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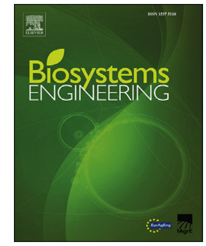

Research Paper

Simultaneous localisation and mapping in a complex field environment

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The usefulness of image registration techniques in mapping and localising a robot in an agricultural environment by using readings from a laser range scanner was investigated. The proposed approach used frequency domain and correlation. Translational and rotational differences that occur between successive readings of the scanner and that correspond to the movement of the robot were used. The approach was tested on 9 test runs, with a total of 252 m in length, recorded in an apple orchard and in a vineyard. The results were then compared to results from the Hector mapping algorithm. It was shown that the present approach performed very well compared to Hector mapping. On average achieved an 4.24% ± 2.9% error rate and the present approach 0.16% ± 0.1%. Hector mapping on the other hand proved better in cases where rotational differences were looked for, reaching an error rate of 1.69% ± 0.7% in comparison to present approach with an error rate of 4.19% ± 3.1%.

1. Introduction

As in other research areas, mobile robot applications are rapidly expanding into different areas of agriculture. Tasks such as arable farming require standard, periodic operations that are increasing in demand. The high demand for diverse food products has led food producers to use a wide range of fertilisers and pesticides in order to achieve optimal crop growth, but they have a negative impact on the environment. In order to minimise unwanted, potentially damaging effects, agricultural tasks should be examined and carried out more precisely, selectively and with care for the safety of people and the environment. This was one reason that we decided to develop a mobile robot that could fit and operate between the crop rows of different agricultural cultures. The use of such mobile robots in agriculture relies on the hypothesis that they can selectively spray plants that need to be treated. The motivation is to use potentially dangerous pesticides as little as possible and to make farming more nature friendly. In addition, such robots could carry out a number of other tasks, such as mechanical weed killing, selective fertilisation, crop assessment, plant damage assessment, detection pest, after spraying or even during the process.

Mobile robots that can perform these tasks need to be independent; this means there should be no intermediate control of human intervention in an individual robot's performance. In addition, a fleet of such robots should be able

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Nomenclature

lrf_{data}	an array of laser range finder readings, mm
$angle(i)$	*i-th* angle of the *lrf* reading, °
I_1	first 2D signal – an reference, -
I_2	second, successive 2D signal – a template, -
M	the width of signal *I*, -
N	the height of signal *I*, -
I_1^*	*a* complex conjugate of I_1, -
S_1	frequency transforms of signal I_1, -
S_2	frequency transforms of signal I_2, -
res	resolution of an image, pixels
$range_{max}$	the scaling factor used in interpolation step, -
W	a template image with $W_w \times W_h$ in size, pixels
dx	temporal shift along the X axis, pixels
dy	temporal shift along the Y axis, pixels
θ_c	temporal angular shift, °
u_x	position of the robot along X axis, m
u_x	position of the robot along Y axis, m
θ	orientation of the robot, °

to form a swarm and work towards a common collective goal, reaching it faster, making the work more precise, while yielding lower production costs. This idea is based on an autonomous field robot system that is able to perform given tasks. Such as basic autonomous system for a mobile field robot is shown in Fig. 1. Localisation and mapping are the means by which it is able to achieve autonomy. Mapping is a procedure indicating out the affected areas and present observations on 2D or 3D maps by taking into account laser range finder (LRF) readings. Here the focus is on building a reliable, odometry free mapping system. Mapping is used in autonomous systems at the medium level (Fig. 1) and provides the system with information about the environment. High control levels take care of all basic application controls, whereas the low level represents the drivers for actuators and sensors. The system takes decisions based on the given environmental status in the form of a map. Odometry is not considered in this study because wheel encoders can produce a lot of undesirable error caused by complex ground structure. Here the focus is not on a low-cost sensor such as wheel encoders, because of the common problems described in Ohno, Tsubouchi, Shigematsu, Maeyama, and Yuta (2003). Oksanen, Linja, and Visala (2005) discussed a low-cost system for outdoor positioning which cannot only rely on odometry. For this reason, the Hector mapping algorithm from TU Darmstadt (Kohlbrecher et al., 2013), since it does not require additional information from odometry. The initial tests of Hector mapping were conducted on ordinary, complex crop rows and they showed that in some cases the result is incorrect and mapping fails. This drove us to develop a new approach for complex structure mapping in natural environments with the goal of achieving the best possible precision on larger areas of crop rows. The algorithm provides a map of the current environment and localisation based on a reference coordinate system that is established at the start of the algorithm. This approach was compared to a Hector mapping algorithm by using the same data sets.

Localisation and mapping is commonly known as the SLAM (simultaneous localisation and mapping) algorithm (Thrun, Burgard, & Fox, 2005). Widely used algorithms for localisation and mapping include Hector mapping and Gmapping. Gmapping is a standard method described in Grisetti, Stachniss, and Burgard (2007) and Grisetti, Stachniss, and Burgard (2005), which is based on use of a Rao-Blackwellised particle filter to create a map and provide localisation information. The method's purpose is to decrease the number of particles with filtering, where precise calculation and exact deviation are considered. It uses the latest information provided by a laser scanner, reduces locational uncertainty and predicts the robot's position in the environment. Gmapping is optimised for long-range laser scanners and environments with large areas. In order to function, it needs laser scan data and, for best results additional odometry. In contrast to Gmapping, Hector mapping as described in Kohlbrecher et al. (2013), Kohlbrecher, Meyer, von Stryk, and Klingauf (2011) and hector_slam software package (2014) is optimised for narrow corridors and the kind of complex environment found in rescue scenarios. Hector mapping does not need additional information regarding odometry and this does not affect its performance. For localisation, it uses the scan-matching method and a Gauss-Newton filter to define

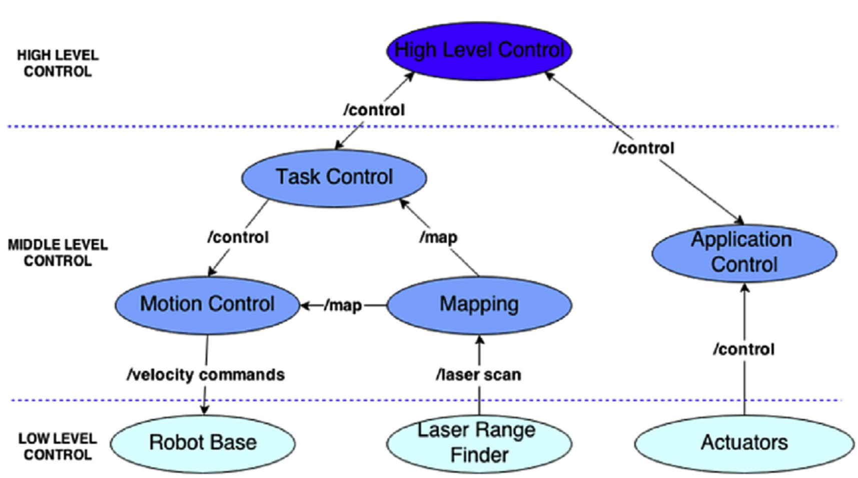

Fig. 1 – Overview of a mobile robot autonomous system.