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A novel data fusion algorithm for low-cost localisation and navigation of autonomous vineyard sprayer robots

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This work is motivated by the lack of manpower to perform vineyard spraying tasks and the exposure to hazardous pesticides during the spraying. The development of an autonomous system for vineyard spraying would reduce the amount of required labour and redirect it to performing tasks that could increase the farm yield and agricultural profitability and economic survival. Localisation, which is accurately estimating the location of the robot, is a fundamental problem in the field of autonomous mobile robotics. In order to allow basic autonomous navigation of a field robot, a path-planning control law is necessary. This navigation algorithm requires knowledge of the accurate state of the robot at every instance (i.e. position, orientation, linear and angular velocity). Many methods for low cost sensors and state estimation were introduced over the years and each method is based on some assumptions that not always hold in the real field robot case. For example, many state estimation algorithms assume Gaussian noise of the sensors reading. This assumption is not always valid when dealing with GPS, or taking measures in a short time window. Hence it is required to develop an accurate state estimation algorithm that will be based on as many sensors as possible, and will use the advantage of each sensor in an optimal way. Therefore, a new data fusion algorithm is proposed for navigation, that optimally fused the localisation data from various sensors. This paper begins with the development of a kinematic model of the robot that is used for model-based state estimation (filtering). How to filter a noisy raw sensor data and the fusion of data from all sensors (DGPS, IMU and vision) are explored. A novel vineyard sprayer, and its new kinematic structure, is introduced. The methodology for designing a high precision localisation system for sensors data fusion, utilising a likelihood ratio test as a decision-making technique for choosing the most probable state estimation. Each sensor was pre-filtered according to its noise distribution. The localisation algorithm was validated using simulation of the robotic platform and using visual odometry based on real field video data.

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List of nomenclature and abbreviations

AI	Artificial intelligence
ARW	Angle random walk
DOF	Degrees of freedom
DOP	Dilution of precision
EKF	extended Kalman filter
GPS	Global positioning system
INS	Inertial navigation system
LRT	Likelihood ratio test
MEMS	Micro-machined electromechanical system
MIMO	Multiple input;multiple output
MSPI	Maximum sum of probabilities intersections
PDF	Power spectral density function
PDOP	Position dilution of precision
PF	Particle filter
RGB	Red, Green, Blue
RKF	Robust Kalman filter
SLAM	Simultaneous localisation and mapping
UERE	User equivalent range error
UKF	unscented Kalman filter
VO	Visual odometry

1. Introduction

1.1. *Motivation*

The main goal of this research was to develop a low cost localisation system for a vineyard spraying robot (Fig. 1) that meets the accuracy requirements of 0.5 m in position estimation. This paper covers the following topics: Development of the robot's kinematic and dynamic model, controller design for path following, a visual odometry (VO) simulation and experimental results in a vineyard, navigation sensors and a novel multisensory data fusion algorithm for localisation, along with simulation results.

The motivation for this research is the lack of manpower for performing the vineyard spraying task and the possible exposure of the operators to hazardous pesticides during the spraying. Using an autonomous sprayer would allow monitoring the quantity of spray and connectivity information (e.g. the quantity of material sprayed, length of spraying time) for other databases that are exported to Europe (ISO 22866, 2005) (EU – Pesticides database) for the purpose of traceability and quality assurance of products. At the same time, the potential financial implications are significant. In recent years, a variety of robot functions for agricultural crops have been developed, such as planting, spraying, pruning and picking. Most research efforts have focused on the three following issues: Identifying objects in an agricultural environment, gripper design and grasping, and independent and autonomous vehicles such as tractors. Such systems must be accurate and reliable, and at the same time affordable in order to motivate farmers to buy them. For instance, accurate localisation systems employed for military uses or geodetic measurements can cost in excess of US$10,000.

1.2. *Literature review/theoretical background*

Research into the navigation systems for wheeled mobile robots consists of selecting sensors, mapping, localisation and path planning. Current navigation hardware systems can be divided into two categories:

1) Vision-based: Based on environment representation either by image databases or by visual landmarks. The idea of using a camera as a navigation sensor began two decades ago, and is currently becoming more available thanks to the development of computational power for image processing. A simplified calculation using an omni-directional camera, that decreased computational time without requiring a precise location was presented in 2004. This was made possible by the characteristics of the normalised RGB (red, green, blue) values, which was used to divide the road image into a road region and a dubious obstacle region, and obtaining related data of the surroundings through stereoscopic vision (Menegatti, Maeda, & Ishiguro, 2004). In 2007, NASA presented a stereo visual odometry (VO) application for the Mars exploration rover with simulation results, concluding that VO is a highly effective tool for land navigation, obstacle avoidance, and for increasing driving safety. It was deduced that the main bottleneck with the VO application was the computational effort required for image processing, meaning, a more robust feature detection was needed. Other methods combined laser sensors and sun sensors to improve the VO accuracy and reduce the sensitivity to light (Lambert, Furgale, Barfoot, & Enright, 2012) (McManus, Furgale, Stenning, & Barfoot, 2013). Their research concludes that such techniques improve the results by adding and integrating the laser sensor with VO. However, the price of sun sensors is circa US$10,000, making unaffordable for agricultural purposes.
2) Non-vision based: Non-vision navigation techniques vary and are commonly based on multi-sensor data fusion. Common sensors are accelerometers, gyroscopes, global positioning system (GPS), sonar, laser proximity sensors, etc. The question of which sensor to choose, as well as how to optimally combine its data for an accurate estimation, is an interesting research problem discussed in many researches to date. Such algorithms need to overcome sensor noise and uncertainties, and choose the best option using decision-making techniques. In Sukkarieh (2000), the theoretical and practical development of a low cost, high integrity, aided inertial navigation system for use in autonomous land vehicle applications is presented with models for drifting errors associated with inertial navigation. The system was based on the global navigation satellite system fused with inertial navigation sensors for accuracy and fault detection. The data fusion implemented in this research is based on Kalman filtering, assuming Gaussian distributions, and does not cover non-Gaussian scenarios that normally relate to GPS errors. The main problem was lack of redundancy in sensors and a long setup time. Also, the sensors used in this project are still rather expensive for agricultural applications. An example of better filter performance is described in Simon (2006). In Claraco (2009), an approach for simultaneous localisation and mapping (SLAM) based on a hybrid metric-topological approach estimation is presented. This research covers the optimal estimation in particle filtering as a tool for robot