "New Artificial Intelligence approaches for future UAV Ground Control Stations", 2017 IEEE Congress on Evolutionary	1%

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ABBREVIATIONS

UAV	Unmanned air vehicle
IOT	Internet of things
EP	Expanded polypropylene
CFD	Computational fluid dynamics
APM	Arduopilot Mega
ESC	Electronic Speed Controller
RPi	Raspberry Pi
CNN	Convolutional Neural Networks
VNC	Virtual Network Computing
IP	Internet Protocol
NACA	National Advisory Committee for Aeronautics
ODC	Optical Dynamic Coverage
MLA	Machine Learning Algorithm
POMDP	Partially observable Markov decision processes
ATF	Autonomous Target Following
MOGA	Multi-Objective Genetic Algorithm

NOMENCLATURE

F_D	Drag Force
F_L	Lift Force
P	Density
V	Velocity
A	Area
C_D	Coefficient of Drag
C_L	Coefficient of Lift
M	Meter
Kg	Kilogram
Ft	Feet
m^2	Meter squared

CHAPTER 1: INTRODUCTION

Motivation

The motivation for selecting this particular project is proposing a cost effective solution for our security, agriculture needs and network coverage.

i. *Security*

As security is the need of hour, we present a solution that satisfies this need and is cost effective. Unmanned Aerial Vehicle that is fitted with cameras and is connected to the ground station where it will give live feed which will be used for surveillance. There is little to no human interaction on UAV, as it is controlled by computer chip on the vehicle, which makes it more convenient to use and more affective for surveillance needs.

ii. *Agriculture*

The application of UAV in agriculture allows the farmers to overlook their fields. Many issues can be identified by having bird's-eye view of the field such as fungal and pest invasions, soil distinction and irrigation problems. In addition to that, the UAV can survey the crops for the farmer intermittently as they like. Images can be used to ovserve the landscape in days, weeks or even months' time at once, this soil analysis and just in case something is wrong can be detected

iii. *Network Coverage*

We can also use the UAV to provide network coverage to remote areas. There are areas where people cannot have direct internet access, UAV can be used in those areas to provide them with internet while flying over the areas.

In order to have increased flight times, which will help us in surveillance for elongated times, the solar panels are implemented on the UAV. Other on board features includes 3D mapping, following and detecting moving targets and flying through tight spaces which is essential for surveillance.

Problem Statement

Our problem revolves around three foci which are described below.

i. *Zero Human Interaction*

The UAV will have little to no human interaction during the operation and the completion of actions. It will not be controlled by a remote on the ground, it will fly on its own by getting data from computer chip that will help the UAV to decide its course of motion. During the course of actions in case of surveillance and the UAV will decide on its own, by gathering data from computer chip, which object to follow and how to fly through spaces to give clear live feed.

ii. *Increased Flight Time*

Solar panel will be implemented in UAV along with batteries. The Implementation of solar panel will enable the vehicle to have increased flight times as batteries alone are not the source of power anymore. This increased flight time will help the UAV to provide extensive surveillance.

iii. *Standalone*

The UAV will operate on its own without reliance on any auxiliary software on the ground. It will not need any assistance from the ground station.

Objectives

The objectives of the project are described below

i. *Design and Analysis*

Designing the unmanned aerial vehicle in a 3D modeling software such as Solidworks or Creo. After the design, performing the analysis of the 3D model by giving close to real world conditions on Ansys.

ii. *Prototyping the UAV*

Manufacturing the prototype based on the results from software analysis and theoretical calculations.

iii. *Ground Testing*

Ground testing of the aerial vehicle to ensure that all the parts are working accurately.

iv. *Maiden Flight of the UAV*

Initial flight of the UAV to make sure it is flying without significant errors.

v. *Development of MLAs*

Development of the machine learning algorithms to automate the aerial vehicle.

vi. *Implementation of Automation*

Implementing the automation with aforementioned machine learning algorithms.

vii. *Automated Maiden Flight*

Initial flight of the UAV after the implementation of Automation

viii. *Field Testing*

Field testing the UAV in variable weather and other environmental conditions.

ix. Debugging

Debugging and finalizing the product.

CHAPTER 2: LITERATURE REVIEW

The focus of our literature review was based on the deliverables proposed. Overall, construction of the UAV, implementation of the control systems and automation using machine learning and other techniques. Studying about solar panel usage in UAVs and other such aerial vehicles.

Table 1 Research Papers Used

Research Paper	Abstract
[1] Deep Learning for Hostile Environment	• Anti-terrorist attack force for the safety of people. • Using IP camera for visual System Broadcasting to the cloud server and for running Machine Learning. • Machine Learning using Neural Network.
[2] Vision and Learning for Deliberative Monocular Cluttered Flight	• Horizontal flight control using monocular vision in dense clutter using Machine Learning, nonlinear regression using for molecular depth prediction. • Non Linear Regression using for monocular depth prediction.
[3] Optimal Dynamic coverage infrastructure for large scale fleets of	• Detection probability be maximized using a little number of drones as possible. • Patrolling System optimization. • Real World Transportation Network Monitoring.

Reconnaissance UAVs.	
[4] Learning Unmanned Aerial Vehicle Control for Autonomous Target Following	• Deep reinforcement Learning (RL) methods. • Tracking a moving target. • Deep Learning Using Neural Networks.
[5] A Decision-theoretic Approach to Detection-based Target Search with a UAV	• Missions for providing coverage and surveillance to a large area • POMDPs • Employ a novel compact formulation to represent the coordinates of the drone relative to the target coordinates.
[6] A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems	• Aerial Based stations to enhance coverage. • Flying mobile terminals. • Guidelines on how to analyze the problem statement, design a solution and optimize a UAV and consequently a wireless network meant for communication.
[7] Automatic classification of trees using a UAV onboard camera and deep learning	• Trees classification using onboard camera and Machine Learning. • Pest and Soil monitoring in farming.

[8] DroNet: Efficient CNN Detector for Real-Time UAV	• CNN enabling vehicle detection under limited environments • Frame rate of 15-18 and accuracy of 95% implemented
[9] Research Issues in Autonomous Control of Tactical UAVs	• Rapid in-flight replanning under uncertainty. • Learning about large scale optimization or learning problem • Solution of large decision problems is discussed using monolithic and decomposition techniques.
[10] Artificial Intelligence Guidance for Unmanned Aerial Vehicles in Three Dimensional Space	• Proportional Navigation Guidance (PNG) algorithm is pitted against AI guidance's algorithm and the results are compared.
[11] New Artificial Intelligence Approaches for Future UAV Ground Control Stations	• New algorithms focused on ground control systems. • Support for multiple UAVs. • Focused on AI-based issues.

