Multi-Agent Cooperative Area Coverage: Case Study Ploughing

(Extended Abstract)

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ABSTRACT

We present two cooperative strategies in area coverage that are aimed to be applied in agricultural robotics domain. Current strategies in this domain rely on explicit forms of communication for task allocation and coordination. One issue with these approaches is the loss of communicating signal. This paper presents two approaches (FIFO, and LIFO) for task allocation and coordination that relies only on local information of the robots.

Keywords

Multi-robot Area Coverage; Multi-agent System; Agricultural Robotics; Cooperative Behaviour

1. INTRODUCTION

In area coverage, a team of robots has to cooperatively sweep the entire area, possibly containing obstacles. The goal is to build an efficient path for each robot which jointly ensure that every single point in the environment can be visited by the robots. Many real world applications require systematic area coverage including search in forested area, demining, distribution of beacons and line searching. In this paper we focus on the application of agricultural robotics and in particular ploughing.

Ploughing is seedbed preparation process and it is carried out by dragging a ploughing mouldboard across the field. The ploughing mouldboard digs deep into the soil and disperses the soil in one direction. Ploughing creates a two-part pattern: (1) A narrow trench which is called *furrow*, and (2) a hill-top soil which is called *ridge*.

Ploughing has four main restrictions: (I) The target locations have to be ploughed only once. (II) Furrows have to be created consecutively so that a furrow is accompanied by a ridge. (III) Two consecutive furrows cannot be created simultaneously. (IV) The order of field processing (which part of the field to be ploughed next) depends on the attached ploughing mouldboards. There are various types of mouldboards roughly classified into reversible and conventional. With reversible mouldboards, the field can be processed consecutively. In this method, ploughing starts from one side of the field and ends on the other side. Whereas with conventional mouldboards, the field can only be processed in a loop. In this ploughing method, the field is processed from sides and ends in the middle. In this paper, it is assumed that robots are equipped with reversible mouldboards.

Ploughing by a team of robots has to be strongly coordinated with real-time task allocation. Current approaches in agricultural robotic domain achieve this level of coordination and real-time task allocation using base-station ([2], [3]) and direct robot negotiations [1]. These approaches require explicit forms of communication (e.g. using WiFi, Bluetooth, Sonar) which are susceptible to the loss of communicating signal or the base station.

The aim of the proposed strategy is to develop a decentralised scalable distributed self-organising robotic system that would require minimum computational effort, no central-based control and communication, and at the same time high-efficient and adaptable to various agricultural tasks and fields.

2. COOPERATIVE STRATEGY

The proposed strategy is based on the principle of indirect communication. As a result of ploughing, the state of the soil changes. This is detectable using image processing and it is being used for navigation purposes [4]. Alternatively, this information could be interpreted differently. In the proposed strategy the problem of task allocation is resolved by real-time ordering of robots.

Initially, robots approach ploughing locations in a fixed order (e.g. $f_1 \rightarrow f_n$) to analyse the state of the soil. The index of the first detected unploughed location becomes the rank of the robot. Once this location is identified, the robot initiate ploughing right away.

In order to assure that robots obtain a linear order, robots approach the field from a unique and single location. This location is referred to as α and it is located outside of the field and near the first ploughing location.

Once the robot enters the field (in linear order), it needs to identify which locations to plough next. However, since furrows have to be created consecutively, $f_i \rightarrow f_{i+1}$, robots have to assure that the targeted location is next to a created furrow. This requires that robots standby somewhere outside of the field. This waiting area is referred to as *Headland*. At the start and end of the field a headland is required. It is an untreated area allowing to position the robot and the

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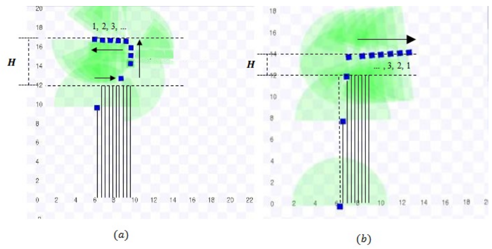

