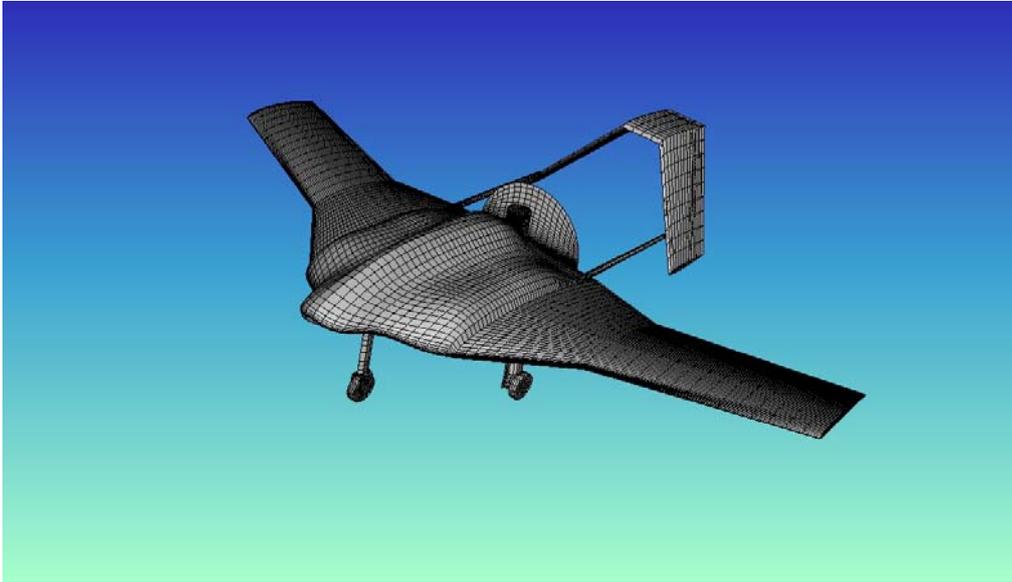


Development of an Unmanned Aerial Vehicle for Reconnaissance Mission



Nihat Karataş
Gökhan Korkusuz
Ezgi Karacaoğlu
Seçkin Köksal
Murat Bronz
Savaş Şen

Abstract

Unmanned aerial vehicles can be very practical for both civilian and military purposes. Searching enemy lands, watering the plants, applying insecticides, taking videos/images of roads/buildings/towns, delivering packages are only a few examples to which the UAVs can be used. When used efficiently, UAVs help saving time and effort as well as reducing the amount of risking pilots' lives. This paper presents the development of an autonomous unmanned aircraft that is designed to fulfill the needs of a basic reconnaissance mission. This specific UAV is to fly autonomously for 30 minutes over a grassy area and detect predefined objects. The control of the aircraft can be safely switched between the autopilot and the RC controller via a safety switch circuit at any time during the mission to avoid any possible accidents. The predetermined flight path can be altered at any point during flight from the ground station. Objects that are supposed to be detected in the surveillance area are located during flight by using image processing techniques and a high resolution camera is used to provide detailed images of the targets. The aircraft is built using composite materials and is given the optimum shape to provide the necessary area for the payload, good flight characteristics and safety. Appropriate communication systems are built to make sure that the connection between the aircraft and the ground station is never cut within 3 kilometers. Researches, calculations and analysis are made to build an aircraft that performs the mentioned tasks altogether.

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INTRODUCTION

Istanbul Technical University's "itUAVci" team is formed by a group of students from aerospace engineering, aeronautical engineering and electrical/electronic engineering departments to compete in the 4th Annual AUVSI Student UAV Competition 2006. The mission profile defined by AUVSI requires an unmanned autonomous aerial vehicle which is capable of finding specific targets within a defined land area and providing high resolution pictures. The UAV should be able to pass through given waypoints and should be able to change the autonomous flight direction via a command given from the ground station. Conceptual design, system design, analysis and production of the ITU team's aircraft that is manufactured to perform this mission is explained in this paper.

