HB-Mini: A new data acquisition sensor- and autopilot system for atmospheric research and its application on different aircraft

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1. Introduction

2. Layout and operation of the Paparazzi System for atmospheric research

3. Used aircraft

4. Results of test and measurements flights

5. The Planar-HB-Mini-Autopilot

6. Conclusion

1. Introduction

- At Hochschule Bremen and Akaflieg Bremen e.V. autopilot systems and MAVs have been developed and constructed since 2006. The position is measured using GPS, the attitude using IR sensors. This work uses the results of the GPL Paparazzi project (ENAC Toulouse http://paparazzi.enac.fr/wiki/Main_Page).

- The IR-attitude estimation system works well under visual flight conditions at day and night and has advantages for IC powered aircraft, since vibrations do not affect the measurement.

- In valleys, towns with high buildings, fog, clouds and inversion weather conditions, in the tropics the IR sensors fail.

- To overcome this problem, first (in 2010) an other measurement hardware (accelerator and gyro based) and software was implemented in Paparazzi and second a new planar autopilot hardware was developed in 2012 by our team.

2. Layout and operation of the Paparazzi System for atmospheric research

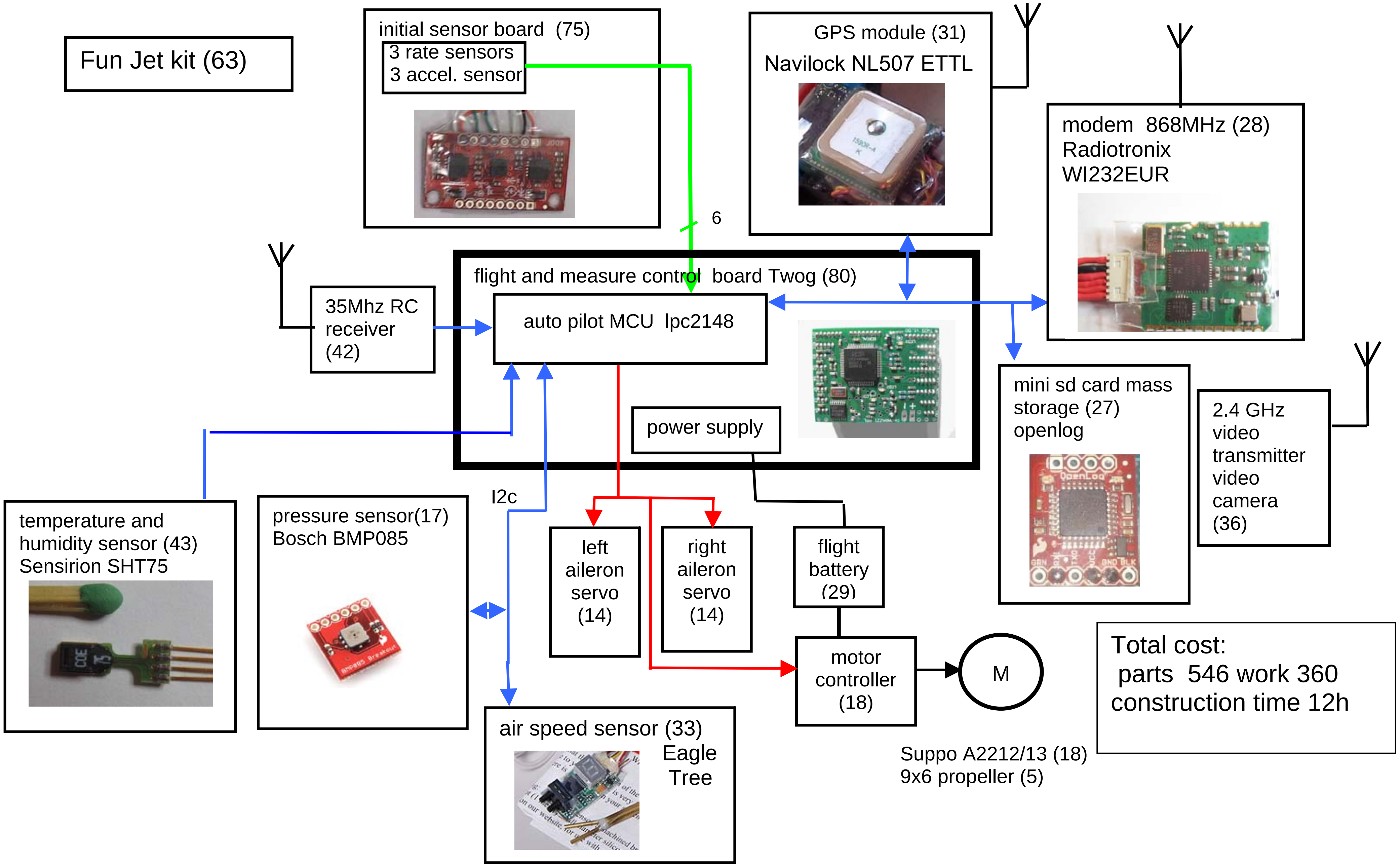
1. aircraft segment

