Development of an Unmanned Aerial Vehicle Platform Using Multisensor Navigation Technology

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Key words: UAV platform, MEMS, IMU, Navigation.

SUMMARY

The Unmanned Aerial Vehicle (UAV) technology is useful for various tasks ranging from aerial surveillance, homeland security and positioning operations. The capability for the unmanned aerial vehicles to operate autonomously in real environments is a great challenge. With a full featured UAV system, an aircraft could be competent for these tasks. Advances in computing, sensors, and communications technology make it possible to achieve autonomous performance and coordination of these vehicles in uncertain environment. This paper presents a design of a UAV control system including hardware selection and firmware development, which aims to control a mini UAV helicopter.

To stabilise and navigate the UAV, a low-cost navigation and control board, called NAVCON, is built, which has a floating-point digital signal processor (DSP) core and MEMS inertial sensors and the GPS. It has a low power consumption featuring a small physical size (8.5cm by 5.5cm) that can be further used to support hand-held navigation.

NAVCON is designed of rich peripherals such as, UARTs, IIC, SPI, LCD, GPIO, USB Host, PWM, and ECAP. The UAV control module for radio sampling, digital servos control and telemetry is designed specifically as a daughter board that can be plugged onto the NAVCON as the extension to complete the UAV helicopter system.

The brain of NAVCON is TMS320C6747 floating-point DSP from Texas Instrument. The inertial sensors consist of three-axis gyros (ITG3205), three-axis accelerometer (BMA180), and magnetometer (HMC5883L) and pressure sensor (MS5611). All sensors are communicated via IIC bus. These MEMS inertial sensors are sufficient for the application of the UAV helicopter system in terms of their vibration tolerance. Utilisation of these MEMS inertial sensors and implementing control algorithm on top of the system, the UAV system can be developed into a fully functional UAV control system.

The operating system of the NAVCON is the DSP/BIOS real-time operating system (RTOS) from Texas Instrument. It is a scalable real-time multi-tasking kernel. It provides a small firmware real-time library and easy-to-use tools for real-time tracing and analysis. The standardised APIs supports rapid application migration and research development. It supports real-time scheduling, synchronisation, and instrumentation and it provides a wide range of system services such as pre-emptive, deterministic multi-tasking, hardware abstraction, memory management and real-time analysis.

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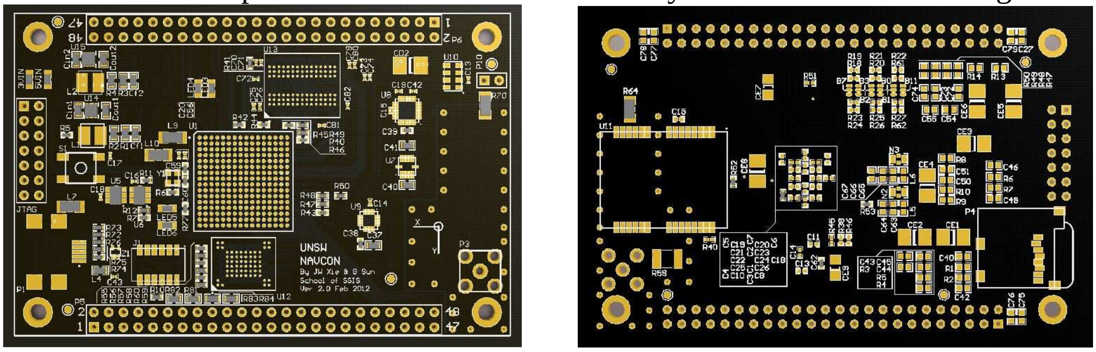
1. INTRODUCTION

UAV is defined as an aerial vehicle capable of sustained flight without the need for a human operator onboard[1]. In recent years, UAVs are playing an increasing significant role in scientific applications. Although UAVs are mostly used in military applications, they can also perform such scientific and commercial tasks as surveying, mapping, search and rescue, traffic flow monitoring, and so on. The development of MEMS inertial sensors also helps overcome some constraints by enabling the production of small, highly functional navigation hardware. Many well known low-cost UAV platforms were built in the past few years. MP2128^{HELI}[2] from MicroPilot, is the smallest VTOL(vertical take-off and landing) autopilot in the world (10 cm × 4cm). MP2128^{HELI} can fly both fixed-wing and VTOL UAVs with a 150 mips RISC processor on the board. It also fully integrated with 3-axis gyros, accelerometers, GPS, pressure altimeter and pressure airspeed sensors, but only with a totally 28 grams weight. UDB3[3] and its upgraded version UDB4[4] are two PIC UAV development boards with inertial sensors being built on board, which are able to perform the navigation control of the fixed-wing airplane. Our previous work[5] was developing an UAV platform for testing positioning technology based on the UDB3. ArduPilot Mega[6] is a pro-quality IMU based on the Arduino Mega platform, which will fly fixed-wing aircraft, quadcopters and helicopters, handling both autonomous stabilisation and GPS navigation. The Navigation Board M3(NavBoard M3)[7] is a miniature GPS and IMU package designed for either stand alone operation with on-board processing or simply as a sensor package for integration into existing systems. The combination of all these sensors with the on-board ARM processing power allows the controlling of the UAVs.

