Real Time Autonomous Transmission line Following System for Quadrotor Helicopters

Chuang Deng, Jun-yong Liu, You-bo Liu, Yang-yang Tan
School of Electrical Engineering and Information
Sichuan University
Chengdu, China
e-mail: eedeng@126.com; liujy@scu.edu.cn; liuyoubo@scu.edu.cn; tyy13683448505@163.com

***Abstract*—A hardware and software system design for transmission line inspection basing on quadrotor unmanned aerial vehicle (UAV) is proposed in this paper. To enhance the inspection efficiency, real time data processing for transmission line detection and following are required. This paper proposes the design of hardware structure, software structure, as well as a Kalman filter. The real flight experiment reflects the feasibility of the system.**

Keywords-transmission line inspection; embedded system; Kalman filter; quadrotor UAV

I. Introduction

Transmission line inspection using unmanned aerial vehicles (UAVs) has aroused significant attentions of related industries. Transmission line inspection uses the UAVs with lidars or cameras can enhance the detection accuracy and efficiency. Among various types of UAVs, quadrotor helicopters are an excellent platform for this mission because of their unique property of landing/taking off without runway, hovering, flying to any direction, easy to take and lightweight. There has been amount of literature focus on the problem [1], [2]. In [3], a transmission line scene classification method using lidar data is proposed. In [4]-[6], lidar sensor hardware design and implementation for transmission line inspection is introduced. In [7], a combination of lidar and stereo vision is used for obstacle avoidance for rotorcraft UAVs. In [8], a path planning method is proposed with obstacle avoidance. In [9], a high efficiency image segmentation method for transmission line detection using camera is proposed. In [10], a stereo computer vision based transmission line inspection system is introduced. In [11], a Hough transform based on transmission line finder from images by using the UAVs is proposed.

Transmission line inspection uses lidars or cameras and UAVs has been considered. However, to our best knowledge, online transmission line tracking is still a challenging work. This mission requires high performance hardware design and transmission line finder. General application of quarotors on inspecting the transmission line is tracking the desired trajectory generated by predefined waypoint, taking picture or video by using cameras mounted on the quadrotor body. The recorded pictures of videos can only be analyzed offline after the mission finished. The captured video is also sent to the ground station to make it easier to interact with the vehicle by using remote controllers for obstacle avoidance and trajectory trimming. However this method limits the range of such application for reasons that the high quality real time video transmitting requires very high bandwidth and electromagnetic background, so that it is very difficult to operate the quadrotor near the transmission line or far from the ground station.

This paper introduces a real time transmission line inspection and following system based on quadrotor UAVs. The rest of the paper is arranged as follows. In Sec. 2, a hardware design is introduced. In Sec. 3, software design is proposed. In Sec. 4, Kalman filter is designed. In Sec. 5, experiment data is proposed. And In Sec. 5, conclusions are given.

II. Hardware Design

The unmanned quarotor helicopter TQuad1000 is updated from a model scale wireless remote controlled (RC) quadrotor helicopter manufactured by Poisson Aviation Co. Ltd, which is shown in Fig. 1. The vehicle is equipped with four brushless rotors, which offers maximum 2kg payloads and 60 minutes flight time by using two lithium-ion battery with 22.2v and 22000mah. The diameters of rotors are 75 cm.

Figure 1. TQuad1000 quadcopter with GPS antennas and lidar scanner.

To update the vehicle to autonomous flight platform for automatic pipeline inspection an external avionics system is designed and installed. Some sensors and equipment are installed in system, including high precision IMU, a Novatel OEM617 double-antenna differential GPS, a Velocyne DLP16 lidar scanner, and a homemade wireless data-link, et al. The original remote control system is reserved for back up and dangerous avoidance. The diagram of electronics is shown in Fig. 2.

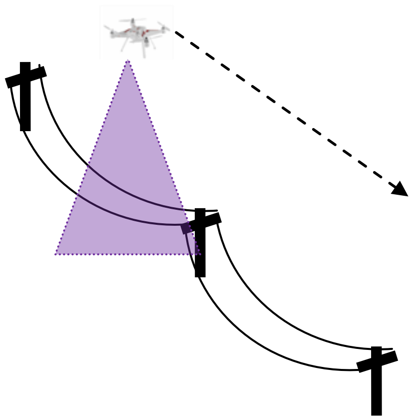

Figure 2. Transmission line detection based on TQuad1000.