consist of aircraft, autopilot and sensors

2. ground segment

laptop with Linux OS,
power supply (from 12 V car battery),
optional 2.4 GHz receiver for video and audio and frame grabber,
USB flash cable,
868MHz modem with parabola antenna,
35 MHz RC transmitter

aircraft segment block diagram and component cost in euro



For the preparation of test and measurement flights within one week during the COST Action ES 0802 between the 4th and 8th of July 2011 as part of the international meteorological field campaign BLLAST at the Atmospheric Research Center in Lannemezan, France we solved the following tasks:

- Determine and test of a low cost and efficient drive train (motor (Suppo A2212/13 50g 1000 rpm/V 80% 4-8A) propeller (graupner cam silm 9x6), controller, propeller saver) for the Funjet (Flight time up to 43 minutes)

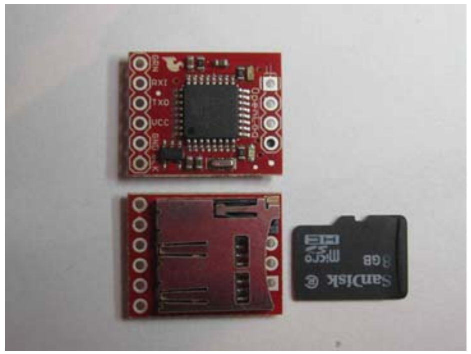
- Integration of a new attitude measurement hard and software in Paparazzi. A DCM algorithm introduced by William Premerlani and Paul Bizard form DiyDrohne project (http://gentlenav.googlecode.com/files/DCMDraft2.pdf) was chosen as the best and ported to Paparazzi by us.

- Design and construction of MAV BUSCA 800 and a opaque labyrinth air sensor box done by Peter Galke

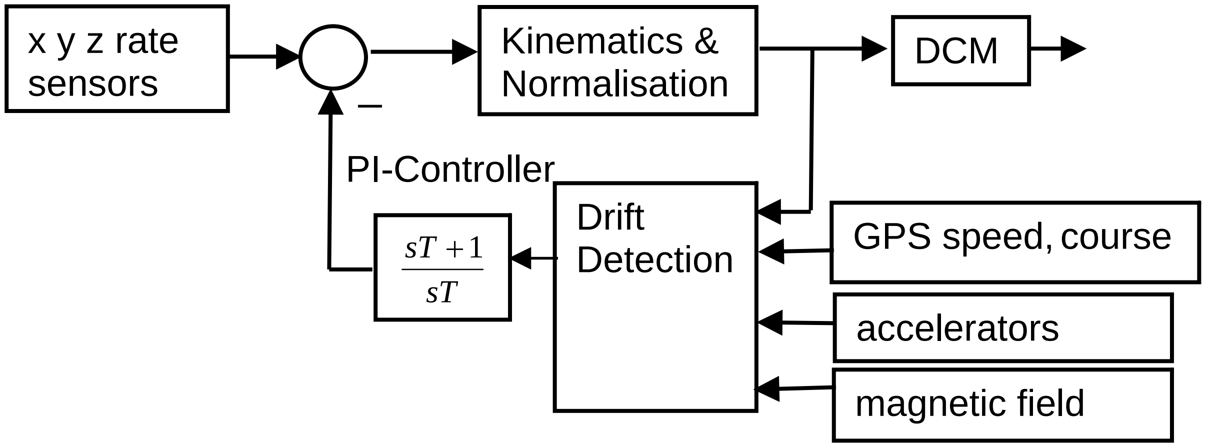
- Construction of 2 Fun Jets and a Paparazzi measurement box as payload of a mikrokopter quadrocopter

