Computers and Electronics in Agriculture 109 (2014) 12–22

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Agricultural operations planning in fields with multiple obstacle areas

K. Zhou [a,*], A. Leck Jensen [a], C.G. Sørensen [a], P. Busato [b], D.D. Bothtis [a]

[a] Dept. of Engineering, Aarhus University, Blichers Allé 20, P.O. Box 50, 8830 Tjele, Denmark
[b] Dept. of Agricultural, Forest and Food Sciences (DISAFA), University of Turin, 10095 Grugliasco, Turin, Italy

ARTICLE INFO

Article history:
Received 14 March 2014
Received in revised form 14 August 2014
Accepted 16 August 2014

Keywords:
Route planning
Agricultural vehicles
Ant colony algorithm
Traveling salesman problem

ABSTRACT

When planning an agricultural field operation there are certain conditions where human planning can lead to low field efficiency, e.g. in the case of irregular field shapes and the presence of obstacles within the field area. The objective of this paper was to develop a planning method that generates a feasible area coverage plan for agricultural machines executing non-capacitated operations in fields inhabiting multiple obstacle areas. The developed approach consists of three stages. The first two stages regard the generation of the field geometrical representation where the field is split into sub-fields (blocks) and each sub-field is covered by parallel tracks, while the third stage regards the optimization of the block sequence aiming at minimizing the traveled distance to connect the blocks. The optimization problem was formulated as a TSP problem and it was solved implementing the ant colony algorithmic approach. To validate the developed model two application experiments were designed. The results showed that the model could adequately predict the motion pattern of machinery operating in field with multiple obstacles.

1. Introduction

When planning an agricultural field operation there are certain field conditions where experience-based planning can lead to low machinery efficiency, for example in case of irregular field shapes and in case of the presence of obstacles within the field area (Oksanen and Visala, 2007). So far, a significant amount of research has been carried out to solve the route planning problem in field operations. These advances include a number of methods for the geometrical field representation (de Bruin et al., 2009; Oksanen and Visala, 2009; Hofstee et al., 2009; Hameed et al., 2010) and a number of methods for route planning within a given field geometrical representation (Bochtis and Vougioukas, 2008; Bochtis and Sørensen, 2009; de Bruin et al., 2009; Bochtis et al., 2013; Scheuren et al., 2013).

In the case of fields with inhabited obstacles, in all developed methods the field is decomposed into sub-fields (referred to as blocks). Due to the specific nature of field operations, existing decomposition methods of the working space from the industrial robotics discipline area (Choset, 2001; Galceran and Carreras, 2013) cannot be directly applied. Oksanen and Visala (2007) developed a field decomposition method based on the trapezoidal decomposition for agricultural machines to cover the field. After decomposition, the trapezoids are merged into blocks under the requirements that the blocks have exactly matching edges and the angles of ending edges is not too steep. Hofstee et al. (2009) developed a tool for splitting the field into single convex fields. Stoll (2003) introduced a method to divide the field into blocks based on the longest side of the field. Palmer et al. (2003) presented a method of generating pre-determined tracks in fields with obstacles. Jin and Tang (2010) developed an exhaustive search algorithm for finding the optimal field decomposition and path directions for each subfield. However, in all of the above mentioned methods the optimum order to traverse the decomposed block was not derived. A first theoretical approach that provided the traversal sequence of the resulted blocks was presented in Hameed et al. (2013). The approach was based on the implementation of genetic algorithms for the optimization of the visiting sequence of the different subfield areas resulted by the presence of the obstacles. However, the computational requirements of the approach were exponential to the problem size (e.g. the number of obstacles in the field area) and the feasibility of the approach has not been tested in terms of their implementation on real farming conditions.

The objective of this paper was to develop a planning method that generates a feasible area coverage plan for agricultural machines executing non-capacitated operations in fields inhabiting multiple obstacle areas. The term non-capacitated refers to

* Corresponding author. Tel.: +45 71474842.
E-mail address: kun.zhou@eng.au.dk (K. Zhou).

http://dx.doi.org/10.1016/j.compag.2014.08.013
0168-1699/

the operations where the capacity constraints of the machine do not allow for covering the entire field area by a single route (e.g. the presented method cannot apply to the case of harvesting). The method consists of three stages. The first two stages regard the generation of the field-work tracks and the division of the field into blocks, respectively, and the third stage regards the optimization of the sequence that the blocks are worked under the criterion of the minimization of the blocks connection distance. The problem of finding the optimal block traversal sequence was formulated as a traveling salesman problem (TSP) and it was solved by implementing the ant colony algorithmic approach.

