Agricultural Field Monitoring Using a Small Robot

Dionysis D. Bochtis, Claus G. Sørensen, Michael Nørremark, Ibrahim A. Hameed, Kishore C. Swain
Aarhus University, Faculty of agricultural science, Dept. of agricultural engineering, Blichers Alle 20, DK-8830, Tjele, Denmark, Dionysis.Bochtis@agrsci.dk

ABSTRACT

Site-specific weed control is critically dependent on continuously updated information on the conditions of the weed occurrence in the field. This fact has generated the idea of considering monitoring as a separate operation. Moreover, economical, environmental and sustainability criteria has lead to the idea of using inexpensive autonomous platforms, equipped with computer vision systems. Such a system can potentially increase the farmer's knowledge on the state of the field and consequently, improve the potential for timely and site-specific treatment of the field. In this paper, operational aspects concerning the field monitoring operation executed by a small robot are presented. A brief description of the hardware systems and the software architecture of the robot (called Hortibot) is given and the mission and route planning aspects of its high level control are analysed. These include the automated field representation and route planning methods for full area coverage as well as for sample-based monitoring operations.

Keywords: Field robot, weed control, mission planning

1. INTRODUCTION

By using site-specific weed control, a reduction in the range of 12 to 80% in herbicide use may be obtained (Timmermann *et al*., 2001; Walter *et al.*, 2001; Nørremark et al., 2008). This type of control is critically dependent on continuously updated information on the conditions of the weed occurrence in the field. Manual weed scouting is costly and laborious as it is reflected in the fact that currently only a limited number of farmers are practising weed mapping and site-specific weed control (Sørensen *et al*., 2002).

Satellite based positioning systems and machine-readable GIS-based geographic maps can be used for the planning and controlling of the equipment for site-specific operations. On the other hand, the newest information is needed to identify the right spots or the right operation. The latter can be achieved by means of on-line real-time sensors, typically using computer vision. In order to cover the whole working width, on-line measurements will, however, require a rather extensive and quite costly network. Besides, it will not be possible to carry out a strategic planning and optimization of in-field treatments, as only local conditions will be known at the time of the operation. This fact has generated the idea of considering monitoring as a separate

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operation. Here, it is important to note that for most conditions, the data would not be stable, even if they were one or a few days old. This allows for thinking in terms of monitoring by use of an inexpensive, slow-moving autonomous platform, equipped with computer vision systems, thereby enabling the determination and logging of information on crop conditions and weed occurrences. The advantages of such a system are that it can be used prior to the field treatment providing global information. The operation will also be inexpensive, because no operator will be required. Such a system will increase the farmer's knowledge on the state of the field, thereby improving the potential for timely and site-specific treatment of the field. The operational output from the monitoring operation will be a computer readable map displaying the in-field weed density and species distribution.

In this paper, operational aspects concerning the field monitoring operation executed by a small robot are presented. A brief description of the hardware systems and the software architecture of the robot (called Hortibot) is given. The robot has been developed on the principles of the Small Field Robots that meet the agronomic, economic and environmental needs of a sustainable agricultural system (Blackmore *et al.*, 2007; 2004). Furthermore, the mission and route planning aspects of its high level control are analysed. These include the automated field representation and route planning methods for full area coverage as well as for sample-based monitoring operations.

2. GENERAL ASPECTS OF MISSION PLANNING FOR FIELD ROBOTS

The mission planning is an integrated part of the operations management adhering to farming. Operation describes the agronomic purpose of an activity, while tasks describe the realization of the operation involving relevant resources in terms of labour and machinery input (Sørensen, 1999). In the case of autonomous vehicles, the task formulation must include route planning and tasks scheduling.

As in any type of field operation, the monitoring operation will involve an overall mission planning problem that includes route planning, task determination and sequencing, which all constitutes problems of high complexity. Hence, an efficient approach should be based on the decomposition of the overall planning problem into a hierarchy of simpler problems that can be solved independently and efficiently:

1. *Field area decomposition.* Decomposition of the coverage region into sub-regions.
2. *Field tracks generation*. Given the sub-fields how the set of the parallel field tracks is generated?
3. *Sub-fields body coverage***. G**eneration of a path that covers each sub-region. This path should ensure that the mobile unit covers the field main body (between headlands and access paths) in an optimum way without overlaps or missed areas avoiding all obstacles.
4. *Sub-fields sequence.* Given that the sub-fields and access paths have been established, what is the sequence that mobile unit machine visits the sub-fields?
5. *Tasks*. This regard the determination of the sequence that the implement and machine operational tasks have to executed?

