DEVELOPMENT OF AN AUTONOMOUS AERIAL RECONNAISSANCE SYSTEM AT GEORGIA TECH

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ABSTRACT

The Georgia Tech aerial robotics team has developed a system to compete in the International Aerial Robotics Competition, organized by the Association for Unmanned Vehicle Systems, International. The team consists of a multi-disciplinary group of students. The team has developed a multi-year strategy to complete all levels and the overall mission. This document summarizes the approach taken and the current status of the project. First the approach taken to achieve the objectives of the required missions is described. Then, the derived requirements for components and subsystems are discussed and designs described.

INTRODUCTION

The Georgia Tech Aerial Robotics (GTAR) team has developed a system to compete in the International Aerial Robotics Competition, organized by the Association for Unmanned Vehicle Systems, International (AUVSI). The mission has been divided into four levels. Level 1 is characterized by the need to fly air vehicle under autonomous control for a distance of 3 kilometers. Level 2 requires an autonomous system to identify a building and open portals (windows and doors) by visual reference. Level 3 requires an autonomous system (not necessarily the same one used for Levels 1 or 2) to enter the building and return a picture of a required object from the building interior. Level 4 requires all levels to be completed by an autonomous system, possibly consisting of sub-vehicles, in 15 minutes. Each level mission must be completed before moving on to the next[1].

The GTAR team consists of a multi-disciplinary group of students, from Electrical and Computer Engineering, Aerospace Engineering, and College of Computing, including both graduate and undergraduate students. The team has developed a multi-year strategy to complete all levels and the overall mission. This document summarizes the approach taken and the current status of the project. First the approach taken to achieve the objectives of the required missions is described. The derived requirements for components and subsystems are discussed based on this approach. The current status of the development is discussed.

APPROACH

An initial assessment of the mission and the associated levels brings out the conflicting requirements on the autonomous system. It must travel long distances and be small enough to enter a *1 m* by *1 m* portal. This naturally leads to a multiple component system, consisting of a primary air vehicle and one or more secondary, possibly multi-mode (travel both on ground and through the air) vehicles. The overall approach to the final mission consists of three stages:

- Flight to designated site and identification of the building and an open portal
- Delivery of sub-vehicle(s) through the portal
- Search operations inside building to locate the required object

Two options are being kept open for the overall mission: (1) a two-component system with a primary air vehicle and a secondary multi-mode vehicle that enters the building, and (2) a multi-component system with a primary air vehicle and secondary (redundant) multi-mode vehicles, which attempt to enter the building. These approaches are shown schematically in Figure 1.