The avionic system in TQuad1000 is designed as the structure of two levels. The higher level is called flight controller, which is based on an Samsung Cortex A9 board running in 1.5GHz with 8GByte flash and 2GByte SDRAM. The processor also includes some external interface resources, such like universal serial bus (USB) hubs, ethernet interface, universal asynchronous receiver transmitter (UART) interface, and so on. The hardware architecture of onboard avionics is shown in Fig. 3.

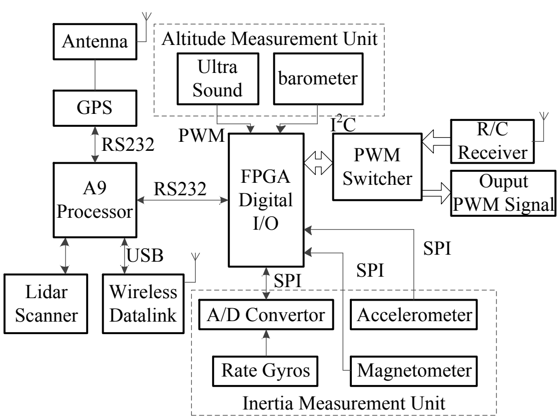

Figure 3. Hardware architecture of onboard avionics.

According to requirement of motor driver installed in the original helicopter platform, the update rate is chosen as 500Hz. It means that the full time of each update period is 2 milliseconds, so that the processor is fast enough, which makes it capable to deal with all of the computation tasks, including sensor fusion and control law computation. However such processor is not sufficient to deal with the rest tasks, including sensor reading and pulse width modulation (PWM) signal generation, due to its limited low level resources. So an FPGA based parallel digital module is designed for lower level input/output (I/O), which includes sensors read and pretreatment, PWM signal capturing, input signal packaging, PWM generation. An AlteraTM Cyclone III series FPGA is chosen for this application, which runs at 50MHz and offers 196 independent I/O ports, is sufficient to deal with the above tasks. The data link between higher level processer and lower level digital I/O is based on a UART with baud ratio 115200 bit per second (BPS).

III. SOFTWARE DESIGN

In the flight processor part, C++ is chosen as programming language. The program is designed with multi-threads structure, which includes three threads with different priorities. The main thread includes function blocks of sensor fusion, controller computation, waypoint generation and lidar data processing. The sub-thread of I/O data receiving and sending is the highest priority, which contains synchronize clock information with sensitive to time delay. The GPS data thread and ground station command thread are lower priority due to their lower processing priority requirements. Once a complete frame of I/O data has been received, the main timer is triggered and function blocks are executed sequentially. Furthermore the data from the lower level thread is updated and stores in the related stacks, waiting for being accessed by the main threads. The software architecture of flight controller is shown as Fig. 4.

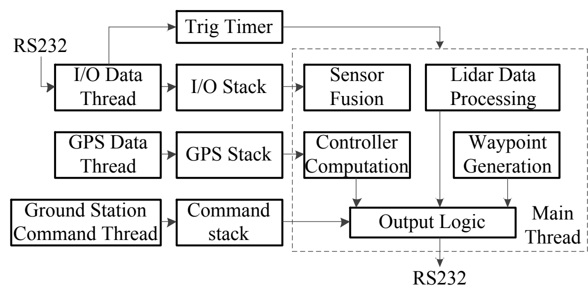

Figure 4. Software architecture of flight controller.

On the I/O data processing part, two data buses are designed using FPGA based on verilog language, due to the real time requirement. The serial bus is designed for transacting data with the A9 processer. To avoid losing data a direct memory access (DMA) buffer is designed to receive serial data from the A9, which can be trigged independently. Furthermore the parallel bus is designed to deal with the tasks of collecting sensor data, capturing PWM signal from the RC receiver and ultrasound module, and generating PWM signal to drive the motors. The tasks on the parallel bus can work independently trigged by the system clock up to 500Hz.The collected data is stored in the output stack. The Software structure of I/O module is shown as Fig. 5.

As the summary of hardware and software design, the executive time is measured by each level respectively. The full signal capturing time, including sensor reading and PWM capturing, as well as PWM signal generation, is lower than 0.3ms. The communication time is lower than 0.2ms.

Furthermore the computation time of sensor fusion and controller computation can be reduced to less than 1ms. So that the total executive time is less than 1.5ms within one period, which offers sufficient capability for advanced data fusion and control strategy.

