# DATA FUSION PRINCIPLES FOR HEIGHT CONTROL AND AUTONOMOUS LANDING OF A QUADROCOPTER

**Nils Gageik, Julian Rothe, Sergio Montenegro**

*University of Würzburg, Aerospace Information Technology (Germany)*
*Würzburg September 2012*

gageik@informatik.uni-wuerzburg.de, montenegro@informatik.uni-wuerzburg.de

## Abstract

A simple algorithm (weighted filter) for data fusion of multiple sensors to obtain the most reliable value without taking wrong measurements into account is presented here. The implemented algorithm is for height over ground measurement of a quadrocopter and fuses an inertial, a pressure and one ultrasonic sensor with two infrared sensors. Using this fused height a height control and autonomous landing has been implemented. The system was implemented within a self-developed quadrocopter (Figure 1). The presented system is just a subsystem of the AQopterI8 project of the University of Wuerzburg, which aims to develop an autonomous quadrocopter.

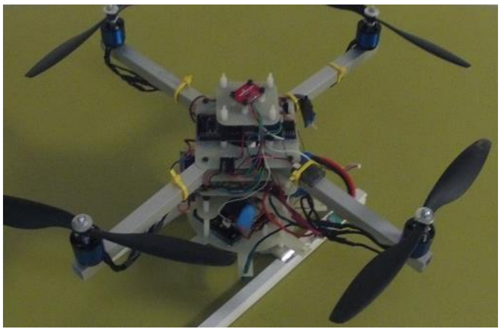

**Figure 1: AQopterI8**

Keywords: data fusion, ultrasonic, infrared, inertial, pressure, height control, automatic landing, quadrotor, quadrocopter

## 1 INTRODUCTION

Nowadays quadrocopters and other civil UAVs (Unmanned Aerial Vehicle) are widespread in the hobby rooms and labs of model-makers, developers and researchers, but not that common in public areas. This may change in the next years as many researchers are working on the improvement and developing applications of such systems. The possible field of applications for an autonomous drone may reach from emergency tool for firefighters and disaster controllers over observation and exploration for both known and unknown areas to many further domains, where ever a small flying machine can help humans in their daily work [2][10][11][12].

A height control is substantial for an autonomous flight of a quadrocopter. The challenge for a stable height control is to receive accurate data with low noise, which are the base of every control system. Solutions exist, which provide such height data, like CPDGPS (carrier phase differential global positioning) receiver [13], optical tracking systems, laser scanners and camera vision systems, but they suffer from different drawbacks like high costs, high weight, the need of external reference or a diaphanous medium. Therefore data fusion is mandatory. Common approaches for data fusion are Kalman Filter, Particle Filter, Bayesian Filter and Neuronal Nets, just to mention some. In contrast to these sophisticated approaches, this paper presents a simple algorithm, which therefore saves processing time.

This paper describes first the implemented algorithm to determine the height and next the system for height control and autonomous landing.

# 2 PROBLEM

Where ever multiple low-cost sensors like infrared and ultrasonic sensors are used together, it is necessary to have an algorithm to decide, which sensor can be trusted and which not. Ultrasonic sensors as well as infrared sensors tend to fail under certain circumstances like soft or diaphanous surfaces, smoke and bad reflections. Furthermore each sensor has a limited range of measurement. There is no low cost infrared sensor known to the authors, which can measure distances from 20cm to 500cm. The used ultrasonic sensor is not reliable after 220cm. Though one sensor nearly always measures the correct distance, most times one or more sensors fail. The difficulty is to detect the wrong sensors just by its measurement in the context of the others and the history, because each sensor returns just a measurement. Furthermore the system has to be capable to detect jumps, as there might be a sudden obstacle on the ground.