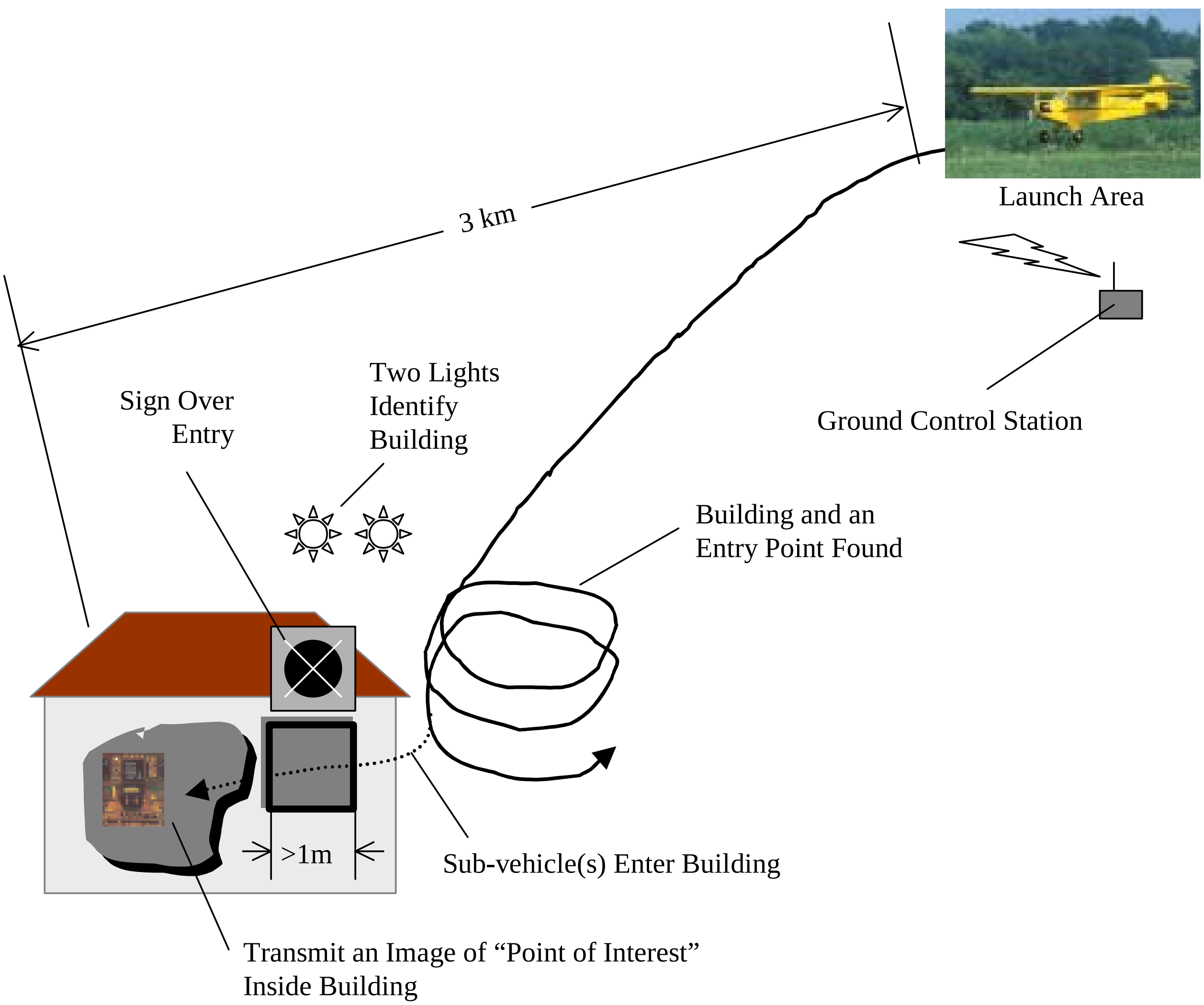

Figure 1. Schematic of level 4 mission approach

A primary vehicle for the mission should have a reasonably high forward speed in order to cover the *3 km* distance with the maximum possible time left to accomplish other objectives. For example, a *60 km/hr* speed would require *3 minutes* to complete the straight-line distance, and is considered a desirable minimum speed. At the same time, a vehicle that could hover or even land near the building would be well suited for delivering a sub-vehicle. A trade-off exists between complexity of the vehicle and complexity of the delivery process. Irrespective of the vehicle choice, it must have a considerable useful payload capability in order to carry a sub-vehicle to its delivery point. A fixed-wing aircraft offering superior speed and payload capabilities, with its inherent stability and simplicity has been chosen over a rotary-wing craft as the primary air vehicle. The added complexity of attaining an autonomous hover would be greater than the complexity of delivering a gliding sub-vehicle into an open window or door.

The mode of the sub-vehicle delivery into the building is under consideration. The primary air vehicle system will provide estimated locations for building portals, and the sub-vehicle guidance is anticipated to be optical. Components of the sub-vehicle must then fly and/or drive within the building to obtain the required images. The option of deploying multiple sub-vehicles may be desirable for redundancy, to achieve an acceptable probability of completing the mission on a given attempt.

PRIMARY AIR VEHICLE

The primary air vehicle is decomposed into: the basic air vehicle (including structural, aerodynamic, and propulsion elements); a guidance, navigation, and control subsystem; an image processing subsystem; a mission manager; and a power distribution subsystem. These subsystems are motivated and described below.

Air Vehicle

Our primary air vehicle is based on a commercial-off-the-shelf (COTS) quarter-scale Piper Cub kit donated by Sig Manufacturing, Figure 2. The large interior, inherent stability, and large wing area makes it desirable, maximizing reliability and minimizing the necessary effort to achieve autonomous flight. The large interior meets our requirements for carrying the necessary electronics. A Zenoah G-23 two-stroke gasoline engine powers the plane. Because the plane is a scale kit, designed to look and fly like the full-scale airplane, a few modifications were made during its construction for our missions.