However, most of them have limitations in different aspects. Under most conditions, the computing resource available on the UAV determinates the performance. The processors used in these platforms do not have enough processing power to execute the more complicated algorithm in future. They may not have enough RAM and flash ROM on board for the further development as well. Some of them may not have a full set of sensors for the UAVs. All these may seriously affect the performance of the platform.

2. HARDWARE ARCHITECTURE

For the problems mentioned above, a new UAV navigation and control board named NAVCON was built. The NAVCON has a floating-point digital signal processor (DSP) core, MEMS inertial sensors and the GPS. It also has a low power consumption featuring a small physical size 8.5cm × 5.5cm × 1.5cm, which has the possibility to be implemented in different areas. The outline drawings of the 8-layers NAVCON with both front and back sides were shown in Figure 1(a) and (b). The hardware block diagram of NAVCON was showed in Figure 2. Detail descriptions about each blocks sorted by function are as following.



(a) Front side (b) Back side

Figure 1. The outline drawing of the NAVCON

2.1 Processor and OS

The heart of NAVCON is TMS320C6747, a 32bit fixed/floating-point DSP from Texas Instrument. The processor can run at 300MHz clock speed. With the special structure in chip, the processor can finish FFT and DFT in signal processing, real or complex multiplication in matrix calculation by short time. It can obviously improve the execution speed comparing to the conventional micro controller.

The operating system on NAVCON is DSP/BIOS real-time operating system (RTOS) from Texas Instrument. It is a scalable real-time multi-tasking kernel. It provides a small firmware real-time library and easy-to-use tools for real-time tracing and analysis. The standardised APIs supports rapid application migration and research development. It supports real-time scheduling, synchronisation, and instrumentation and it provides a wide range of system services such as pre-emptive, deterministic multi-tasking, hardware abstraction, memory management and real-time analysis. The whole system is debugged by the TI's DSP development tool CCS4.1.

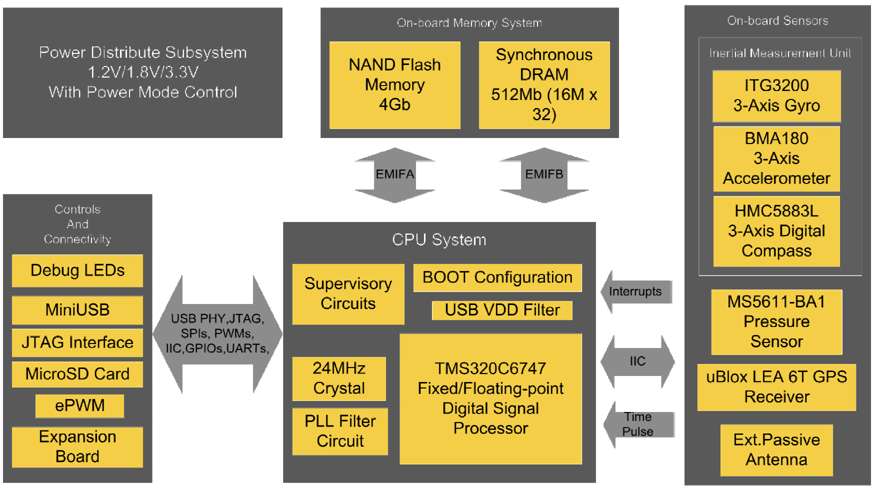


Figure 2. Hardware block diagram of the NAVCON

2.2 Sensors

For estimating the velocity, position (latitude, longitude and altitude) and attitude (pitch, roll and yaw) of the UAV, MEMS sensors are selected for the NAVCON in terms of their vibration tolerance, including accelerometer, gyroscope, magnetometer, pressure sensor and GPS. All the sensors are connected to the IIC bus with unique address. For that, more peripheral resources can be saved for users. Some primary technical specifications of these sensors are shown in Table 1.