Deep learning for Hostile Environments

Discussion about contemporary teleoperated robots for the purpose of combat, rescue and recon by placing them in hostile environments where humans are under threat of either opposing forces or other environmental factors like cold, heat etc. Proposed solutions are.

- UAV with an IP camera which is broadcasting visual data in the form of a live stream video that is connected to a server using VNC.
- Due to advances in machine learning and also computer vision we can incorporate CNNs for object detection or terrain detection in the case of any invasion or any intruders or even illegal activities like drug trafficking or human trafficking. In the process the output is predicted out of the network and the result is overlaid on the video stream itself using either shapes or colored regions to indicate the desired results of the work desired from CNN itself. The accuracy of the result may or may not be mentioned as well.
- If a head gear is designed such that the output coming from the UAV can be streamed to a human on ground then that human will be able to see the results of the CNNs real time and a first person view can be established so the final decision rests in human hand.

Vision and Learning for Deliberative Monocular Cluttered Flight

Cameras are a great source of visual information. They provide the data required not only well but also at a cheaper and lightweight and small UAVs. Receding horizon control which is widely used in ground vehicles, it uses monocular vision as the only mode to sense during flight of an autonomous UAV during dense clutter. It's feasibility in UAVs can be implemented as follows:

- Perception and control is coupled in a novel way using imaging technique which uses the camera mounted all around the UAV. This technique provides not only a wider lens and field of view but also provides more data to work with and navigate around.
- Cost effective features can be selected and showcased in case of a budget shortage or only limited availability of funds. Monocular depth prediction that uses fast non-linear regression method makes us able to make the UAV avoid obstacles and dense areas as well as other such terrains can be avoided.

This paper demonstrates the efficacy of the above by navigating a dense area around using the aforementioned pipeline more than 2 km with built in off the shelf parts. Moreover, above pipeline can combine information from other modalities like LIDAR etc.

ODC Infrastructure for recon UAVs

Contemporary research of UAV activation relies solely on human operators for the design and adaptation of the drones flying routes. Furthermore, this is being done today on an individual level (one vehicle per operators), with some exceptions of a handful of new systems, that are comprised of a small number of self-organizing swarms, manually guided by a human operator.

How can detection probability be maximized using as little number of drones as possible. This paper proposes a novel approach for the optimization of large scale recon swarm drones — which can produce many coverage strategies for any given recon mission on demand. If estimated cost of threat's potential damages can be provided, also if the types of monitoring drones and their performance is available, an analytically provable strategy can be defined which can be used to decide which types of drones to deploy and how many to deploy, while staying cost effective. Previous process allows us to monitor region for targets that can be predefined.

Learning UAV Control for ATF

RL methods have garnered a reputation for being extremely successful in the face of many challenges of the field. They are mostly used in a limited manner to simulation or game domains due to the high sample complexity and also the efficacy of the trial and error process. But in our case we needed a data-efficient learning process that did have safety constraints of the critical nature. The challenging problem of the tracking a moving object through a UAV is considered in the paper which was especially useful to us.

- A hierarchical approach was developed that not only uses a model free policy gradient method with a PID controller to enable learning under a stable environment without any failure.

- Raw images and games using self-play are used to in combination to supervise learning of the neural network.
- The proposed approach can learn a target following algorithm in a simulator with high efficacy and the behavior learned can be transferred to a UAV or any other type of areal robot for real life implementation.

A Decision-theoretic Approach to Detection-based Target Search with a UAV

An important part of typical search and rescue mission involves search for targets in a large area. UAVs are used for this task. They are equipped with cameras which enable them to detect a target and move towards it. However, the common approaches used make two simplistic assumptions. First is the assumption that the observations that are made by them from different heights are correct.

- Practically, there is a lot of noise in the observations, and with the increase in height, noise also increases.
- Secondly, they ignore wind and other environmental factors, which may hinder the proper execution of motion commands.

In order to cater for these issues, we have proposed a sequential algorithm which can make real time actions based on their observations by using POMDPs (Partially observable Markov decision processes). This handles errors due to both observation and motion uncertainty. Offline simulations led to a new policy, which is run on UAV to enable it to find targets efficiently. A compact formulation is adopted which is used to represent the coordinates of the drone relative to the target. Compared to a heuristic policy, POMDP policy finds targets up to 3.4 times faster.

Automatic classification of trees using a UAV onboard camera and deep learning

Unmanned aerial vehicles (UAV) has been expected to be an easy-to-use, cost-effective tool for remote sensing of forests, and deep learning has attracted attention for its ability concerning machine vision. In this study, using a commercially available UAV and a publicly available package for deep learning, they constructed a machine vision system for the automatic classification of trees. In their method, they segmented a UAV photography image of forest into individual tree crowns and carried out object-based deep learning. As a result, the system was able to classify 7 tree types at 89.0% accuracy. This performance is notable because they only used basic RGB images from a standard UAV. In contrast, most of previous studies used expensive hardware such as multispectral imagers to improve the performance. This result means that their method has the potential to classify individual trees in a cost-effective manner. This can be a usable tool for many forest researchers and managements.

DroNet: Efficient Convolutional Neural Network Detector for Real-Time UAV Applications

UAVs can be used extensively for both environmental scanning as well as surveillance for any parameter in general ranging from a warzone to a housing facility to farms. On board cameras are used for a feed which then are fed into a CNN which provides results due to training provided to it using machine learning techniques. Vehicle detection, traffic detection, terrain detection and in general object detection are its main functions. The paper explained and explored the compromises needed to perform a task such as object detection in a restrained environment such as a UAV by using the technique of single shot analysis using CNN. The paper presents us with an approach to help us not only train the CNN for the object detection and the terrain detection we require but also optimize the process such that under restrained environments of UAV we are still capable of performing the task with accuracy. Using the techniques provided in the research paper we are capable to produce a CNN and a UAV which is capable of processing a video feed of 15-18 frames over the span of a second in real time and also provide us with an accuracy of 95%. The CNNs can be optimized such that they can keep their efficiency and accuracy even when presented with an environment like a UAV with limited processing power.

Artificial Intelligence Guidance for Unmanned Aerial Vehicles in Three Dimensional Space

Unmanned Aerial Vehicle (UAV) are used in various applications like visual surveillance of natural resources, product delivery, armed attacks, disaster relief etc. This research proposes use of Artificial Intelligence (AI) for dynamic target tracking capability of an UAV. The AI guidance algorithm performance is compared against standard guidance algorithm like Proportional Navigation Guidance (PNG) algorithm.

New Artificial Intelligence Approaches for Future UAV Ground Control Stations

New AI techniques are the focus of many of the new works to help the UAV's operations successful execution from the Ground Control Stations. Workload operator reduction and the automation of the process which trains are top priority subjects of this field. This paper focused on the following aspects:

- MOGAs used for mission planning and replanning operations of UAVs.
- Procedure Following Evaluation methodology based on Petri Nets.