Goal

ITU team's goal is to design a flight platform that manages to accomplish the mission that is set by AUVSI. The flight platform should be able to recognise the targets, take good quality images of the targets, fly to specific waypoints, change attitude when commanded so from the ground station, be safe, be reliable and have low cost.

SYSTEMS OVERVIEW

Flight platform carries a laptop mainboard on which an image processing program is run. The image processing program scans the real time images taken from a web-cam and if it detects images that fit the requirements it commands a digital camera of 3.2Mpixels to take a picture at that instant. Meanwhile, the autopilot (MicroPilot) is connected to the mainboard as well and the ground station software of the MicroPilot is run on this mainboard. Once the settings of the systems are done correctly, the UAV is capable of performing the tasks even though it loses the link with the ground station. Remote desktop connection is used to connect the ground station to the flight platform, providing the ground station with the capability of controlling the mainboard on the aircraft. Therefore, only one modem is enough to reach both the image processing data and MicroPilot's ground control software (Horizon). On the other hand, a regulator is manufactured to provide different systems with various power requirements with the necessary power they need by using only one main battery. A safety switch circuit is produced to protect the aircraft from a possible crash if the autopilot is somewhat not working properly.

AIRCRAFT

An aircraft that carries the necessary payload, flies safe and has good flight characteristics is designed and built.

Payload

The platform carries a laptop main board, a webcam, a digital camera, main power source batteries, a power regulator, a safety switch, usb modem and the flight controller micropilot. The platform is designed to become a smart UAV, so that the aircraft can perform the mission even when the connection is lost.

Calculations and Analysis

The payload covers considerably a large amount of space. Therefore, conventional trainer airplanes are not capable of carrying the system. In order to overcome this problem, an aircraft that can carry the necessary payload is designed.

Main challenge for the design of the aircraft is to make it large enough to carry the system while making it able to fly slow enough to get accurate images of the target objects that are present on the ground.

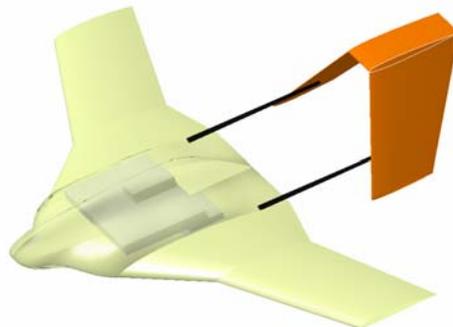
First, a weight break down table of the system is made in order to obtain an opinion on the total aircraft take off weight. The table is as follows:

Structural		Avionics		Imagary		Thrust		Power	
Wings	1200	Autopilot	250	CCD camera	150	Engine	600	Main battery	460
Landing Gear	400	Computer	750	Web-cam	80	Fuel	600	extra	150
Fuselage	1100	Modem	290			Fuel tank	110	extra	100
Bağlantı cubuk	150	Cables	100			misc.	100	Regulator	120
Booms	120	Switch	160						
Empennange	180								
Radio(servo+receiver)	200								
	3350		1550		230		1410		830
								GrossWeight	7370 gr

