Ref: C0266

# Autonomous Unmanned Ground Vehicle as Sensor Carrier for Agricultural Survey Tasks

*Vincent Meiser, Rene Henke and Dejan Šeatović, Institute of Mechatronic Systems, ZHAW, Technikumstrasse 9, CH-8401 Winterthur (Switzerland)*

*Toby Rotach and Hanfried Hesselbarth, Institute of Mechanical Systems, ZHAW, Technikumstrasse 9, CH-8401 Winterthur (Switzerland)*

## Abstract

For agricultural surveys, the use of unmanned ground vehicles (UGV) as sensor carriers is becoming increasingly attractive. These vehicles can be equipped with multiple sensing devices to achieve a high level of autonomy in order to improve productivity and profitability in agriculture.
For this application, special requirements for the UGV must be fulfilled. The system presented in this paper is designed to adapt to the plant row spacing in an orchard with a flexible track width of between 0.8 and 1.2 meters. It uses 29-inch wheels to provide a ground clearance of at least 40 centimetres. The payload (sensor platform) is fully separated from the driving unit and will be provided with electric power from the battery.
The four wheels are each equipped with electric motors. A hinged axle enables a small turning radius for the transfer from one leg of the survey to the next. First tests with the UGV show stable steering characteristics and sufficient power for up-hill motion.
The arrangement of a sensor head with multiple sensors for environmental modelling and navigation, as well as the realisation of a hard real-time control system for the drivetrain and sensors results in this concept study being a very challenging task.

**Keywords: automation, robotics, remote sensing, perception, navigation, real-time**

## 1 Introduction

In highly developed countries, conventional agricultural machines are reaching their maximum capabilities and additional productivity has to be achieved by other means. Agricultural robots can potentially take the place of manual labour, in particular for performing hazardous tasks such as the protection of plants from pests, but also to improve productivity and profitability in farms, occupational safety and environmental sustainability.
The application of mobile robots is one conceivable scenario for data acquisition as a base for both decision-making and actuation in an autonomous manner. A large variety of sensors and actuators are used for navigation, environment acquisition and modelling tasks as well as for protection against pests.
Autonomous platforms are widely used in the air and for ground tasks. For agricultural research, special boundary conditions require a non-standard platform layout. At the Zurich University of Applied Sciences such a specialized UGV was designed and built. This paper gives a brief description of the requirements and the hardware as designed and built.
The paper considers theoretical prerequisites for an autonomous unmanned ground vehicle as sensor carrier and subsequently the requirements for processing hardware.

## 2 Requirements for an Autonomous Platform for Agricultural Survey

The sensor carrier platform must be able to drive through a crop under harsh environmental conditions over rough and skewed ground. Thus the ground clearance is set to at least 400 mm and an adjustable wheel distance between 0.8 and 1.2 m is targeted. Further the intended payload for sensor equipment amounts to 50 kg. The vehicle shall be able to turn at the end of the plant rows with a small radius and low friction with the ground for minimal disturbance to the crop.

The sensor equipment carried by the UGV requires suspension and damping. Stable driving characteristics of the vehicle are required to ensure reasonable data acquisition (low noise, no image blur). Past developments in a project called 3D-Mosaic (3D-Mosaic, 2011), which made use of a FORBOT (FORBOT, 2014) robot and a custom track vehicle as sensor carrier exposed the importance of such driving characteristics. Both vehicles showed adverse behaviour such as shaking and vibrations when driving over uneven ground.

Additionally, the positioning of sensors shall be variable to provide high flexibility for different field applications. To increase the profitability of UGVs for farming, the robot shall follow the plant rows in an autonomous manner with minimal human supervision and interaction. The costs for the UGV shall be in a range affordable for scientists.

## 3 The Unmanned Ground Vehicle

After a market study and basic calculations for the motor strength, battery capacity and structural loads, the design was developed by generating and comparing several solutions to find the best fit to the requirements.

After the design phase, the UGV was constructed. The central box and the wheel suspensions are constructed from aluminium (Figure 1). The main body includes the battery and has space for a computer. The motors and gears are integrated in the tubular telescopic legs. The wheel axles are driven by chain drives. This drivetrain design can accommodate track width and height changes (Figure 2, left). Furthermore it allows a very compact storage arrangement by folding the wheels to the sides of the central body (Figure 2, right). The UGV can be handled by two persons without the need for a crane (Table 1).