# 3 CONCEPT OF DATA FUSION

The main idea of the data fusion is to use any kind of information to pick the best sensor. Information is the history of every sensor, the total history and the bearing of every sensor in this as well as the current measurements of each sensor. The sensors are divided between **main** data and **reference** data sensors. Main data are absolute (good) distance measurements like the distance measurements from an ultrasonic or an infrared sensor. Reference data are sensors, which cannot stand alone, but are used to evaluate the reliability of the main sensor data and help to decide between those sensors, wherever they exclude each other. Reference data can be the height change computed from an inertial or pressure sensor. On a long-term basis the height cannot be computed from an inertial sensor without huge errors because of integration drift, but it is quite accurate in short terms.

By comparing all possible sensor combinations of main data and reference data using a norm and by adding the own plausibility, a weight for every sensor is calculated. This weight is used to decide, which sensor is taken for the final result. The other sensor values are rejected following the idea, that only one out of several different measurements can be true.

## 3.1 General Concept Weighted Filter

The weights used for the decision can be divided into three categories:

### *3.1.1 Main Weight*

The Main Weight describes how good the measurement of one sensor fits to the measurements of the other main sensors. For every combination of main sensors, a *norm* value is calculated which depends on the measurement of two main sensors. Using three main sensors this would lead to two norms for every sensor. The main weight of every sensor is then the sum of the weights. One possible norm can be the Euclidean Distance (Euclidean Norm) or any other proper function.

Hence, the Main Weight $M_i$ of Sensor i can be computed with

$M_i = \sum_j \{\alpha_j * norm\ (m_i\ ,\ m_j)\} = \sum_j\ \{\ \alpha_j * (m_i - m_j)^2\},$

where $m_i$ and $m_j$ are the measurements of Main Sensor i and j, respectively. $\alpha_j$ is a weight for every main sensor j.

### *3.1.2 Reference Weight*

The Reference Weight describes how good the measurement of one sensor fits to the measurements of the reference sensors. The Reference Weight $R_i$ of every Sensor i is the sum of the same *norm* depending on the measurement $m_i$ of Sensor i and the measurement $r_j$ of each Reference Sensor j:

$R_i = \sum_j \{\beta_j *\ norm\ (m_i\ ,\ r_j)\}$

$\beta_j$ is a weight for every reference sensor j. Inertial sensors may use the last output of the fusion.

### 3.1.3 *Own Weight*

The Own Weight describes how good the measurement $m_i$ of one sensor fits to its previous measurement. With the last measurement $L_i$ an expected measurement $E_i$ is computed using the estimated change S. Then the Own Weight $O_i$ is computed for every main sensor i using the norm between $E_i$ and $m_i$:

(1) $E_i = L_i + S$ (2) $O_i = \gamma * norm\,(m_i,\ E_i)$

*S* can be computed using an inertial sensor or any other reference sensor or a combination, as proper.

### 3.1.4 *Total Weight*

The Total Weight $T_i$ of Main Sensor i is computed using an exponential filter and the sum of all three sub weights:

$$T_{i,k} = \delta * T_{i,k-1} + (1-\delta) * (M_{i,k} + R_{i,k} + O_{i,k}),$$

with k being the time index. The exponential filter brings the history into account using the cut-off factor $\delta$.

## 3.2 Implemented Concept

Though any number of main and reference data sensors can be implemented using this algorithm, the algorithm has been implemented twice with two main and two or three reference sensors. Because for most distances the two infrared sensors exclude each other because of their different measurement ranges and to overcome this problem merging these sensors in one total filter, first the infrared measurements are fused and the result is merged with the ultrasonic sensor in each case using the presented algorithm.

# 4 IMPLEMENTATION OF HEIGHT ESTIMATION

The implemented data fusion merges first two infrared sensors as main sensors using as reference sensors one ultrasonic, one pressure and one inertial sensor. The result is then merged with the ultrasonic sensor using as reference the same pressure and inertial sensor (Figure 2).

For sensors the infrared sensors GP2Y0A710K0F (100 – 550cm) and GP2Y0A02YK (20 – 150cm) from Sharp, the Pressure Sensor BMP085 from Bosch and the ultrasonic sensor SRF02 from Devantech has been implemented (Figure 3).

