SEARCH AND RESCUE: A UAV AIDING APPROACH

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ABSTRACT

This paper describes the construction of an unmanned aerial vehicle (UAV) with indoor navigation system as a prototype to compete in the CANCAM 2011 Global Engineering Design Challenge. A radio-controlled helicopter is modified and upgraded with essential avionic hardware which includes two Gumstix embedded computers, an Inertial Measurement Unit (IMU), a servo controller, a camera and a laser scanner. In the indoor environment, where GPS signals are unavailable, vision and laser scanner based navigation system can be used as a substitution for compensating IMU drift. In this paper, an embedded vision and laser scanner system is designed and implemented. It is compact and light enough to be carried along by the UAV in flight. A computer working as a ground station will generate the map in real time using Simultaneous Localization and Mapping (SLAM) algorithm.

Keywords: UAV, Indoor Navigation, SLAM.

Figure 1: One of the NUS UAV family – FeiLion

INTRODUCTION

With the recent rapid development in robotics field, unmanned aerial vehicle (UAV) technology has reached a mature stage. Most of the UAV available in the market are of task based. For example, the US Coast Guard rescue service has employed unmanned helicopters, such as Bell Eagle Eye UAV and MQ-9 Reaper [1] [2], for coastline patrolling and monitoring. In general, autonomous vehicles with navigation system can be utilized for a wide range of application, such as search and rescue, disaster monitoring, or other tasks that are risky or impossible for human to perform.

Traditionally, localization and mapping employ the use of Inertia Measurement Unit (IMU) together with Global Positioning System (GPS) to measure and estimate the vehicle position. However in an indoor environment, where GPS signal is unavailable, the problem of localization and mapping unknown environment is typically solved by using a laser scanner or other range sensors. Recently, several research teams have employed vision sensor for obstacle detection and vehicle position estimation [3].

With these advancements in the development of UAV, our team has proposed a solution to speed up the process of search and rescue in the post-disaster environment in developing countries. Disasters such as earthquakes and land-slidings have always caused huge damages to the society, especially in the developing countries such as China and India. A recent news reminds us of the 33 miners from Chile who were trapped underground for weeks before being rescued. One may still remember that two years back, thousands of people were buried after an earthquake in Sichuan, China. The main reason for the delay in rescuing is the inaccessible environment caused by the disaster, such as trapped buildings or trapped space.

In this paper, the construction and development of the UAV specifically for the search and rescue task is proposed. The UAV, with largest dimension less than 50 cm, are able to explore trapped areas behind narrow cavities which human rescuers cannot pass through. Moreover, comparing with ground robots which have inherent limitations in accessing post-disaster locations due to terrain complexity and ground obstacles, UAVs in this case are better candidates for the mission.

Our developed UAV, codenamed FeiLion, will search for open paths and navigate autonomously in the trapped area. With sensors including camera and laser scanner mounted onboard, FeiLion can retrieve physical information about the trapped environment and pro-

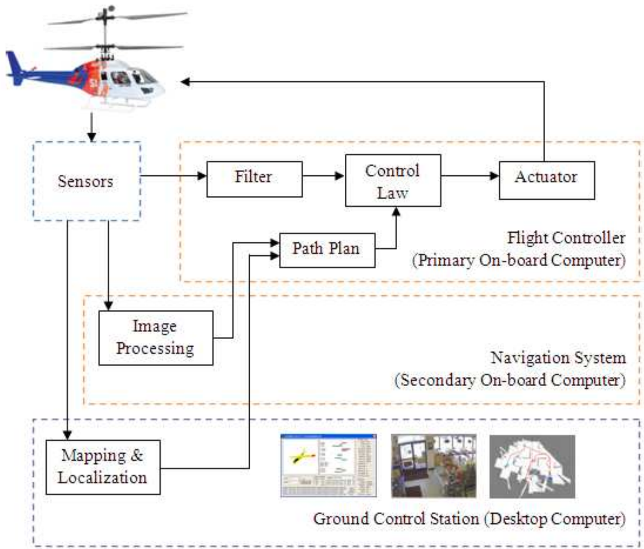

Figure 2: System Overview Block Diagram

vide accurate locations of the victims. With all these information, rescuers can set up better rescuing plans and distribute manpower more effectively. The cost of our proposed UAV is reasonable. It can be modified from a common RC toy helicopter by equipping low-cost sensors such as MEMS-based IMU, short-range laser scanner and web camera. Once the first prototype is designed and verified, it can be implemented and manufactured for mass production.