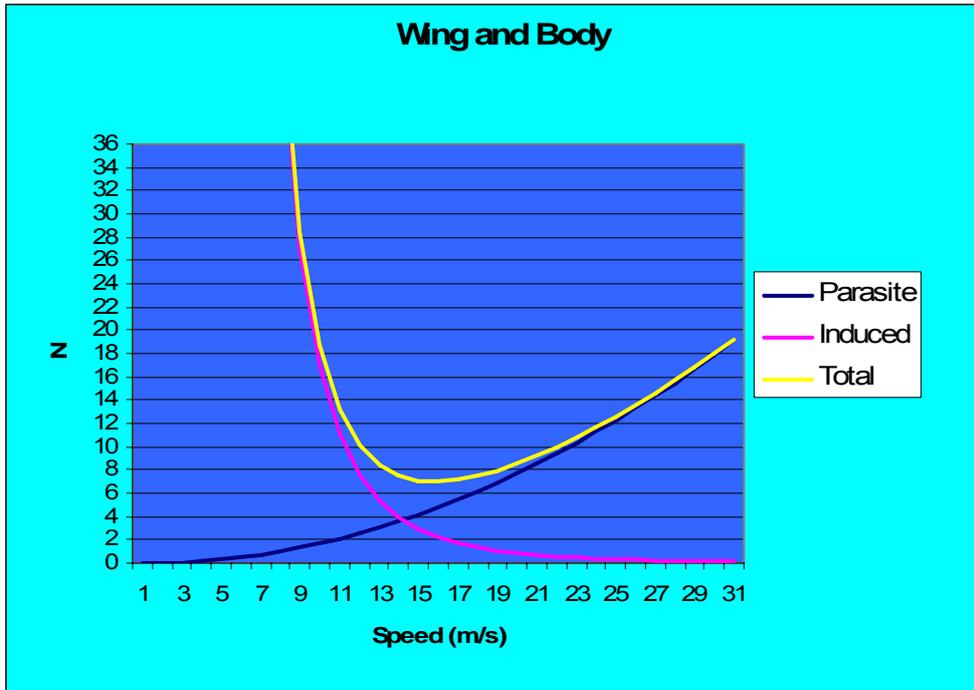
After the total takeoff weight is estimated, various configurations are considered and making a blended wing body is decided upon. Then, a revision is made as to add empennage to the aircraft to make it more stable and the flight safer.

The aerodynamic team made necessary calculations and modifications on the design of the fuselage and the empennage to achive the best flight performance possible. A pusher propeller is selected and to avoid the propeller's slipstream an inverted V-tail is chosen.

After the body and empennage design, the wing configuration is made to achieve the desired cruise speed, the parasite drag, the induced drag and the total drag components as shown in the following figure:

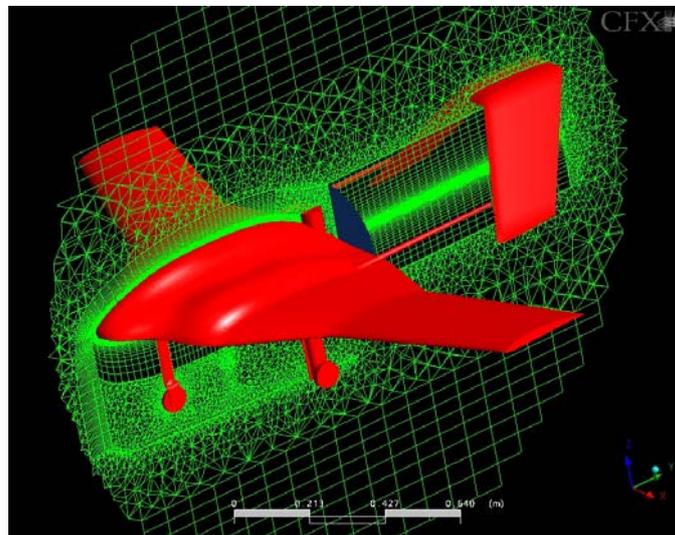


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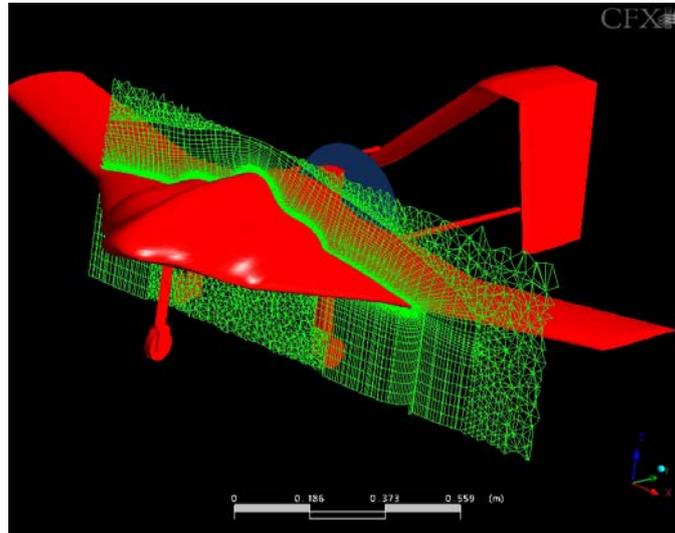


As indicated in the graph above, the optimum cruise speed is 16,2 m/s. This value is adequate for capturing images while flying. Aerodynamic team used several analytical formulations to estimate the lift and drag components. After getting fairly good results, a CFD analysis of the aircraft is made to make sure that these values are acceptable.