*Table 1: Weight and dimensions*

| | |
|---|---|
| UGV-Weight | 65 kg |
| Max. Pay load | 50 kg |
| Transport dimensions | 1050 x 1250 x 770 mm (l x w x h) |
| Minimum Ground Clearance | 450 mm |

The control of the prototype is realized with standard remote control components as well as an *ArduPilot* board for waypoint navigation. Safety is taken care of through software and a physical emergency stop button on the prototype.

*Figure 1: The ZHAW Sensor platform, side view.*

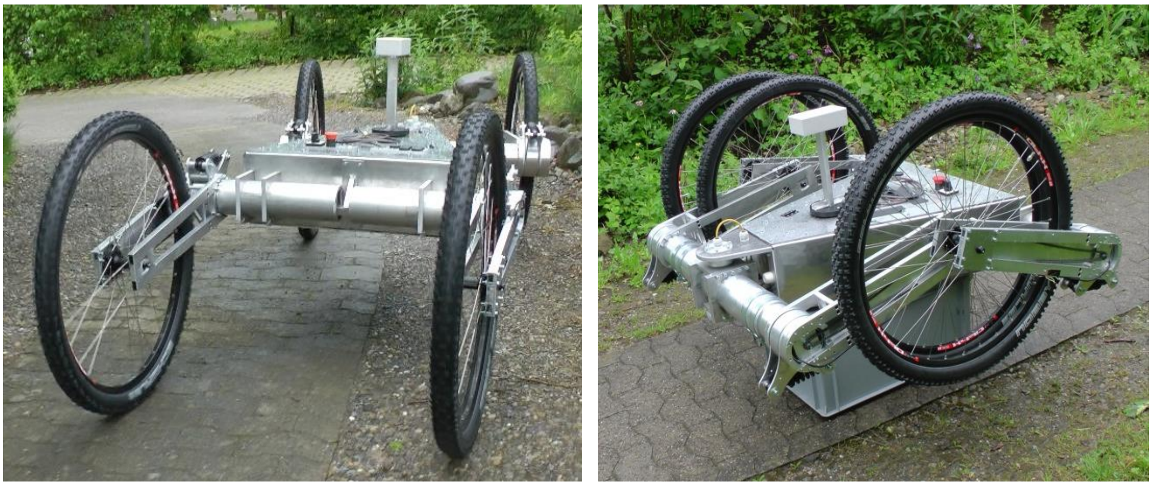

*Figure 2: ZHAW Sensor Platform - left: rear view with minimum axle width, right: platform folded for transport*

## 4 Testing of UGV

First functional and motion unit tests were very successfully performed. In the next step, a sensor system shall be integrated to analyse vehicle and sensor behaviour with a fully setup system. The tests will also include processing of acquired data to analyse the signal to noise ratio achievable with the given design.

## 5 Sensors

For the different field tasks such as vehicle navigation, environment acquisition and modelling as well as real-time data processing for object recognition, a large variety of sensors is conceivable. The most common and well-established sensors for UGV applications, environmental acquisition and modelling are machine vision, LIDAR (Light Detection and Ranging), Inertial Measurement Units (IMU), dead-reckoning (odometry), geo-magnetic direction (compass) and GNSS (Global Navigation Satellite System, e.g. GPS) sensors. The use of these sensors in different combinations allows comprehensive environment modelling and full vehicle control in real-time in the field (Hamner, 2010; Kurashiki, 2010; Stentz, 2003).
An example of a UGV as multi-sensor platform is the project 3D-Mosaic, a European research project which dealt with environmental acquisition and modelling for a farmers decision-making. A main component of the project was the development of the UGV with a multi-sensor system for environmental acquisition and vehicle control. The system setup can be seen in Figure 3.
It is planned to equip the UGV presented in section 3 “The Unmanned Ground Vehicle” with an advanced sensor platform consisting of stereo vision and LIDAR for environmental acquisition and modelling as well as an IMU, odometry, compass and GPS sensor for autonomous navigation and drive control.

*Figure 3 Measurement head of 3DMosaic sensor carrier with stereo cameras and LIDAR, GPS antenna is not depicted.*

## 6 Hard real-time control system

For the near future, an investigation into a hard real-time capable control system for motors and sensors is envisaged. Such a system would allow sensor data processing within a constant time frame and also enable a certain safety margin for vehicle operations, such as an emergency shutdown of the entire system when crucial system components fail.

Today's real-time operating systems provide the possibility to recognize a timeout of a certain software task and report a message to indicate the danger state of the system or to stop the entire system depending on the severity of the task. With a hard real-time capable system it can be guaranteed that safety sensors and emergency stops will be handled in time.