This paper uses a framework that simulates a ground control station with ability to support multiple UAVs. The function of this framework can be described fully with the following two directions it focuses on. On one hand it deals with Mission Designing as well as as Automated MP and eventual replanning. On the other hand, it deals with analyses of the tasks of the UAV operators. This framework has been used to execute and debrief a rest mission while focusing on the AI related problems.

CHAPTER 3: METHODOLOGY

In order to complete the objectives of the project mentioned in the previous section, the process needed to take on various aspects. The process included the actual manufacturing of the UAV which included deciding which airfoil to use and which material to use, then the actual control systems needed to be worked on describing how the circuit had to be set up and how it responded to the many different flight variables and parameters that need to be controlled. Machine learning needed to be implemented to achieve the procedure required to automate the UAV itself for the navigation of the landscape which in turn would provide the surveillance or other usages suggested in the sections above. The final aspect was to establish a network so the different aspects of the projects could communicate with each other with maximum efficiency and minimum latency. Last but not the least the solar panel application would be under consideration which would depend on what types of panels to be applied and also how to apply them. Hence, the methodology was divided into 4 different aspects which were worked on:

1. Manufacturing of the UAV
2. Implementation of control systems
3. Implementation of automation of UAV
4. Making an IOT environment for intercommunication of components
5. Application of solar panels

Manufacturing of UAV

Manufacturing of the UAV was the primary objective, ultimately a UAV was needed minimum stall speed, maximum lift given the general conditions that the UAV might flight in, lower weight to power ratio, easy to fabricate and assemble, reparability and also minimum cost required to manufacture different parts of it.

The different aspects that were worked on to make sure maximum efficiency with least amount of funding needed can be described as follows:

- Material Selection
- Airfoil Selection

i. Material Selection

Different properties were required given the usage and the timeframe we had set for this project which included low cost, maximum reparability and ease of fabrication in the first place. Three materials were shortlisted to serve the purpose with their properties mentioned below:

Table 2 Shortlisted Materials for UAV Manufacturing

Balsa Wood[12]	**Depron[13]**	**Expanded Polypropylene[14]**
Balsa has excellent sound, heat, and vibration insulating properties, suitable for composite materials	Depron actually has a good strength to weight ratio	Lightweight, enhanced functionality, durability and recyclability, EPP density range, from 20 g/l through 200 g/l

Material waste while designing the body of the plane	Nearly 50% lighter, just as strong and in aerodynamic performance	Suitable thermal insulation properties and structural strength *Tensile strength (kPa) 270 to 1930*
Cutting and assembly requires special materials in the process e.g. special glue	Tensile Stress *(@ break, length direction):* 1.30MPa 0.90MPa Tensile Stress *(@ break, transverse direction):* 0.70MPa 0.90MP	Isotropic deformation behaviour, irrespective of impact's direction
Requires extensive milling operations to fabricate different parts of the plane	Easy to manufacture, flexible, easy to handle, easy to glue (hot glue gun)	Easy to machine
Costly manufacturing, Rs. 8000 required for 18 strips of balsa wood	Reasonably priced around Rs. 5000 (spare remains)	Another thing that makes EPP great is that, it is CA compatible
Repairing the material is extremely difficult		Environment friendly

EP sheets were used to make the fuselage and some parts of the wings including the outer covering. Depron was used to make housing sections for the motor of the propellers and also used as the inner layer of the wings to give it not only extra strength but extra durability.

After the material was finalized. Work had to be started on first and foremost choosing the suitable airfoil and then constructing the wings of the planes and then installing motors, propellers and various control systems to ensure the UAV would take flight and sustain a stable flight for a desirable period of time.

- Rudder
- Ailerons
- Flaps
- Elevators

ii. *Airfoil Selection*

Second step was the airfoil selection. Airfoil is the cross-sectional area of the wing which not only determines how much lift will the wing produce but also determines the overall drag that will be applied on the airplane midflight. In order to ensure maximum lift and minimum drag along with minimum stall speed in the crucial step we performed our analysis on 4 selected airfoils which namely were:

- NACA 0006
- NACA 0009
- NACA 4142

The figures of the aforementioned airfoils are given below also the CFD analysis of each one of the three shortlisted airfoils:

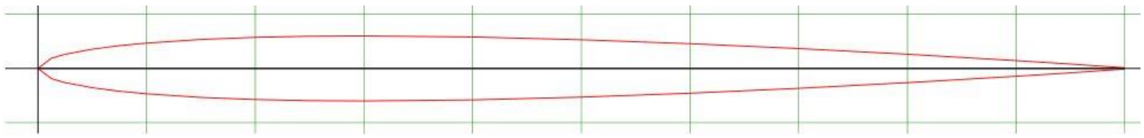


Figure 1 ***NACA 0006 Airfoil***

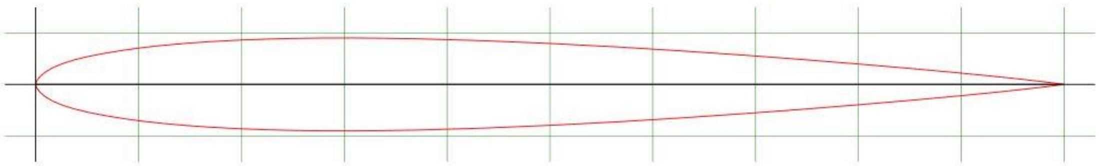


Figure 2 ***NACA 0009 Airfoil***

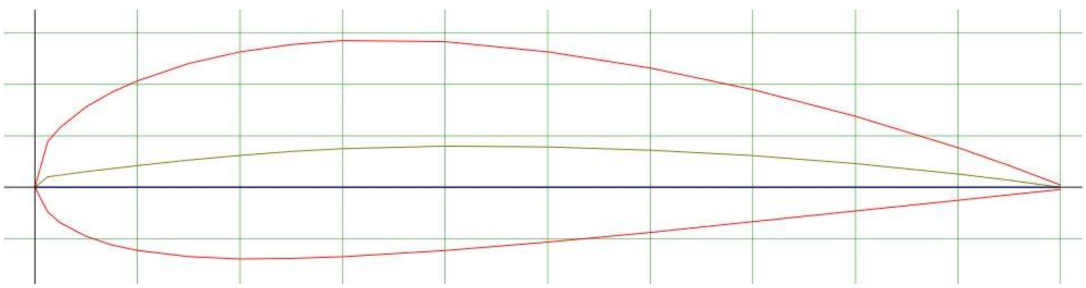


Figure 3 ***NACA 4142 Airfoil***

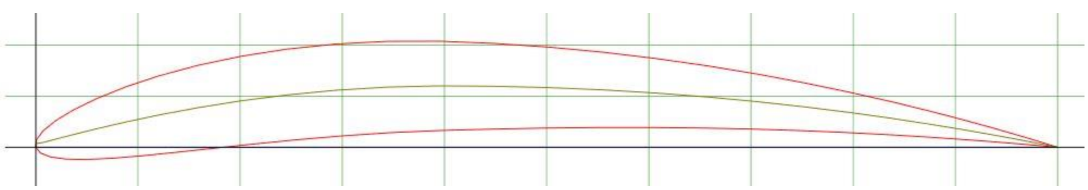


Figure 4 ***NACA 6409 Airfoil***

- NACA 0006 Analysis:

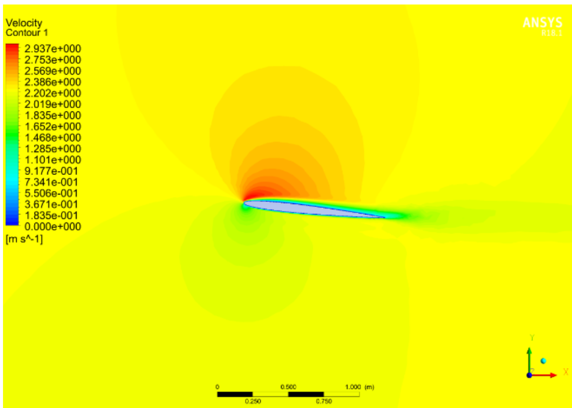


Figure 5 ***NACA 0006 Velocity Contour***

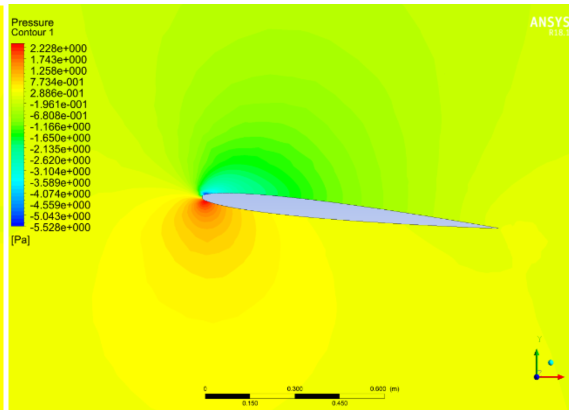
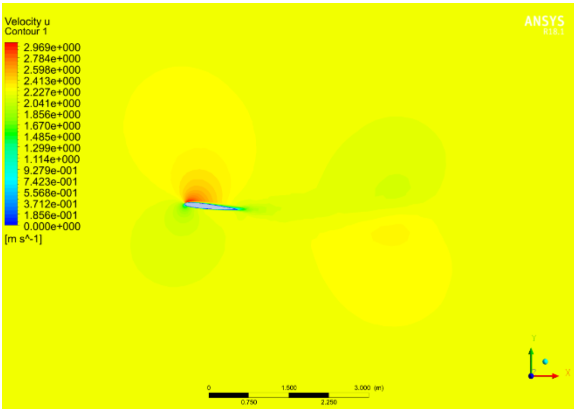


Figure 6 ***NACA 0006 Pressure Contour***

Table 3 NACA 0006 Lift and Drag Calculations

NACA 0006					
Coefficient of Lift	C_L	0.64	Coefficient of Drag	C_D	0.016
Density of Air	**ρ**	1.225	Density of Air	**ρ**	1.225
Velocity of Air	**v**	45	Velocity of Air	**v**	45
Area of Wingplan	**A**	0.278541	Area of Wingplan	**A**	0.278541
Lift Force	F_L	221.1058	**Drag Force**	F_D	5.527646

➢ NACA 0009 Analysis:



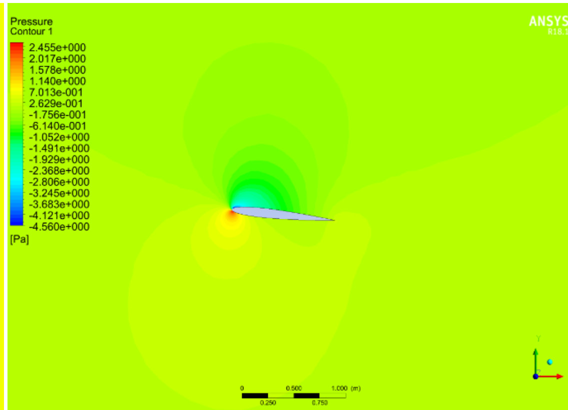


Figure 7 ***NACA 0009 Velocity Contour*** **Figure 8** ***NACA 0009 Pressure Contour***

Table 4 ***NACA 0009 Lift and Drag Force***

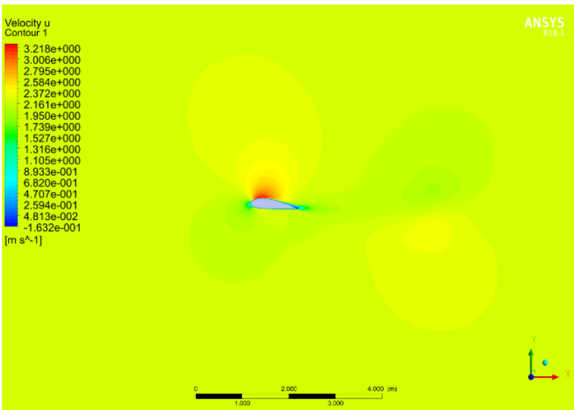
NACA 0009					
Coefficient of Lift	C_L	0.55	Coefficient of Drag	C_D	0.0476
Density of Air	**ρ**	1.225	Density of Air	**ρ**	1.225
Velocity of Air	**v**	45	Velocity of Air	**v**	45
Area of Wingplan	**A**	0.27854	Area of Wingplan	**A**	0.27851
Lift Force	F_L	190.012	**Drag Force**	F_D	16.4447

Both of these airfoils although produced some decent results but we continued our testing on the remaining airfoils and the third airfoil that is mentioned below along with the details was eventually used for the following reasons:

- Stall speed decreased
- More lift for lesser speeds
- Weight to airspeed ratio

- Easier to emulate the effects of and fabricate
- Spokes and ribs can be implemented

➢ NACA 4142 Analysis:



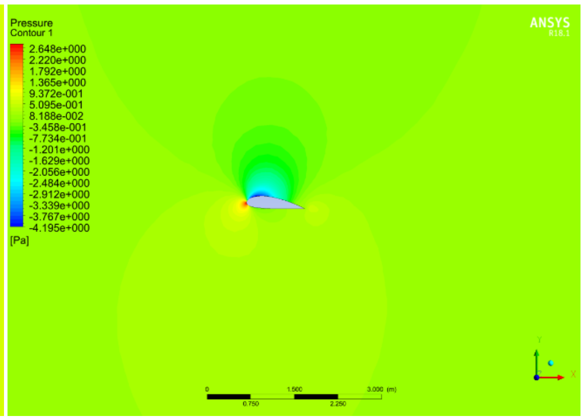


Figure 9 ***NACA 4142 Velocity Contour*** **Figure 10** ***NACA 4142 Pressure Contour***

Table 5 NACA 4421 Drag and Lift Calculation

NACA 4421					
Coefficient of Lift	C_L	1.11	Coefficient of Drag	C_D	0.011
Density of Air	**ρ**	1.225	Density of Air	**ρ**	1.225
Velocity of Air	**v**	45	Velocity of Air	**v**	45
Area of Wingplan	**A**	0.278541	Area of Wingplan	**A**	0.278541
Lift Force	F_L	383.4805	**Lift Force**	F_D	3.800257

Implementation of Control Systems

In order to ensure flight controls in the UAV for the purpose of not only initiating the flight itself but also for the flight to be sustainable, safe and be as optimized in order to get the maximum flight time out of the limited resources on board. In order to do that a certain circuit with certain components had to be implemented, which are not only mentioned but also illustrated below:

i. *Components*

- Arduopilot Mega
- Raspberry Pi
- Battery
- ESCs
- Servo motors
- GPS module
- Telemetry device
- 4G device

ii. *Working of the circuit*

Heart of the whole assembly is the APM. It controls the elevation, the balance and the flight path of the UAV itself. It has connections to the GPS module, the ESCs, servo motors and the RPi (which will be responsible for the automation of the whole process as discussed in the later portion of this report). It is also connected to the ground control we have set up with the help of 4G device over the internet. Based on the path defined the APM controls the rudder, ailerons, elevators and the flaps to make the UAV follow that path. APM is an extension of the Arduino Mega microcontroller. Hence it controls the signals sent to the various components and thence the UAV is controlled including the propeller speed. The whole operation is powered by the battery, augmented by voltage dividers along certain parts to ensure the voltage requirements are being fulfilled. An autoflight system was implemented to send signals to the flight control system. The pilot or in our case a ground control can decide what mode to choose e.g. hold heading or hold altitude mode.

Implementation of Automation of UAV

Process of automation is divided into four categories.

- Connection with ground control system and servers through VNC.
- Visual Object detection through Machine Learning (Neural Network)
- GPS and control systems tracking.
- Fails safe (Back Track in case of signal or vision loss.)

i. Virtual Network Computing (Ground Control connection with UAV).

Ground controller needs to know the position of the UAV and the video feed that is been captured by the UAV multiple cameras. With current radio components such as telemetry, it has limitations. It has low range and the data transfer loss rate is high.

We chose, VNC, a technique which has a data loss of less than 0.01% and the range is virtually unlimited. It works on the principal of LAN network. We create a virtual LAN network.

  - UAV with the help of 4G dongle is connected with a central Cloud Server.

- Central Cloud Server connected with the Ground Control System.

Cloud Server is also running Deep Learning algorithms, storing data and optimizing the vision recognition algorithm. (Optimizing MODEL).

ii. Visual Object detection through Machine Learning (Neural Network)

Neural Network is an algorithm of Machine Learning. We are using one its branch named Convolutional Neural Networks (CNNs).

The CNNs have several different filters/kernels consisting of (randomly initialized) trainable parameters depending on the depth and filters at each layer of a network, which can convolve on a given input volume (the first input being the image itself) spatially to create some feature/activation maps at each layer. During this process, (through back-propagation) they learn by adjusting those initial values to capture the correct magnitude of a spatial feature on which they are convolving. Hence they can successfully boil down a given image into a highly abstracted representation which is easy for predicting. Steps we followed:

- Captured Data and created a database
- Trained our own convolutional neural network object detection classifier for multiple objects
- Once model was trained we ran simulations tuning APM flight controller and ground controller (Mission Planner software)

The libraries we used were:

- OpenCV:

  It is used to get image from the camera and convert it to an array.

- *Tensorflow/ Keras:*

  Used for training the MODEL and optimizing the CNN algorithm.

- *MavLink:*

  It acts as a bridge connecting APM to RaspberryPi and the Ground Controller enabling us to control flight controller over VNC.

iii. GPS and Control Systems Tracking

Our UAV also has a GPS module (Global Positioning System). Its purpose is to keep track of the location and is used for mapping the terrain. It has major advantage in unmapped areas helping the UAV navigate. It also closely works with Machine Learning Algorithms and APM (Flight Controller) stabilizing the flight and navigation.

Making an IOT environment for Intercommunication of Components

The components namely, the APM, the RPi and the 4g device, hence, the plane itself and the ground station control need to communicate with each other. In case of UAV's usage as surveillance unit the feed needs to be observed. In case of any other usage of the UAV's automated flight's usage the flight controls need to be observed in case any changes need to be made or for maintenance. To accomplish that we established an IOT environment where the RPi (hence the plane) and the ground control unit are connected in a server using VNC and hence both the components have specific IP addresses through which they can communicate with each other and transmit data.

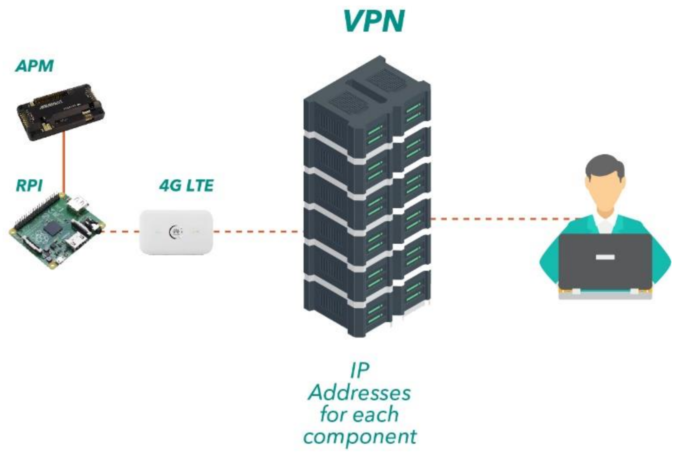


Figure 11 ***Visual Representation of the IOT***

Application of Solar Panels

Monocrystalline solar panels will be used because of their low cost and their higher tolerance towards heat. Since our UAV will be flying at moderately high altitudes often in areas with clear sunlight, the heat absorbed by the solar panels will be high. Flexible sheet of solar panels will be used and the energy will be used to recharge the battery cells we will be using. Due to this extra energy coming in the flight time will be extended, crucial to any of the UAV's proposed functions.