This paper describes the construction of such UAV mentioned above. In this paper, a brief system overview will first be introduced, subsequently by the detailed selection of hardware components. Next, the control system architecture and navigation system of the UAV will be discussed, followed by the design of the Ground Control System (GCS). Finally, conclusion and future work are listed in the last section.

SYSTEM OVERVIEW

A major technological challenge to ensure the robustness of the autonomous miniature air vehicles in cluttered indoor environment lies in the reliability of the on-board components. Also, to realize this UAV search and rescue system in the developing country, cost of the components are taken into account. Today, the challenges to miniaturization and cost reduction are often met through the development of microelectronic technology. Thus, our main focus in building the UAV lies in the selection of the components and the design of indoor navigation system, where the GPS signal is unavailable.

The overall UAV system consists of 3 major parts [4]: 1) Physical aircraft with engines; 2) An onboard avionic system for automatic flight control and navigation, which include processor, sensors, and actuators; and 3) A GCS for monitering and data collecting.

The designed UAV codename FeiLion (Fig. 1) is capable to navigate autonomously in an unknown indoor environment. A diagram showing the interaction between the parts is illustrated in Fig. 2. There are two on-board computers in the avionic system. The first computer runs the control algorithm which guarantees the stability of the UAV, and the second one mainly focuses on vision processing and navigation. Hence, once the system is activated, the UAV will carry out all the aspects of the mission autonomously.

GCS consists of a single notebook computer running OpenGL based visualization software. The flight criteria software, such as sensor data filtering, control and navigation algorithms are written in C language for the ease of modification by other users.

Figure 3: ESky Big Lama Co-Axial Helicopter

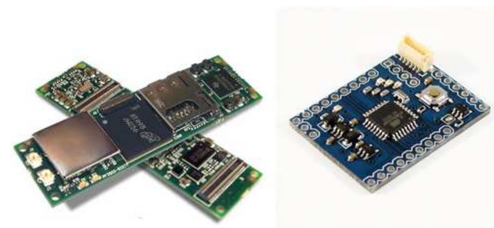

Figure 4: Gumstix Overo Fire (left) and Arduimu+ v2 Flat (right)

SYSTEM DESIGN

A. Bare Helicopter

A high quality RC helicopter, ESky Big Lama Co-Axial (Fig. 3) is chosen as the raw platform for our UAV. In order to improve the performance of the UAV, the original engines are replaced by two brushless DC motors to increase the take-off weight, and the blades are replaced with longer and stiffer blades to improve the stability of the UAV. Some key physical parameters of the upgraded helicopter are listed in Table 1.

Table 1: Specifications of the ESky Big Lama Co-Axial helicopter

Specifications	Big Lama
Main rotor diameter	460 mm
Full length without tail	160 mm
Full width	110 mm
Weight	352 g

B. Processors

The onboard embedded processor is the brain of the whole system. It collects data from various sensors, processes the data, and sends information to the servo controller to execute control actions. Selecting suitable processors out of the available products in the market is crucial to ensure a successful implementation of the UAV system.

We have chosen 2 Gumstix Overo Fire (Fig. 4) coupled with Overo Summit expansion boards for both control and navigation process. This unit has a 720 MHz main processor, a DSP coprocessor and a Wi-Fi module. At the core of this system is a Texas Instruments OMAP3530 ARM processor, and is one of the fastest low-power embedded systems as of writing. This unit is small in physical dimensions and weighs 18 grams in total. To improve the performance of the system, the operating system provided by the manufacturer has been replaced by QNX Neutrino Real Time Operating System

Figure 5: Hokuyo URG-04LX

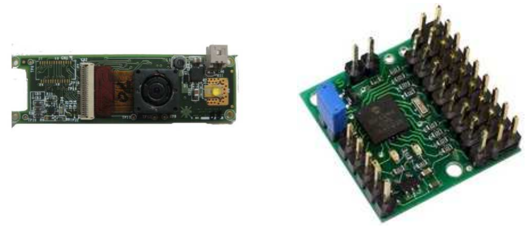

Figure 6: e-Cam32 (left) and Pololu Servo Controller (right)

(RTOS). A custom built autopilot software developed by NUS UAV Research Group [8] is used to realize autonomous flight.

