# Towards UAV contour flight over agricultural fields using RTK-GNSS and a Digital Elevation Model

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**Abstract**

Drone technology represents a significant potential in precision farming. Most applications, however, require accurate positioning of the drone. The aim of this work is to perform accurate low altitude contour flight above an agricultural field using a low cost multirotor drone and the AutoQuad[1] flight controller. We hypothesize that at wind velocities below 5m/s the drone absolute positioning accuracy is better than 0.5m and the absolute height accuracy is better than 0.5m.

This paper presents our preliminary results, components have been developed but are not yet fully integrated: A dual frequency RTK-GNSS was adapted to drone installation. Output from the GNSS is processed and passed to the flight controller firmware which has been modified to support input from an external absolute positioning source. A cloud based route planner has been developed for calculating field contour route plans using elevation data from a Digital Elevation model.

A preliminary experiment was performed to test the hypothesis: A route of length 512m was navigated autonomously at 5m/s. The result shows an average lateral distance from the route of 0.45m. The 95'th percentile was 1.11m and the maximum distance was 1.35m. The average vertical distance from the route was 0.26m, the 95'th percentile was 0.72m and the maximum distance was 1.52m. Based on this the hypothesis is false, but identified potential error sources should be investigated before a definitive rejection of the hypothesis. Future work will focus on improving and integrating components, more rigorous testing as well as migrating to a larger multirotor and testing lower cost RTK-GNSS.

**Keywords:** Drone, UAS, Precision Farming, Precise positioning, Digital Height Model.

## 1. Introduction

In recent years, technological advances in Unmanned Aerial Vehicles (UAV) aka drones has led to a large number of novel applications in the industrial sector as exemplified in (House Of Lords, 2014). In agriculture an emerging application is drone aerial photography providing the farmer valuable information about crop fields, supporting decisions on weed or pest control, administration of fertilizer etc. Examples are (Rasmussen *et. al.* 2013; Grenzdörffer 2014). Aerial photography of agricultural fields is not novel in itself, but drones have made this a much more accessible tool to the farmers, and the products are continuously being improved through research and development.

The drone is typically navigating a predefined route plan at a fixed altitude with respect to the mean sea level (MSL) reported by the on-board Global Navigation Satellite System (GNSS). The images are then post processed to create orthophotos or point clouds of the field. Drone technology has a significant potential in precision farming beyond this, examples are online stitching based on accurate pose estimation of the drone, online processing of the images leading to adaptive behaviours such as automatic close-up measurements, photography of weed patches or distribution of pesticides and beneficials etc. This requires accurate positioning of the drone platform with respect to the geographical position and height above ground level (GL) For online mapping applications being able to navigate at a specific altitude above GL compared to a specific altitude above MSL is huge advantage. Combined with a small variance of the position, height and velocity obtained by using Real Time Kinematics (RTK) GNSS this affects the capacity of the system due to smaller requirements for image overlaps. Often mapping applications are limited by the time it takes to create a mosaic image because of the large image processing time, however methods such as (Laursen et al. 2016) indicates that projecting the images based only on accurate IMU and GNSS sensor data allows for near real time projections.

This work focus on the accurate positioning of a low cost drone performing precision farming operations at low heights above GL. In Denmark a Digital Elevation Model (DEM), referred to as the Danish Height Model (DHM) which models the terrain topography with a grid distance of 0.4 m is freely available. By equipping the drone with a dual frequency RTK-GNSS receiver and planning the route using the DHM we aim to demonstrate accurate navigation of an agricultural field at a height of 5 meters above GL with a steady velocity of 5 m/s. We hypothesize that at wind velocities below 5 m/s the drone absolute positioning accuracy with respect to the planned route is better than 0.5m and the absolute height accuracy with respect to the GL is better than 0.5 m.