The three-axis accelerometer is BMA180 from BOSCH. It's an ultra high performance, g-range programmable and low power g-sensor with integrated thermometer.

The three-axis gyroscope is ITG3205 from InvenSense. There will be a big and frequent vibration in either aerial or ground vehicles, which should be considered primarily when choosing an appropriate gyro. And the gyros from InvenSense are famous for its good anti-vibration ability.

The three-axis magnetometer is HMC5883L from Honeywell. It can obtain absolute orientation angles with respect to the earth by sensing earth's magnetic field. It related to attitude estimation of the UAV.

The pressure sensor is MS5611-01BA03 from Measurement Specialties. The testing result from the blog of Blue Fly Vario development[8] showed that it has a higher resolution, more stable and more accuracy output than BMP085. The latter is also a pressure sensor but from BOSCH, which had used in many other platforms.

An uBlox LEA-6T GPS receiver was used in the NAVCON for providing the absolute position information. This SBAS (Satellite Based Augmentation Systems) enabled receiver has 50 channels for GPS L1/ C/A code acquiring. High sensitivity (-162dBm) and short Time-To-First-Fix (TTFT) (26s for cold start) help the receiver initialise very quickly, so the backup battery can be removed from the board. Up to 5Hz navigation information update rate is very useful for a high dynamic application in UAV. LEA-6T is differing from the other modules in LEA-6 series for its precision timing and raw data features. There are two configurable time pulse outputs with long-term accuracy and stability, which can be used for time synchronisation in either system clock or data fusion algorithms. Raw data output can help users to access the carrier phase with half-cycle ambiguity resolved, code phase and Doppler measurements, which can be used in external applications that offer precision positioning, real-time kinematics (RTK) and attitude sensing.

A connector for extended active antenna is reserved on the board. Comparing with the patch passive antenna, it is space saving for the board and it can avoid being disturbed by the working motor with a high electromagnetic radiation and covered by some metal objects.

Table 1. Technical specifications of the sensors

Accelerometer	Programmable g-ranges(1g, 1.5g, 2g, 3g, 4g, 8g, 16g) Selectable 14 or 12bit ADC for read-out acceleration Zero-g offset(fine tuning): ±5mg Zero-g offset temperature drift: ±0.5mg/K Noise density: 150 – 200ug/√Hz Nonlinearity: ±0.15 – ±0.75%FS
Gyroscope	Range: ±2000°/s Sensitivity scale factor: 14.375 LSB(°/s) Initial ZRO tolerance: ±40°/s ZRO variation over temperature: ±40°/s Temperature nonlinearity: 0.2% Total RMS noise: 0.38°/s-rms
Magnetometer	Enables 1° – 2° compass heading accuracy, even in strong magnetic environment
Pressure sensor	10 – 1200mbar range with 24 bit ADC High resolution: 10cm Accuracy(std.): ±1.5mbar
GPS receiver	Update rate: 5Hz Horizontal accuracy: 2.5m Velocity accuracy: 0.1m/s Heading accuracy: 0.5° Time pulse signal accuracy: 30ns (15ns after compensation)

2.3 Peripheral interface

As shown in Figure 2, the NAVCON reserved rich kinds of peripheral interfaces to expand its application. Such as the general communication buses including IIC, UARTs SPI and USB, the LCD controller, GPIOs, PWM and ECAP. The NAVCON also offers a standard micro-SD (TF) card slot for the real-time data logging. It is very convenient for users to add additional parts, modules or daughter boards to the NAVCON for different implements, with the powerful computing capabilities offered by the DSP.

2.4 Flight control board and aircraft

Since there are not enough PWM channels on the DSP to control all the digital servos, a flight control daughter board is designed, which can be plugged on top of the NAVCON, as an extension to complete the UAV system. The flight control daughter board is equipped with a microcontroller which can monitor and sample the PWM/PPM input from the RC radio input and direct these data as packages to NAVCON, and update the PWM servos controls according to the NAVCON's control output.

The aircraft used for testing the platform is Blade 400 3D, as shown in Figure 3, a hobby grade Cyclic Collective Pitch Mixing (CCPM) radio control helicopter with 120deg of swash plane. The Blade 400 3D is designed for advanced helicopter pilots, a ready-to-fly (RTF) model. It is equipped with Spektrum's advanced DX7 2.4GHz DSM2 7-channel programmable computer aircraft system (Spektrum 2011). The radio control system also includes the 14gram Spektrum AR7000 Receiver.