C. Sensors

Sensors are essential components to control a UAV. A few sensors are present in the avionic system, including an IMU, a laser scanner, and a camera.

1) IMU

Usually the primary sensor for UAVs, it outputs linear accelerations and angular rates which are the most important raw measurements for stabilizing UAVs in flight. In our design, we have adopted Arduimu+ v2 Flat (Fig. 4) as our IMU. This IMU consists of an Arduino-compatible processor that runs an Attitude Heading Reference System (AHRS) code, based on Direction Cosine Matrix (DCM) algorithm [5]. In other words, estimated angular position measurements will be provided. This hardware consists of a tri-axis accelerometer and three gyroscopes, dual power regulator (3.3 V and 5 V), GPS serial port, and it runs with Atmega328 processor at 16MHz. At the weight of 6 grams, it is currently one of the smallest IMU-AHRS device in the market.

2) Laser Scanner

Since GPS signals are unavailable indoor, other types of sensors are needed to provide the UAV position reference relative to the environment. Among all the commonly used range sensors including sonar, infrared and laser-based range sensors, a laser range scanner is the most promising one for a compact and multi-functional UAV design. As such, we have chosen the Hokuyo URG-04LX (Fig. 5) scanning laser range finder. It has attractive features such as high accuracy (1% of distance measurement), high resolution (0.36 degree step) and wide scanning angle (240 degree) despite its compact size ($50 \times 50 \times 70$ mm), light weight (160 g) and minimal power consumption (500 mA over 5 VDC). Moreover, it is insensitive to illumination differences, thus can operate in hazardous environments such as complete darkness.

3) Camera

The e-Cam32_OMAP_GSTIX expansion board is an integrated camera system which works with the Gumstix Overo Fire Computer in a simple plug and play fashion. With a high resolution of 2048 $\times$ 1536 and 30 fps capture rate, it has a tiny size of 10.0 $\times$ 10.0 mm and only weighs 4.4 g (see Fig. 6). The image sensor embedded on the board is CMOS based and has auto focus capability. By integrating such a smart camera into the avionic system, the UAV will have vision information which is critical for object detection and survival identification. Moreover, the built-in Wi-Fi module on the Gumstix Overo Fire Computer can be used to transmit the captured image to the remote ground station for human inspection. This onboard camera plays a significant role in enabling the UAV to fulfill the search and rescue mission.

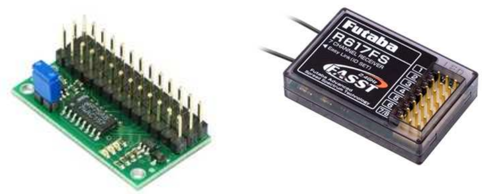

Figure 7: Pololu Servo Multiplexer (left) and Futaba R617FS Receiver (right)

D. Actuators

To realize control actions, servo motors of the bare helicopter will be controlled by the PWM (Pulse Width Modulation) signal generated by the controller. This customized servo control system consists of a digital servo controller, a failsafe multiplexer, and an RF receiver.

1) Digital Servo Controller

At only 23×23 mm, the Pololu Micro Serial Servo Controller (Fig. 6) is the smallest serial servo controller found in the market. With individual speed and range control of eight servos and over 12 bits of resolution, this servo controller can be purchased at affordable price.

2) Failsafe Multiplexer

Pololu RC Servo Multiplexer (Fig. 7) is chosen to realize the failsafe function of the UAV. This compact device serves as a four-channel multiplexer of PWM pulses, allowing easy switching between two independent signal sources. A fifth channel selects whether the output is from the master or the slave source. In our UAV, master source is selected as the input signal from the pilot's transmitter, while slave source is selected as the control signal from the servo controller.

3) RF Receiver

A Futaba R617FS 2.4GHz receiver (Fig. 7) is used in our UAV. It is a high sensitivity receiver which weighs only 9 grams. It features simple one-touch linking and dual antenna diversity to allow Futaba transmitter to select the best reception between the two receiver antennas with minimal signal loss.

