The Mizari Project

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Abstract

This paper provides an overview of the first participation of the design developed by the undergraduate students of American University of Sharjah to meet the requirements laid forth in the 2008 Association for Unmanned Vehicle Systems International (AUVSI) Student UAS competition. An unmanned aircraft was designed and equipped with autonomous functionality and aerial imaging system to accomplish the objective of the competition. A ground station and supportive software were used to keep track of the aircraft routine and log the raw data gained from the flight. The overall objective of the competition was to identify and locate ground based targets within a confined area. These targets will be based on different alphabets with different colors. Achieving complete success depends upon mission elements which include autonomous take-off and landing, autonomous control and waypoint navigation, ability to change or revise targets while during the flight and finally to locate the target. Onboard equipment used was 3DM-G IMU, Garmin GPS, Camera and an air data system for flight control. Additionally, safety features such as manual override was also installed on the aircraft, R/C Trainer, to accommodate turbulence and therefore taking control of the aircraft anytime. Presented in this report are the competition requirements, aircraft design and testing, the processes involved in accomplishing the goal, and the results and achievements.

1 Introduction

1.1 Overview

Unmanned Systems especially Unmanned Aerial Vehicles (UAV) have gained a wide range of applications over the recent years. These include civilian applications in addition to military applications. One of the most significant civilian applications is the use of UAV's to access inaccessible regions such as nature stricken areas. For this region (Middle East) a very important use of UAV is the monitoring of remote oil pipelines.

The Team AUS started the design on this project by identifying the minimum requirements, the approach it has to take and the secondary requirements.

1.2 Minimum Requirements

According to the competition rules, it is at least required to build a partially autonomous unmanned aerial system that can navigate a set of given waypoints defined by GPS co-ordinates after a manually controlled take off. Once air-borne the UAV should be able to detect and identify certain target images and transmit back the GPS co-ordinates of their positions, and finally return to the launching point for a manual remote controlled landing.

The safety of the vehicle as a whole was given utmost importance in this project. To enhance safety several steps were taken such as having components placed to avoid interference, use of an RPM sensor to monitor engine stall and having a manual override circuit to switch from autonomous to RC flight.

1.3 Approach

In order to accomplish this project, it was first necessary to learn how it can be carried out. This was the very first task of the AUS-Mizari team members. Apart from the basic tutorial sessions, an extensive literature review was done, in which team members went through all the journal papers available in the competition organizers website. After completing this step we developed the following 3-stage approach:

1. **Monitoring**: In this stage, sensors like the IMU, GPS, and Air Data unit were tested individually in the lab and their output is obtained in the ground station. These sensors are then mounted in the aircraft and their output is monitored via transceivers in a remote-controlled (RC) flight test.

2. **Basic Autonomy**: In this stage, basic autonomy like altitude hold, speed hold, altitude rate hold, Turn Compensation, Turn Coordination, Turn Rate Control, Bank Angle Hold, Heading Hold etc are developed and tested.
3. **Full Autonomy**: This is an advanced level. In this stage, the aircraft navigation capability is developed. These include automatic take-off and landing, climb, cruise, and loiter. The path planning is also developed in this stage and tested.

1.4 Secondary Requirements

Besides fulfilling the minimum requirements our team identifies the sturdiness of the vehicle and its capabilities to flexibly adapt to different types of systems as a priority.

2 Vehicle and component integration

2.1 Airframe:

The airframe used is a standard high wing trainer. It is remote controlled and has servos for controlling of throttle, elevator, rudder and ailerons. The basic dimensions of the airframe are as follows:

Wingspan	214 cm
Fuselage length	147 cm
Chord length	44 cm
NACA airfoil number	8316
Gross weight (with components)	6.1822 Kg

2.2 *Payload and their function:*

The payload used onboard to accomplish the mission is as follows:

Payload	Function
IMU (inertial measurement unit): Microstrain 3DM-GX1	To obtain the orientation of the aircraft and also the accelerations in x, y & z directions.
GPS (global positioning system) Garmin 15L	To obtain the position in terms of latitude and longitude
Air data unit comprising of an absolute pressure sensor and a differential pressure sensor	Absolute measures altitude whereas the air speed is measured by the differential pressure sensor
Transceiver (i.e. a wireless modem) Maxstream 9xtend	To communicate data to and from the vehicle.
RPM sensor	To measure the engine RPM
Camera Black Widow KX131	To achieve target location and identification