CHAPTER 4: RESULTS AND DISCUSSIONS

Constructed UAV

In the end based on the calculations we performed and selection of material and airfoil we were ready to go ahead and start the actual construction itself the material's fabrication was relatively quick and easy and the research we did earlier came in handy. EP was used to create the fuselage of the UAV, housing of the motors for the propellers, inside lining of the fuselage along with the wings. In the end the UAV ended up looking like this:

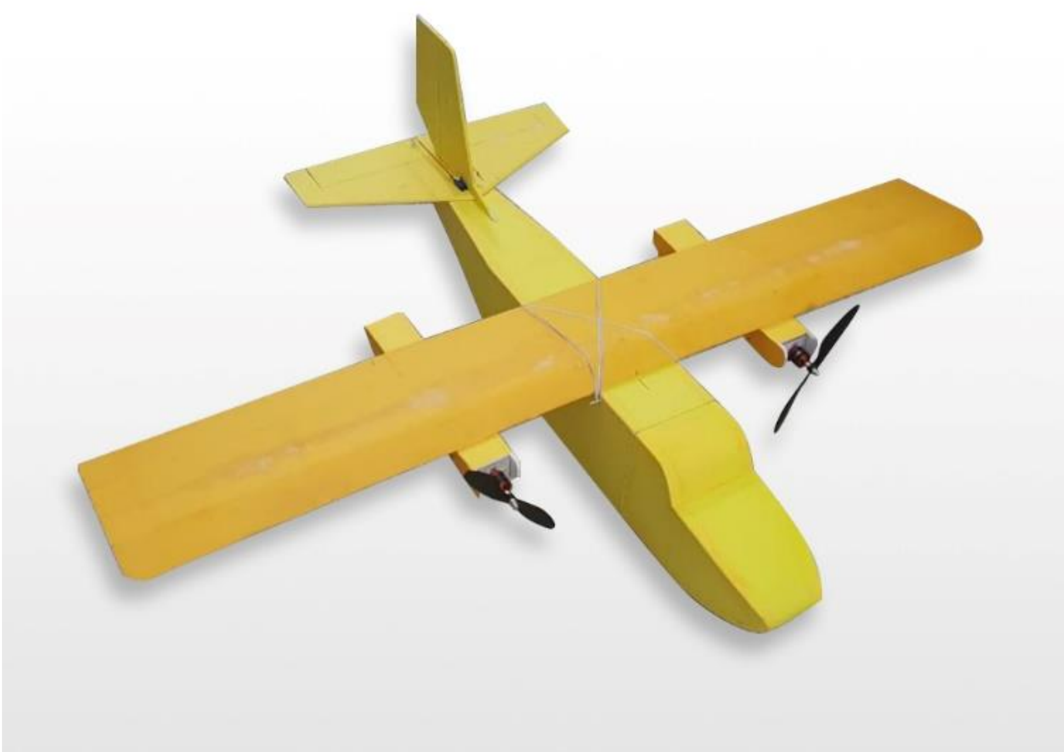


Figure 12 ***Fully Constructed UAV***

As a reference we have also attached the initial CAD model that was developed during the start of the project, some aspects of it had to be compromised for it to meet the standards that were mentioned in the previous section.

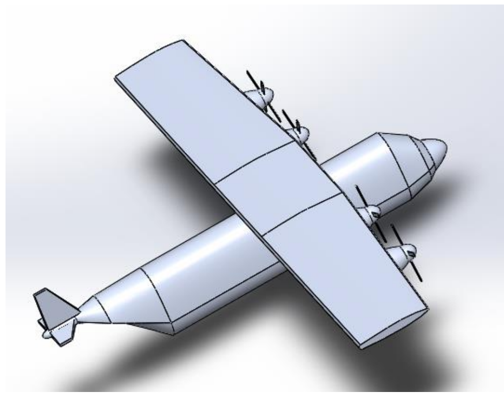


Figure 13 ***CAD Model of UAV (Initial)***

The materials held up really well during the flight and little to no damage was seen just based on the lift and drag forces acting on it or any significant abrasions on the surface based on the dust and other such particles in the atmosphere. There was no bending caused in any of the parts of the UAV specially the wing. The motor housing and the propeller housing in turn was not disturbed even after the thrust force that was inflicted upon it. The movement of the rudder, elevators and the flaps although a little stiff at first was later smoothed out which ensure the UAV to have a smooth flight along with all the components in the fuselage. The airfoil also served its purposes very well. One of the key factors that the NACA 4142 was selected for was its minimum stall speed, results depicted the choice to be true as the stall speed was significantly lesser than it would have been for the other airfoils under consideration.

The final constructed plane had following specifics:

Table 6 *Specifications of UAV*

Wingspan	1.5 m
Radius of propellers	0.1 m
Width	1 m
Height	0.12 m
Rudder height	0.24 m
Battery	3300 mAh
Battery (backup)	800 mAh
Payload	4 kg
Empty weight	.800 kg
Wing surface area	0.3 m^2
Radio range	1.2 km radius
Camera-A	2 MP
Camera-B	5 MP
Sensors	• GPS • Accelerometer • Gyroscope

	• Speed sensor • Temperature sensor • Horizon detector
Ceiling height	1200 ft

Test Flights

i. *First Test Flight*

After the assembly of the APM and other components along with it, the UAV was ready for the test flights. We first initiated a flight using the flight control on board that were controlled using a remote control and the ground control station using the Mission Planner software was used to observe the data provided. The flight lasted 15 minutes which was followed by a safe ending.

During the first flight the issues that were realized were the movements of the elevators was not smooth because of the mechanism along with the servo motor that was being used. Another issue that arose was thermal management of the whole system showed weakness. Due to which the flight time was reduced. There were also vibrations produced in the fuselage because of the components and because of that heading of the UAV was disturbed.

ii. *Second Test Flight*

Second test flight was automated which included the RPi taking flight controls based on the commands given to follow a certain terrain, in this case, a road. The flight continued till 18 minutes. During the flight the terrain detection that was done using machine learning algorithms was implemented, RPi would then process this and send signals to the APM which would in turn control the elevation and the heading to make sure the pathway was followed by the UAV. The second flight was a success in many ways but unfortunately it ended in a crash. The second flight revealed a lot of problems that would help us optimize the design of the fuselage and ensure a crash does not reoccur.

