2014 International Aerial Robotics Competition

in congruence with research into

Intelligent Sensing based on Low-Cost Unmanned Aerial Vehicles (UAV) for Bridge Condition Assessment

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Abstract

The eventual completion of this project envisions the use of an Unmanned Aerial Vehicle (UAV) to inspect bridge infrastructure. This project may also be expanded to encompass general object detection and inspection in order to unburden this technology so that it may reach its fullest potential. The project requires research and development in three distinct areas of image processing, control structures, and integration of systems. Initial undergraduate research sets the base knowledge for the overall project, explores the areas of concentration that are desired to expand upon in the future project, and provides a base UAV model that new researchers can easily understand and expand upon. The undergraduate research starts from baseline knowledge gained from previous students, organizes their work, and develops their research into a more workable design. The immediate application of this research will be a competition in August of 2014 where the UAVs potential can be measured against other designs. This will also be a learning experience to help improve the current UAV design.

INTRODUCTION

Even with recent advances in the area of non-destructive evaluation of bridges [1], visual inspection is by far the most common approach used in practice. The quality of a visual inspection may be influenced by the subjectivity of an inspector and their experience, but the method has proven relatively effective and is likely to remain the standard for the foreseeable future. Beyond the challenges with subjectivity, the visual inspection process suffers from a number of shortcomings such as limited line of sight, the time required for inspection of long spans, and difficulty accessing undersides when the bridge spans large water bodies or major highway corridors. These representative scenarios require the inspector to access locations that are potentially hazardous and have the potential to influence the quality of the inspection results. In addition this project has possible applications to object condition assessment in multiple environments. The modularity of the system components should allow for relative ease of transition between bridge inspection and space related inspections.

The scientific merit of the proposed work are: 1) a new approach of super-resolution image reconstruction from low resolution images based on a non-stationary imaging system (a gimbal-mounted sensor platform) and 2) a new control mechanism framework that incorporates the vibration control of a gimbal-mounted sensor platform into the UAV flight control operations. A benefit of the proposed strategy is that both the super-resolution image reconstruction algorithm and control mechanism are independent of the UAV platform, coupled with a modular sensor platform, allowing for the components to be adapted to alternative UAV platforms with minimal cost.

OBJECTIVES

The final goal of this project is to develop an unmanned aerial vehicle (UAV) as a platform to perform object condition assessment using gimbal mounted high resolution cameras, modularization of detection instruments, remote processing, and variable automatic control. These technologies will have applications in the inspection of hard to reach areas such as external spacecraft integrity, and on a broader aspect, it will also have application in such areas as infrastructure inspections in atmospheric conditions. The research will create a system of tools that will increase the quality of inspections by providing visual records and minimizing the risks that personnel may encounter in dangerous environments. With a UAV as a platform, this research will incorporate a modular design such that instruments and measuring devices can be easily upgraded or replaced. It will use a high definition camera mounted to a gimbal mount in order to take pictures more accurately and obtain images of hard to reach areas. The control system will use various sensing elements such as thermal, LiDAR, image processing, and feedback from the gimbal mount for stabilization. This portion of the project aims to provide a base of knowledge that will allow for the completion of this project and the continuance of research by future academics.

DESIGN

The project requires research and development in three distinct areas of image processing, control structures, and integration of systems. This initial undergraduate research sets the base knowledge for the overall project, explore the areas of concentration that are desired to expand upon in the future project, and provide a base UAV model that new researchers can easily understand and expand upon.. All of these areas will need to be addressed at the same time to minimize the time taken for error corrections, but they will be developed progressively in the order already mentioned to maintain project flow. The current research will setup the initial development and the baseline for the separate components.

Image Processing

In order to minimize the weight and alleviate the computation tasks, extra sensor inputs and the image processing will be wirelessly tasked to a ground station computer. This computer has to have sufficient processing power to input and analyze the streamed video and will run the open source Linux operating system software called Ubuntu. The video used to control the UAV will be analog and streamed via a separate channel from the control signal. A separate high resolution camera may be used to independently record video to be later analyzed or wirelessly streamed for viewing purposes only. Software such as OpenCV will be used as baselines of image processing and will be improved upon for the final design.

Initially image streaming was accomplished by previous UAV teams by utilizing a GoPro Hero with high resolution and wireless network capabilities. The GoPro camera works fine and produces excellent quality photos, but the streaming of video lags by a few seconds. The lag is unacceptable as the images still need to be processed by software such as OpenCV. In order to curb this problem, a lower resolution CMOS camera with 640x480 resolution has been incorporated into the UAV design to obtain live analog video for the UAV control. This analog video is streamed to a remote computer by a5.8 GHz transmitter and receiver system. An analog, USB video capture device also needs to be used on the computer side in order to input the video onto the computer. The video capture device acts as a webcam to the computer and can be easily utilized by the OpenCV software.

