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Altitude Estimation based on Multi-Sensor Fusion for Indoor Navigation of UAV

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Abstract—*For Unmanned Aerial Vehicles (UAV) altitude measurement with high authenticity is a very difficult issue, not because of the sensors complexity and requirements but due to the quality of the signals and fast changing environment conditions.*
This paper focuses on the problem of the vertical movement measurement of UAV. The height over ground measurement of UAV is measured using two Ultrasonic Sensors and an Infrared sensor. Confidence Weighted filtering method is employed for fusion of sensor measurements. With the fused altitude information the vertical motion of flying vehicle can be controlled by the flight controllers.

Keywords: *Altitude Estimation, Multi-Sensor Data Fusion, UAV, Weighted Confidence Filtering.*

1. INTRODUCTION

Unmanned Aerial vehicle (UAV), commonly known as a drone is an aircraft without a human pilot on board. Its flight is either controlled autonomously by computers in the vehicle, or under the remote control of a navigator, or pilot on the ground or in another vehicle. UAV considered as a system comprises of many sub-systems, the primary of which is a Sensor suite.

For guidance, navigation and control (GNC) of UAV the sensor measurements are the input to all control process, so the requirement of sensors increases to improve the overall performance of the system. Autonomous GNC are required to achieve certain missions without direct or continuous human control of UAV. The role of sensors becomes indispensable for UAV operation and to improve its capabilities.

Development of Micro Electro Mechanical Systems gave the opportunity to design very small in size and powerful electronic circuits that consist of miniature sensors and high performance microprocessors [4].

Despite that fact, the problems with accurate measurements and proper data processing still exist. One of them, addressed in this paper is an altitude estimation issue.

The height control of UAV is important during landing, and hovering operations. Also the Autonomous takeoff and landing can be performed easily when the altitude information is accurate. For low altitude measurement number of sensors could be employed like Infrared Sensors, Ultrasonic sensors, LASER Range finders. So there is a need for sensor fusion arises when number of sensors employed for a common purpose. Multi Sensor Data Fusion (MSDF) refers to the process of combining data from a variety of sensors that are able to act in cooperation such that the total effect is greater than the sum of effects taken independently. The concept MSDF was initially developed for military applications [7], and afterwards applied to civil industries [8-9], including battlefield surveillance, automatic multi-target tracking and recognition, guidance and control of autonomous vehicles and robotic systems. Traditionally, MSDF is considered as a data/information processing technology; covering a wide range of disciplines, for example, estimation and identification theory, control engineering, statistics and decision theory, signal processing and pattern recognition, artificial intelligence and knowledge engineering. This paper presents a Weighted Confidence Filtering approach for fusion of three sensor data.

This paper is organized as section 2 describes the hardware (sensors and Processor) employed for data fusion. Section 3 explains the fusion methodology and section 5 shows test results.

2. 2. HARDWARE DESCRIPTION

2.1 Arduino Board

Arduino is an open-source single-board microcontroller, descendant of the open-source Wiring platform, designed to make the process of using electronics in multidisciplinary projects more accessible. The hardware consists of a simple open hardware design for the Arduino board with ATmega328 processor and on-board input/output support. The software consists of a standard programming language compiler and the boot loader that runs on the board.

Arduino hardware is programmed using a Wiring-based language (syntax and libraries), similar to C++ with some slight simplifications and modifications, and a Processing-based integrated development environment, which allows the interfacing of analog and digital sensors easily.

2.2 Data Logger Shield

Data logger shield is an interfacing module to be connected to any of the Arduino boards. It has a Real time clock and SD card slot inbuilt. It enables the recording of sensor measurements in real time environment. Using the recorded data the measurements from sensor measurements are analyzed off board.