A review of related literature shows that the use of RTK-GNSS on small drones for various applications has been an

1 http://www.autoquad.org

active area of research for the past few years. Examples are Skulstad *et. al.* (2015) demonstrating field tests of a system for autonomous precision recovery of fixed-wing UAV's using low-cost single frequency RTK-GPS (u-Blox-LEA-6T) modules and the open source RTKLIB (Takasu and Yasuda 2009). The paper describes a relevant problem of loosing fixed solution at roll angles of 30 degrees or more. This problem is mitigated by mounting the GNSS antenna on a servo actively compensating the roll angle, still the percentage of flight time where the system provides RTK fixed solution is only 25-60%, which is in line with the findings presented in Jensen (2014). Erling et al. (2013) presents a newly developed position and attitude determination system using a RTK system based on a Novatel OEM628 dual-frequency GPS board. The GNSS antenna weight was reduced from 350 g to 100 g and the georeferencing system with sensors, connectors and controllers weighs 260 g. The system is designed for a modified Mikrokopter Oc-toXl. In a described test RTK fixed solution was available 97.5% of the time. Hosseinpoor et. al. (2015) demonstrates a real-time process for the identification and geolocation of ground targets based on video imagery acquired by a small UAV equipped with RTK GPS. The resulting target location accuracy is at the order of decimeters.

Using DEM for UAV route planning in a precision farming context appears to be a novel approach, most likely because it requires an accurate absolute positioning of the drone to fully utilize the DEM information. An alternative approach to estimate the distance to the ground while in flight would be to use an optical or ultrasound based range sensor. This approach may be challenged by parameters such as the crop height and type etc. and if RTK-GNSS is also needed for an accurate horizontal positioning of the drone, then one less sensor is needed. DEM is being used in related applications such as drone position estimation and route planning at a larger scale. Examples are Eroglu and Yilmax (2013) who presents an algorithm for detecting the location of a lost or GPS disabled UAV throughout a planned flight by using only the terrain data. Meng and Xin (2010) present a method for UAV route planning based on the genetic simulated annealing algorithm. In relation to precision farming Stark 2014 presents a method for using DEM for shadow estimation at a certain time of day to find the optimal time for aerial imagery collection.

## 2. Materials and Methods

### 2.1. Flight controller

The EduQuad drone shown in Figure 1a was used in this work. EduQuad is a small quadrotor drone developed and produced by the company Viacopter. It is equipped with an AutoQuad (AQ) flight controller which has some advantages compared to many other flight controllers on the market: AQ is open source (GNU Public License version 3); it scales from small quadrotors weighing few grams to larger octo-rotors; it supports Quatos (closed source) which is an adaptive dynamic controller that has demonstrated efficient control of drones at strong winds and gusts; most of the inter-drone communication is handled via a Controller Area Network (CAN) bus; it is relatively low-cost.

The AQ M4 v2 is equipped with a ublox Max M8Q GNSS module which on the EduQuad platform is connected to a ceramic patch antenna mounted on top of the drone geometric center. The GNSS module communicates with the AQ CPU through a serial port. To enable support for a retrofitted RTK-GNSS receiver two changes were made to the AQ firmware: a) The CAN bus interface was updated to support 6 new packet types containing the geographical position, velocities, Dilution Of Precision (DOP) values and accuracy values required from a GNSS by the AQ. b) In the existing GNSS interface the function updating the GNSS data was modified to support updates from either the internal GNSS or the CAN interface depending on a switch on the Transmitter (TX).


Figure 1: (a) The EduQuad drone used in this work. (b) Trimble BD920 RTK GNSS with the external interface board. The total weight including the GNSS antenna, a small stubby GSM antenna and antenna cables is 183 g.

The GNSS data is stored in a struct which is read by several modules in the AQ firmware: Navigation, Unscented Kalman Filter (UKF) for pose estimation, telemetry link, On Screen Display (OSD) link and logger. The firmware was carefully examined to ensure that all relevant variables in the struct are properly updated in order not to interfere with modules that rely on them. The AQ UKF and Navigation modules are the essential receivers of the GNSS data, they are closely tied to the data available from the ublox GNSS receiver, specifically they use the variables: lat, lon, height, hAcc, vAcc, velN, velE, velD, vDOP, tDOP, nDOP, eDOP. These variables must therefore be updated by the RTK-GNSS interface.

## 2.2. RTK-GNSS

RTK provides centimeter-level positioning accuracy to GNSS by utilizing measurements of the phase of the signal's carrier wave. The accuracy of RTK-GNSS with a good sky view solution is 1 cm + 2 ppm horizontally and 2 cm + 2 ppm vertically[2] (Bevly and Cobb, 2010). While prices are continuously dropping, most survey grade RTK-GNSS still cost more than US$ 10,000. Recently low-cost RTK-GNSS OEM products have entered the market, examples are the Piksi[3] and NEO-M8P[4]. These are single frequency (L1) receivers only and are thus limited by long initialization times and requirements of short baselines compared to the survey grade multiple frequency receivers. This may result in periodical degradation of the positioning accuracy as exemplified in (Skulstad 2015; Jensen 2014).