- Fine tuning of the control systems (integration of airspeed, altitude and new attitude measurements)

- Integration of the micro SD mass storage Openlog. Therefore we developed a new software-component, that sends defined timestamps from the autopilot, enabling us to decode the recorded data afterwards. Second the Openlog software was changed to prevent mode changes by control commands within the data stream.



2.1 DCM algorithm with a feedback control system (proportional integral) for bias correction



DCM based complementary filter with PI-Controller

- The kinematics equations are integrated in a notation of the direction cosine matrix (DCM) 50 times per second.
- To save orthogonality of the DCM for every integration step small adjustments of the matrix elements are applied.
- The centrifugal accelerations are calculated $\vec{\varpi}\times\vec{v}$ and subtracted from the accelerations measurements to calculate the true earth acceleration

- For bias and drift error correction a PI feedback controller is used. To estimate the errors the acceleration data the GPS ground speed and rate signals are considered. To correct the yaw angle the GPS course or magnetic data vector is used.
- By calculating the centrifugal accelerations fixed wing aircraft can fly circles and helixes continuously
- This filter is very robust by low computer cost. The run time is only 0,59ms for float calculations.
- Automatic flight with fixed wing aircraft and Paparazzi work well and with better performance compared to the old IR-system (all weather compatibility, better dynamics, larger roll angle).

3 Used aircraft

Fun Jet 1 ↑ Mikrokopter ↓

Funjet 2 ↑ Busca 800 ↓

3.1 Technical data of the used aircraft

	Fun Jet	Busca800	Mikrokopter[1]	Twin Star[2]	U CAN FLY[3]
span /cm	80	79	65	142	146
pay load /g	250	600	250	500	450
max weight/ g	900	2000	1280	1900	2000
trans. box /cm	83x83x15 (24)	83x83x24	50x20x20	103x19x33	117x21x30
flight time /min	43	28	9	-	20
max speed /ms	30	28	13	-	cruise 15-17
handling	easy	easy	very easy	very easy	very easy
construction time /h	12	46	10	15	7
part cost in Euro	564	586	1131	737	554
total cost[4] with 30 Euro/h	924	1966	1431	1187	764

by the use of a current IMU Board (Drotek, 17 Euro) with the MPU6050 chip 58 Euro can by saved

1 The mikrokopter is expensive; to construct a multirotor using a Paparazzi design the part costs are about 620 Euro
2 First Paparazzi flight in 2007 currently under development for future use with new motor set and water landing gear
3 Data evaluated from Rolf Nölleburg first Paparazzi flight in 2012 (YAPA autopilot). Tanks for the data
4 For the ground segment (RC-Transmitter,(210) battery(80), laptop(400), 868Mhz modem and parabola antenna (90), 2,4Ghz video (46) receiver) add about 826 Euro

4. Results of test and measurements flights

In the duration from 4th to 8th of July 2011 we took 21 measurement and test flights with the following results:

- by an overload of the motor controllers (wrong propellers and great heat) the mikrokopter fails to get measurements after a few minutes of flight by de soldering power transistors