In the numerical analysis both structured and unstructured grids are used and combined with Chimera technique:



CFX-10 solver is used with SST turbulence model. Solutions are obtained steady, incompressible. 200 iterations are made with 45.75 CPU hours.



All the numeric solutions are consistent with the analytical values that are found.

The angle of attack of the wing is taken as 4.5 degrees during calculations. Obtained lift value is enough for maximum take off weight at the cruise speed. Obtained drag force is found as 2N and the engine selection is made accordingly. After the market search the O.S.91Fx 2 Stroke engine is chosen.

Aircraft structure and production

Composite materials are used to construct the aircraft. The fuselage is produced from carbon fiber, the foam wings are covered with carbon fiber and the foam empennage is covered with kevlar. Carbon fiber booms are used to connect the empennage to the fuselage. Landing gear is produced from carbon fiber as well.

Composite production techniques such as moulding, vacuuming and applying heat are used. Following is the picture of the carbon fiber fuselage:

IMAGE PROCESSING

The image system is designed to detect specific targets on the ground and to provide high resolution images of these targets. To accomplish this goal, real time image processing via a web-cam and a laptop mainboard, and high resolution image capturing via a 3.2 Mpixel digital camera is used. Each second, 2 image samples are stored that are taken from the web-cam. 2 samples are more than enough for an aircraft that flies at an altitude of 30m with a velocity of 20m/s. The stored images are scanned with an image process program to locate the target objects. Then, if any objects are found a command is given to the digital camera from the parallel port of the laptop to take a picture at that instant.

In order to achieve real time processing, the laptop mainboard is decided to be put in the aircraft. The advantages of placing the mainboard in the aircraft are as follows:

- the aircraft continues to perform the task and obtains necessary images even when the communication with the aircraft is lost
- voluntarily, images may not be sent to the ground station to avoid any possible hacking.

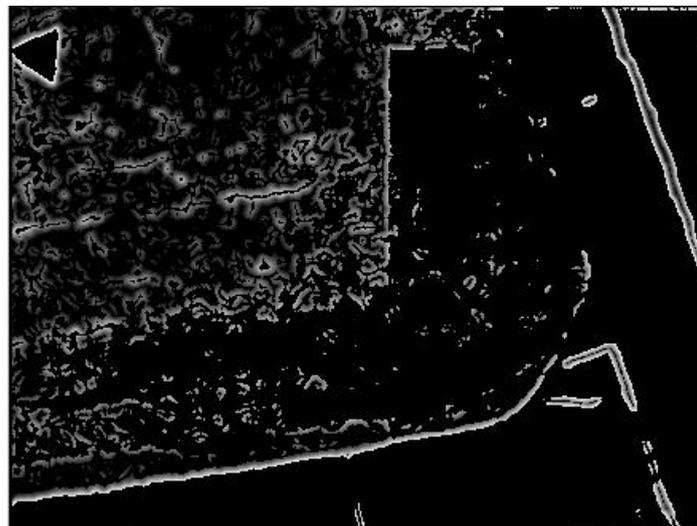
- The increase in the amount of disturbance in the images are avoided when they are transferred to the ground station
- The delay of real time imaging is avoided