- Load bearing members of the wing were reinforced in consideration of future heavy payloads. The plane will eventually carry its own autopilot as well as a sub vehicle with video equipment.
- Wing dihedral was increased slightly for added stability.
- Hardpoints were installed in the wing to mount the sub vehicle.
- Solid fuselage formers were hollowed out to increase interior payload volume.
- Material was added in several places in the fuselage for mounting of electronics.
- Copper foil was added to isolate the electronics from the engine's ignition.
- Fuselage paneling was converted into access hatches for installed electronics.
- The superfluous cowling was discarded.

Guidance, Navigation, and Control

To accomplish the mission objectives, for levels 1, 2, and 4, our primary vehicle must perform autonomous Guidance, Navigation, and Control (GN&C) functions, for flight distances of more than 3 km. In addition, position and attitude estimates available for image processing functions must be sufficiently accurate and updated with sufficient frequency to accomplish the level 2 and 4 missions. We have also derived a requirement that manual control of the vehicle must be available, to: (1) support a flight test program of the vehicle, (2) to enable manual takeoff and landing of the vehicle during any normal mission, and (3) as a backup in case of failure of the autonomous GN&C subsystem. The GN&C subsystem must be able to fly to a flight plan consisting of waypoints. This flight plan must be updateable in flight, from a ground controller (Level 1 and to support flight test) or from an image processing and mission planning subsystem (Levels 2 and 4).

Figure 2. Sig Manufacturing quarter scale Piper J-3 Cub kit, basis of primary air vehicle

To meet these requirements, we utilize a MicroPilot MP2000 autopilot and sensors onboard the vehicle, a Freewave wireless modem link to the ground, NovAtel GPS reference station, and a laptop computer on the ground. This architecture is illustrated in Figure 3, where onboard and ground-based components have been delineated.

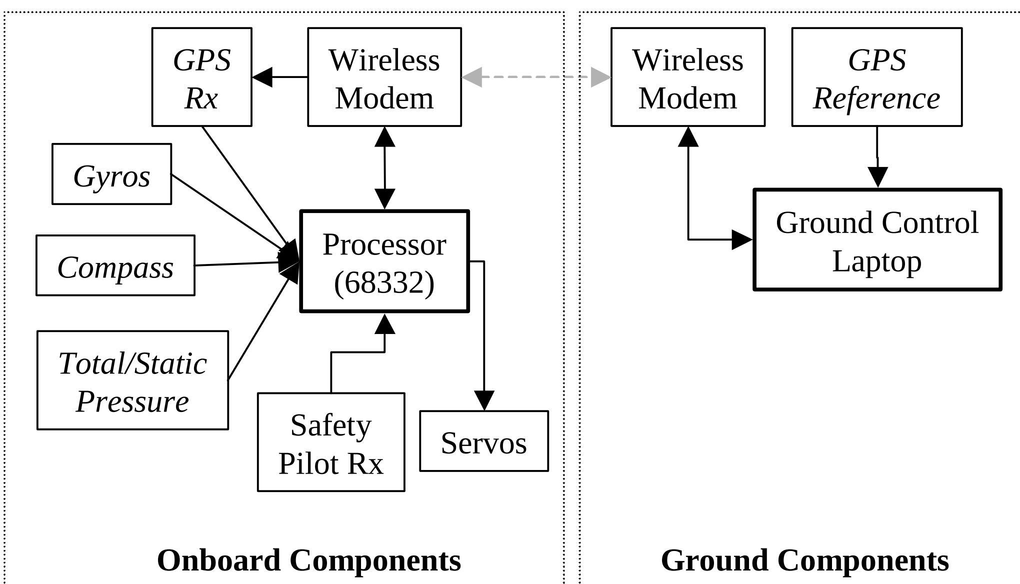

Figure 3. Autonomous guidance, navigation, and control architecture for primary air vehicle

The MP2000 is a miniature, low cost autopilot. Its capabilities include airspeed hold, altitude hold, turn coordination, and GPS navigation. Data logging and manual overrides are supported. All feedback loop gains and flight parameters are user programmable. Our MP2000 is configured with a GPS receiver, 3 rate gyros, a single-axis magnetometer/compass, a static pressure sensor, and a total pressure (i.e., airspeed) sensor. The MP2000 utilizes a 68332 processor[2].