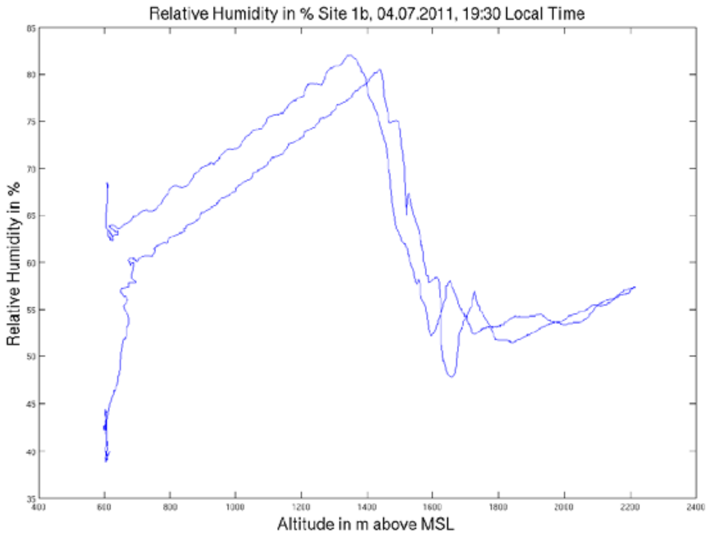
- flying to maximum allowed altitude of 1600m AGL: (We estimated that Busca800 and the Funjet can fly up to 2800m AGL) By the use of a parabola antenna 868MHz for the ground station we have got never a lost telemetry link

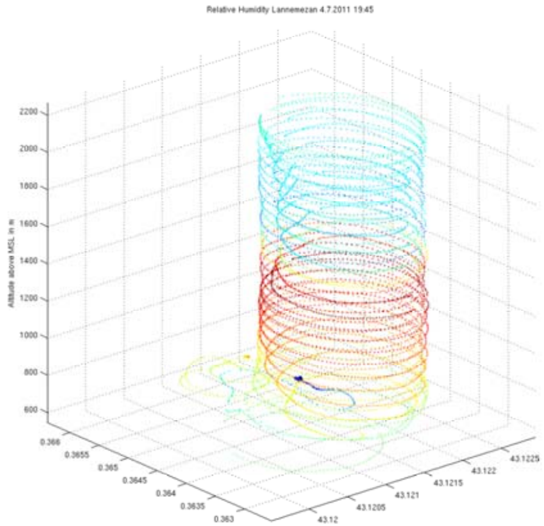
- flying into clouds, flying in rain: a water drop got into the pilot tube and air speed estimation gets wrong values, the humidity sensors gets wet an need some time to get dry and measure right values. The DCM attitude estimation works perfect. All flights where save and stabile. For the preparation flight of the 2011 MAV Competition in Netherlands the Busca800 did a perfect flight at a wind speed of 18m/s. The ENAC team won the endurance competition by using the implemented DCM algorithm

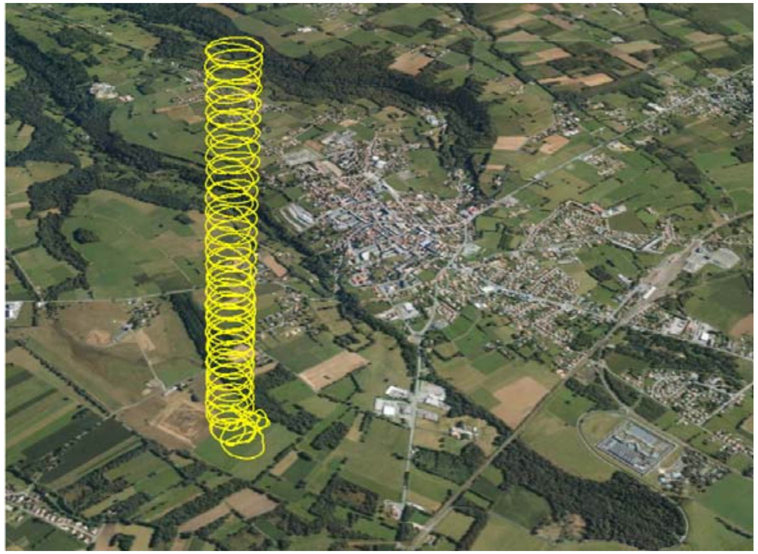
- flying with multiple Fun Jets: Funjet 1 was leading and Funjet 2 following the flight path with lower altitude