Figure 3. The helicopter platform Blade 400 3D

2.5 Wireless communication

Two wireless communication channels are available on the current system. The first channel is the two way communication link between the PC ground station and the UAV. This is achieved by using two 2.4GHz Xbee RF modules. The second channel is the RC control link from the RC controller to the UAV. Except for the normal flight control, the RC channel is able to control the flight mode of the UAV. An open source PC based ground station software "QGroundControl"[9] is used to support in-flight manipulation of waypoints and on-board parameters, real-time plotting of sensor and telemetry data, logging and plotting of sensor logs, UDP, serial (radio modem) and mesh networks.

2.6 Consumption

It's significant to control the consumption of the UAV platform for the very limited battery capacity. There is only one 5V power input on the board. Three power chips (two TPS62065 and one TPS76318) are used to generate the 3.3V, 1.8V and 1.2V output. As shown in Table 2, the consumption of every part is listed. The total consumption can make a good balance between the performance and flight duration time.

Table 2. System Consumption

Part Name	Consumption(mW)
TMS320C6747	1365(Max)
uBlox LEA-6T	240(Max)
BMA180	3.6
ITG3205	21
SDRAM	430
NAND Flash	115
Flight control board	130(Max)
HMC5883L	1
MS5611-01BA03	5
Total*	2500(Max)

*Assuming 95% efficiency of power utilisation

3. APPLICATIONS

The NAVCON is designing with a large expansion capability, which means it can be used in many relative applications, not restrained on the UAV.

3.1 MEMS IMU

For integrating the processor and kinds of MEMS inertial sensors on one board, NAVCON is naturally a MEMS IMU. It can be easily held on user's hand, fastened on user's body or just put in user's pocket for the pedestrian navigation. The low consumption supports long-time navigation. By the output data of accelerometer and gyro from different parts of human body, the algorithm can calculate the parameters of gait, which information even can help doctor to make the diagnoses in health of patients.

3.2 Tightly and ultra tightly integrated navigation

The GPS receiver on the NAVCON can output the raw data including carrier phase, code phase and Doppler measurements, which can be combined with the inertial sensors for the tightly-integrated navigation. If the GPS component is replaced by an open-source GPS receiver such as NAMURU[10], an ultra tightly- integrated navigation platform can be built, through which the IMU data can aid to estimate and predict the Doppler shift of the GPS signals.

3.3 Indoor positioning

Inertial aid can bridge short GSP outage. But in an indoor environment, without the GPS signal, NAVCON with additional modules such as Bluetooth, WIFI or RFID can also find out the right orientation and position.

4. CONCLUDING REMARK AND FUTURE WORK

A new UAV platform called NAVCON was developed in this paper, to meet the requirement of the small low-cost UAV system with powerful processing capacity and good versatility. The whole hardware has been designed and described in detail in this paper. The NAVCON has a bright prospect for many advanced applications. The future work is to test the board and finish the software with RTOS. Finally a complete autopilot system will be realised on the NAVCON and the flight control board.

5. ACKNOWLEDGEMENTS

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"**Yong Li** obtained a Ph.D. in flight dynamics in 1997. He is a senior research fellow at the School of Surveying & Spatial Information Systems at the UNSW. He worked at the Beijing Institute of Control Engineering for GPS aerospace applications from 1997 to 2000. From 2000 to 2002, he was a Science and Technology Agency fellow at the Japanese Aerospace Exploration Agency (formerly the National Aerospace Laboratory of Japan). Before join UNSW, he worked on the GPS sports application at Royal Melbourne Institute of Technology University under the Cooperative Research Centre for Micro Technology from 2002 to 2004. His current research interests include multisensory integration of GPS, INS, and pseudolites (Locata), attitude determination, GPS receiver technologies, and optimal estimation/filtering theory and applications."

"**Chris Rizos** is currently head of the School of Surveying & Spatial Information Systems at the UNSW, Sydney, Australia. He has been researching the technology and applications of GPS since 1985 and established more than a decade ago the Satellite Navigation and Positioning group at UNSW, today the largest academic GPS/global navigation satellite system (GNSS) and wireless location technology research laboratory in Australia.

Rizos is the president of the International Association of Geodesy and a member of the Executive and Governing Board of the International GNSS Service. He is an Editor-in-Chief of the Journal of Applied Geodesy, and a member of the editorial boards for several other navigation/GPS/GNSS journals and magazines. He is an author or coauthor of more than 500 journal or conference papers."

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