For the level 2 and 4 missions, the image processing and mission management subsystems will receive input from the onboard processor, giving estimates for primary air vehicle position and attitude. We anticipate that some of these functions may be located on the ground, where inputs of vehicle position and attitude (and perhaps other information) will be received from the ground control laptop computer.

Image Processing

To accomplish level 2 and 4 missions, the primary air vehicle vision systems are responsible for target acquisition, i.e. locating the building and the open portals. In order to fix the location of the target, vision systems interface with GN&C to obtain air vehicle co-ordinates. Figure 4 shows the overview of the vision architecture.

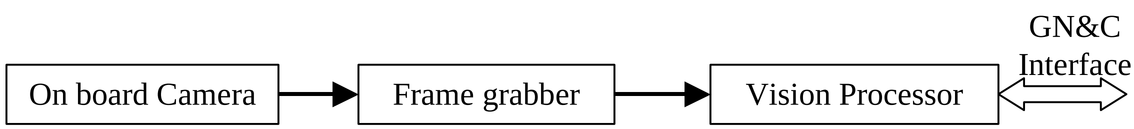

Figure 4. Image processing architecture for primary air vehicle

After the acquired image is tagged with the necessary vehicle state information, it is passed on to the Target Acquisition Module (TAM). TAM is composed of three sub-modules: edge detector, morphing, and statistical pattern matching. The template used determines which target is currently being acquired.

Building Identification

For the assigned missions, a visual symbol (a circle with an "X") surrounded by two lights is used to identify the building. The acquired image is scanned for the presence of one or more buildings. Sanity checks are performed and then any building acquired is scanned for the presence of the identifying mark. If there is a positive match, the coordinates of the building are determined, which are then passed the mission management subsystem.

Portal Identification

The primary air vehicle flies a pattern around the building determined by the mission management subsystem. The TAM is now operating in the "Portal Identification" mode. The template is now a rectangle with sides greater than one meter. The co-ordinates of any positive matches are recorded and also passed on to the mission management module.

Mission Management

For level 2 and 4 missions, the mission management subsystem must determine a flight plan to the target building, once the image processing subsystem has estimated its position. This includes a portal search pattern to be flown after arrival. For the level 4 mission, a pattern is flown to support precise delivery of the sub-vehicle.

Power Subsystem

The power distribution subsystem required for level 1 must provide power for the primary air vehicle GN&C subsystem. The power system is broken into three parts. These are the battery, regulators, and the external connections, illustrated in Figure 5.

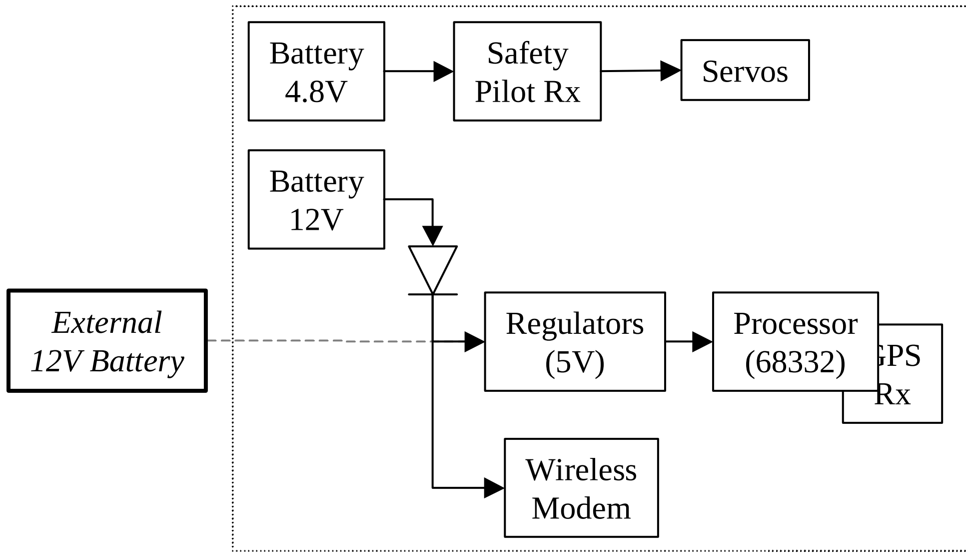

Figure 5. Primary air vehicle power distribution subsystem, level 1 mission

A battery is needed to provide power during flight. All of the required systems on the aircraft need power at *12-V* or less. For this reason, a *12-V* battery has been chosen. Generator options were considered, but for the short length of the required mission, *15 minutes*, a battery is preferred.