The main issues that arose were as follows:

- Overheating of the RPi during the processes which caused slow processing of the feed being provided to it. This in turn caused a delay between the actual movement of the plane and the terrain analysis that was to direct the plane's heading and elevation. Eventually, an obstacle presented itself before the UAV but due to this lag of processing the UAV could not change course in time and hence it crashed into the obstacle, ending the flight in failure.
- As mentioned above, thermal management was again under our consideration after the first flight. Fuselage's design was modified a bit again by adding small vents on the side of the fuselage so naturally aerated convection could be carried out throughout the length of the fuselage and the overheating problem would not occur again.

There were, however, many positive outcomes of this flight some of them have been mentioned below:

- The feed being provided by the camera to the RPi was stabilized such that a continuous video of around 14-18 FPS was provided to the RPi for the purposes of processing for terrain scanning.
- The MODEL that we developed using the CNN techniques in order to detect several objects in the frame itself proved to be very accurate. With accuracy reaching as high as 87.3%

As a result of the two flights mentioned above, we introduced certain fail safes to ensure that the UAV does not crash or malfunction or even in the case of an emergency the ground control station can be used to eradicate the issue as soon as possible.

iii. Fail Safes

- A perimeter is defined around the flying zone. This act as a virtual barrier preventing UAVs from flying beyond the perimeter.
- In case UAV loses GPS signal, it is programmed to solely rely on its visual navigation tracking its path back to take-off location.
- In case of Vision loss, UAV directly relies on its on boards sensors such as GPS, accelerometer, speed sensor and gyroscope helping UAV to navigate.

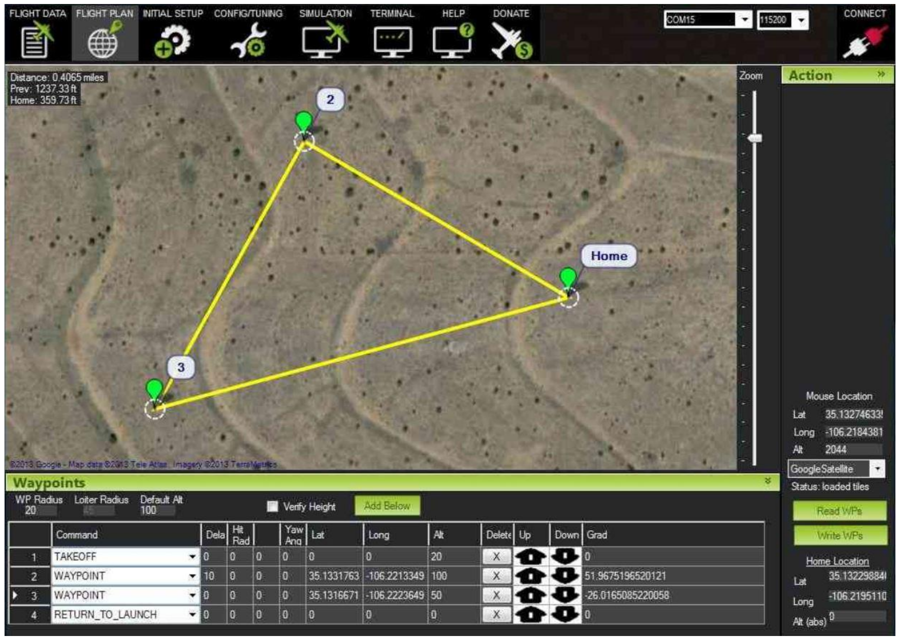


Figure 14 ***Mission Planner Interface***

Response of the IOT system

During all of this the communication between the plane i.e. the RPi and the ground control station was carried out using 4G internet device and on ground connectivity through a server using VNC. We used python scripts and the libraries mentioned in the previous section (MavLink) to achieve this. Although due to this there was some connectivity lag between the two components mentioned above but the latency was kept minimum to an extent that a continuous link was established between the two using the VNC and hence there was connectivity over the internet. Telemetry device could have been used for better coverage of the whole flight but due to some legal limitations we had to stick to the 4G device’s usage.

Figure 15 Initial Testing for Object Detection

During the initial testing 3-4 objects were being detected at the same time by the algorithm but as the algorithm was optimized and the processing as result got faster, and eventually we were able to detect 6 objects in the frame. We eventually trained the algorithm to scan for and detect various terrains.

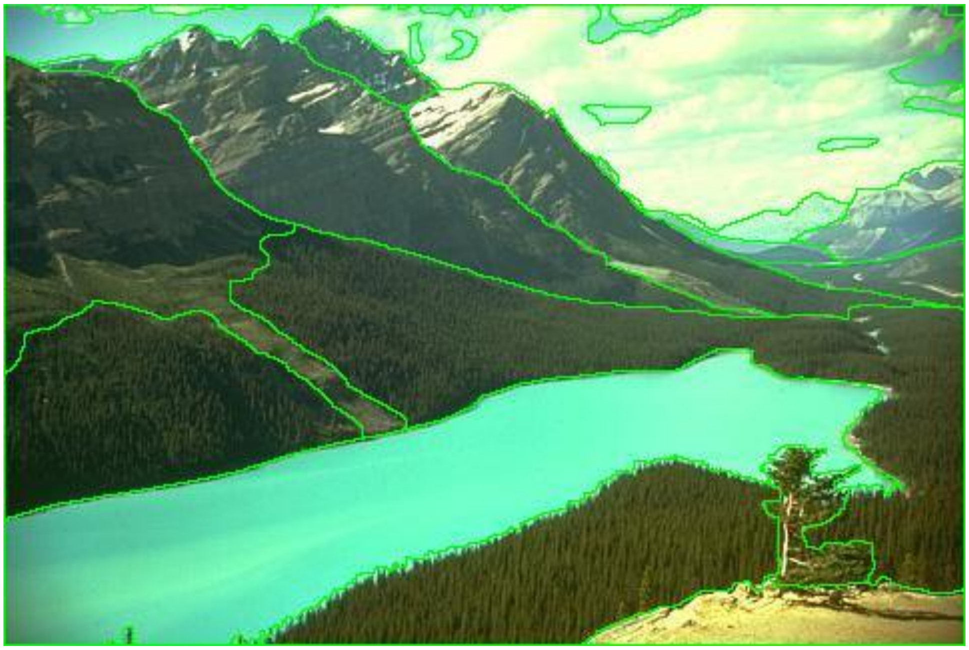


Figure 16 Screenshot of Terrain Detection during Initial Testing

Further testing will be required with automated flights to optimize the algorithm. Data collected during the flight can further be used to optimize the terrain detection. Better thermal management will be implemented along the way to further increase the flight time along with keeping the RPi to an optimized temperature.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

After material selection based on the testing and shortlisting and selection of airfoil, the UAV has been constructed. It came to our knowledge that due the nature of the material used the thermal properties of the UAV can be improved upon by a significant margin for which the following recommendation will be taken under consideration:

- Addition of vents of the body of the UAV special in the fuselage so that better aeration can be guaranteed and all the electronic components inside the UAV can perform better under the conditions in which the UAV will mostly operate
- Covering the outer surface of the UAV with a lighter shade is also being considered so that better sunlight reflection is ensured and with it temperature inside the fuselage can be decreased
- Installation of a heat sync along with the RPi

During the second flight UAV crashed, the reasons came out to be mostly related to thermal management. RPi under the prolonged exposure to the sun both before and during the flight caused its processing power to slow down and eventually it caused a lag in the response of the UAV while facing an obstacle which caused a collision which in turn caused a crash. Overall, the flight was a success because it did provide us with a live feed during the automated flight and provided us with a lot of useful data to work with further on in the process.

