MSC Aerial Robotics' 2000 Millennial Entry

Kevin Stallard
MSC Aerial Robotics

ABSTRACT

A balance of mechanical and electronic functionality is necessary to increase opportunity for mission success. We have identified and focused on four basic mission requirements. Mechanical design, logical system design, vehicle/human interaction, and sensory classification to help us achieve the goals of the contest. Controller Area Networks are key in reliably delivering time sensitive data and increasing strength of the system through a distributed architecture that extends beyond the physical bounds of one craft or vehicle. The adaptation of these key features to many types of vehicles or systems without extra programming is trivial.

INTRODUCTION

For MSC Aerial Robotics and Mesa College to succeed in meeting the goals of The Association for Unmanned Vehicle System's year 2000 Millennial Event, we must build a craft that is structurally & mechanically robust enough to survive the pressures it will experience in a mock disaster site. In addition, an equally well designed electronic system is vital to giving the craft its autonomy and ability to work with other vehicles, whether ground based or aerial.

Our objective is to balance mechanical and electronic design so the two complement each other in extreme environments. This will increase the overall reliability of the system and our opportunity for success. To help us understand this balance, we have extracted four basic requirements necessary for our system's success and have structured our mechanical and electronic designs to meet them. These requirements are:

1. The aerial robot must be safe to operate, with a high degree of reliability, under a wide range of potentially harmful circumstances and events.

2. The aerial robot should be a single part of a fully autonomous synergetic system of machines.

3. The aerial robot should interact with its surroundings.

4. The aerial robot should have a wide range of sensory inputs to help it understand the environment in which it is working.

While we are currently focusing on the aerial platform, it has not deterred us in designing a framework from which other aerial and non-aerial platforms may interact. Our system is designed to accept any type of autonomous machine as long as it follows the general framework we have created.

Our strategy has included the above requirements with priority on the mechanical, as we need a craft that is superior to that which is commercially available. We have found this to be the most difficult task as there will be many physical and environmental obstacles in the contest arena. In addition, a sound mechanical design simplifies the electronic requirements and improves the reliability of the unit as a whole.

Even with focus put upon mechanical designs, we have also seen it necessary to be inclusive with respect to other types of machines that may need to operate along with the aerial platform. This open system of devices will eventually have the ability to interact with each other in a way that closely resembles nature. This will be made possible by designing the system around a set of many cooperating tasks or processes. The system will be capable of demonstrating a form of emergent behavior in all aspects of its motion and operation.

Mechanical Design

The aerial robot must be safe to operate with a high degree of reliability under a wide range of potentially harmful circumstances and events.

Our craft consists of an eight horse power, twin cylinder, 2-cycle, quarter scale aircraft motor. The motor runs a drive shaft coupled with a centrifugal clutch to a custom designed and built gear box. This gear box supports two vertical shafts that turn counter to each other.

The cylinders of the engine are vertically opposed and move in opposite directions which reduces vibration when compared to single cylinder engines. The engine is started with a "Pattern-60" electric motor from Astro-Flight and doubles as a generator during normal operation, providing between 18 and 20 volts of power at around 1000 watts to the electronic systems. This allows our craft to run and operate as long as fuel is available.

The engine and gear box are mounted to a small frame fabricated from seamless 4130 chromium-molybdenum alloy tubing which meets the MIL-T-6736 specification. The 4130 was chosen because it is relatively easy to weld and because it retains its stiffness and strength much better than aluminum after it has been exposed to the extremes of welding.

The output shafts of our gear box support control mechanisms like those found on medium sized model helicopters except that our craft includes two rotor heads and two swash plates rather than one of each. These controls are actuated with model R/C helicopter servo motors controlled by the craft's computer system. Custom built rotor blades with a four inch chord are mounted to the rotor system.

Our rotor blades are unique because of their width and length in that they are wider and shorter than what is usually found in the R/C helicopter world. Each rotor system is 44 inches in diameter and rotates at around 2,500 RPM. The increased width, the increased speed of the rotor system and the fact that there are two rotor systems has made up for losses which occur in shortening the length of the blades. To help us with our design process, we have taken the time to estimate the performance of this system (1). According to our calculations, we should experience at least 40 pounds of lift from our system with four degrees of pitch in the rotor systems.

In order to operate in an extreme environment, it was necessary to create a body for the craft designed to shield it from obstacles that could damage it. Additionally, the body also shields humans from danger of injury if they happen to be in close proximity of the craft. To state it differently, trees, light posts, buildings, antennae and other protrusions that would normally be problematic to normal open rotor helicopters are of less significance to our craft.

