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ELECTRONIC ENGINEERING

Guidance, Navigation and Control of MAEU-01 UAV using MEMS Inertial Sensors

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***Abstract*—Applying Micro Electro-mechanical Systems (MEMS) inertial sensors for the Guidance, Navigation and Control (GNC) of an autonomous Unmanned Aerial Vehicle (UAV) is an extremely challenging area. This paper presents a practical approach of applying an Inertial Navigation System (INS) using MEMS inertial sensors, Global Positioning System (GPS) receiver, Magnetometer and Barometer for the GNC. The INS/GPS/Mag/Baro integrated navigation loop provides continuous and reliable navigation solutions to the guidance and flight control loop. The guidance loop computes the guidance demands from the current UAV states to satisfy mission requirements. The flight control loop generates actuator control signals to transports the UAV to the desired location. The whole GNC algorithm was implemented within an embedded flight control computer.**

***Keywords*: micro-electro mechanical system (MEMS); unmanned air vehicle (UAV); global positioning system (GPS); flight control; navigation**

I. INTRODUCTION

Unmanned air vehicles are nowadays seen as an area of great importance in the aerospace industry. In order to become successful, the cost of these systems has to be affordable. Thus researching on the Guidance, Navigation and Control (GNC) of a UAV using Micro Electromechanical Systems (MEMS) sensors is important. This paper present a MEMS sensor-based micro GNC system which is successfully applied to a UAV, as shown in Fig. 1. The physical UAV system comprises of the flight platform, onboard systems, communication links, and ground station. The UAV states are down linked to the ground station for UAV state monitoring. There are two flight control modes. In remote operation mode, the pilot on the ground sends the control signals to the actuator via wireless uplink channel. In autonomous mode, the navigation output is fed into the guidance and control loop and the onboard Flight Mode Switch redirects the computed control outputs to the actuators. The whole GNC algorithm was implemented within an embedded flight control computer. The UAV is a fixed wing platform with a pusher prop configuration. The real-time flight tests show that the navigation system can provide accurate and reliable 3D navigation solutions as well as to perform the guidance and control task reliable.

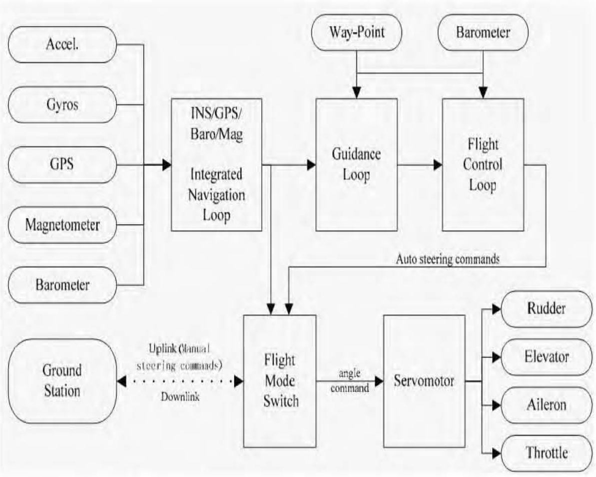

Fig. 1 The structure of MEMS sensor based GNC

II. AIRCRAFT SYSTEM

To meet the need of remote distance flight mission, the flight platform is designed as fixed wing platform with pusher prop configuration, as shown in Fig. 2 (a) and (b) It is capable of flying at 110 ft/s and up to 700 ft. The platform can carry 4 lb of additional mission payload. The following table shows the specifications for the flight platform.

TABLE 1
THESPECIFICATION FOR MAEU-01

UAV type	Short range platform
wing span	8 ft
overall length	5 ft 10 in
take off weight	20 lbs
payload	4 lbs
Endurance	30 min
Range	20 miles
Max: flight speed	110 ft/ sec
Min: flight speed	55 ft/ sec
Fuel weight	3 lbs
Takeoff/ landing	conventional runway (Using 10 channel Radio)
Communication System	LOS and Autonomous system

Fig. 2 (a) MAEU-01 UAV

Fig. 2 (b) Overall Testing of MAEU-01 UAV

III. SENSORS

MEMS inertial sensors are of utmost important in the GNC system. Processed by using Silicon-On-Insulator (SOI) techniques. The MEMS inertial sensors structure has the advantages of low stress and high aspect-ratio. Fig. 3 shows avionics system of MAEU-01 UAV.