Image processing program

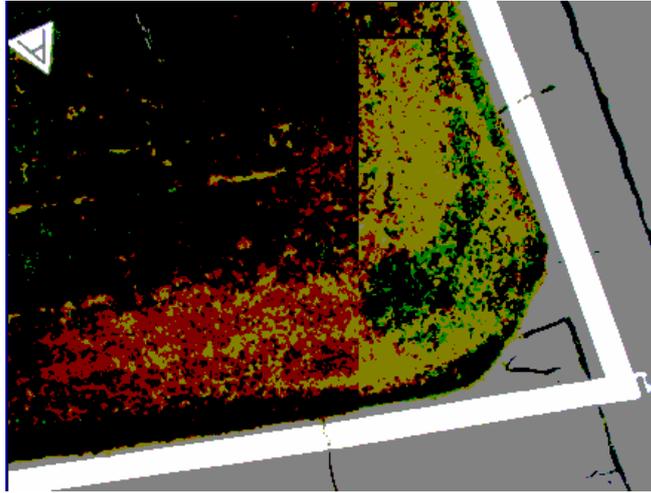
The goal is to obtain good quality pictures of the target objects. The size is the criteriaon for determining whether there is a target object or not. An image processing program with an algorithm that fulfills this purpose is run. An example photo from last year's AUVSI Student UAV Competition is used while determining the aspects of the image processing program:



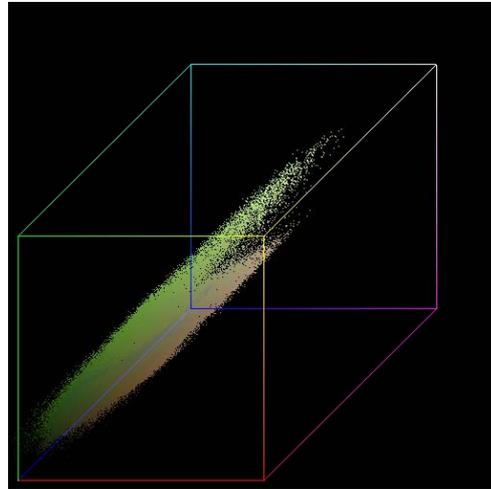
Sobel filter is used to emphasize the edges of the objects that are in sight of the web-cam. Unfortunately the grassy area caused a lot of disturbance due to large amount of color fluctuations:



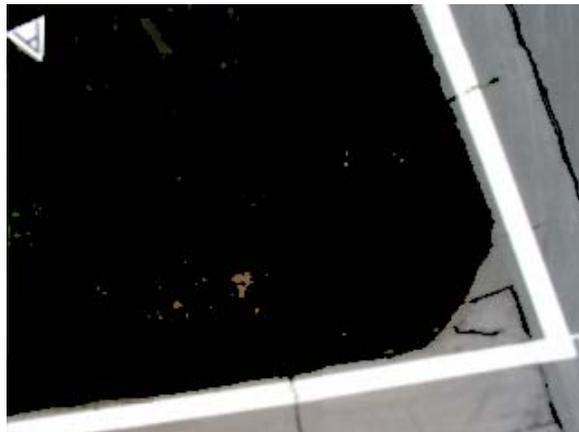
Via bit cutting technique, the number of colors present is reduced to 27, but still the grassy area caused a disturbance:



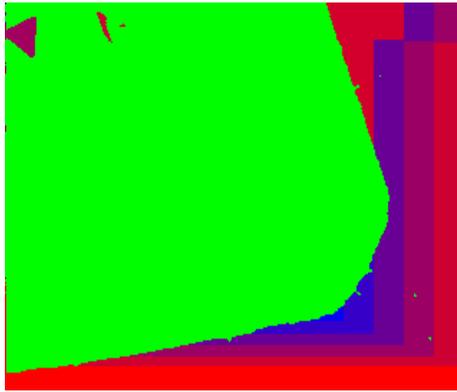
The Bayes method, which is also used in skin detection procedure, and which helps to make the statistics of a desired/undesired area's color is used to obtain a characteristic for the grassy area:



After getting rid of the disturbance of the grassy area, connected component labeling based algorithm that scans the image is developed:



The following is an example of the final processed image:



High resolution camera and web-cam

Samsung Digimax 301 is used as the high resolution provider camera of the system. Although this model is very cheap, it captures 3.2 Mp images via its ccd sensor. Another advantage of this model is that its memory card can be upgraded by changing the SD card. It is also light weighted.



A small electronic board is placed between the camera's button and the parallel port of the flight computer so that the camera can be controlled from the image processing program. When the program detects an object it takes a photo with this camera automatically.