The body provides a protective duct for the rotor system as well as an insulated area for the electronics. To prevent a large weight penalty, it has been fabricated with carbon fiber and Kevlar composites in order to withstand the extremes of the environment in which it will fly. Kevlar is the dominate material on the duct and was chosen because of its excellent durability properties. Kevlar has good chemical resistance and does not melt or support combustion. It is also much more durable than carbon or fiberglass as the aramid fiber provides good resistance to vibration, damage and crack propagation.

However, along with these great durability properties, Kevlar is much less rigid than carbon fiber, and in order to make a duct for the rotors that is rigid enough to not become deformed and cause possible damage to the rotors, carbon fiber is used to increase the rigidity of the duct in critical areas. We used carbon fiber sparingly as stress and vibrations cause carbon fiber to crack and fatigue. However, the combination of these two composites provide the durability and rigidity necessary to protect the rotors from obstacles and protect the craft as a whole from heat, flame and minor collisions.

There are other features of the duct design that give our team some advantage. The duct is in a somewhat open configuration, meaning that gusts and other sudden aerodynamic changes have less of an impact upon the craft. It is also important to note that because of our unique design, only a small amount of surface area can be acted upon by such changes. In addition, the electronics are stored in a water tight, but sufficiently ventilated, compartment which will help to prevent a malfunction if the craft encounters some moisture.

The physical properties of the craft are such that the dynamics of a disaster scene pose less of a risk to the vehicle itself. This makes our craft desirable not only from an operational and longevity point of view, but more importantly, these attributes contribute significantly to the craft's safety.

Logical System Overview

The aerial robot should be a single part of a fully autonomous synergetic system of machines.

The aerial platform is only one part of the search and rescue system. From the beginning of this endeavor, we have desired to not emphasize any specific type of vehicle and still be able to obtain the desired results of the system. In other words, when we introduce other types of vehicles into operation, we want them to perform effectively within their physical limits while keeping the amount of custom programming for that particular vehicle to a minimum.

Seamless Communication

We have also desired to eliminate communication barriers between vehicles that they may more effectively communicate with each other without knowing specifically how to communicate. They are able to talk to another robot with as much ease as talking to their own internal components. It is irrelevant when processes actually execute across the system, making tasks like debugging a ground vehicle from an aerial vehicle possible..

Imagine a scenario wherein an aerial vehicle was to carry a ground based vehicle over some distance and deliver it to some location on the ground. If the distance is great enough, the ground based vehicle will not be able to communicate with the base station. In our design, it would not be necessary. Any information the ground vehicle gathers can be used directly by the aerial vehicle or be relayed back to the base station from the aerial vehicle. In other words, the ground based vehicle doesn't know and doesn't care about where its data is going to be received.

This greatly extends the range and versatility in which the system can operate. Aerial vehicles can control any other type of vehicle (including other aerial vehicles) and vice-versa. It also leads itself to making humans a natural extension of the system. One of the "vehicles" can be a computer console with a human-machine interface that would allow direct and indirect inputs to the direction of the ground and aerial units. A user could, for example, cause the operational units to focus on a particular area, oversee vehicle allocation, and locate malfunctioning units very easily. Everything the robots would experience while in operation can thus be viewed and managed without having to write special communication code to interface with the robots.

Our system can theoretically be designed on any platform or operating system. However, we have chosen the QNX and QNX Neutrino operating systems to help us with our design because they lend themselves to the very design we have chosen. Processes running on one particular platform "see" other processes on other platforms as though those other processes were local. This type of transparency can occur with practically any type of physical communication mechanism available, thus we aren't restricted to any particular communication scheme, and have the flexibility to use whatever makes sense.

As an example, crafts operating in close proximity may wish to use a high speed wireless Ethernet-type communication system. As they move further apart, it may make more sense to use a wireless modem that has a much greater range. The software necessary to make this switch is trivial thanks to the architecture of the QNX operating system.

This ability for robots to communicate across machine boundaries without really knowing, lends itself to another valuable aspect of our system: redundancy. By adding additional computer hardware that is duplicate to what is already on board, the craft has a backup if one computer system fails. Each system knows about all the data and sensory information transacted, but only one has physical control of the craft. If the other senses a failure, it can take over flight and other processing functions as necessary.

With communication barriers eliminated, we can focus on the architecture of our system. We are writing the system as a collection of cooperating processes that are limited to one or two specific tasks. This not only makes debugging and verification of the system easier, it is also makes it easier and faster to develop and write the actual code. Because these processes are running independently of each other in separate memory spaces, if one process crashes, it cannot bring the whole system down. Even device drivers run in user space, allowing them to be started and stopped from the command line, and debugged without a specialized diagnostic system. Again, this increases reliability and safety.