It has to be noted that although the area coverage problem has been studied extensively in the robotics literature motivated by applications such as cleaning, mapping unknown environments, mine detection etc. (see Choset (2001) for an extensive presentation of relative algorithms), the developed approaches cannot be used for agricultural operations because of the special features and agronomic constraints inherent in these operations. In agricultural operations, some additional constraints must be taken into account, which deal with soil compaction, operating while following contour lines, the fact that a typical agricultural machine usually cannot operate while manoeuvring, etc. Another important factor influencing the planning is the technique that was used by the previous treatments or by other machinery types. So, the area coverage planning is mostly determined by agronomic structures and constraints.

Figure 1. Hortibot field robot.

3. THE HORTIBOT FIELD ROBOT

The HortiBot is an autonomous platform prepared for further research and development in agricultural application. The HortiBot hardware and software structure is oriented at making it capable of performing monitoring tasks with a special focus on pests and weed monitoring. A central element is the development of an integrated management system for the planning and activation of the monitoring task. The internet based architecture of the system includes:

- A station unit that works as a mobile operating console
- A mobile unit – Hortibot (Fig 1)
- Field server for generating and storing maps
- A pulled implement corresponding to the selected field operation to be carried out

The station unit is responsible for communication with 'Farm Management' and for global planning, while the mobile platform has to implement the movements among waypoints in a route computed by the station. During the movement, the implement performs its operation – in the present case by use of cameras – to estimate weed density and species distribution.
The Hortibot has the following main characteristics:

- It enables an "around the clock" automatic execution of one-sided repetitive field operations in row crops of agri- and horticulture. It works on a commercial row detection system with no or minimal use of Global Positioning Systems (GPS)
- Provides high precision of field work by automatic navigation of small sized or minimum draft force implements
- All operational data is automatically send to an internet based database
- Minimum of button approach - users of the HortiBot are able to operate it with a minimum of training and by using a pictogram as an operational guide.

The operation of the Hortibot has been documented in terms of feasibility, operational capacity, and economy (Sørensen et al., 2005; 2007).

3.1 Hardware

Each wheel module consist of a hydraulic motor for propulsion, a DC motor for steering, speed and wheel angle sensor, and a control module. The engine is also controlled by a control module, a lift arm with a control module is mounted, and a central Hortibot Control Computer (HCC) has been mounted. The communication between all units is based on a proprietary high speed CANbus. A common control module based on a 16 bit Atmel AVR microprocessor has been developed for the 4 wheel modules, the engine control, and the lift arm module. The overall mechanical setup and electrical interfaces of the Hortibot can be seen in Figure 2.
The Hortibot Control Computer (HCC) is responsible for performing the Hortibot principle tasks such as position estimation, path following control, payload handling, emergency response etc. The HCC is an embedded computer based on the industrial standard PC/104 architecture. It contains an Intel x86 compliant 300 MHz CPU module, a CAN bus module, a serial interface module, and an Ethernet module. The regular hard disk has been replaced by a Compact Flash card in order to avoid problems caused by the inevitable vibrations and temperature variations, the Hortibot experiences when operating in the field.
The vision module from Eco-Dan A/S, Denmark, is a new stereo vision system which captures color and 3D information from horticultural and agricultural scenes. The output from the latter system is expected to be adequate for the Hortibot navigating within transplanted onion parcels. A powerful Digital Signal Processor (DPS) analyze the data and output the relevant information from the scene. This will normally be offset and orientation relative to a desired track characterized by either color (small plants), contour (tramline, furrow, ridge, etc.) or both color and contour (big plants). Another use could be height or distance measurement in a complex scene. The communication between the HCC and the Eco-Dan vision module is via the CANbus.

3.2 Software

The operating system of the HCC is an embedded Linux distribution, iComLinux developed by Cetus, Denmark (www.cetus.dk). The iComLinux mounts the Compact Flash card read-only, and during normal operations all writing operations are performed on a RAM-disk. This has the advantage that the HCC can be switched off at any time without causing file system errors. The HCC is connected to the sensors, actuators and communication interfaces via external modules interfacing to the HCC via a Controller Area Network (CAN) bus or via a serial port (Fig. 2).
The software architecture of the HCC is structured as a set of software modules interfacing to each other via a shared data structure. Each software module is compiled as a Linux program, and it uses the built in Linux shared memory and semaphore features to access the shared data structure. Hence the software modules can be started, stopped, added and upgraded independently.