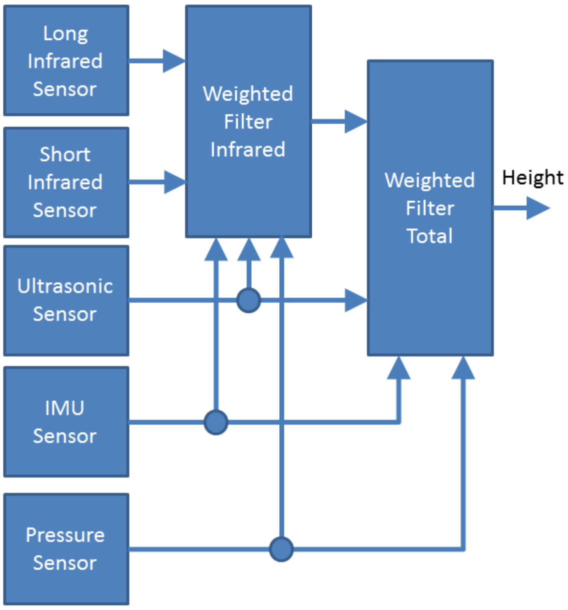

**Figure 2: Implemented Concept**

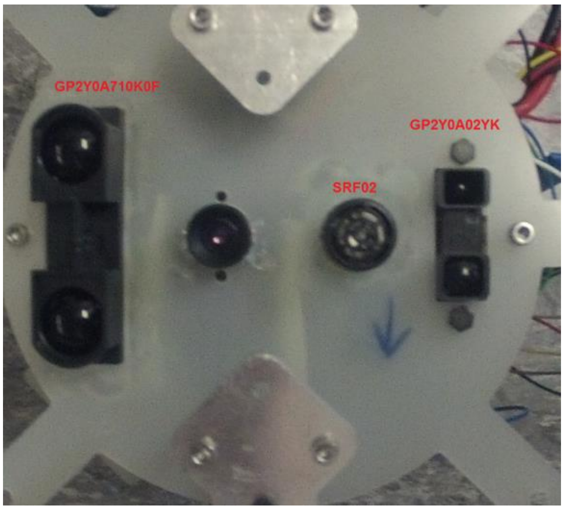

**Figure 3: Bottom Plate**

Left: Long IR Sensor GP2Y0A710K0F
Middle Right: Ultrasonic Sensor SRF02
Right: Short IR Sensor GP2Y0A02YK

## 5 HEIGHT CONTROL AND AUTONOMOUS LANDING

For Height Control a PID Controller has been implemented using the Height Estimation as input. The set point for height can be changed by remote between 50cm and 300cm and the PID Controller is stable for every set point.

For Autonomous Landing a state machine with three states has been implemented (Figure 4). Initially, the system is in state 0 using the height controller with set points defined by remote. If the Landing Commando is given, the quadrocopter switches to state 1 with a new set point for height of 30cm and the PID parameters of the system are changed for optimal landing. Since the lowest measurable height is ca. 20cm, just changing the set point to 0cm is not possible. Furthermore, for a safe landing from any distance, a higher set point with room for overshoot is better. As soon as the measured height is less than 60cm, the set point is lowered to 10cm for a smooth landing. After a distance of less than 30cm is measured, the input of the motors is no longer the output of the PID Controller, but the motors are simply steered and counted down beginning from the current valid hover gas, if not already less, to zero.