OpenCV is an open source image processing software with many examples to get the beginner used to the ideas involved. The version of OpenCV used required a Linux operating system, so the user friendly Ubuntu LTS operating system was chosen. Some basic knowledge in the command line programming and a few hours are needed to install all of this software. There have been several hiccups in the software that have required troubleshooting and have created setbacks. The OpenCV examples have been used to obtain an idea of what programming will be needed to control the UAV from interpreting the environment detected in the streaming images. These examples should lead to more specific UAV C based code that more efficiently process the images and determines appropriate actions for the UAV. The received images will be combined using the ground station computer or a subsequent system. The imaging system will be used to detect the UAVs surroundings but the emphasis will be placed on super-resolution visual image reconstruction in real-time.

Control Structures

The main stabilization control of the UAV will be performed by the APM 2.5+ microcontroller on the UAV but the movement and decision making will be done based on the image processing. The ground station host computer will serve as the control center. All mobility device and sensor brick components will automatically establish a wireless connection to the control center. The sensor brick component will first read data from the sensor and then transmit the sensor data wirelessly to the control center. This will also give the operator the ability to change the level of automatic control and allow for the operator to be able to take control the UAV from the base station.

If the sensor brick component receives motion commands for the gimbal originating from the control center, it will move the gimbal to the desired position. In the meantime, the mobility device component will automatically compensate for vibration to stabilize the UAV. Additionally, the mobility device component not only receives commands to move the UAV, but automatically provides safety control (e.g. collision prevention for its surrounding environment and crash prevention during a communication failure with the control center). The distance between the UAV and the operator is limited to a good visual line-of-sight without any aids to vision, such as binoculars. In the rare case of a loss of control signal, the UAV will maintain a static position to allow time to reestablish the wireless connection. If the connection cannot be reestablished, the UAV will autonomously land in a designated area so that the operator can retrieve the UAV quickly and safely. The UAV will also be equipped with a floatation device in case it lands in water and potentially it will have a shroud to protect the UAV in case of a collision.

Integration of Systems

The ArduCopter with the APM 2.5+ controller has been chosen as the initial UAV platform for this proposed work for its safe and orderly operation. This platform has the capacity to have sensors looking up, instead of looking down, without occlusion; a feature, which is essential and cannot be achieved with fixed-wing aerial vehicles or helicopters. The propeller configuration of ArduCopter is flexible allowing for evaluation of a quadcopter, hexcopter or octocopter to determine which will be best suited for the anticipated environmental conditions of a bridge. The battery can support approximately 20 minutes operation at the current stage, but it is expected that this will increase over the next few years as the technology advances. Nevertheless, the research team will design an indicator on the control interface to display the power condition and provide a user-friendly module to swap the battery. Currently, the battery is mounted with industrial grade Velcro and can be swapped with relative ease. Although ArduCopter [2] provides several manual and automatic flight modes to avoid collision with its surrounding environment, and monitors via on-board sensors (3D gyroscope, 3D accelerometer, tilt compensated magnetometer, absolute pressure sensor, GPS, etc.), it is tied to its own design. Attempts have been made to redesign a new control structure, but it seems the best course of action has been to modify the ArduCopter code. This allows for the already fully developed stable code to utilized and allow for further coding to be primarily oriented towards the design intent. This is still in the design phase and future designs of the software will provide a more user friendly GUI instrument panel for the user to intact with the copter.

The eventual design intent is to have all of the extra sensing components incorporated into a modular sensor brick unit. This unit will be robust, compact, modular and independent. This should allow for the user to place the unit onto an ArduCopter and simply plug it in to provide an instantly upgraded low cost UAV. This will allow for over the counter replacement of parts in order to keep the price down on the overall design. Ideally the design for the sensor brick will also be such that it can be mass produced allowing even lower cost for a fleet of object inspection UAVs. The modular design of the sensor brick will also allow for the sensors to be swapped out for more appropriate devices depending on the environment that the UAV is used. If the subsequent sensors are inexpensive and light, they may be hardwired into the design to allow for more expensive and sensitive devices such as LiDAR to be easily swapped out without removing the main capabilities of the sensor brick. The initial design of the brick will be towards visual sensing.

CORRELATION TO NASA'S MISSION DIRECTIVES

This research into the development of the different systems has correlations to NASA's "TA04: Robotics, Tele-Robotics and Autonomous Systems" in several specific areas of concentration. [3] The ability of the operator to observe and control the UAV's operations has improved correlation to "TA 4.4.2 Supervisory Control" which mentions the direct control of a device by the operator. The ability of the UAV to automatically control itself for variations in its environment has correlations to "TA 4.5.3 Autonomous Guidance and Control". The variable level of autonomy has correlation to "TA 4.5.5 Adjustable Autonomy" which mentions the ability of the operator to control the level that the operator has to interact with the device controls.

