Using low-cost Sensor Systems for Driverless Tractor Navigation

Degree programme: Master of Science in Engineering | Specialisation: Energy and Environment
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The goal of this work is the study of different sensor fusion methods for absolute position, heading and speed estimation. The focus was on absolute position estimation using Global Navigation Satellite System (GNSS) receiver. Three low-cost GNSS receivers were tested and a dual-antenna System for improved heading calculation implemented.

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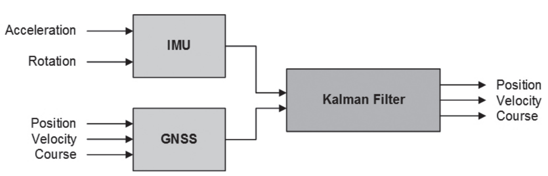
Motivation
The need to maximize agricultural productivity while minimizing damage to the environment is one of the 21st century's biggest challenges. Small and light-weight driverless tractors could be a part of the solution. They cause less soil-pressure than traditional tractors and can potentially increase user safety thanks to self-driving capabilities.
For a vehicle controller it is essential to get high accurate positioning, velocity and heading information. The precision of these values is always limited through the inaccuracy of the sensors. However, these problems can be reduced using filter algorithm – and sensor fusion techniques such as a Kalman Filter. Although similar commercial products are already available, the wide market penetration did not occur due to the high price of those products.

Objectives
The goal of this Master Thesis is to evaluate off-the-shelf sensors for the use in agriculture vehicles, implement appropriate filter algorithm and further verify the implemented low-cost navigation system in field tests.

Approach
One method to tackle this problem is to combine the GNSS receiver data with Inertial Measurement Unit (IMU) information. GNSS receiver have indeed a long-term accuracy but slow update rate of 1–10 Hz compared to the IMU with short-term accuracy but high update rate (0.1–1 kHz). The advantage of this approach is a position estimate at a higher update rate and a better dynamic behaviour compared to the use of GNSS data only.



Block diagram of a so called loosely coupled GNSS and IMU sensor fusion system.

For the position data acquisition, three different low-cost GNSS systems with centimetre level precision, namely the Piksi from Swift Navigation, the Emlid Reach and the C94-M8P application board from U-Blox, were tested.

Results
Two variants were implemented. First, a loosely coupled approach was designed (see figure) where GNSS, IMU, compass and wheel speed data were processed using an Extended Kalman Filter. It turned out that the heading calculation is more challenging than initially expected, especially at low speed (<1m/s) or when turning the vehicle with radius close to zero. Even though the dynamic behaviour of the heading output has been improved trough the Kalman Filter, discontinuities and delay problems have not yet been eliminated completely.
Therefore a second variant was implemented using two independent GNSS receivers to stabilize the measurement of the vehicles heading. This approach is highly promising, since the heading is also available when the vehicle is not moving. Another advantage is the higher robustness to magnetic interferences compared to an electronic compass. The result is a position error within 4–6 cm and the deviation of the heading is smaller than 1°. On the other hand, the filter initialization process stays challenging due to the Integer Ambiguity Resolution Fixing problem of the two GNSS receiver.

Outlook
This work has shown that off-the-shelf low-cost sensors are suitable for the use in unmanned agriculture vehicles and the heading detection problem can be reduced by using a dual-antenna system. A weak point is still the initialization process of the Kalman Filter and the time variant identification of the sensor output uncertainty.