For the design of the control system it is important that all common sensor and actuator interfaces (RS232, USB, Ethernet, PROFIBUS, etc.) are directly supported to shorten the implementation time and to enable easy and straight-forward modifications of the system components.
The system should provide appropriate computing performance to process a large amount of data (especially vision data) in real-time. This is a high-level requirement if the system is intended to execute any actuation steps such as the deployment of fertilizer and for navigation purposes of the UGV. The faster the data and control command processing, the higher the UGV velocity can be and subsequently the treatment in the field. A hard real-time capable industrial computer is provided by *Beckhoff* and its *TwinCAT 3* software platform with C/C++ support, see (Beckhoff 2014a). The system allows development of hard real-time drivers within the Windows 7 operating system. The vehicle control is located in the OS kernel and communicates with the user or user-mode application via alternate data stream (ADS), see (Beckhoff 2014b). With ADS it will be possible to integrate data processing libraries and applications which are not able to fulfil real-time constrains but have been already tested and implemented, i.e. OpenCV and Point Cloud Library (PCL).

The above mentioned control system would bring along that vehicle drivetrain and sensor control/processing are tightly coupled since both parts would be controlled by one central computing device. The current implementation with the ArduPilot board would be replaced. An advantage of retaining the ArduPilot board and implementing the hard-real time part only for the sensor platform would be the independence of both parts. Our aim is to design and implement both crucial parts of the software: vehicle control and navigation, and sensor control and processing on one single platform. The software components will be implemented in order to be scalable, reusable and portable to all Beckhoff computer platforms, however, the extent of the portability has to be analysed. The final goal of our both groups is to be able to design, assemble and test UGVs for the purposes of data acquisition without tedious and error prone ‘start(s) from scratch’. The use of industrial-level automation components will enable rapid hardware and software development and will allow more efficient research which focuses on the issue and not on marginal problems, such as control system selection and integration.

# 7 Results and Discussion

The UGV acting as sensor carrier for agricultural field survey tasks is very promising so far. First tests confirmed the expected driving characteristics. The vehicle fulfils the given design requirements (variability of track width and body height, compact storage arrangement) and thus is fully flexible to be applied in different scenarios.
Testing of the full system setup with sensors mounted to the vehicle body is pending. An improvement compared to the 3D-Mosaic setup is very likely, but needs to be confirmed. A challenging aspect will be the behaviour in critical situations (rough ground, jarring and vibrations).
The realisation of a hard real-time control system for the drivetrain and sensors is a work in progress. Further work on this issue will show the suitability of such a system for the foreseen tasks.

# 8 References

3D-Mosaic (2011), ICT-AGRI project “3D-Mosaic: Advanced Monitoring of Tree Crops for Optimized Management - How to Cope with Variability in Soil and Plant Properties?”, www2.atb-potsdam.de/3d-mosaic, Leibniz Institute for Agricultural Engineering Potsdam-Bornim (ATB), Germany

APM (2014), APM Multiplatform Autopilot. www.ardupilot.com, San Diego, CA, USA

Beckhoff. (2014a). *TwinCAT 3 C/C++.* Retrieved May 30, 2014, from http://infosys.beckhoff.com/english.php?content=../content/1033/tcadscomlib/html/tcadscomlib_intro.htm

Beckhoff. (2014b). *TwinCAT ADS.* Retrieved May 30, 2014, from http://infosys.beckhoff.com/english.php?content=../content/1033/tcadscomlib/html/tcadscomlib_intro.htm

Hamner, B., Singh, S., M. B. (2010). Improving Orchard Efficiency with Autonomous Utility Vehicles. 2010 ASABE Annual International Meeting, Carnegie Mellon University.

Kurashiki, K., Fukao, T., Ishiyama, K., Kamiya, T., & Murakami, N. (2010). Orchard traveling UGV using particle filter based localization and inverse optimal control. In System Integration (SII), 2010 IEEE/SICE International Symposium on (pp. 31–36). doi:10.1109/SII.2010.5708297

Müller, L., & Rotach, T. (2013). Entwurf und Grob- Dimensionierung eines Agrar-UGV. Focus project PA13_hsbh_5, ZHAW, Winterthur.

Rotach, T. (2014). Entwurf, Realisierung und Test eines UGVs für Agraranwendungen. Bachelor thesis BA14_hsbh_5, ZHAW, Winterthur.

Roboterwerk (2014), Der Roboter FORBOT. www.roboterwerk.de, Ruhpolding, Germany

Stentz, A., Kelly, A., Rander, P., Herman, H., Amidi, O., Mandelbaum, R., Salgian, G., & Pedersen, J. (2003). Real-Time, Multi-Perspective Perception for Unmanned Ground Vehicles, Paper 16, Robotics Institute, Carnegie Mellon University.