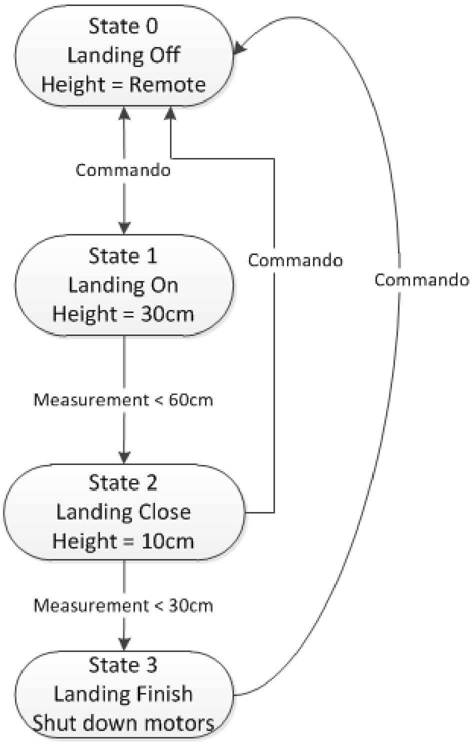

**Figure 4: Autonomous Landing State Machine**

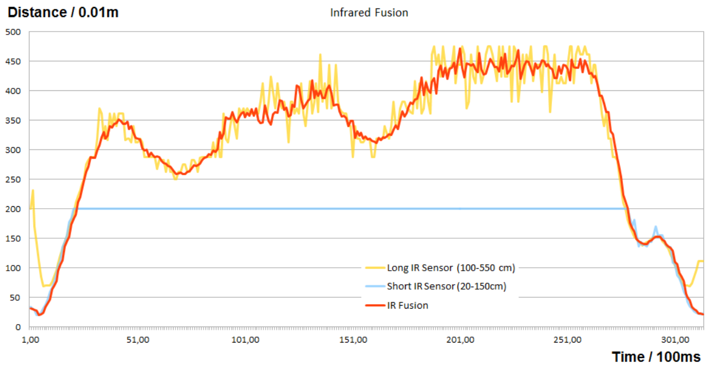

**Figure 5: IR Fusion**

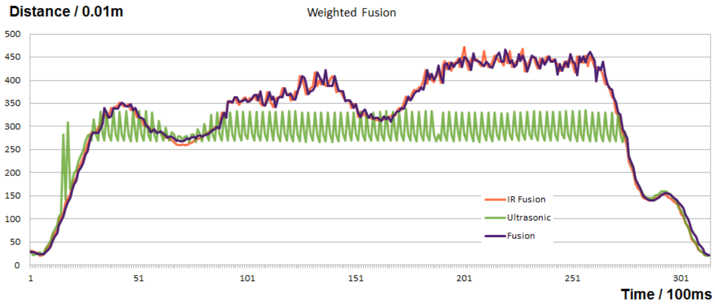

**Figure 6: Total Fusion**

## 6 EVALUATION

The performance of the height estimation, height control and autonomous landing has been separately evaluated using the optical tracking system PPT X4 from WorldViz [4] [14].

### 6.1 Height Estimation

The Height Estimation has been evaluated in two main experiments. In the first experiment, the quadrocopter was flying on different heights up to 450cm. The evaluation shows the drawbacks of the sensors and the total problem. The Long IR Sensor measures wrong values up to ca. 60 cm. The short IR Sensor fails at ca. 200cm. Nevertheless the IR Fusion picks the correct sensor [Fig. 5]. This result is forwarded to the total fusion. Figure 6 shows the result of the total fusion. Though the ultrasonic sensor has problems with measurements higher then 250cm, the correct sensor is picked. In the second experiment a jump simulating a sudden appereance of an obstacle has been simulated, to figure out, if the filter is able to detect it. The system has been moved over a table. Figure 7 shows, that the table has been detected correctly when moving forth and backward.