The nose of the UAV has a slight bump on it which does cause a downward force due to aerodynamic forces. Due to this we had to constantly keep our elevators up to keep the flight straight. In order to combat this we will redesign the nose of the plane for it to be smoother so this problem does not arise.

The wing needs to be reinforced, for further structural integrity. This can be changed through using a carbon fiber rod to act as a back bone for the wing to stay stable during long flights even in windy conditions.

Figure 17 Damaged wing after the Second Flight

The control system we implemented worked to a very accurate degree. The RPi and the APM communicated with little to no lag in between. The flight controls worked fine. The hold heading controls and the hold elevation control both worked fine as well. There are however some issues that were observed even in this aspect of the project itself. Just like the previous aspects of the project, thermal management seems to be a concern. We however do have certain recommendations which will eradicate the issues we faced:

- Usage of silicon wires instead of silver wires to ensure overheating of wires does not occur
- RPi module to be updated to a newer version (3B+) which will increase our processing power as well as our thermal management

Another aspect that does require further optimization is continuing the training of the CNN to further make the object detection faster and more accurate. Further data collection will also help us to make our object detection more accurate which will cause the accuracy go from 87% to a very desirable 93%, this will significantly improve our response times too.

REFRENCES

[1] Abhishek Sawarkar, Vishal Chaudhari, authors Faruk KaziPublished 2016 in ArXiv. HMD Vision-based Teleoperating UGV and UAV for Hostile Environment using Deep Learning.

[2] Debadeepta Dey, Kumar Shaurya Shankar, Sam Zeng, Rupesh Mehta, M. Talha Agcayazi, Christopher Eriksen, Shreyansh Daftry, Martial Hebert, J. Andrew Bagnell lessFSR2015. Vision and Learning for Deliberative Monocular Cluttered Flight.

[3] Yaniv Altshuler, Alex Pentland, Shlomo Bekhor, Yoram Shiftan, Alfred M. BrucksteinArXiv2016. Optimal Dynamic Coverage Infrastructure for Large-Scale Fleets of Reconnaissance UAVs.

[4] Siyi Li, Tianbo Liu, Chi Zhang, Dit-Yan Yeung, Shaojie ShenIJCAI2018. Learning Unmanned Aerial Vehicle Control for Autonomous Target Following.

[5] Aayush Gupta, Daniel Bessonov, Patrick Li2017 IEEE/RSJ International Conference on…2017. A decision-theoretic approach to detection-based target search with a UAV.

[6] Mohammad Mahdi Mozaffari, Walid Saad, Mehdi Bennis, Young-Han Nam, Mérouane DebbahArXiv2018. A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems.

[7] Masanori Onishi, Takeshi IseArXiv2018. Automatic classification of trees using a UAV onboard camera and deep learning.

[8] Christos Kyrkou, George Plastiras, Stylianos I. Venieris, Theocharis Theocharides, Christos-Savvas Bouganis2018 Design, Automation & Test in Europe…2018. DroNet: Efficient convolutional neural network detector for real-time UAV applications

[10] Chethan Chithapuram, Yogananda V. Jeppu, Ch Aswani Kumar2014 International Conference on Contemporary…2014. Artificial Intelligence guidance for Unmanned Aerial Vehicles in three dimensional space.

[11] Cristian Ramírez-Atencia, Víctor Rodríguez-Fernández, Antonio González-Pardo, David Camacho2017 IEEE Congress on Evolutionary Computation…2017. New Artificial Intelligence approaches for future UAV Ground Control Stations.

[12] G Newaz, M Mayeed, A Rasul 2014 in Sage Journals. Characterization of balsa wood mechanical properties required for continuum damage mechanics analysis.

[13] DPSpecDepronCore Retrieved from: https://dragonplate.com/Content/Images/uploaded/Weights%20and%20Specs/DPSpecDepronCore.pdf

[14] Expanded Polypropylene (EPP) Retrieved from: http://www.bpf.co.uk/plastipedia/polymers/Expanded_Polypropylene_EPP.aspx

APPENDIX I: TITILE OF APPENDIX I

Early Development and Problems

i. *No Fly Zone*

Our location, that is NUST is a no fly zone for UAVs. Because of overlapping problems such as weather conditions and the flight approval from NUST admin, each test flight took us weeks of preparation and planning.

ii. *Made in CHINA or US*

In Pakistan, there are very few Hobby Shops and RC plane markets hence the price of material varied a lot. Other major hurdle was, none of the components we required were made in Pakistan. All of them either it is Depron or brush less dc motors were imported from China and US. We even experimented with different kinds of Cardboards, Wood, and Foam. In this process we discovered new custom materials.

iii. *Summer and High Temperatures*

We started our test flights in early June, peak time of Summer. Temperatures varied from 40 to 45 C. Due to high temperatures, components on board UAV would heat up and stop working completely, hence we were forced to keep our flight time less than 15 min.

iv. *Machine Learning*

The time we started working on Machine Learning, we were bottle neck by the CPU and GPU we had. We lack resources to train our model. Training model alone took us days and nights. Gathering data for training was major hurdle. Classifying Google and Stock drone footages took us a whole month.

v. Raspberry Pi

We were forced to use Raspberry Pi 3 because of multiple factors as stated before. Weight and Power were the major reasons but this compromised computing power. Raspberry Pi is powerful enough to detect object and hurdles in flight but is not quick enough to react quickly. This caused us major pushbacks as our early test flights crashed because of this. We had to custom make OpenCV library and tweak Tensorflow to increase frame rates and decrease reaction time. Other major problem is, raspberry pi heats up from prolonged usage. Hence after first 20 min, raspberry pi would crash causing UAV to loiter (fly in circles) as long as the raspberry pi cools down, reboot and become fully functional. We are planning on using heat sink to resolve above stated issue.

vi. Street Light Pole

During our early test flights, we flew UAV from the road. After making multiple passes over the C3 football ground, UAV had to land back on the road. During landing procedure, we forgot to keep in record the light pole. UAV was unable to react and crashed into the pole.