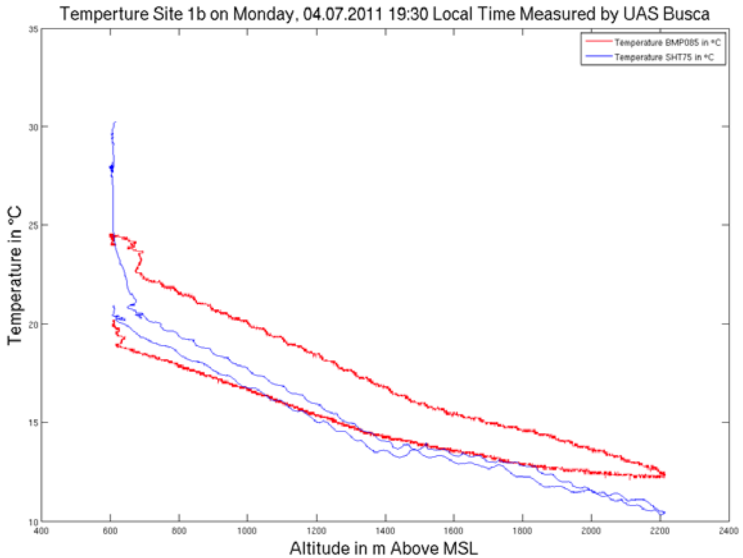
- Estimation of the boundary layer with flying of helixes. The use of the air speed measurement and the new DCM attitude estimations for the feed back control systems gave an improvement in flying helixes and circles