Technical Specifications;

Max resolution:2048x1536

Effectice pixels:3.1 Mp

Sensor type:CCD

Autofocus:Yes

FLIGHT CONTROL SYSTEM: MICROPILOT

The Micropilot MP2028g is used as the flight controller of the aircraft. Micropilot uses gyros to stabilize the aircraft around its roll/yaw/pitch axis, GPS antenna to track its own location, ultrasonic altimeter to calculate altimeter while close to ground (landing), pitot-static tube to calculate airspeed and altitude.

Micropilot can be programmed via 2 main programmes: Hyperterminal and Horizon. The flight paths are easy to be programmed with the Horizon interface. The GPS coordinates that the aircraft should travel through are preprogrammed to form a predetermined flight path. The predetermined flight path can be changed via Horizon during flight as well, if sending the aircraft to a waypoint that the Micropilot is not preprogrammed to fly through is necessary. Micropilot uses PID controllers to determine and control the attitude of the aircraft. The gains of the aircraft are set by trial and error to maintain a stable flight.

GROUND CONTROL STATION AND COMMUNICATIONS

Ground station includes a laptop and an access point. The hardware and the software which are used in ground station is chosen as the simplest ones that respond to the demands. The only function of ground station computer is accessing the flight computer by using remote desktop program. So, the only necessary feature of this computer is that it has a 10/100 ethernet port. Today almost every computer has ethernet ports; therefore, the cost of the ground station computer is very low.

Technical Specifications of ground station computer:



FUJITSU SIEMENS AMILO M1451G-AG

- Intel Centrino Mobile Pentium M 750 Processor (1,86 Ghz 2MB Cache)
- 1024MB (2x512) DDR2 RAM
- 80 GB HDD
- **10/100 ethernet**

Ground station's most important feature is the access point. Airties WOB200 is used as the access point. Wob 200 provides 2.4ghz 802.11b/g connection between ground station computer and flight computer.



(Wob 200)

WOB 200 802.11 b/g Access Point

Range:400m@54Mbps

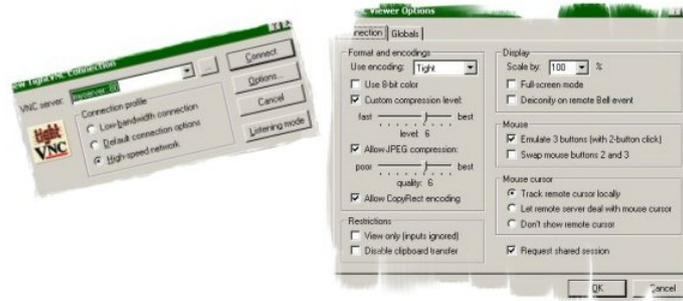
1km@18Mbps

[3km@5.5mbps](#)

Weight 200gr

Security:64-128 bit WEB

TightVNC is used in ground station computer which uses Windows Home as the operating system. TightVNC brings flight computer's desktop to ground station's monitor.



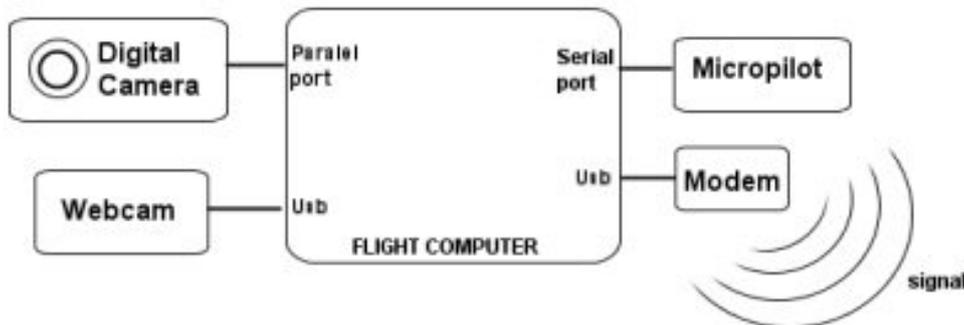
-Tight VNC screen shots-

The advantages of TightVNC against other remote desktop programs are as follows:

- It is an open source program. So it can be modified according to the user's desires
- The efficiency of system bandwidth usage is extremely high
- Orders taken from ground station computer have priority
- Maximizes efficiency by setting up the optimum image resolution for system bandwidth
- Allows file transferring
- Starts up when the system starts up

The same program's server edition is installed into the flight computer.