To avoid the limitations of single frequency RTK-GNSS in this work, a Trimble BD920 embedded module supporting GPS L1/L2 and GLONASS L1/L2 was used. The accompanying evaluation board has a large form factor, and an interface board optimized for size, weight and power was therefore developed in this work. The board features a wide input power regulator, SIM card holder and access to communication ports. Figure 1b shows the BD920 with interface board and antennas.

## 2.3. RTK-GNSS Interface

The purpose of the RTK-GNSS interface is to receive serial data from the Trimble BD920 via the NMEA 0183 protocol and based on this send position updates to the AQ via the CAN bus. To this end a Raspberry Pi 2 running ROS (Quigley *et. al.* 2009) is used. Figure 2 shows the data flow between hardware devices.

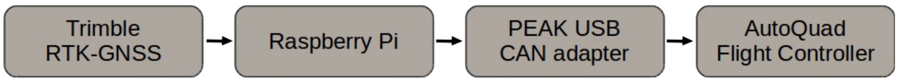


Figure 2: RTK-GNSS interface data flow between hardware devices: The Raspberry Pi 2 receives serial NMEA data from the Trimble BD920 GNSS. The data is processed and sent to the AutoQuad flight controller via a PEAK USB CAN adapter.

To update the variables required by the AQ firmware UKF and Navigation modules some simplifications were made. Latitude, longitude, altitude are available via the messages $GPGGA and $GPRMC of the RTK-GNSS NMEA 0183 protocol. velN and velE are calculated based on the ground velocity and heading obtained from the $GPRMC message. velD is calculated based on the altitude change over time. The DOP values, hAcc and vAcc are estimated based on the hDOP available in the $GPGGA message using a scaling empirically observed in logs obtained from the drone while using the onboard GNSS. When a RTK fixed solution is available the hAcc and vAcc are set to 0.5 m and 0.75 m respectively. The AQ onboard logger and the log viewer built into the qgroundcontrol-aq software was used to monitor the transitions of values while switching between the onboard GNSS and the RTK-GNSS.

## 2.4. Contour route planner

A contour route planner was developed for this work. It supports fields of a convex shape and takes as input a polygon describing the field, the drone start position, desired heading, desired height above GL, width between each parallel leg, drone desired velocity, drone max flight time and drone maximum legs in one route plan.

The route planner outputs a list of GNSS waypoints where the altitude above MSL is based on the desired height above GL and the DEM which in this work is the Danish DHM with a 0.4 m grid resolution, specified to maintain a horizontal accuracy of 0.15 m and a vertical accuracy of 0.05 m (Miljøministeriet 2015). In the preliminary test performed in this work the list is uploaded to the drone before takeoff. When introducing intermediate waypoints along the legs to adjust the height above GL, the AQ waypoint buffer is too small to accommodate the full list, and it must be transmitted dynamically from the ground station to the drone via the telemetry link.

2 http://water.usgs.gov/osw/gps
3 https://www.swiftnav.com/piksi.html
4 https://www.u-blox.com/en/product/neo-m8p

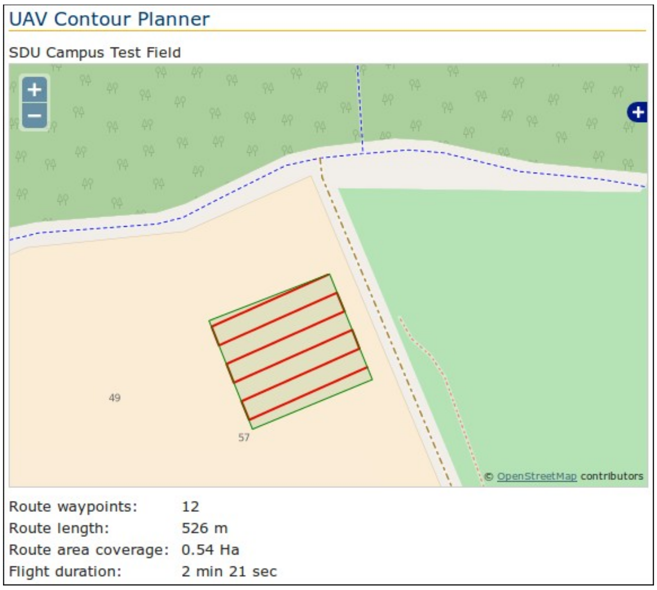


Figure 3: The contour route planner showing the route plan used for testing the hypothesis.