CAN

Another feature of our system is the use of Controller Area Networks or CAN. It has been generally accepted that sensors needing high rates of digital sampling should reside close to the sampling electronics to reduce the effects of transient noise and signals that could potentially degrade the quality of the data. These sampling electronics have also needed to be almost directly attached to the CPU responsible for manipulating that data. This makes a fault tolerant system near impossible unless the sensors were also duplicated. In the late 1980's, automobile manufactures had to be able to communicate with remote sensors on an engine. Their solution was CAN. In the early days, the throughput was slow. Today, throughputs of up to 1Mbaud are possible.

CAN is a fault tolerant, self-recovering data network. The wire protocol is on-chip, and so no extra programming is necessary to handle the wire protocol. It automatically detects errors and resends data if it is lost or corrupted. It also has automatic line contention resolution.

We are using both Philips Semicoductor's SJA1000 and Microchip's MCP2510 in our aerial robot. The MCP2510 allows 8 bit micro-controllers to send data at high speeds to the main computers on the craft. Likewise, the computers can communicate fairly easily with the micro-controllers when necessary. The physical transmission layer is a single twisted pair of wires using a differential mode of transmission. This has the effect of seeing much of the noise and interference subtracted from the signal. Any device that wishes to 'listen in' on the transmissions occurring can do so without diminishing the performance of the network. This allows any of the onboard computers to participate in the control of the craft if and when the original flight controller drops off line.

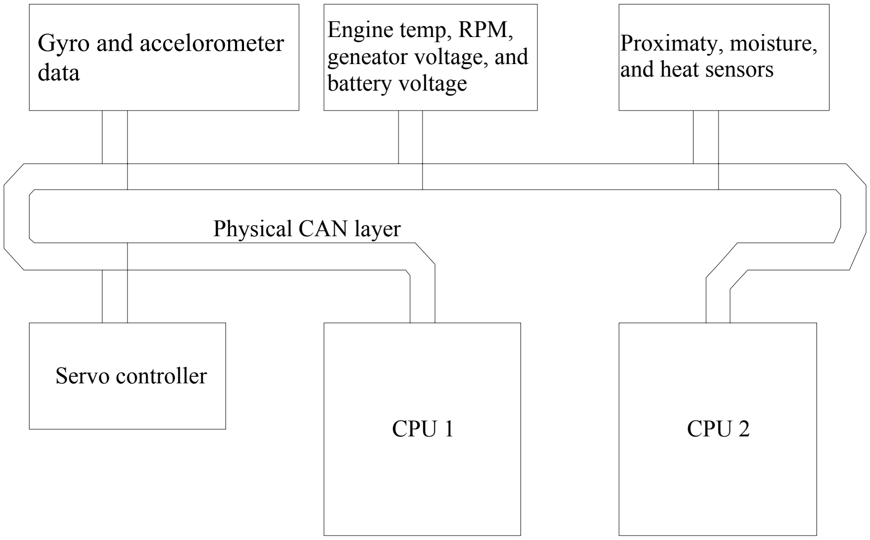

Figure 1 *Using CAN, sensors may be placed in optimal locations irrespective of where the actual CPU hardware has been placed.*

Platform Interaction

The aerial robot should interact with its surroundings.

Our aerial robot should have capabilities that are more than just observational. In a disaster environment, rescuers need equipment and supplies if they are to work effectively in the field. During and immediately after major a disaster (as the one depicted by the Millennial Event) rescue teams can easily become overwhelmed as their numbers may be relatively few. Some survivors may be coherent enough to take care of some of their own needs if they had supplies (i.e. blankets, water, or food). Therefore, our aerial robot has a far greater potential of assisting in a disaster if it has the power and capability of carrying items that may be needed by victims and ground personnel.

Ground support personnel should be able to communicate and give direction to an aerial robot without sophisticated communication equipment (i.e. a laptop with wireless Ethernet). They should be able to give directions through hand and arm gestures, some sort of signaling system using cloth and symbols, or even sound. Until this level of interaction is technically feasible, we propose low power radio links or infrared using handheld PDA systems with *very* simplified user interfaces. As always, ground personnel could radio the base station and request assistance and the base station personnel would then identify which ground vehicles would be of most assistance and then summon them.

Aerial vehicles should also be able to assess dangers to ground personnel and victims. They should have ways of informing ground personnel of possible dangers and also be able to prioritize victims or at least give information that would allow rescuers to assess who they need to treat or retrieve first. These possible dangers might include fire, thick smoke or proximity to hazardous materials.