2.2 *Payload integration:*

In integration of the components in the aircraft, payload and its allocation is the most important factor. This is due to the fact that the components assembled on the aircraft can shift the centre of gravity and this in turn can affect the stability of the aircraft during the flight causing serious consequences. Beside effects on the CG, these components can cause interference either from their wires or from the transmission frequencies. This will lead to loss or corruption of data from the sensors. Onboard sensors used include Garmin GPS, 3DM-GX1 IMU, Chip S-12, and Transceiver, RPM sensor, Black Widow Camera, Air Data system, Battery and power distribution PCB. Finally to avoid interference or any short circuits during operation, we have created separate compartments to separate the components from each other. It also improves management of the components and their reliability.

2.3 Safety and reliability:

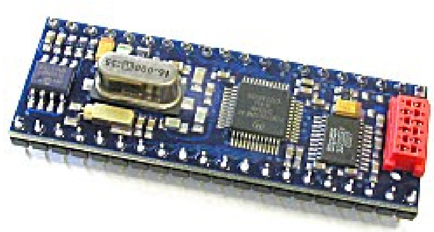
To enhance safety the following steps are undertaken:

- A manual override circuit is designed so that switching from autonomous flight mode to manual mode is always possible
- An RPM sensor is also added so that if the engine stalls during flight it can be detected earlier on.

3 Autopilot

3.1 On board processing microcontroller network:

The heart of the autopilot system is the processor network that is to be used. In our case a ready made autopilot is not being used but instead an autopilot is being designed from the basic components. To read the measurements from the various sensors and to execute the control algorithm any autopilot requires an onboard microcomputer or a microcontroller. For our task we have chosen a microcontroller from the HCS12 series of Motorola. It is mc9s12C128 microcontroller which is mounted on a chip that adds interface for using the microcontroller. The chip is manufactured by Elektronikladen, Germany and is called ChipS12. One of these microcontrollers are not enough to carry out all processing hence we are using three of these chips networked together via a CAN (Controller Area Network) bus.



Each ChipS12 has one serial port, one CAN port and 5 PWM channels and several analog-to-digital ports. All of these options enable to design an autopilot by the integration of the ChipS12 with the necessary sensors.

3.2 Sensors used

To design an autopilot the most important equipment other than microcontrollers are sensors to obtain the necessary measurements for accurate navigation. The most important component is an IMU. We are using a ready made IMU from Microstrain 3DM-GX1. This is a very accurate sensor because the output is filtered and gyro stabilized for accuracy. The output is an RS232 signal and is read at the serial port of one of the ChipS12. The IMU gives us the measurement of the Euler angles, the angular rates about each of the three axes and also the accelerations in theses axes. The IMU is itself subdivided into 3 accelerometers, 3 rate gyros and a magnetometer.

Another main component of our autopilot system is the GPS. In our case we have used a low cost Garmin 15L GPS of reasonable accuracy of less than 5m. It has a refresh rate of 1 Hz. Latitude and longitude measurements are extracted from it and it can also be used to obtain the ground velocities. Also the GPS gives RS232 format output and it is read at another ChipS12.