Estimation of the boundary layer





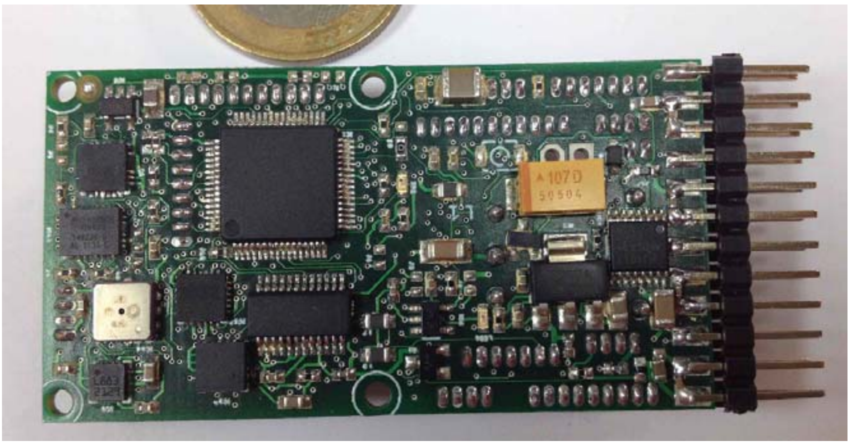


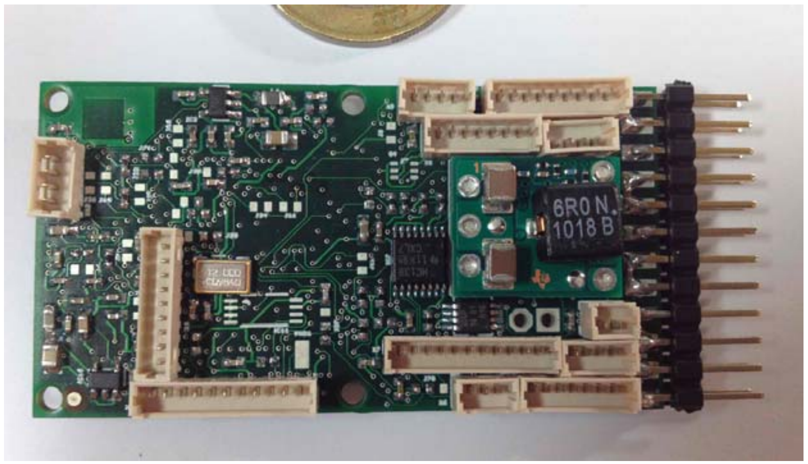


5. The Planar-HB-Mini-Autopilot

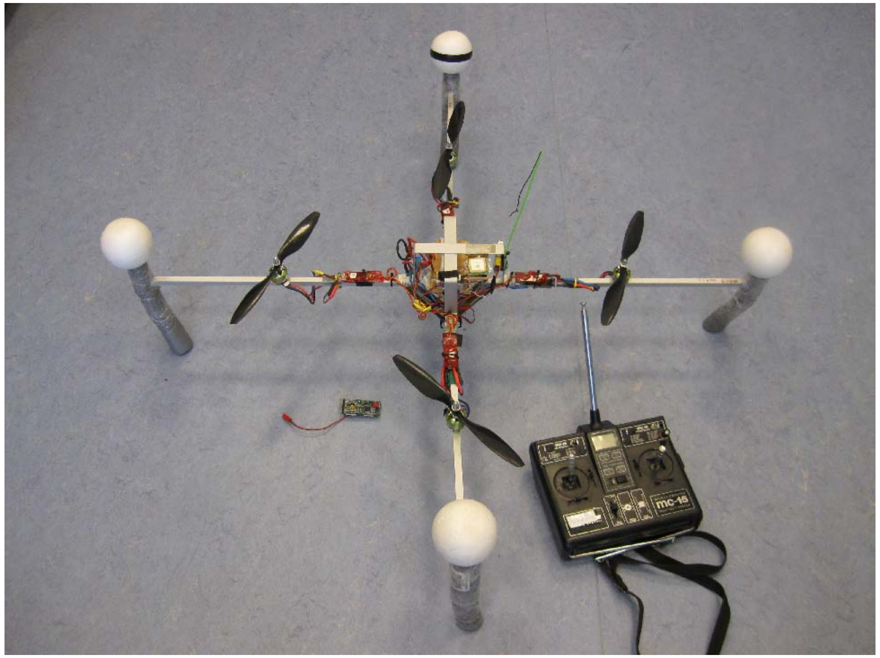
In 2009 a two pcb based HB-Autopilot (41mm*57mm*27 mm, 27g) autopilot was developed and tested on quadrocopter in Bremen. Due to the progress in sensor electronics in 2010, it was possible to design an autopilot with one planar PCB with lower mass (17g) and dimensions (57mm*30mm*11mm) called HB-Mini. In 2012 a modern single inertial sensor chip MPU6000 was added for future use and the autopilot was integrated into the paparazzi software system for normal aircraft and multirotors. (https://github.com/elemhsb/paparazzi) The new autopilot offered the following features:

- usability for all kind of aircraft in the 200g to 20kg range (separate power for the servos)
- power supply 2.3A 5V output
- use of modern MEMS sensors: Invensense MPU6000 (MPU6050, MPU9150) rate and acceleration, HMC5883L magnetometer, BMP085 pressure sensor
- switches: two power 1A, camera, buzzer output
- optional 8 channel 16bit analogue input, noise free 3V and 5V power for external sensors
- interfaces: USB, 2 UART, SPI with 5 CS, 3V I2C and 5V I2C, 10 servos output, RC input, 8 analogue 10 bit or general I/O 6 JTAG or general I/O connections.





Aircraft with the HB-Mini autopilot



MAV Wanze, 206g, motor distance 100mm

HB_Copter, 1102g, motor distance 40cm

6. Conclusion

Low cost unmanned air systems where realized and used for measurement flights up to 1600m AGL by extending the standard hard and software of the paparazzi autopilot system with

- Use of inertial measurements and the DCM algorithm for attitude estimation and
- Extension with humidity, pressure, temperature, air speed sensors and a low cost micro-sd-card mass storage.
- Robust and stable automatic measurement flights under difficult weather conditions (flight in rain, clouds and strong wind) have been shown.

An new universal autopilot/ data acquisition system, HB-Mini for all kind of aircraft like planes, quadrocopters and helicopters, was developed an tested.

All hard and software can be used by other groups since the software and hardware plans are published and set under GPL. Tanks to the Paparazzi team especially to Martin Müller for the integration of the sensors drivers.

The future work will be

- Development of a free (GPL) turbulence measurement system and use of new sensors
- Adaptation of other model aircraft like Schwalbe (hotliner 2,4m, 50m/s) and Wotan (8kg, IC motor) Multicopter (3kg, 8 motors)
- Swarm flights