2.5. Experiment

To test the hypothesis a test route plan was generated using the contour route planner. The route length is 526 m consisting of 6 legs each approx. 75 m and interspaced by 12 m. At each leg end the drone is instructed to hover for 3 s. Estimated flight duration is 141 s. Figure 3 shows the output from the contour route planner.

## 3. Results and Discussion

The test route flight was completed successfully in 143 s. 715 GNSS track points were recorded at 5 Hz. The GNSS did maintain an RTK fixed solution during the entire flight. Lacking external observations of the drone position the GNSS output is used as reference. The expected GNSS inaccuracies described in section 2.2 have been neglected in calculation of the results below. The UAS Test Center Denmark 14 km away (EKOD) METAR reported a wind velocity of 3.6 m/s. Figure 4 shows a map of the planned route and the tracked flight.

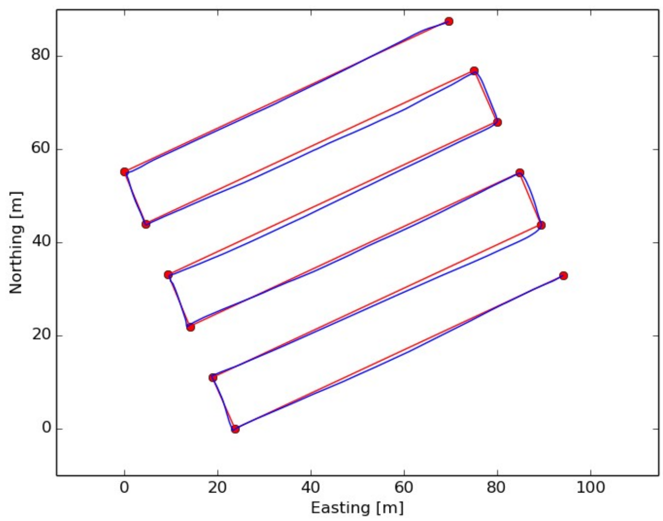


Figure 4: Map of the planned route (red) with waypoints (red dots) and tracked flight during the test flight (blue).

The logged data did not provide information about the autonomous state. The route flight begin and end were thus estimated to be at the logged positions with the minimum distance to the begin and end waypoint respectively. The horizontal lateral distance is calculated as the distance to the closest point of any of the route legs. This approach results in some inaccuracy at the end of each leg, and the hovering at the end of each leg skews the result slightly as well. The measured average horizontal lateral distance from the route was 0.45 m. The 95'th percentile was 1.11 m and the maximum distance was 1.35 m. Figure 5 shows a histogram of the horizontal lateral distances from the planned route. The average vertical distance from the route was 0.26 m, the 95'th percentile was 0.72 m and the maximum distance was 1.52 m.

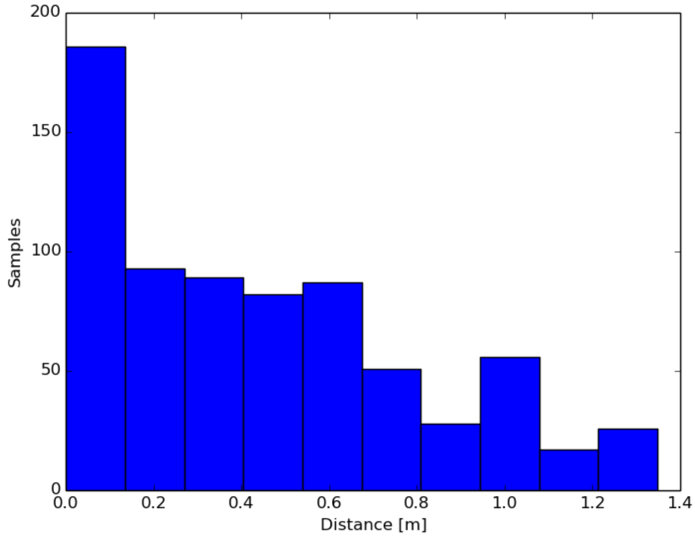


Figure 5: Histogram of the horizontal lateral distance from the drone to the planned route during the experiment. The total number of GPS track points (samples) is 715.