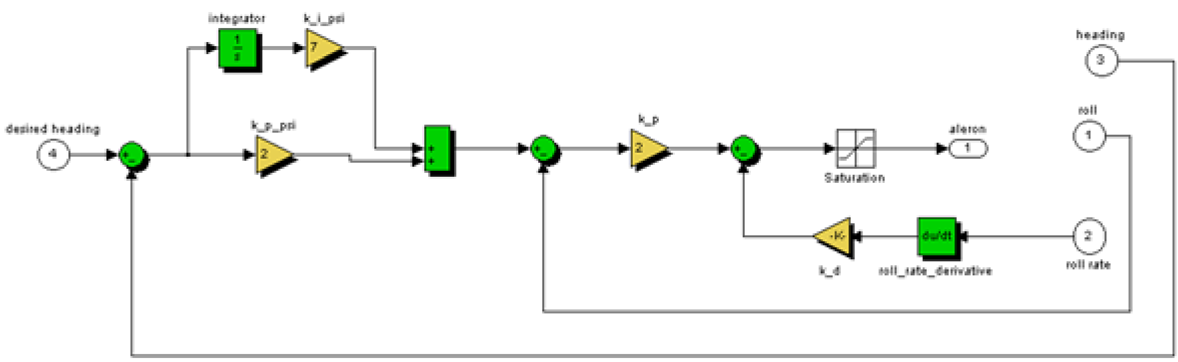
An air data unit is also constructed from an absolute pressure sensor and a differential pressure sensor. Both of these sensors give analog outputs which are read at the analog-to-digital port of the microcontrollers. The differential pressure sensor is connected to a Pitot static tube attached on the wing. The differential pressure gives the air speed measurement by calculation of difference of static pressure and total pressure. The absolute pressure sensor is used to measure height by change in absolute pressure due to elevation changes.

An RPM sensor is also used to measure the engine RPM.

3.3 Control and Path Tracking

The autopilot design was made using simple PID controllers. The autopilot control consists of longitudinal and lateral autopilot. The control consists of two stages: stability and navigation. The stability autopilot consists of altitude hold, speed hold, altitude rate hold, Turn Compensation, Turn Coordination, Turn Rate Control, Bank Angle Hold, Heading Hold etc. These were built using a technique called successive loop closure, which included controlling the rates in the inner loop. This stabilizes the transient response of the parameters being controlled.

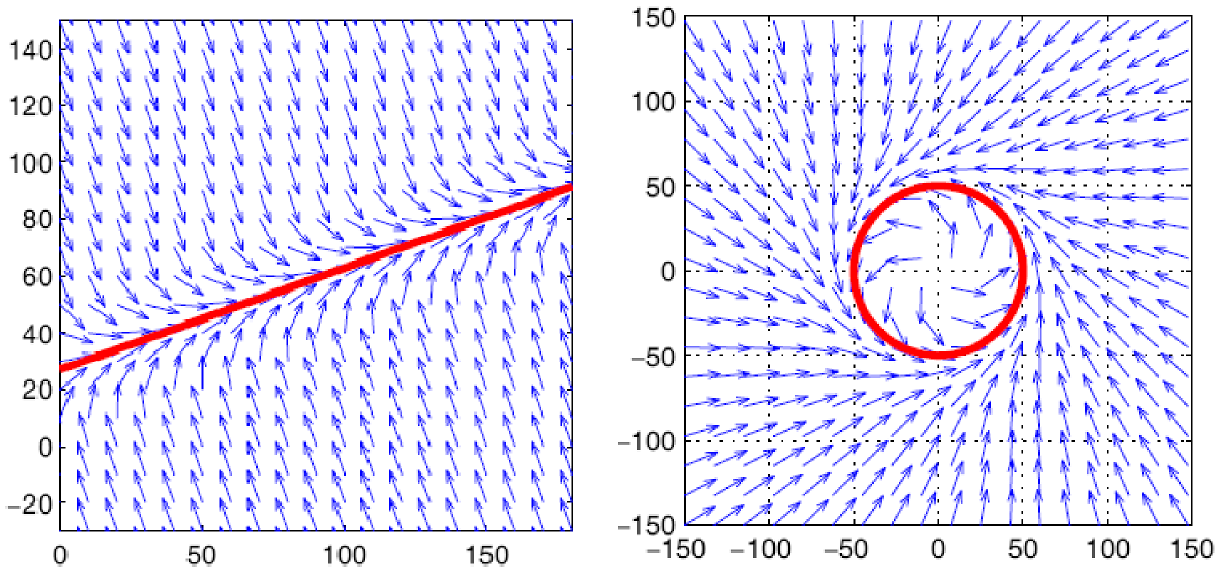
The autopilot was first built and simulated in Simulink/Matlab using the Aerosim toolbox.



The control system is based on the Vector Field Path approach [1]. This method was developed to provide accurate path following for miniature UAVs under the presence of wind. According to the tests carried out by its developers, the system demonstrated a mean path following error of less than one wingspan for straight lines and orbit paths, and less than three wing spans for paths with frequent changes in direction.