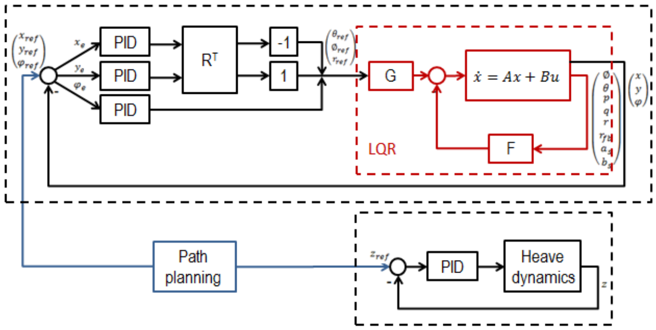

Figure 8: Overall Control Structure

NAVIGATION AND CONTROL SYSTEM

Indoor navigation and control is often hindered by the poor GPS signals. To date, most autopilot algorithms for UAV rely heavily on GPS, thus it is not suitable for our indoor navigation, where GPS signal is not available. Here, our solution is to combine a low cost laser range finder and a camera to replace the traditional GPS-aided navigation system.

A. Control System Architecture

Generally, a co-axial helicopter is installed with a mechanical stabilizer bar, acting as a passive controller for pitch and roll stabilization. In addition, the platform was further upgraded with a heading lock gyro. Not only it aids the pilot during the manual take over, it also improves the overall system stability in the autonomous mode.

Taking advantage on the inherent stability of the co-axial helicopter platform, a dual-loop cascaded control architecture is used to realize position control of the UAV. In order to achieve good control performance, state-feedback control methodology is adopted. First, the dynamical model of the UAV in state-space description is identified with the assistance of a frequency-response-based identification software package named Comprehensive Identification from FrEquency Responses (CIFER) [6]. Specifically, FeiLion's model is identified through the combination of first-principles approach and the system and parameter identification method as proposed in [7]. Once the linearized model is obtained, state feedback controller is designed based on LQR method for angular control in the inner-loop, while 4 individual PID controllers take care of the x-, y-, z-position control, together with heading angle control in the outer-loop. The overall control structure block diagram is shown in Fig. 8. Experimental results show that the controlled system is able to achieve reasonably good performance.

B. Navigation System

The original navigation system developed by NUS UAV Research Group [8] relies heavily on both the IMU and GPS receiver. In this project, laser scanner and camera will provide local map to the UAV, to replace the GPS navigation system.

To effectively aid the search and rescue mission as proposed in this paper, it is essential to build a map of the surrounding unknown environment and to estimate the position, velocity and orientation of UAV in the map. This is referred to as the SLAM problem. The laser range finder equipped on-board will detect the relative distance and bearing of the obstacles in the immediate vicinity of the UAV. Together with the measurement of IMU, it is possible to accomplish the SLAM task. The measurement data are first obtained from IMU and laser range finder, then transferred to ground station for SLAM computation. Since the UAV is modelled in the state-space form, the Kalman filter is utilized to deal with the inherent nonlinearity of the UAV dynamics and measurement sensors.

GROUND CONTROL STATION

GCS is of fundamental importance in the UAV system, serving as a terminal for end users to monitor and command the UAV via wireless communication channel. The GCS's tasks are categorized into three parts, i.e, displaying, computing and communicating. The displaying part includes displaying the inflight data for observing the vehicle status and displaying the images captured from the onboard camera. The computing tasks consist of generating and updating flight trajectories according to path planning algorithms and carrying out the SLAM algorithm. Lastly, the communicating part serves as sending control command to the avionic systems and receiving data packages from the UAV.

CONCLUSION AND FUTURE WORK

With technology advancement in miniature sensors, processors and actuators, low-cost indoor UAVs equipped with efficient navigation systems are perfect candidates for search and rescue tasks in post-disaster environments. This paper has described in detail the proposed UAV system, including the hardware structure, controller design, as well as navigation methodology. This UAV system, which is still under vibrant development, is going to fulfill tasks including SLAM, obstacle detection and avoidance, survival identification, and remote video transmission. In the near future, all the above mentioned ideas need to be realized on our platform – FeiLion, and the actual performance of the whole system will be tested thoroughly.

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