2. Methodology

2.1. Overview

The headland pattern is one of the most common field coverage patterns for agricultural machines, in which the field is divided into two parts, the headland area and field body area. The field body is the primary cropping area and it is covered with a sequence of straight or curved field-work tracks. The distance between two adjacent tracks is equal to the effective operating width of the agricultural machine. The headland area is laid out along the field border with the main purpose to enable the machines to turn between two sequential planned tracks. The order in which the agricultural machines operate in the two types of areas depends on the type of the operation; for example, the headland area is harvested before the field body, while the field body is seeded before the headland area. When a field has obstacles headlands are also laid out around the obstacles. The field body is split into a number of sub-fields (or blocks) around the obstacles, such that all blocks are free of obstacles.

The planning method involves the following three stages:

(a) In the first stage, the field area and the in-field obstacle(s) are represented as a geometrical graph. This process includes the headland generation, the obstacle handling, and an initial generation of field-work tracks (ignoring the in-field obstacles until stage 2) (Section 2.2).
(b) In the second stage, the field body is decomposed into block areas and the previously generated field-work tracks are divided and clustered into these block areas (Section 2.3).
(c) In the third stage, the problem of the optimal traversal sequence of the blocks (in terms of area coverage planning) is derived (Section 2.4).

The input parameters of the planning method include:

- The boundary of the field area and the boundaries of the in-field obstacles. All boundaries are expressed as a clock-wise ordered set of vertices.
- The number of the headland passes (h) for the main field and around each obstacle.
- The driving direction (θ). It determines the direction of the parallel fieldwork tracks that cover the field area.
- The operating width (w). This is the effective operating width of the implement and also represents the width of the field-work tracks.
- Turning radius (c). This is the minimal turning radius of the agricultural machines.
- The threshold parameter (r), for the classification of the obstacle type (explained in Section 2.2.2).

A graphical description of the proposed planning system is presented in the diagram in Fig. 1.

2.2. First stage

2.2.1. Generation of field headland

The field headland area is obtained by offsetting the boundary inwardly by a width equal to the multiplication of the operating width, w times the number of headland passes, h. The distance from the field boundaries to the first headland pass is half of the operating width, $w/2$ while the distance between subsequent headland passes equals to the operating width, w. An inner boundary between field headland and field body is created at distance $w/2$ from the last headland pass.

2.2.2. Categorizing of obstacles and generation of obstacle headlands

There are different types of obstacles in terms of their effect on the execution of a field operation. For example, certain physical obstacles due to their relatively small dimensions do not constitute an operational obstacle resulting in the generation of sub-fields (e.g. in Fig. 2a: Obstacle 5 is potentially such an obstacle). Other obstacles might exist that are close to the field boundary such that the generation of sub-fields is not required (e.g. obstacle 1 in Fig. 2). Finally, there are obstacles in close proximity that from the operational point of view should be considered as one obstacle (e.g. obstacles 2 and 3 in Fig. 2).

Four types of obstacles are defined:

Type A. An obstacle that due to size and configuration in relation to the driving direction does not affect the coverage plan generation. In order to classify an obstacle as type A, the minimum boundary box of the obstacle polygon is generated with one of its edges parallel to the driving direction. If the dimension, Δd of the minimum bounding box that is perpendicular to the driving direction is less than the threshold parameter r, this obstacle is considered as a type A obstacle. Fig. 3a and b present how the driving direction θ determines the classification of an obstacle as type A or not.

Type B. This type includes obstacles where their boundary intersects with the inner boundary of the field. Type B obstacles are incorporated into the inner boundary of the field and the field headland is extended around this obstacle.

Type C. This type includes obstacles where the minimum distance between another obstacle is less than the operating width, w. In this case both obstacles are classified as of type C and a sub-routine is used to find the minimal bounding polygon (MBP) to enclose these obstacles. For instance, assuming that the minimum distance between the obstacle 2 and 3 in the Fig 2a is less than the operating width, w, then the minimal bounding polygon is gained by the sub-routine to represent the boundaries of these two obstacles as shown in Fig 2b.

Type D. All remaining obstacles are considered type D. Also the resulted new obstacles derived by the connection of two or more obstacles of type C are classified as type D obstacles. Headland areas are generated only for the obstacles of type D. The method of generating obstacle headland is analogous to the method of field headland generation; however, the offset direction of the boundary is outward.

2.2.3. Generation of field-work tracks

Track generation concerns the process of generating parallel tracks to cover the field body. The minimum-perimeter bounding rectangle (MBR) of the inner field boundary is generated using the method of rotating calipers (Toussaint, 1983). In the first step, depicted in Fig. 4, the MBR is generated around the inner field boundary, and a reference line l parallel to θ is created intersecting one vertex on the MBR while all other vertices of MBR are located on the same half-plane determined by the line l. Let v be the vertex of the MBR with the longest perpendicular distance from l, and let v' be the projection of v on l. Then the number oft he field-work