The MTi-G is a combination of a MEMS IMU, GPS and barometer. Yet, the MTi-G is more than just a sensor assembly. The IMU, GPS and barometric information is blended together in Xsens' sensor fusion algorithm to estimate the most accurate orientation and position possible. Because of this fusion, the output is more accurate than the output from the IMU or GPS receiver only. For example, the MTi-G copes with transient accelerations; a typical error source for any AHRS using the gravity as its reference estimating rolls and pitches. The loose coupling works both sides: double-integrating the accelerometers for short periods, the MTi-G are able to calculate position and velocity even during short GPS outages. There are several more corrections realized to aid the IMU functionality and to enhance the GPS measurements.

The XStream module provides OEMs and integrators with reliable, long-range wireless data communications. It is smaller than a credit card and is available as a 900 MHz (North America) and 2.4 GHz (worldwide) RF solution. The 9XStream (900 MHz) is pin-for-pin and software compatible with the 24XStream (2.4 GHz), allowing for flexible deployment of your products throughout the world (only one OEM board design needed).

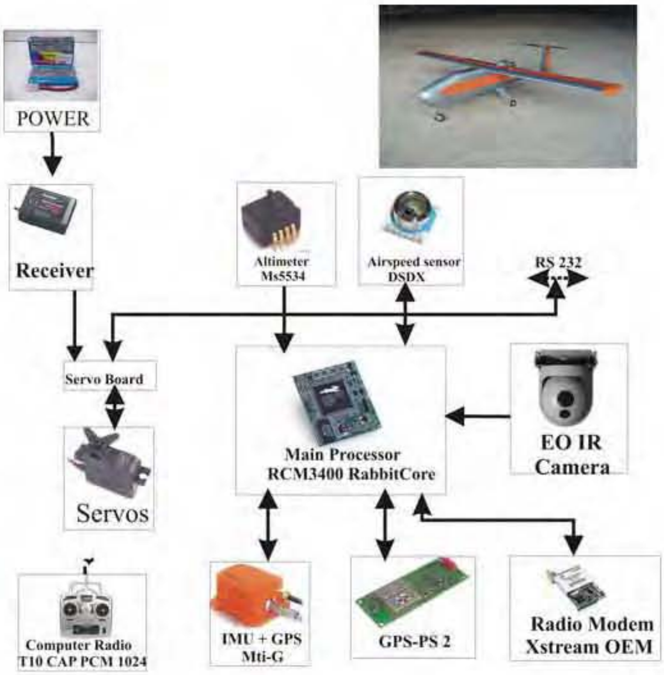

Fig. 3 Avionics system of MAEU-01 UAV

The DSDX series offers a digital interface on a very cost-effective basis. This family is fully calibrated and temperature compensated using an on-board ASIC. These sensors are intended for use with non-corrosive, non-ionic working fluids such as air and dry gases.

The GPS-PS2 receiver is a fully self-contained receiver module for the Global Position System (GPS).The module provides complete GPS signal processing from antenna input to serial data output (NMEA or SiRF proprietary data format).A second serial port accepts differential GPS data. GPS-PS2 operates at a nominal voltage of 5 volts.

The MS5534C is a SMD-hybrid device including a piezoresistive pressure sensor and an ADC-Interface IC. It provides a 16 Bit data word from a pressure and temperature dependent voltage. Additionally the module contains 6 readable coefficients for a highly accurate software calibration of the sensor. MS5534C is a low power, low voltage device with automatic power down (ON/OFF) switching. A 3-wire interface is used for all communications with a microcontroller. The MS5534C is fully software compatible to the previous versions (MS5534A and MS5534B). Compared to the previous versions the ESD sensitivity level has been improved to 4kV on all pins.

The RCM3400 analog RabbitCore provides a known-good processor and analog input subsystem for OEMs to quickly integrate into custom designs. The RCM3400 features a low-EMI Rabbit® 3000-based CPU subsystem running at 29.4 MHz, with 512K Flash / 512K SRAM or 256K Flash / 256K SRAM, 5 serial ports, and 8 channels of programmable gain analog input in an extremely small footprint (1.37" × 1.16" / 34 × 29 mm). The RCM3400 comes with a pre-assigned MAC I.D. to be Ethernet ready and the development board features 10/100Base-T Ethernet and can be used as a reference design in conjunction with Dynamic C's royalty-free TCP/IP software libraries. Extensive demo programs and software application templates make it easy to get the RCM3400 up and running in record time. Rabbit Cores mount directly on a user-designed motherboard and can interface with all manner of CMOS-compatible digital devices. Two 34-pin connectors route 47 digital I/O (shared with serial ports), power, and other signals to the motherboard. Built-in low—EMI features, including a clock spectrum spreader, practically eliminate EMI problems, helping OEMs pass CE and regulatory RF emissions tests. The RCM3400 is equipped with 5 V tolerant I/O, quadrature encoder inputs, PWM outputs, and pulse capture and measurement capabilities. The RCM3400 also features a battery-back able real-time clock, glue less memory and I/O interfacing, and low-power "sleepy" modes. A fully enabled 8-bit slave port permits easy master-slave interfacing with another processor-based system, and an alternate I/O bus can be configured for 8 data lines and 6 address lines.