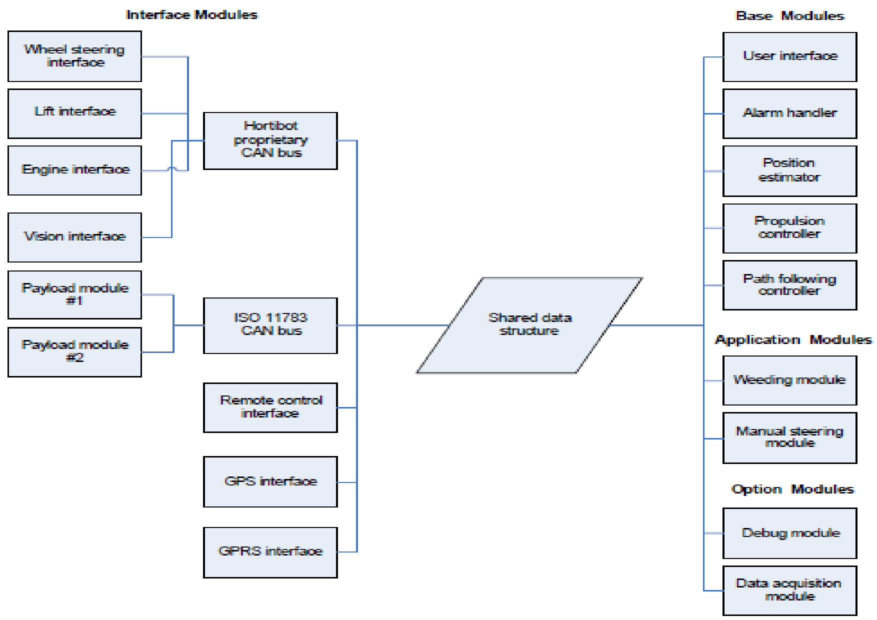

Figure 2. Software architecture for the Hortibot Control Computer.

4. MONITORING OPERATION

4.1 Field Representation

A field area is represented as a closed loop, double-digitized 2D polygon and stored in shape-files with associated informational attributes that describe the geometric features. Three individual files are normally mandatory to store the core data that comprises: a shape format which stores the feature geometry itself, a shape index format which stores the positional index of the feature geometry and an attribute format which stores the columnar attributes for each shape. Following the two algorithmic approaches will result in the geometrical representation of a field, described by a shape file, as an entity that can be used for the path determination and route planning of the mobile unit.

4.1.1 Straight Field Coverage Algorithm (SFCA)

SFCA works in two stages. In the first stage, it generates *n* tracks parallel to the field edges from inside to be used as row headlands. In the second stage, the algorithm selects the longest edge of the field. Figure 3 presents the implementation of the algorithm on the shape file of a field located at the Foulum research center, Denmark [N 56^0 29´ 21.55, E 009^0 34´ 59.40].

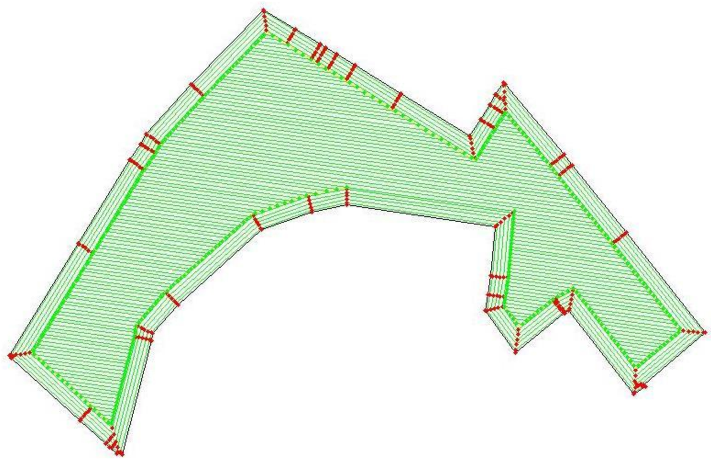

Figure 3. An example of a field operated using the SFCA.

4.1.2 Curved Field Coverage Algorithm (CFCA)

The first stage of CFCA is the same as that of the SFCA. In the second stage, instead of using the longest edge of the field as the reference edge for generating parallel rows, the longest set of neighbor edges will be selected and parallel rows are generated parallel to it. The criteria for selecting edges is that if the slope of an edge is less than the slope of its previous edge by a certain threshold value or equal to it, both edges will be selected. The same field as previous is presented in Figure 4 after algorithm's implementation.