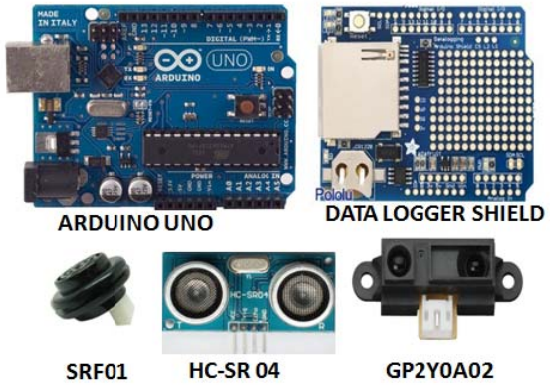

Fig. 2.1: Hardware Elements

2.3 Ultrasonic Sensor HC-SR04

The HC-SR04 ultrasonic sensor uses sonar to determine distance to an object. It offers excellent non-contact range detection with high accuracy and stable readings from 2cm - 400cm. It comes complete with ultrasonic transmitter and receiver module. Two numbers of HC-SR04 is used to determine Height over Ground. This sensor has a Dihedral angle of 15 degrees and resolution of about 0.3cm.

When the trigger pin is kept HIGH (5V) for a minimum of 10µS, this will initiate the sensor to transmit 8 cycle of ultrasonic burst at 40 kHz and waits for reflected ultrasonic burst. When the sensor detects ultrasonic from the receiver the Echo pin is set to HIGH for a period of time, which is proportional to the distance. Distance the wave travels is calculated using the width of pulse (T) in µS

$$\text{Distance} = (T/2)/29.1 \qquad (2.1)$$

where speed of sound is 29.1 microseconds per cm or 340m/s.

2.4 Ultrasonic Range Finder SRF01

The SRF01 is a single transducer ultrasonic rangefinder, connected to controller board using one-wire UART serial interface. Distance function could be measured in centimeters using this sensor from 18cm-600cm with a resolution of about 3cm.

2.5 Analog Infrared Sensor GP2Y0A02

GP2Y0A21YK0F is a distance measuring sensor unit, composed of an integrated combination of PSD (position sensitive detector), IRED (infrared emitting diode) and signal processing circuit. The variety of the reflectivity of the object, the environmental temperature and the operating duration are not influenced easily to the distance detection because of adopting the triangulation method. This device outputs the voltage corresponding to the detection distance and this analog sensor offers range measurement from 20cm-150cm accurately.

3. CONFIDENCE WEIGHTED AVERAGING

Method of Confidence Weighted Averaging (CWA) is proposed for fusion of three different sensors. This method eliminates the sensor measurements which are out of their range, so this will eliminate most of the erroneous data.

The sensor fusion equation is given by

$$X_{fused} = \left[\frac{X_{US1}W_{US1} + X_{US2}W_{US2} + X_{IR}W_{IR}}{W_{US1} + W_{US2} + W_{IR}} \right]$$

where

X_{US1} is the HC-SR04 sensor reading

W_{US1} is the weight function of the HC-SR04 sensor reading

X_{US2} is the SRF01 sensor reading

W_{US2} is the weight function of the SRF01 sensor reading

X_{IR} is the GP2Y0A02 sensor reading

W_{IR} is the GP2Y0A02 sensor reading weight function

The assumption made here is the sensors provide correct measurements within the range of operation.

The Weight value for each sensor is 1 within their range of operation and is zero for measurements out of the ranges.

4. IMPLEMENTATION

The proposed concept has been implemented in a self developed quad-copter UAV for height control of the flying vehicle. The sensor suite is mounted underneath the flight controller board of UAV.

The sensor has been mounted such that it faces the ground to obtain the height over ground data. The sensor fusion algorithm fuses three sensors in the indoor environment of UAV.

The maximum height that can be reachable with these sensors is 6m. Two sensors GP2Y0A02 and SRF01 provides analog information which are converted to digital data with suitable analog to digital converters and Ultrasonic range finder HC-SR04 provides direct measurement of distance using the time of travel of sound waves.

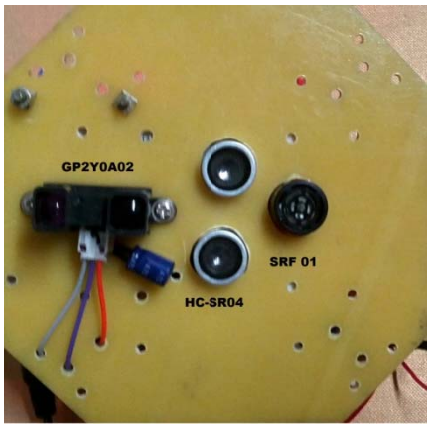

Fig. 4.1: Sensor Suite

5. TEST RESULTS

The sensors are calibrated individually before fusing with other sensors and their error variance is calculated by comparing against the actual height in the measurement setup.