IV. GUIDANCE, NAVIGATION AND CONTROL LOOP

The navigation loop plays a key role in the GNC system. Its navigation outputs are used in guidance and control and affect the performance of the UAV. The core of the navigation loop is the strap-down INS using MEMS inertial sensors and the Kalman filter. The strap-down INS provides reliable position, velocity and attitude with sufficiently high rates. The Kalman filter estimates the navigation errors by blending the GPS observation, baroaltimeter or magnetometer data running as a background task. The guidance loop forms an outer control loop in autonomous mode. It computes the guidance demands from the current UAV states and the next way-point information to force the vehicle to follow the desired way-point. The flight control loop forms the inner control loop and it generates the actual control signals to follow the guidance objectives as well as to stabilize the UAV attitude and rate.

A. Strap-down Inertial Navigation System

Figure 4 shows a block diagram of how a strap-down inertial navigation works. The inertial navigation system is the heart of the navigation sensor system of the UAV. In the last decade, inertial navigation systems using MEMS sensors have been a subject of great interest. The development of MEMS has permitted mass production of devices, though reducing the cost of previously expensive sensors. A strap-down inertial navigation system uses three orthogonal accelerometers and gyros triads mounted to the vehicle to sense the linear and angular motion of the vehicle. The angular motion of the system is continuously measured using the rate sensors. The accelerometers do not remain stable in space, but follow the motion of the vehicle. In this equipment, Navigation is accomplished by a computer using gyro information to resolve the accelerations that are sensed along the carrier axes. This integration of the raw measurements to obtain position and attitude can be done in different coordinate systems. Common are the mechanization in a local level and in a geocentric earth fixed Cartesian coordinate frame. The INS provides high relative accuracy but the absolute accuracy deteriorates with time if the system is running in stand-alone mode and no external update measurements are available. As the INS uses integration techniques to obtain the actual position and attitude, the positioning and attitude errors grow with time. Most of the error sources that corrupt the navigation solution are sensor errors or random disturbances. The MEMS inertial sensors errors like bias error, scale factor error and random walk noise dominate the INS error growth. These INS errors are typically low dynamics and its models have been well developed.

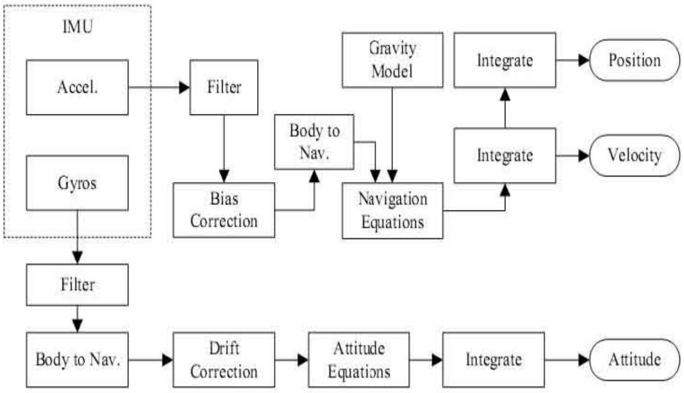

Fig. 4 Flow chart of a strap-down INS

B. Fusion Kalman Filter

The Kalman filter is an alternative way of formulating the minimum mean square error filtering problem using state space methods. The fusion Kalman filter is the central part of the integrated navigation system, where the components that are usually used in integration are the INS, GPS, magnetometer and the baro-altimeter. The INS alone has an unavoidable error that grows unbounded as time lapse. The GPS and magnetometer provides the position estimate at relatively slower rate. A Kalman filter was developed to estimate the errors of the system and then update the navigational solution. The purpose of combining navigation subsystems into an integrated system is to take advantage of complementary strengths of the subsystems. Thus the integrated navigation system offers very attractive feature.

(1) The integrated navigation system accuracy improves considerably than that of individual sub system.

(2) The integrated navigation system has a higher fault-tolerant property because each individual subsystem can still provide (part of) the navigation solution while others are temporarily unavailable because of jamming, GPS signal blockage, or any other reason.