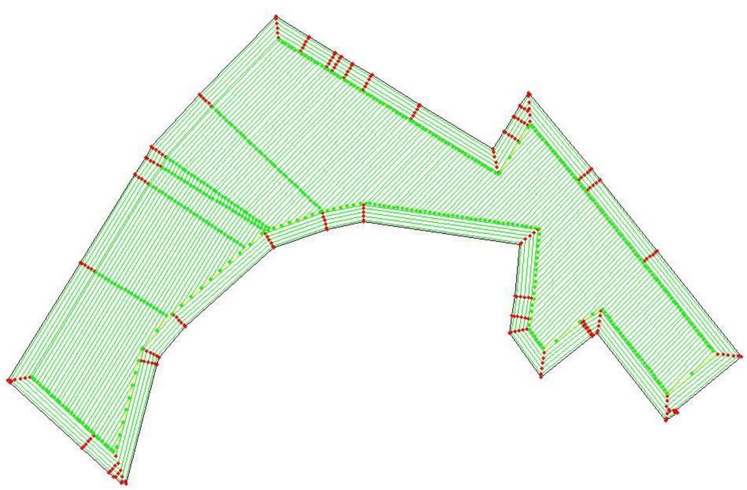

Figure 4. Example of a field operated using the CFCA.

4.2 Mission planning

4.2.1 Coverage planning

Given the geometrical field representation, the problem of optimal route planning can take place. An algorithmic approach towards computing traversal sequences for parallel field tracks that has been introduced by Bochtis (2008) is used on this. The approach improves the field efficiency of an agricultural machine, by minimizing the non working travelled distance. Field coverage is expressed as the traversal of a weighted graph and the problem of finding optimal traversal sequences is equivalent to finding shortest tours in the graph. According to this devised procedure, field coverage is expressed as the traversal of a weighted graph, and the problem of finding optimal traversal sequences is shown to be equivalent to finding the shortest tours in the graph. The traversal of the graph is subject to the constraint that the tour has to be of minimum total cost while each node has to be visited exactly once and any sub-tours should be excluded of a feasible solution. For the solution of the optimization problem, a heuristic graph search algorithm was constructed. An implementation of the previous procedure in conventional agricultural machines, supported by auto-steering systems, was presented in Bochtis and Vougioukas (2008). The same approach has been implemented for the mission planning of an autonomous tractor for area coverage operations such as grass mowing, seeding and spraying (Bochtis *et al.* 2009)

4.2.2 Sable-based monitoring operation planning

For a sable-based monitoring, a sampling and a route plan for the monitoring-mobile unit have to be generated. The sampling plan regards the generation of sampling locations derived from prior statistical analysis. The route plan is a determination of the sequence that these locations should be visited as well as the generation of the paths for their connections.

The selected planning algorithm had to cover also the perspective of the "dynamic planning" extension of the monitoring operation. Path planning algorithms are, in general, high time consuming. Furthermore, a number of paths should be created iteratively in each re-planning of the executed operation in the dynamic case. For the reasons above, a method for path planning, with low computational requirements, for agricultural vehicles operating structured field environments has been implemented. The proposed method takes the advantage of the abstract structure inherent in farming, where machines operate driving on parallel field tracks. According to this method, the metric that is used is not the *Euclidian* but the *Manhattan metric* (also known as L_1 distance) according which in a two dimensional space (R^2) the length of a path is obtained by moving along an axis-aligned grid. For example, the distance from (2, 2) to (4, 7) is 5 by travelling two blocks to the left and three blocks up. According to this, the discrete planning involves a two-dimensional grid of integer coordinates where the unit takes discrete steps in one of four directions (up, down, left, right) each of which increments or decrements one coordinate. Under these assumptions, path planning is cast as a variable length (or unspecified length) discrete optimal planning. The optimization method that is used is dynamic programming based on forward value iteration where optimal cost-to-come functions from the initial stage are computed.

4.2.3 Dynamic Planning as a future aspect

The low computational requirements of the algorithmic procedures previously described, makes it possible to adopt a whole planning system in operations of dynamic nature using the re-planning strategy in which a group of new static optimization problems are solved based on the latest information.

The central part of such a planning concerns the dynamic re-evaluation of the initial plan sampling and route plan based on on-line sampling analysis on the weed detection. This provides the basis for a fully sequential adaptive adjustment of the sampling procedure after each individual sampling. It is expected that such a dynamic targeted sampling and routing system will reduce the costs and time consumption of the sampling.

5. CONCLUSIONS

Operational aspects concerning the operation of monitoring of the in-field weed density and species distribution, executed by a small robot (called Hortibot), were presented. These include the automated field representation and route planning methods for full area coverage as well as for sample-based monitoring operations. Such a system can potentially increase the farmer's knowledge on the state of the field and consequently, improve the potential for timely and site-specific treatment of the field.

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