Flight platform



One of the worst problems of UAV systems is losing the link between the ground station and the UAV. Lost or disturbed link between the image processing camera and the image processing program prevents the program to work correctly. The same situation occurs if the link between the ground station and the micropilot breaks. So data link is very important for the vehicle to run properly.

Laptop mainboard which is placed in the flight platform helps the system to run properly. Image processing program, Micopilot's ground station program and TightVNC are installed in this computer. Via the remote desktop connection between this computer and the ground station computer, these programs can be controlled from the ground station computer. The webcam used with the image processing program and the modem used are plugged into this computer from the usb port, micropilot is plugged in from the serial port and the digital camera is plugged in from the parallel port to this flight computer.



Technical Specifications of ARMA ELEGAN laptop mainboard;
Cpu:AMD mobile sempron 1800Mhz
Ram:512 mb
Hard disk:40gb
 4 Usb Port,10/100Lan ,parallel port
weight 658 gr
Power required:1.1 A/h

Image processing program is installed into Usb 2.0 memory stick for the sake of safety. If an accident occurs and the plane crashes the data which has been processed until that time will be saved in usb storages.

Via the systems used; UAV gets the ability to complete the mission and return home without any link from the ground station.

Modem

Systems' orientation and location always changes;therefore, the antennas used for communication must be multi directional. To connect the UAV to the ground station computer SignalMax Wireless USB LAN Adapter is chosen. This specific modem is chosen due to its range and the antenna type. The antenna used in this modem is multidirectional omni antenna, so it has no dead zone. Modem is attached to the bottom of the fuselage to make the communication with the ground possible. Another advantage of this modem is that it can be plugged in from the usb port, so no extra power is required.



Technical Specifications:

- One MILE open-field line of sight performance*
 - Resistance to RF interference
 - 802.11b/g compatible
 - 128 WEP Encryption Security
 - Direct Sequence Spread Spectrum
 - Designed to optimize broadband throughput over maximum distances
- Power requirement : ~500 mAh

SAFETY

Safety is an indispensable aspect of an UAV design. Therefore, great importance is given to this issue while developing the aircraft systems. UAV's should not risk human lives and should protect the systems it carries within.

Safety according to the team is, being able to make a safe flight, being able to perform the tasks given, and if an accident happens anyway, being able to keep the collected data safe and available still.

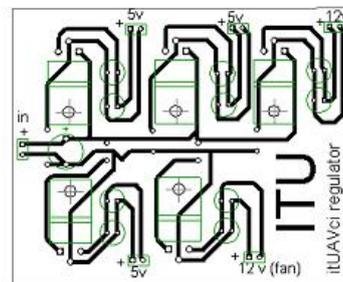
Thus;

- Components that are effected by magnetic interference are covered with magnetic fields (aluminum Faraday cages)
- Image processing is done inside the aircraft so that if the link with the aircraft is lost, the targets will still be found
- Ground station program is ran in the mainboard that the aircraft carries; therefore, passing to safe mode due to short link losses are avoided
- Since the image processing program runs in a USB flash memory, in the event of a crash the thumbnails of the taken photos and the log file of the image processing program is kept safe
- In case of a complete loss with the RC link, the autopilot continues to perform the mission
- If the main battery that is being regulated fails, other batteries that are connected to the receiver activates

Regulator



-High Current Regulator-



-Regulator scheme-

A regulator is produced to provide the electronic components (receiver, safety switch, autopilot) with the appropriate amount of voltage and current. One 12V and three 5V voltage outputs are provided by the regulator from a 15-35V unregulated voltage. The problem of over heating due to high currents is solved by placing a cooling block and a fan over the regulator. To avoid the fan from stop rotating, the fan chip is separated from the system. Advantages of using the regulator:

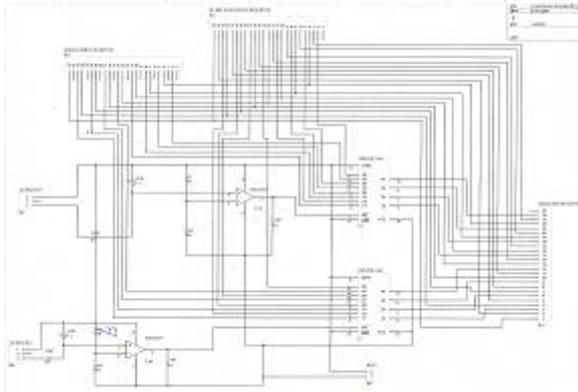
- Instead of using several batteries, only one battery is used
- Lighter payload
- The risks generated by several batteries are

Technical inspections of the regulator is as follows:

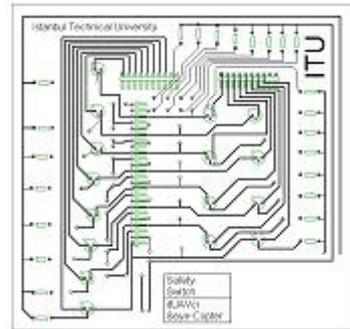
	Voltage	Current (Max)	Required current
Input	13-35 V	12 A	~ 4,1 A
Output (1)	12V (+/- 0.03V)	3 A	~0,9 A
Output (2)	5V (+/- 0.03V)	3 A	~1 A
Output (3)	5V (+/- 0.03V)	3 A	~0.5 A
Output (4)	5V (+/- 0.03V)	3 A	~0.3 A

Safety switch

Safety switch is the most important safety unit present in the overall system. Safety switch is designed to give the control to the RC controller at the presence of a failure in the autopilot.

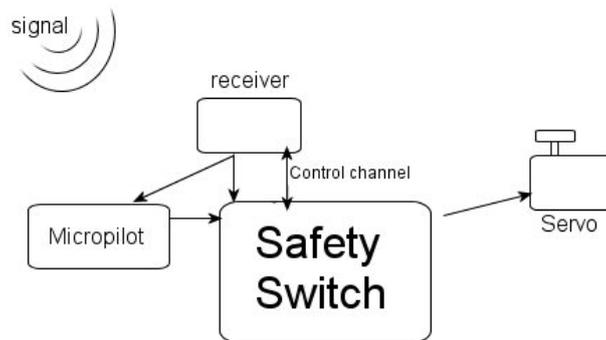


Safety switch #1#

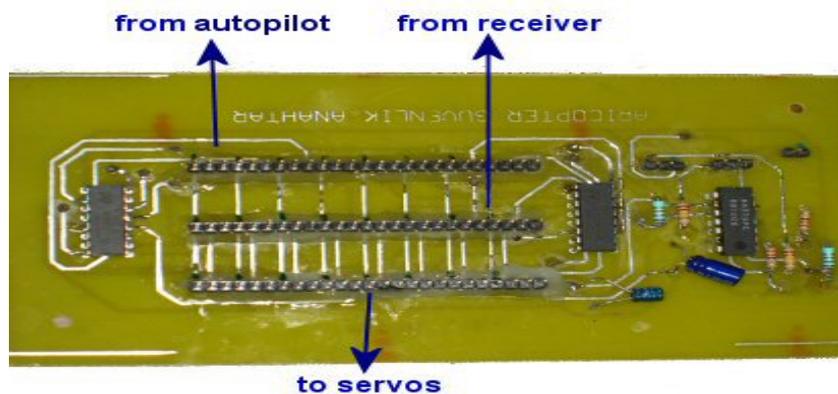


Safety switch #2#

After several tests, the first model of the switch is chosen since it carries fewer components and the signal transfer rate is higher than the second model.



-Safety switch scheme-



Signals coming from the RC controller is divided by a y hornest. One of the cables connect to the micropilot and the other to the safety switch. Safety switch can be controlled by a switch in the RC controller.

The manufactured safety switch has low cost and is easy to produce. Yet, it is one of the most functional components in tha aircraft.

Thanks to...