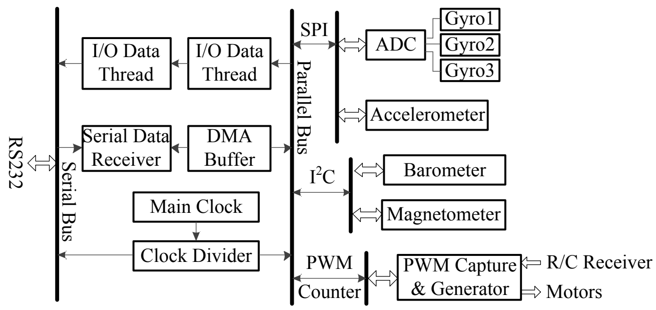

Figure 5. Software structure of I/O module.

IV. Kalman Filter Design

The Kalman filter is an efficient way for noisy data filter and fusion with high performance [12]. In this paper, we design a discrete Kalman filter for lidar data processing, since the raw lidar data is with serious noise and not continuous. The state equation is shown as

$$\bar{x}_{k+1} = \Phi\bar{x}_k + \bar{\xi}_k \tag{1}$$

where $\bar{x}_k$ represents the k^{th} step state vector, Φ is the state transition matrix, and $\bar{\xi}_k$ is the process noise which is usually zero mean and Gaussian. The state of the system is shown as

$$x_k = [P_x \quad P_y \quad P_z \quad V_x \quad V_y \quad V_z]^T \tag{2}$$

where P_x, P_y and P_z stand for positions, V_x, V_y and V_z for velocity, respectively.

The measurement equation of the k^{th} iteration is

$$\bar{z}_k = H\bar{x}_k + \bar{v}_k \tag{3}$$

where $\bar{z}_k$ stands for the measurement vector, H for the measurement matrix and $\bar{v}_k$ for measurement noise, which is zero mean with white Gaussian.

The discrete Kalman filter can be expressed as

$$\begin{aligned}
\bar{x}_k &= \Phi\hat{x}_{k-1} \\
\bar{P}_k &= \Phi P_{k-1}\Phi^T + Q_k \\
K_k &= \bar{P}_k H^T (H\bar{P}_k H^T + R_k)^{-1} \\
\hat{x}_k &= \bar{x}_k + K_k(z_k - H\bar{x}_k) \\
P_k &= (I - K_k H)\bar{P}_k
\end{aligned} \tag{4}$$

where P_k stands for the error covariance, K_k for Kalman filter gain updating in each iteration, I is the identity matrix. The lidar data processing and the Kalman filter are integrated.

V. Flight Experiment

A real flight experiment was carried out using the prototype TQuad1000. The way points were set such that the quadcopter can go above the transmission lines. To evaluated the performance of the prototype a scenario of one single transmission line was selected. The quadcopter was manually operated to the position near one of the power line. And then the vehicle began to follow the detected transmission line. The collected data was sent to the ground station. Fig. 6. shows the reconstructed data of the transmission line detection and following. One can see that the prototype system was able to work, which successfully detected the transmission line and followed it.

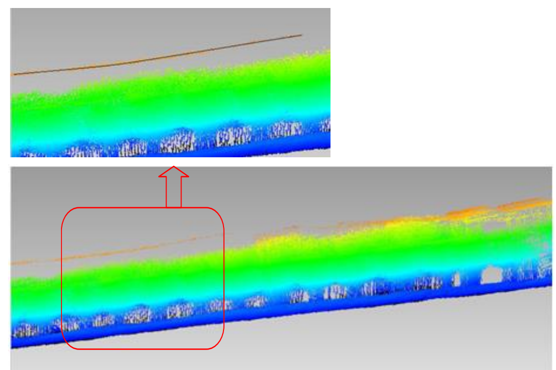

Figure 6. The reconstructed lidar data, the filtered transmission line was successfully captured by the quadcopter and plotted as black line, as shown in the upper figure.

VI. Discussions and Conclusions

In this paper a transmission line inspection system is designed using a quadrotor helicopter, in which a double antenna GPS, a laser scanner and a flight computer are mounted. The software of the flight computer designed as two levels, the lower level for sensor data collection and the higher level for control law computation and filtering. The position of the transmission line was obtained from the GPS and the laser scanner using a Kalman filter, which generated the relative positions, velocities and headings. A real flight experiment was carried out, which verified the feasibility of the designed system. In the future work, a new algorithm will be designed to detect multiple lines simultaneously. And the controller will be designed in which the prior knowledge of the external disturbance is considered, such that the robust tracking performance can be obtained.

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