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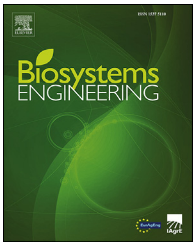

Research Paper

Trajectory planning for robotic maintenance of pasture based on approximation algorithms

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This paper addresses the problem of trajectory planning of a mobile robot for pasture maintenance comprising mulching weeds, reseeding patches without vegetation and spreading cowpats. Based on the sensor-based acquired data (points of interest), the proposed approach is to first use an approximation algorithm for data clustering in the form of non-convex and convex hulls. These hulls are then delimited by stair-shaped limits with respect to the working width of the robot, and their centres of gravity calculated. To minimise the travelled distance between the centres of gravity of the defined areas, the Travelling Salesman Problem is addressed via an evolutionary algorithm. Finally, kinematic and dynamic properties of the robot are considered in order to generate the final trajectory. The capabilities of the proposed approaches are highlighted through the processing of several datasets.

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1. Introduction

The world population will surpass 9 billion by 2050, confronting contemporary agricultural production with new challenges (Ray, Mueller, West, & Foley, 2013). Based on this forecasting, demand for meat and dairy products will globally increase and lead to higher retail prices. This trend is influenced by higher living standards, rising incomes and urbanisation, leading to increased consumption of higher value meat (e.g. beef) and of dairy products. Moreover, not only more quantity is demanded, but also even higher quality. By 2050, in comparison with the production levels in 2005/07, the required increase in annual meat production is estimated at 200 Mt (OECD/FAO, 2012).

The total number of dairy farms in the EU-27 was nearly 2.5 million in 2007 with sizes varying from region to region. However, 98% of the farms owned less than 100 dairy cows, with an average herd size of 9.8 head per farm (Coyette & Schenk, 2011). In such a context and in the framework of the reformed Common Agricultural Policy, EU animal products should become more competitive and ensure a fair standard of living for farmers (Coyette & Schenk, 2011). The increased productivity will, however, remain constrained through limited resources. The productivity gains will depend on the extent to which available resources are protected, as well as research and development and on the ability of the industrial sector to adapt latest technologies such as robotics to suit farmer requirements (OECD/FAO,

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2012). The introduction of robotic technology in agriculture aims to replace or support the tedious tasks carried out manually and/or to improve the quality of work and products. Field robots produced by the largest machinery manufacturers are still not commercially attractive and the great variability of situations which could be encountered under field conditions are still challenging. However, enquiries in manufacturer, farmer and public community sectors indicate that introduction of robotics in the agricultural sector can be expected in the coming years (see Böttinger, Doluschitz, Volz, Paterson, & Jenane, 2010; Pedersen, Fountas, & Blackmore, 2007; Sørensen et al., 2010).

Field robots able to carry out selected operations at relatively high working speeds are still rarely referenced. The required steering accuracy and reliability of the robots moving fast under off-road conditions including slopes, slippery surfaces, varying soil conditions, obstacles, and rollover-risk remain challenging, particularly under consideration of trajectory planning and control (Cariou, Gobor, Seiferth, & Berducat, 2017; Wang & Low, 2007). The described approaches are limited to robots moving at very low speed and based on classical control algorithms neglecting the sliding and skipping effects. Moreover, for advanced solutions, the robot must be able to detect and avoid static and dynamic obstacles during motion (e.g. in field objects such as hedges and trees, other machines, animals, humans etc.) Making mobile robots safe and reliable is an absolute prerequisite for their market introduction. Considering agricultural field robotics, the 2006/42/CE Machine Directive can be referenced. This directive demands from the manufacturer analysis of relevant and appropriate solutions and the taking of any necessary measures in order to ensure a high level of risk protection for users and other exposed persons. Furthermore, the design of robots is required to ensure protection against injury risk. Specifications for safety with agricultural machines automated to a high degree are also included within the draft standard ISO/DIS 18497.2.

In such a context, the development of modern methods is expected for pasture maintenance via field operations selectively accomplished with robots. The main problems and strategies for advanced pasture management using robotics are addressed within the ICT-AGRI project i-LEED (Cariou et al., 2017; Gobor et al., 2015; Seiferth, Cariou, & Gobor, 2016). Trajectory planning of a non-holonomic robot with kinematic and dynamic constraints is particularly challenging, and several algorithms are required to adequately process the target points in order to then generate feasible and suitable trajectories.

This paper proposes to focus more specifically on the problem of trajectory planning of pasture robot work covering a set of target points with weeds, cowpats and patches without vegetation. Based on these collected multi-layer data, the objectives are to: (1) define the areas of interest and assign the adequate operation to the robot by calculating the smallest area (Gobor, 2017) covering points of interest detected during the measurement; (2) find the shortest path for the robot starting from the entrance to the paddock, operating each area in the optimal order and returning to the starting point; (3) from this path, create a feasible trajectory for the pasture robot taking into account both its kinematic and dynamic constraints and its working width, in order to carry out the assigned tasks properly.

2. Materials and methods

2.1. Datasets and pasture robot

Considering the operative path planning issue, Fig. 1a presents an experimental pasture and Fig. 1b–e the corresponding datasets based on simulation (see Appendix A) for weed map, cowpats distribution and areas without vegetation (these data are supposed to come from sensor measurements).

The main characteristics of the pasture robot are presented in Fig. 2. This robot was developed within the ICT-AGRI project i-LEED (www.i-LEED.eu). It is based on a commercially available mobile platform which was originally intended for mowing public green areas using radio remote control. The front wheels are steered via linkage activated by a double acting hydraulic cylinder, and the rear wheels are driven hydraulically via a separate hydraulic circuit. The implement for mulching weeds and pasture leftovers is a flail mulcher mounted between the front and rear axles of the vehicle. A seeder was developed to spread seed mixtures on the areas without vegetation. For the project, the remote-control system was replaced by a low-level controller based on myRIO hardware (National Instruments) combined with an X-CAN adapter (Stratom) allowing the possibility of controlling all actuators of the machine directly through CANopen commands. Furthermore, a software solution developed within the i-LEED project (i-LEED GUI) in combination with the Effinav box (Effidence company) provides the possibility of carrying out autonomous navigation tasks. More details are given by Seiferth et al. (2016).

2.2. Methods

After calculating the non-convex and convex hulls and the centres of gravity (CoG-s) for each dataset, an evolutionary algorithm is used to define the optimal order for processing the hulls. Finally, feasible trajectories for the robot are defined to process successively the areas with weeds, cowpats and without vegetation.

2.2.1. Prerequisite

A prerequisite of targeted operations is an accurate and reliable identification of the areas of interest in the pasture such as areas without vegetation, areas on which fertiliser needs to be spread, leftover vegetation after grazing, or cowpats. The weed management strategies can be optimised through relating to the findings considering weed patches and their distribution (Krohmann, Gerhards, & Kühbauch, 2006), and an early detection of weeds allows their selective management (Christensen et al., 2009; Lamb & Weedon, 1998; Lottes, Hörferlin, Sander, & Stachniss, 2016). Due to the heterogeneous distribution of weeds, maps with discrete sampling

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