In order to provide the correct voltages to the other components on the aircraft, regulators are used. Linear regulators are used rather than DC-DC converters. The primary reason for this is the low current draw of the devices requiring regulated power. These devices also weigh less than DC-DC converters, allowing more payload for the future mission levels.

An external power connector was designed into the system to allow for ground testing of the onboard electronics without the need to run the system on onboard battery power. By designing the system to run on a DC *12-V* source, a simple car battery can be used as the ground power supply source. This is an important capability, allowing the aircraft to be operated in remote locations without the need for wall current.

SUB-VEHICLE

The Level 3 and 4 missions require the collection of visual information from within a building structure. An autonomous vehicle must be able to navigate inside the building, capture images of desired objects and transmit these images to monitoring personnel at the launch site up to 3 km away. Work on an initial prototype has been initiated. A general strategy for the development sub-vehicle is described below.

1. Build a multi-mode (ground and air) robot, which can perform the required tasks without being overly concerned with the problems of delivery within the building.
2. Optimize the sub-vehicle for minimum cost, size, and weight.
3. Develop a system for delivering the robot into the building.
4. Modify the primary air vehicle for delivery the sub-vehicle(s).

Mission Requirements

The main allocated mission requirements related to the execution of indoor reconnaissance are:

- Robotic movements performed inside a building constructed and equipped for human habitat are fundamentally different from the movements required to perform a high-speed flight along a *3 km* course: The use of specialized robots, optimized for navigation in their respective environments is seen as essential, but introduces additional challenges to the overall mission.
- If a separate robot, a sub-vehicle, is used for the indoor reconnaissance, this sub-vehicle must be transported and delivered into the building in such a way that it is capable of initializing its own navigation with a high level of confidence. The design and complexity of the sub-vehicle is therefore closely related to the mode of delivery:
    - If the sub-vehicle is "thrown" or "crashed" in to the room, a higher level of complexity will be required in the robot to ensure a successful transition to own navigation.
    - A more controlled delivery method will transfer complexity to the delivery system, and will allow the use of a simpler and smaller sub-vehicle.
- The sub-vehicle must be able to navigate itself around in a building structure based solely on sensor data collected during the current mission. The robot is not expected to open (or move) doors, but should be able to move wherever humans normally move, including over doorsteps and up/down short flights of stairs. The robot should not exit the building through doors or windows once it has entered. One of the primary design decisions are therefore concerned with the robots main mode of operation:
    - A ground based robot (rover) is easier to design and control, but must be delivered to a floor, and will not be able to cross vertical obstructions. Also, a ground-based rover may not be able to capture the desired information in the building because of the low position of the camera (A control panel in a nuclear power plant is difficult to see from the floor.).
    - An aerial robot would be the ideal choice for the mission, but it's implementation poses a set of serious challenges relating to the issues of limited size/weight, energy storage, stability, and collision avoidance.
    - Ground based robots which are able to jump or perform short flights, may be suitable, but introduce new challenges as the robot needs to know what it is jumping into.
- The robot should be able to search its environment in a somewhat systematic way and avoid becoming stuck under or between objects inside the building. To achieve this, the robot must be able to develop a map of the visited rooms in order to know when it is time to proceed to another room. Also, the robot must also avoid objects (furniture, etc.) and narrow passages.

CONCLUSIONS

The Georgia Tech aerial robotics team has developed a multi-year approach to complete all levels of the International Aerial Robotics Competition mission. The program approach is flexible enough to allow lessons learned to be incorporated into the design as the project moves forward. A primary air vehicle has been developed, which is expected to meet the requirements of the first level of the competition missions. Parallel development progresses on other subsystems, including an image processing subsystem and a sub-vehicle intended to enter a target building after deployment from the primary air vehicle.

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