While we are building these search and rescue capabilities into the design of our system, we won't be able to demonstrate these features during this contest. However, it won't be long thereafter that our aerial robot will be able to exhibit some of these behaviors. Our first endeavor is to use the Palm Pilot from 3-Com to give the craft instructions and to receive information.

Platform Sensory Information

The aerial robot should have a wide range of sensory inputs to help it understand the environment in which it is working.

There are four areas of sensory input required for a vehicle to operate autonomously: first, how the craft moves and keeps its stability while operating, second, obstacle avoidance, third, navigation, and fourth, a group of sensors with the sole purpose of understanding the environment in which the craft is placed. This group of sensors coincides with the purpose for which the craft has been designed. In our case, this purpose would be finding survivors after a major disaster.

Stability

For a ground based vehicle, stability is relatively simple. For slower ground vehicles, no sensory input is required. For faster vehicles, inertial input may be desired to keep the vehicle from becoming unbalanced and tipping or to keep the vehicle on course. For vertical take-off and land (VTOL) aerial vehicles, this first level of sensory input, or stability, is vital. There has to be a frame of reference to which the onboard computers can refer in order for them to perform their function and keep the craft airborne. We are using two frames of reference for our craft: quartz solid state gyros from Systron Donner, a division of BEI Sensors and Company, Inc. (which were donated to us) and accelerometers from Summit Instruments, Inc.

Model Number	**QRS-11**
Power Requirements	+ and - 5volts DC
Range	0 to 100 deg/sec
Short Term Bias Stability (100 seconds at constant temp)	.002°/sec
Startup time	< 1 second
Bandwidth (-90°)	> 60hz
Non-Linearity	0.05% of F.R.
Threshold/Resolution	0.004°/sec
Output Noise (DC to 100Hz)	0.01°/sec/

Table 1 General specifications of Systron-Donner's QRS-11 Quartz Crystal Gyro

With the proper temperature compensation applied, the quartz crystal gyros have been known to have a drift of only 10 degrees an hour, indicating that they are very stable. However, our electronics are not capable of obtaining such stability. To compensate for gyroscopic drift, we have used a combination of accelerometers, an electronic compass and a GPS to reorient the gyros on a periodic basis. In time we will improve the data acquisition portion of our system to further increase the accuracy of our readings.

Obstacle Avoidance

The second area of autonomous operation involves obstacle avoidance. From this level of sensory input and on to the third level (navigation), the sensors become craft independent. In other words, sensors necessary for obstacle avoidance can be used on flying craft or on terrestrial based vehicles. The software necessary to use them is the same, making them completely interchangeable.

The obstacle avoidance system responds like the reflexes in animals or humans. Course corrections are input based upon the initial knowledge of the obstacle. Our system is only sophisticated enough to know that there is an obstacle there, and that the craft should stop. In the case of heat or moisture, through the use of its sensors, our craft needs to retreat opposite the source of the obstacle.

Navigation

The third level of sensory input is purely navigational. Sensors of this type include GPS receivers, vision systems or even sensors capable of tracking non-manmade celestial objects. Magnetometers or accelerometers that depend upon the earth's magnetic field or gravity may also fall into this category as long as they are accompanied by proper signal processing that would result in position information.

Our aerial platform is using a differential GPS system provided by Novatel. Its differential capabilities allow our craft to navigate with sub-meter accuracy.

Target Acquisition

The fourth level of sensory input are those sensors necessary for the craft to carry out its purpose. They give the craft the necessary understanding of its environment in order for it to complete its tasks. In our case, it is required that they detect people located on the ground from the air. Our craft will accomplish this by relying mostly on image capture. Sound is another possibility as well as a radar system that uses an extremely short wavelength radio frequency.

Our craft can be fitted with an array of sensors that can conceivably be used for many types of tasks. Some examples are portable spectrometers (gas chromatography, mass spec, IR, etc.), mine detectors and infrared cameras. Any of these sensors can easily be integrated into our system.

Conclusion

We believe that the main objective of the competition isn't to only find people in trouble, but rather to develop a system that can reliably operate in environments that range from the sublime to the very dynamic and hostile. Different circumstances also warrant different types of robots, and therefore our system, out of necessity, needs to be inclusive and work with various robot types. As we continue to work and are successful in developing this type of system, the possibilities for its use will be many.

References

1. Please refer to ”Autonomous Aerial Reconnaissance Search and Rescue Platform”, Kevin Stallard, June 1999. Written for the 1999 Association for Unmanned Vehicle Systems International symposium.