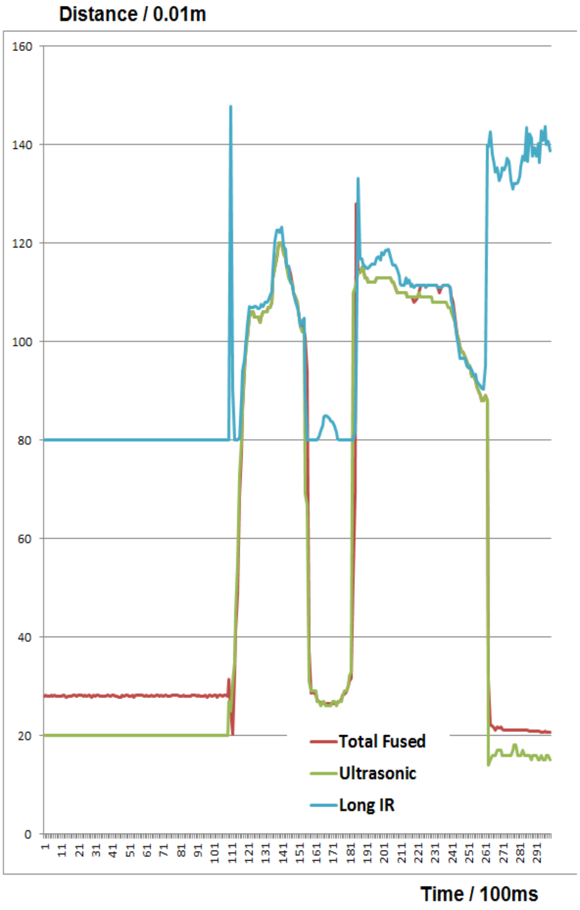

Figure 7: Jump Simulation

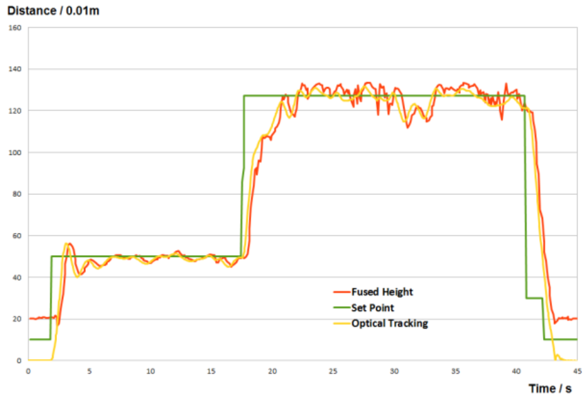

Figure 8: Height Control

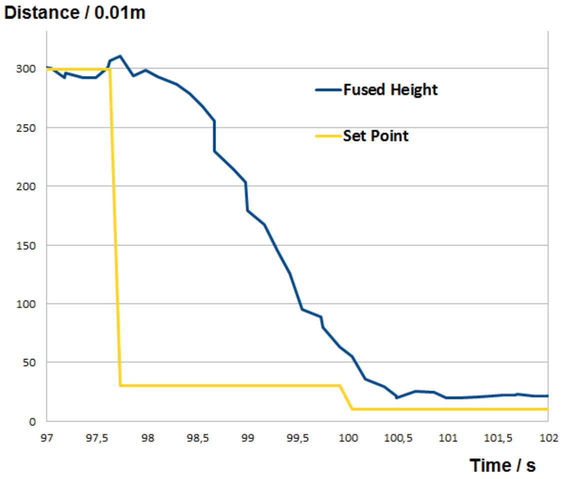

Figure 9: Autonomous Landing

## 6.2 Height Control and Autonomous Landing

The Height Control has been evaluated by flying on different heights between 50 and 400cm. Figure 8 shows the results of one flight starting from 50cm, chaning to about 125cm, changing back to 50cm and landing. The new height is reached within about 5 seconds and hold stable. The correctness of the height could be verified with the optical tracking, which was only used as reference and for evaluation [Fig. 8].

The Autonomous Landing has been investigated by landing from different heights. One big issue was the trade off between smooth and fast landing. The faster the quadrocopter comes down, the higher is the risk of overshooting and crashing on the ground. Beside that, as soon as the quadrocopter reaches the bottom level, wind reflected from the ground causes an extra force, which may make him to raise again. This has to be taken into account when setting up the landing control and therefore a easy approach like set total gas lower then the hover gas turns out to be not appropriate. The described algorithm (Fig. 3) has been implemented, enabling smooth landing from every level. Figure 9 shows one experiment, where the quadrocopter lands from 3m height within ca. 3 seconds.

## 6.3 Height Level Detection

A Height Controlled Flight upwards a stairway [Fig. 10] demonstrates that the air pressure sensor is capable to detect the absolute level of the quadrocopter and therefore can be used to detect the level of a building, where the quadrocopter is at the moment. This is necessary for an autonomous indoor flight.

