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Artificial Landmarks for Autonomous Vehicles Based on Magnetic Sensors†

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Abstract: We propose to use an integration process based on Transducer Electronic Data Sheets applied to a magnetic sensor system for the realization of artificial landmarks. Magnetic sensors provide an advantageous alternative in surroundings where GPS and optical sensors do not work. These landmarks can be used by passing autonomous vehicles, e.g. drones, for re-orientation and re-calibration. To facilitate the usage of these landmarks also by any vehicle, known or unknown, a standardized process for automatic connection and identification of the landmarks is suggested. During this process, all necessary information such as protocols, calibration data etc. is made known to the vehicle passing by. Based on the provided information, the vehicle itself can decide whether and how to use the provided sensory information.

Keywords: wireless sensor network; magnetic sensor; sensor calibration

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1. Introduction

Localization of autonomous vehicles in general, and drones in particular, is a complex topic, which, among other factors, strongly depends on the current environment. Common Radio Frequency (RF) approaches using frequencies in the gigahertz range, like GPS work best in open spaces, but show significant deficiencies in buildings and environments where radio waves suffer from reflections due to the environment. Visual approaches like [1] depend on having a clear Line of Sight (LoS) to the surrounding area and have problems if this LoS is construed by fog, smoke or other influences. This paper investigates the use of near field magnetic sensors working in the low radio frequency domain to determine three Degrees Of Freedom (3DOF) for localization. Such a magnetic system provides advantages since it is robust against reflection of waves, and the localization can be facilitated without the necessity of vision based on cameras or other optical sensors. These magnetic sensors are developed for the use as artificial landmarks to be used in, e.g., landing platforms. These landmarks are further automatically detected and integrated into the Robot Operating System (ROS). The ROS can be employed on a drone which comes into the vicinity of such a landmark, but also on any other vehicle equipped with the necessary hardware. The sensory data can then be used on the drone to re-calibrate its localization algorithm and other devices necessary for its path planning or operation. The description of the landmark and its properties, such as the employed encoding used for the transmitted data, are stored in form of a Transducer Electronic Data Sheet according to the IEEE 1451 standard [2]. This information is consequently transmitted to the drone to enable an automatic configuration of the system. Chapter 2 gives an overview over the architecture of the proposed system and chapter 3 gives more information on the developed and used magnetic sensors.

1.1. Related Work

In [3], artificial landmarks based on photoelectric scanning are introduced. In [4], a Pedestrian Dead Reckoning (PDR) based approach combined with QR code based landmarks is presented. Optimization of artificial landmark placement is discussed in [5]. Related magnetic sensing principles were shown in [6] where 3-axis magnetic sensor arrays are used. In [7] a detailed presentation of the considered magnetic sensor is given. The employed processing and read-out hardware, which is based on a Software Defined Radio (SDR) platform, are presented in [8].

2. Architecture

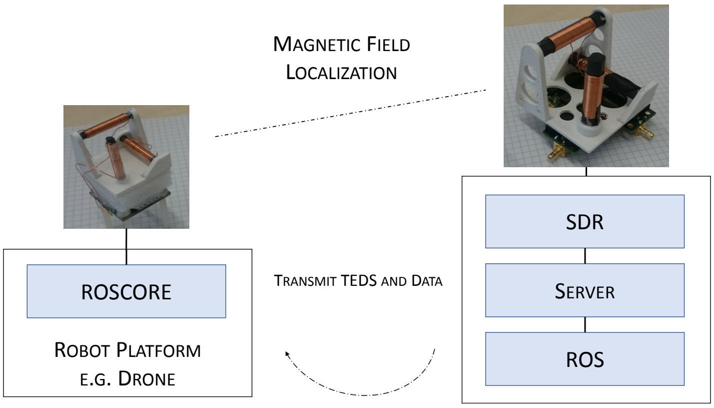

Figure 1. Left is the schematic of the mobile system equipped with a smaller coil setup. Right is the artificial landmark station with a static pose and holds a larger coil system. On the side of the landmark, the coil system is connected to an SDR platform for further signal processing.

2.1. Transducer Electronic Data Sheet (TEDS)

A TEDS after the [2] standard has mandatory components of META TEDS, CHANNEL TEDS and CALIBRATION TEDS. In the META TEDS, meta information about the artificial landmark like the number of sensors or actuators is specified. The CHANNEL TEDS holds information specific to each sensor, such as the physical units measured in SI units, the encoding e.g. the number of bits per sensor sample, and uncertainty of the sensor. Finally, the CALIBRATION TEDS contains the calibration information of the sensor according to the used calibration algorithm. It is typically a matrix of polynomial coefficients with one dimension the number of coefficients and the other one defining the number of sensor channels used in the calibration of one specific channel. For the artificial landmark a user-defined TEDS has to be added as well, containing the absolute position of the landmark itself given in the used coordinate system of the mobile robot.