Figure 1: Stage simulation environment: (a) FIFO in a team of 10 robots. (b) LIFO in a team of 10 robots.

plough at the start allowing transitions at the end of a furrow. Headlands are uncultivable as they are not ploughed, and therefore the productivity of the field is affected by the width of headland: *the wider the headland, the less productive the field*. The productivity of a field can be expressed as follows:

$$PR = \frac{l_p}{L} \times 100 \tag{1}$$

Where L is the length of the field, and l_p is the length of the ploughed furrow. l_p can be obtained from $l_p = L - h_1 - h_2$. In here, h_1 and h_2 are the width of the headlands on both sides of the field.

Robots have to standby in headland areas to avoid congestion and to maintain the designated order while the productivity of the field is kept as high as possible. For this we proposed two cooperative models: (I) FIFO: First In First Out, and (II) LIFO: Last In First Out. In FIFO, robots aim at maintaining the original order by queuing behind the first robot (see Fig. 1(a)). In this strategy, robots are lined-up in a fixed width ($n \times f_d$: where n is the number of robots and f_d is the distance between two ploughing locations) but in variable length which affects the width of the headlands. In FIFO, the required width of the headland depends on the team size and it can be evaluated as follows:

$$H_{FIFO} = (\lambda + \epsilon)(n - \lfloor \frac{d_f(2n-1)}{\lambda + \epsilon} \rfloor) \tag{2}$$

In this strategy, ploughing restarts by r_1 whenever it detected that r_n is out of its field of view. This is carried out using image analysis on teammate modelling. In here, we used color detection as robots are homogeneous and look alike.

In LIFO, the original order is reversed on each round of furrow transitioning. In here, the advantage is to increase the productivity of the field by reducing the required headland. Robots line-up in front of each other and move reversely to avoid collision while in the queue (see Fig. 1(b)). While waiting, robots utilise their camera to observe and to predict the behaviour of the front robot. Ploughing restarts whenever the last robot, which becomes the first robot for the next round, completes its current ploughing. In-depth analysis of LIFO reveals that this method requires less headland area.

$$H_{LIFO} = \zeta + \lambda \tag{3}$$

The result obtained from simulation and mathematical numeric visualisations of various team sizes approve that the

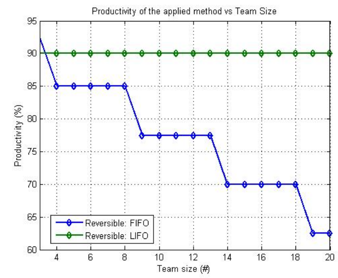

Figure 2: Stage simulation environment: (Blue) FIFO in a team of 10 robots. (Green) LIFO in a team of 10 robots.

LIFO is more productive since headland navigation strategy is independent of the team size (see Fig. 2).

3. CONCLUSION AND FUTURE WORK

In this paper, we addressed the problem of area coverage in the case of ploughing, a fundamental task in agriculture. In the described solutions, task allocation is based on indirect communication between robots. This consists of detecting changes in the soil pattern at particular locations. For cooperative behaviour and coordination, two strategies are proposed: FIFO and LIFO. The approaches are different in terms of required headland for traffic handling by which the productivity of the field will be affected. In FIFO, the productivity of the field is affected as number of participating robots increases. Whereas in LIFO, the productivity of the field remains as constant.

The proposed approaches are only applicable if the robots are equipped with reversible mouldboards, but reversible mouldboards are not always available. Alternatively, robots may be equipped with conventional mouldboards which disperse soil in a fixed direction. In that case, a different strategy is needed to be developed.

Ploughing is a special case in which robots can interact with each other through changes created in the soil. However, in other agricultural tasks, spraying in particular, this facility does not exist. Spraying does not have long term impact on the soil, hence different approach is required.

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