This method is applicable only for a flight course made up of straight lines and arcs, and hence can cope with most practical applications including ours.

Following are the vector fields generated for straight and circular paths. [1]



It can be noticed that these vector fields act similar to potential fields which have been used widely for path tracking in the robotics turf for a long time now.

When converting a flight course into straight lines and arcs for this method, one needs to be sure of what he wants. That is to fly the UAV in a way to preserve equal path lengths or fly directly over the waypoints or to turn in early to minimize the flight time (summarized in the figure below [1]). In our case, the AUVSI competition rules state that the UAV must pass through the given GPS waypoints.

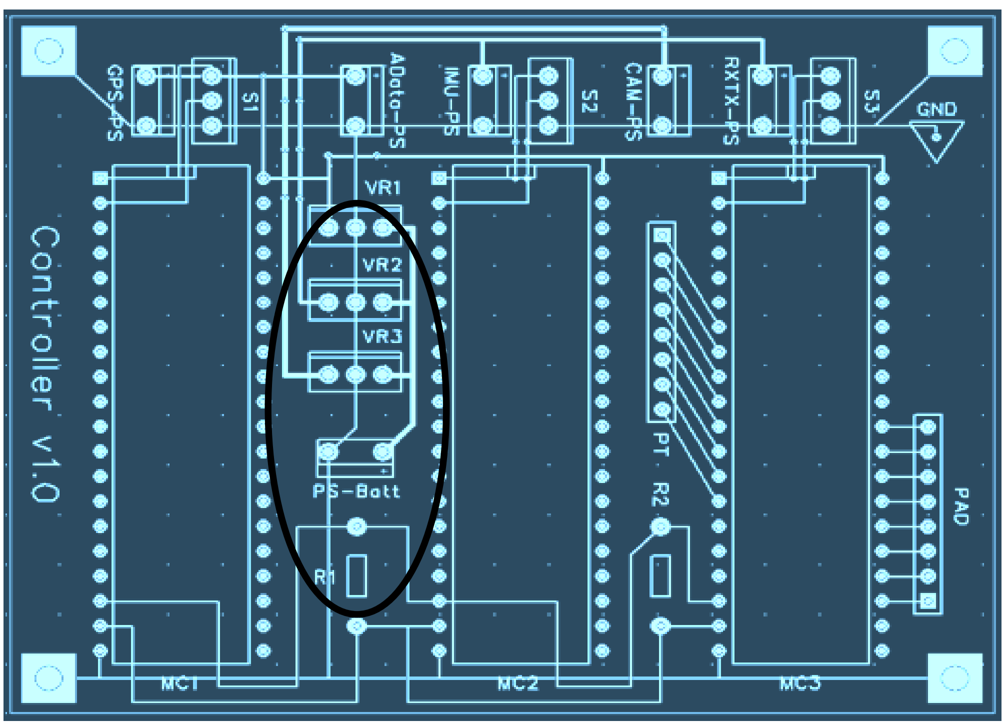
4 Electrical Systems

4.1 *Battery*

The whole control system, which includes the micro-controllers and the sensors, is powered using one single 4-cell *Thunder Power Lithium-Polymer 4600mAh, 14.8v* batteries pack.

4.2 *Power Distribution Circuitry*

To avoid the usage of several batteries to power up the whole system containing the micro-controllers and the sensors, a power distribution mini-system was developed. This system consists of one main battery mentioned above (Thunder Power Li-Po 14.8V) and a few voltage regulators.



It can be seen from the figure that three voltage regulators have been employed. VR1 will supply 5volts output to the GPS, the Air Data unit and the three microcontrollers. The other two regulators output a voltage of 9volts, one of which is being used to power the IMU and the Radio Transceiver, whereas the other will be used to power the camera alone due to its relatively high current requirements.

Note that the power supply for the aircraft servos has not been included in the layout above. This has been done to isolate the critical components of the aircraft required to control or maneuver it if in case the autonomous controller fails. This way the pilot will have complete secure control over the aircraft after switching it to manual mode using the manual override switch.