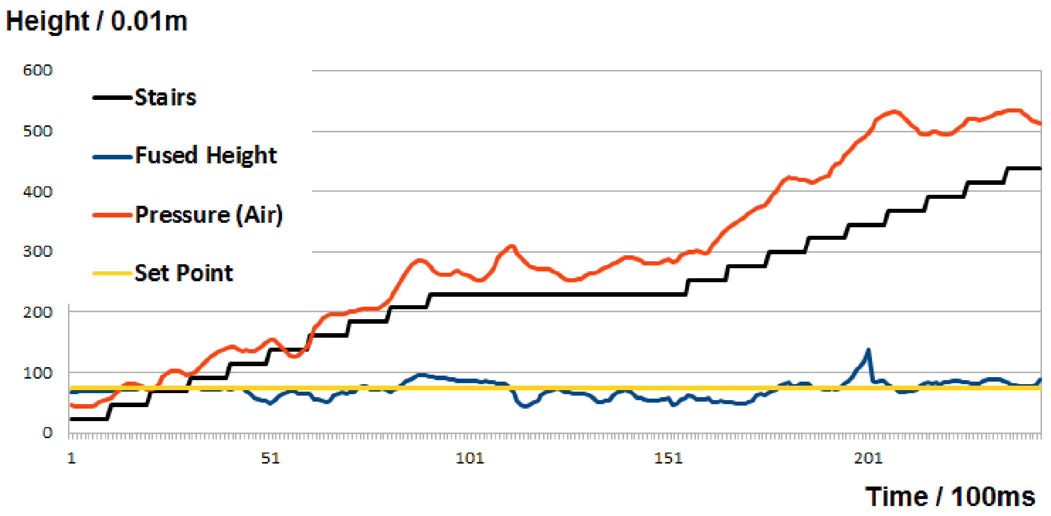

**Figure 10: Stairway Flight**

## 7 CONCLUSION AND PERSPECTIVE

An easy to implement and powerful algorithm for multisensory data fusion has been presented and in a real-time control system proved. The implemented height control is capable to keep the height of the quadrocopter and therefore enables autonomous flight. Nevertheless, there is still space for optimization.

One big issue is that the Height Controller needs either much time to reach the set height or overshoots, depending on the voltage of the battery. Therefore an initial starting algorithm computing the hover gas would be beneficial. Furthermore a different controller might be necessary for more accuracy and speed. The evaluation also shows that the system is able to land autonomously.

## REFERENCES

[1] Autonomous Flying Robots, Spring 2010, Kenzo Nonami

[2] I4Copter: An Adaptable and Modular Quadrotor Platform, SAC 2011, Peter Ulbrich

[3] Implementierung und Evaluierung eines Systems zur Hinderniserkennung und Kollisionsvermeidung für Indoor-Quadrokopter, Thilo Müller, December 2011

[4] WordlViz, www.worldviz.com

[5] Quadrotor Using Minimal Sensing For Autonomous Indoor Flight, 2007, Roberts , EMAV2007

[6] Coaxial helicopter for autonomous navigation and exploration in gps-denied indoor missions, 2011, Casassa

[7] Toward obstacle avoidance on quadrotors, de Perrot, DINAME

[8] Development of an autonomous aerial vehicle using laser range finder, 2010, Raviteja

[9] Multi-Purpose Environment Awareness Approach for Single Line Laser Scanner in a Small Rotorcraft UA, 2011, Krause, Springer 2011

[10] Development of Micro UAV Swarms, Bürkle

[11] Autonomous Landing for a Multirotor UAV Using Vision, 2008, Lange, SIMPAR 2008

[12] Modelling and Control of a Quad-Rotor Robot, Pounds

[13] Implementation and Evaluation of a Differential GPS System, August 2012, Christian Hofmann

[14] Implementierung und Evaluierung einer Höhenregelung für einen Quadrocopter, Juli 2012, Julian Rothe