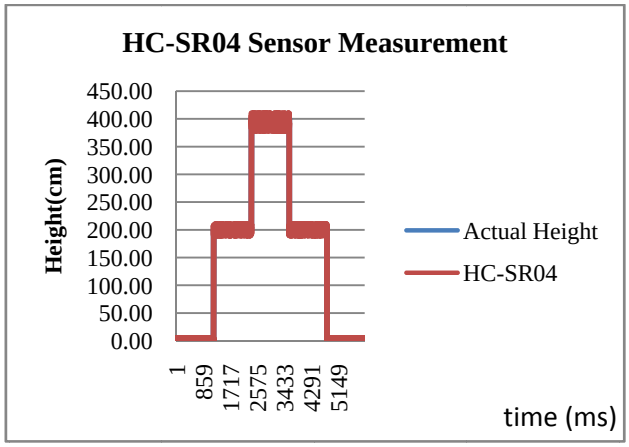

Fig.5.1 HC-SR04 Sensor Data

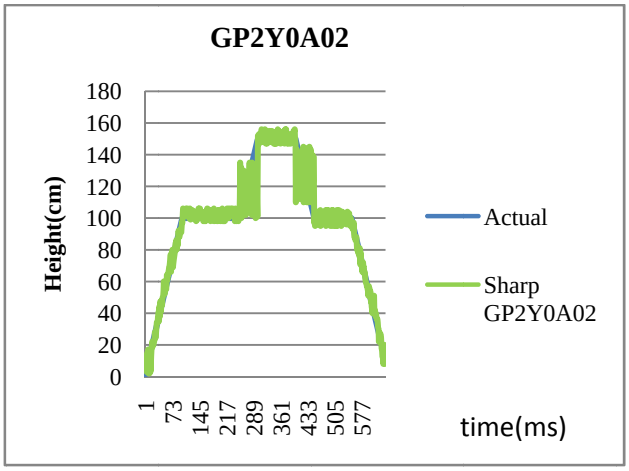

Fig. 5.2: Sharp Sensor Measurement

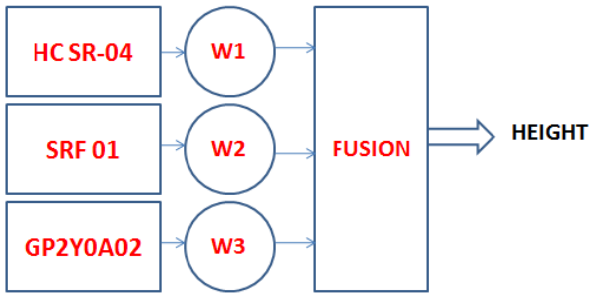

Fig. 5.3 Fusion Algorithm

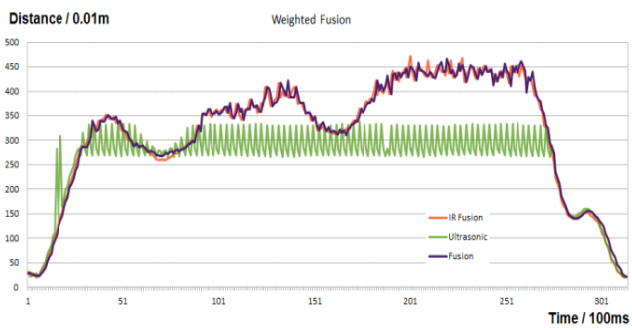

Fig. 5.4: Total Fusion Result

The results are analyzed after recording data in data logger shield and the root mean square error obtained with the measurement is 4cm.

6. CONCLUSION

The results were analyzed by comparing against actual altitude information and the obtained error variance is about 4cm. Hence this algorithm could be employed for auto landing and for the height control of UAV.

This algorithm eliminates sensor measurements out of the ranges of the sensors; thereby it eliminates the chances of faulty data.

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