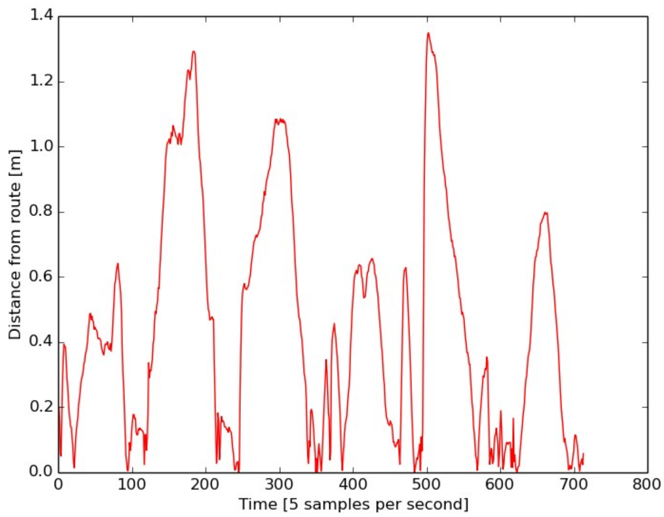


Figure 6: The drone distance from the route plotted as a function of time.
The accuracy is higher while hovering than when navigating the 6 legs.

Based on these results the hypothesis is false. There are however some potential sources of error concerning the RTK-GNSS position input which should be investigated before a definitive rejection of the hypothesis: a) The accuracy input to the UKF and navigation was set to 0.5 m which is significantly less than the actual accuracy. This causes the UKF to trust the GNSS positions less. The reason is to avoid sudden jumps of the drone when switching to the RTK-GNSS, this can however be mitigated by defining the accuracy as a function of time since the switch. b) In the current setup the GNSS update rate is set to 5 Hz. At a velocity of 5 m/s this means only one absolute position update per meter. The GNSS is capable of update rates up to 20 Hz, but it was decided to use the same update rate as the flight controller onboard GNSS in order not to introduce potential errors at the flight controller firmware. c) About 350 g payload has been added to the drone without updating the Quatos controller model which may result in a less than optimal performance. d) The velocity may influence the navigation accuracy, a quick examination of the data (Figure 6) reveals that the accuracy is higher while hovering at the waypoints and lower while navigating the legs. e) The RTK-GNSS antenna is placed at a distance from the drone geometric center in order not to shade the onboard GNSS antenna. This is not expected to cause significant errors, but it should be investigated.

## 4. Conclusions

This paper presents the current progress towards UAV contour flight over agricultural fields. The required hardware and software components have been developed but are not yet fully integrated and tested: A L1,L2 RTK-GNSS module has been retrofitted for drone installation, the weight including GNSS and GPRS antennas is 183 g. A multirotor drone using an AutoQuad flight controller has been modified to support alternative absolute positioning input via an onboard CAN bus. A Raspberry Pi 2 embedded computer converts the GNSS serial output to CAN packets. A cloud based route planner has been developed for calculating field contour route plans. Surface elevation is based on the freely available Danish DHM which models the terrain topography with a grid distance of 0.4 m.

An experiment was performed to test the hypothesis: A route plan of length 512 m containing 6 legs interspaced by 12 m was navigated autonomously at 5 m/s and completed in 143 s. The wind velocity was reported to be 3.6 m/s. The result shows an average lateral distance from the route of 0.45 m. The 95'th percentile was 1.11 m and the maximum distance was 1.35 m. The average vertical distance from the route was 0.26 m, the 95'th percentile was 0.72 m and the maximum distance was 1.52 m. The hypothesis is therefore false, however some potential sources to the inaccuracies were identified and need to be investigated before a definitive rejection of the hypothesis.

Future work will focus on improving and integrating components, more rigorous testing as well as testing lower cost RTK-GNSS and migrating to a larger drone capable of carrying implements for precision agriculture applications.

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