(3) GPS, magnetometer and baro-altimeter may be used for the initialization process of the INS and even for calibration. Fig. 5 shows the block diagram of the complementary INS/GPS/Baro/ Mega Kalman filter that deals with the INS error state instead of the total vehicle states using the INS error model.

C. Guidance

The guidance loop computes the guidance demands from the current UAV states and the next waypoint to satisfy mission requirements. The guidance demands are desired UAV airspeed, height and bank angle. In autonomous mode, it selects the appropriate next waypoint depending upon the guidance state. Then it decides if the waypoint has been intercepted or missed. If it is not intercepted, it determines the Line Of Sight (LOS) angles and LOS rates to the next waypoint. Based on this information it computes the lateral acceleration required to intercept the next waypoint and converts this acceleration to the desired bank angle with a set of additional guidance demands: airspeed and height. The guidance loop updates guidance demands every 30Hz.

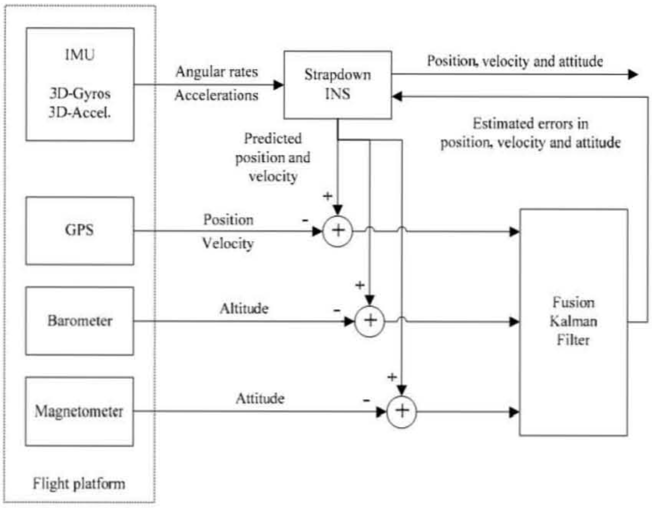

Fig. 5 Thestructure of INS/GPS/Baro/Mag Kalman filter

D. Flight Control

The flight control generates servomotor signals for the rudder, elevator, aileron and engine throttle. Using the guidance outputs and measured vehicle states, the flight control performs speed control, height and height rate control, bank angle control, heading control, turn compensation and elevation control. It controls the UAV's attitude, attitude rates and the airspeed. It generates the control signals every 20ms which is limited by the bandwidth of the servomotor. The control loop is the most time critical task in autonomous flight mode. A servomotor is a compact electromechanical device consisting of a DC motor with a built-in feedback circuit. These servomotors accept pulse-width modulation (PWM) signals as the reference input. Fig. 6 shows the block diagram of the control loop.

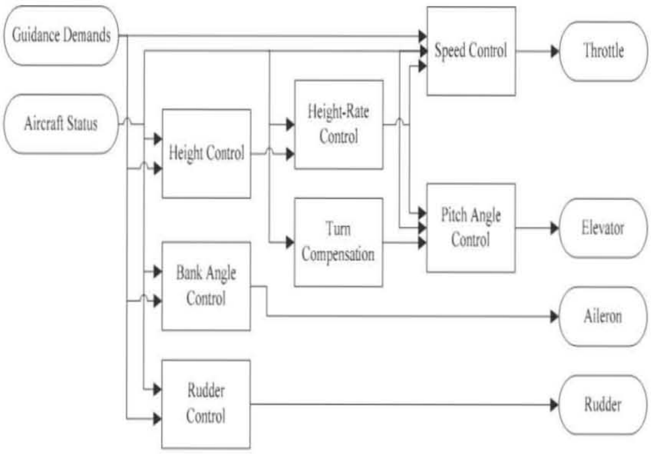

Fig. 6 The control structure

V. FLIGHT TEST RESULT

Due to the standard of wood of UAV structure, it is difficult to evaluate the performance of the GNC by adopting a more precise reference system. Thus 50 min flight test was performed to verify the real time autonomous flight with desired waypoint scenario. To get optimum point and record error data, extended Kalman filter approach to estimate the location of a UAV.If the measurement error contains additional dynamic error, modeled inside the filter. And the real-time control loop is the most time critical task in autonomous. Most of the Guidance and control algorithms were verified and tested using The Hardware-In-The-Loop (HIL) simulator which use the Vehicle model and simulated sensor data in the laboratory using C++ methodology for the GNC algorithm.

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