4.3 Wireless Communication

The information link between the ground-station and the onboard vehicle controller is established via the *Maxstream XT09* transceivers. Micro-controller (3), after receiving all the information from the other micro-controllers via CAN interface, generates a DATA Packet that is transmitted to the ground-station.

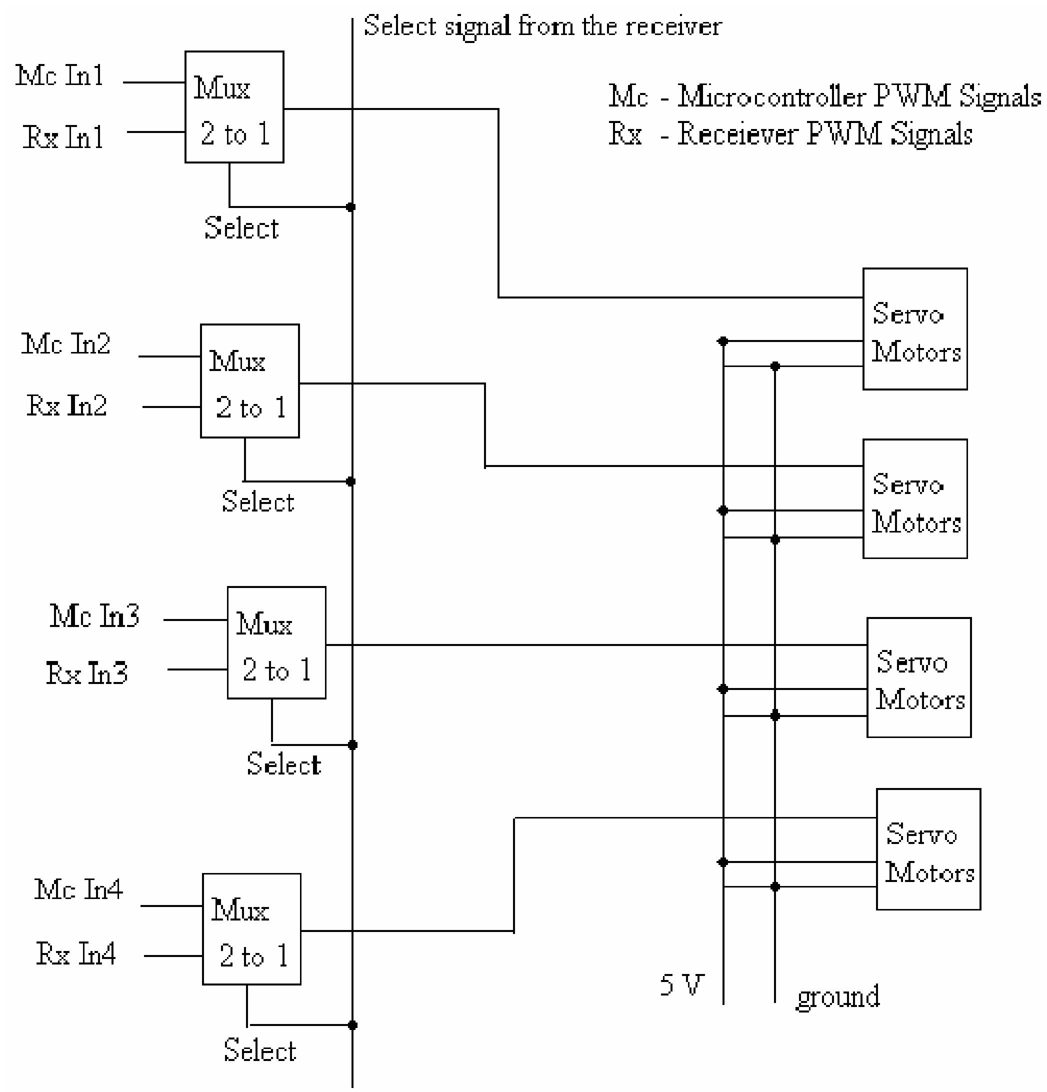
Following is a DATA packet extracted from a test flight log:

@089.80!001.20#-008.80$2519.2622%05529.8768^0234.43*

@089.80	Signifies the beginning of the packet with the '@' symbol and gives the yaw Euler angle in degrees.
!001.20	Roll Euler angle in degrees.
#-008.80	Pitch Euler Angle in degrees.
$2519.2622	Latitude (ddmm.mmmm).
%05529.8768	Longitude (dddmm.mmmm).
^0234.43*	Time Stamp in seconds with '*' indicating the end of this packet.