2.2. Software Architecture

The software architecture consists of two components as can be seen in Fig. 1: first the artificial landmark and second the mobile robot platform. The artificial landmark prototype consists of a coil setup made out of three coils, which is connected to the read-out hardware, i.e. the SDR platform, via coaxial cables using SMB plugs. The SDR is connected to a Laptop via a 1 GBit/s Ethernet, this in turn runs software that does the post-processing of the incoming sensor data of the coils. It calculates the position information relative to the artificial landmark. The mobile robot platform drives a smaller coil setup generating a Pulse Width Modulation (PWM) with a frequency of $f_c = 457\,\text{kHz}$. Additionally, it runs ROS for its own path planning and logic and a Network Capable Application Processor (NCAP) according to [2] specifications with a Wireless Network Processor (WNP). The WNP creates a low power wireless sensor network. As soon as the artificial landmark is in range of the NCAP and WNP, running on the mobile robot platform, it connects to the NCAP. The NCAP then identifies itself as a newly connected sensor node and requests the Transducer Electronic Data Sheet (TEDS) stored on the landmark to identify how to interpret the incoming data stream and identify which information is provided. After this step the NCAP converts the raw data stream, coming from the artificial landmark, into position information, creates a ROS node for the sensor and sends the data into the ROS system. The absolute position of the landmark, and the uncertainty of the magnetic sensors is stored in its TEDS, and transferred into ROS as a parameter of the created ROS node. The controller running on the mobile robot platform checks available ROS nodes and, as soon as a node classified as artificial landmark giving position information is found, it requests the absolute position of the landmark from the ROS parameter server and hooks into the incoming position information data stream coming from the artificial landmark ROS node. From both, the absolute position of the landmark, and the relative position information gained, the controller then calculates its own absolute position with respect to the uncertainty of the sensor.

2.3. Hardware Architecture

One motivation for these artificial landmarks employing magnetic sensors is, that localization of a drone drifts over time in Global Positioning System (GPS) denied environments. This results in the drone missing its goal, if set to fly to a position starting at the last well-defined position. Therefore these artificial landmarks are used to counteract the drift of the drones' localization. In Fig. 2, the position marked with a black dot, is where the drone passes an artificial landmark, which automatically connects to the drone and supports the drone with the relative position of the drone and the landmark as well as the absolute position of the landmark. Using this information, the drone calculates its current absolute position, with respect to the uncertainty of the magnetic sensor and adjusts the planned route to reach its goal. Additionally, a possible position drift can stem from a scale error of a visual Simultaneous Localization and Mapping (SLAM) system [9] if the system is equipped with a camera. If only an inertial measurement unit (IMU) is on board, such a drift stems from using the PDR approach as mentioned in [4]. Fig. 2 shows a simulation of a flight path via an IMU navigation where the noise is modeled as Arbitrary White Gaussian Noise (AWGN) and the noise and specifications of the analog devices ADIS16448 are used. The flight path is defined by the white noise behavior of the accelerometer, which leads to a second order random walk behavior in the position information [10].

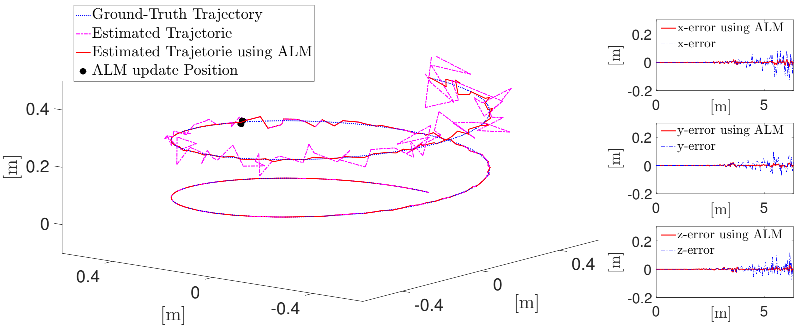

Figure 2. Simulation of drone flight with drift and drift correction through artificial landmark.

The used magnetic sensor for the artificial landmark is a 3D-printed prototype, consisting of three orthogonally placed magnetic coils, where the relative position of each coil is known. Three smaller and, more important, lighter magnetic coils are placed on the drone and used as transmitters. The relative position of the drone with respect to the artificial landmark is estimated by using the received signal strengths. The transmitting frequency is located in the low RF band in order to be robust against reflections. The known absolute position of the landmark, and the estimated relative position of the passing vehicle can be used to recalibrate its navigation system.

3. Conclusion

In this paper an approach to automatically connect artificial landmarks, consisting of magnetic sensors, to passing mobile robot platforms is proposed. The magnetic sensors consist of two parts, with a transmitter on the mobile robot platform and a receiver on the artificial landmark. The authentication and configuration is done via IEEE 1451 TEDS stored on the artificial landmark.

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Conflicts of Interest: The authors declare no conflict of interest.

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