The ability to remote process the information allows for the modularity of the sensors to be fully realized with easy replacements on the UAV without needing major adjustments to the control network and has correlations to “TA 4.7.1 Modularity/Commonality”. The overall UAV testing platform is based on atmospheric conditions with a propeller propulsion system, but the controls design will allow for the UAV to operate based on its environment. This and the modularity of the system should allow for the transition to different levels of gravity and for use in space as a device to perform station inspections. Some research with modeling and simulation will be needed to perform varying environmental tests before deploying the device into zero gravity areas like space to minimize the cost of development and testing. [3]

2014 IARC Competition

The 2014 International Aerial Robotics Competition located in Alabama will provide a good venue to test the capabilities of the developed UAV and provide a goal to strive towards. The current competition is on its seventh mission with increasing levels of difficulty being added each year to the competition. The IARC will not continue onto the next mission until a significant number of competitors can successfully complete the task in the current mission.

The Mission 7 is somewhat different from the previous year’s missions. In previous missions, the UAV has had to enter a simulated building through a window, retrieve a memory stick, and return to its point of entrance. A person can enter a room and move around without the use of extraneous instruments such as GPS. The current mission holds the UAVs to this standard and will not allow for the UAVs to use these sorts of outside instruments. The UAVs will have to use an optical flow sensor for stabilization and cameras to determine their environment. In addition the actual task in Mission 7 is completely different. In this mission the UAV is required to enter a 20 meter square arena shown in Figure 1 with meter wide white squares that can be used for navigation.

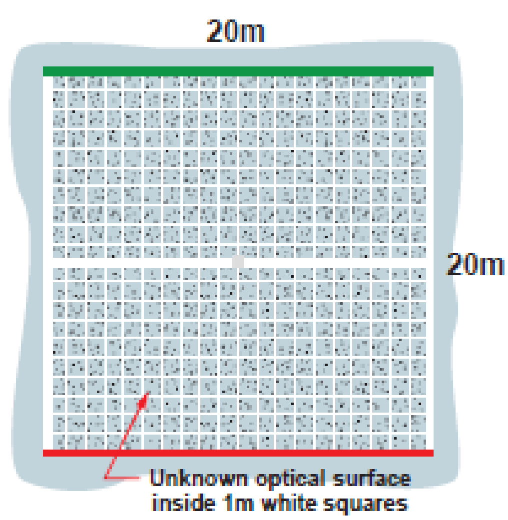

Figure 1. UAV Arena **[4]**

Once the UAV can prove that it can move around in this environment, the UAV will be required to herd ground based robots towards a green line. The ground based robots will change directions randomly when they interact with obstacles. There will also be two robots with large cones that will move about and interact with the ground robots to make the movements even more random. Once a ground robot reaches an edge, it will be removed. The UAV will be able to change the ground robots direction by either using a magnet or by getting in the robots path.

This provides an interesting set of requirements that will test the image processing capabilities of the UAV and the control structures used to efficiently move the UAV around the area at different elevations. The UAV will need to be lighter in order to lower the momentum and change directions quickly. In addition, the UAV will need to have sufficient battery power in order to last for the entirety of the competition. The UAV may need to have two downward facing cameras in order to observe the grid for navigation and another for detecting the overall movement of ground based robots. It may be possible to use the same camera and extrapolate different data from the same images. In the end, the object inspection UAV will either need to be improved upon to meet the requirements of the competition and thereby making a more robust UAV for the current project. [4]

SUMMARY

This project is the first step in the development of a new modular UAV device that could drastically change the way that infrastructure inspections are performed. There is much work that still needs to be completed to allow for the forward movement of the development even with the elements addressed with this first phase. The work completed with this proposal has for the most part set up the basic structure for the larger project that will continue into the following semesters. There are many obstacles that have been encountered in the coding and connection of different devices. At the current stage, the development of the UAV may be slightly more expensive than the final result as different components are needed to be tested for the final design. With a basic UAV design currently built, it is up to the software development in the integration of the systems, the development of the image processing, and the final control structures to come up with a final design. The IARC competition will help to provide extra motivation and a fun aspect to the current design. This will also allow for the development of a more robust system. The next steps are going to be the collection of the current devices into a modular design, the software development, and the subsequent field tests. These tasks should be within reach for a final design being developed within the time limits of the future competition.

REFERENCES

[1] N. Gucunski, "Nondestructive Testing to Identify Concrete Bridge Deck Deterioration," *Transportation Research Board Second Strategic Highway Research Program (SHRP 2), Report S2-R06A-RR-1,* 2013.

[2] Various, "ArduCopter," 12 February 2012. [Online]. Available: http://code.google.com/p/arducopter. [Accessed 26 April 2014].

[3] National Aeronautics and Space Administration, "Robotics, Tele-Robotics and Autonomous Systems Roadmap Technology Area 04," April 2013. [Online]. Available: http://www.nasa.gov/offices/oct/home/roadmaps/. [Accessed November 2013].

[4] International Aerial Robotics Competition, "Official Rules for the International Aerial Robotics Competition MISSION 7," 2014. [Online]. Available: http://www.aerialroboticscompetition.org/downloads/mission7rules_041914.pdf. [Accessed 26 April 2014].