3.5.2 Manual override circuit

The manual override circuit is designed so the human pilot who is on the ground station can take full control over the aircraft in case of any emergency. The manual override circuit is installed on the avionics unit where it switches between the signals coming from the microcontroller or the signals coming from the RC receiver as shown in the block diagram.



MANUAL OVERRIDE BLOCK DIAGRAM

5 Ground Station

5.1 Overview

Ground station is a very important part of the project. It is a piece of software that basically communicates with the aircraft from the ground. A ground station is necessary to:

- Monitor the various parameters of the aircraft
- Perform a path planning between defined GPS points
- Transmit information like optimal path or any other user defined information to the aircraft

- Control the aircraft if necessary

According to the AUVSI rules, the Ground station must have the following features:

1. The system should have the capability to adjust mission search areas in flight. If the system has the capability to change mission search areas in flight, the new boundaries shall be displayed to the operator.
2. The system should be able to automatically detect/cue targets with a false alarm rate that does not exceed the detection rate.
3. The system should be able to provide imagery and actionable intelligence in real time.
4. The ground control system displays shall be readable in bright sunlight conditions
5. The system shall display "no fly zones" to the operators and judges
6. The system shall display search area boundaries to the operators and judges
7. The system shall display current air vehicle position with respect to the "no fly zones" and mission search areas to the operator and judges
8. The system shall display altitude (MSL) to the judges and operator

The ground station was built in Visual Basic. The ground station consists of four parts:

- Telemetry gauges
- Telemetry value display
- Map display
- Parameter adjustment controls

5.2 Telemetry gauges and display

There are six gauges that display the aircraft parameters. These are similar to the standard aircraft cockpit dials and gauges. These gauges are ActiveX controls that can be programmed in Visual Basic. In addition, the parameters are also displayed in a text box. Gauge position, size and units of measure can be adjusted by the user.

5.3 Map display

The ground station has a GMS moving map ActiveX control that can display the latitude and longitude of the aircraft's current position on a map. The map also has a breadcrumb trail feature, by which it is possible to display the path which the aircraft has travelled. The current position in the map is displayed by a small airplane, which changes its heading by the value of Yaw and changes its position by the longitude and latitude reading from the GPS.

5.4 Parameter adjustment controls

The ground station consists of standard variable boxes that allow the user to adjust the various control gains.

6 Imaging

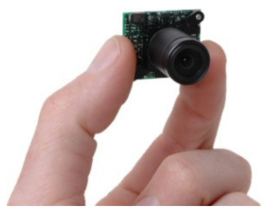
6.1 Overview of minimum threshold:

The minimum requirements as per the rules are to exactly get the position of the targets and also to identify each of the targets by identifying the target color, the character on the target and its color. This can be done completely autonomously or the identification can be human. Human detection is employed in the system. The approach is to select the target by clicking on the video feed. The image from the video is taken and stored along with the GPS coordinates of the target which are obtained by some basic processing.

SAMPLE IMAGE OF TARGETS ON DIFFERENT TERRAINS.

6.2 Camera:

The camera used is a very light one from Black Widow (12.2 grams) (kX141). It is mounted in a gimball for safety. It has its own video transmitter and receiver.



6.3 Video interface with ground:

This is part in which work is in progress. All that is known is that the camera is supplied with a receiver that should be connected with the ground station. To connect the camera to the laptop an analog to digital video converter card has to be installed to the computer.

The initial plan is to use the video feed from the air along with the other telemetry data on the same laptop which will serve as the primary ground station.

7 Conclusions

The competition has given us the opportunity to enhance our skills and creativity and improved our knowledge in vast fields. This paper, in short, describes the way we have proceeded with our design, the obstacles we faced in our project.

8 References

Derek R. Nelson, D. B. (2005). Vector Field Path Following for Miniature Air Vehicles. *IEEE TRANSACTIONS ON ROBOTICS* .

Beard, R, & McLain, T (ND). *UAV Book*.NA: Brigham Young University.