PLANNING AND REPLANNING EVENTS FOR

AUTONOMOUS ORCHARD TRACTORS

by

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ABSTRACT

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Orchard farming is an ideal task to apply autonomous tractors. Orchard farms tend to be large controlled environments where the same operations are performed hundreds of times over many years. The task that has the potential for the largest increase in productivity is that of efficient path generation for orchard operations. More efficient paths will reduce the time taken and resources used in completing tasks. An automated path planner that utilizes its knowledge of the area as well as the constraints on the tractor can plan paths that greatly reduce the human error that is inherent in any manually driven course. A method for planning paths through orchard blocks was introduced and incorporated into an existing path planner. Two replanning methods were also developed that dynamically replan the path when a sprayer on a tractor is empty. These methods were studied to determine which produced more efficient orchard operations.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

A farmer's income, for the most part, is outside his or her control because marketing boards or world prices regulate revenue from the crops. In order to sustain current incomes, farmers must be more productive. More efficient farm field operations can eliminate waste and dramatically increase profit. In recent years the agricultural industry has addressed efficiency concerns by automating tasks that either do not require human interaction, or that can be performed better by computer-controlled machines than by a human. The ideal future for the farming industry would be fully autonomous systems that can perform all the tasks that a fleet of farmers and farm hands perform, but in a more efficient manner. Efficiency depends on the operations being automated and can be in terms of time taken, overall profit, distance traveled, resources used, etc. Much of the technology already exists and can be seen in numerous autonomous robots that are quickly making their way into society.

Orchard farming is an ideal task to which to apply fully autonomous tractors. Orchard farms tend to be very controlled environments where the same operations can occur hundreds of times over many years. Once an orchard block is planted, little change occurs and the farmer tends to drive the same path for the duration of its existence, which, depending on the type of tree, can be between 20 and 40 years. Long and monotonous operations lead to fatigue and carelessness of the driver, which in turn leads to lower overall productivity. Operations such as spraying are more efficient when performed at night; however, the driver must be monitored at all times to make sure he has not fallen asleep or been knocked off by overhanging tree branches. The law is also making it more difficult and expensive for orchard farmers to spray chemicals on their trees. Numerous chemicals have either been banned or a more dilute concentration is required due to the ill effect they have had on the people working the orchard farms and the surrounding environment. In many cases it is required to either equip the tractor with an expensive, tightly enclosed cab or the driver must wear protective clothing and a large air mask. Large amounts of money are spent every year to keep the farmers and farm hands safe while in orchards. Large amounts of money are also lost every year due to human error and carelessness. By removing the human completely, orchard farming can be more efficient and productive.

The task that has the potential for the largest increase in productivity for orchard farming is that of efficient path generation for field operations. Currently, the tractor is driven along a course that is planned out by the driver according to his or her visual knowledge and estimated distances of the area. After many hours of driving (usually in the dark), it is highly unlikely that the driver of the tractor will be able to choose the most efficient route to complete the desired tasks for the day. Fatigue and tired eyes may cause miscalculations in distances or a wrong turn. An automated path planner that uses its knowledge of the surroundings along with constraints on the system to plan a path can greatly reduce human error that is inherent in any manually driven course. Add this improvement in efficiency to the increase gained by removing the human completely, and the cost of orchard operations can be reduced dramatically.

Large orchard farms usually consist of a few hundred to a few thousand acres of trees all requiring maintenance regularly. In order to keep an orchard tractor fully autonomous (it never requires a human to sit on it), the path planner must be able to react to certain events as they occur by dynamically replanning the path to account for these events. Events that may require replanning include a sprayer becoming empty, unexpected obstacles, low fuel level, or mechanical troubles. A typical sprayer can usually run 3 to 5 hours before running out of chemicals depending on what chemical is being sprayed, the density of the trees, and the amount of chemicals consumed. The remainder of this thesis will focus on replanning the path in the event that the sprayer becomes empty.

All orchard farmers react differently when a sprayer needs to be refilled. Some wait until the sprayer is completely empty before refilling, others go to refill at the end of the last full row that can be sprayed, and some have trucks that drive to the tractor to refill the sprayer. This thesis focuses on the first example: running the sprayer until it is completely empty before going to the fill station. For this reason, the path planner will not try to be smart in replanning for empty sprayer events, meaning it will not try to anticipate when best to refill the sprayer. Replanning will only occur as soon as the sprayer is empty. This leads to the two methods of replanning for an empty sprayer event that will be considered in this thesis: refill and resume where the tractor left off, or refill and replan the entire mission. The first method only affects the tractor that is in need of a refill while the second method affects all of the tractors in the fleet. If one tractor needs to refill its sprayer, the entire mission is replanned. Goals and goal ordering are reassigned to all the tractors in order to optimize the remainder of the mission. The idea is that while one tractor is going to the fill station another tractor close by can finish the remaining portion of the unsprayed orchard block so as to reduce the overall amount of time and resources used. A study will be conducted in order to find the method of replanning that is more efficient and robust enough for a farmer to safely use in a large orchard farm.

1.2 Problem Description

When an orchard farmer is thinking about investing in new technology or new equipment, the number one concern is productivity. Will the new investment reduce cost and increase profit over its lifetime on the farm? In order for a farmer to get the most gain out of an autonomous orchard tractor, it must have a good path planning system that can generate more efficient courses for orchard operations than a human is capable of driving. This thesis attempts to solve this problem by introducing a method for generating efficient paths for orchard operations as well as two methods for dynamic replanning of the path when the sprayer is empty. The methods will be incorporated into an existing path planning system to be used on an autonomous orchard tractor. An empirical study of the two replanning methods will be carried out in order to investigate the performance of each method under certain conditions.

Before continuing, two terms need to be defined. For the remainder of this thesis, the term orchard block will refer to a single block of trees. One block always contains the same type of tree throughout (i.e., apple, cherry, pear, etc.). Orchard blocks are generally very uniform. Each row of trees runs parallel to each other with the distance between them fairly constant throughout the block. An orchard farm is made up of any number of orchard blocks with farm roads running in between them. Each block in an orchard farm can be a different type of tree. Using these two terms, a clear description of the problems being solved is summarized in figures 1, 2, and 3.

Given:
Orchard block
Row direction (orientation)
Row width
Reference row
Minimum turning radius of tractor

Find:
A path through the orchard block

Such that:
Every row of trees is traveled down once and only once
Path cost is minimized

Figure 1. Path planning through a single orchard block.

Given:
Current mission
Position of tractor(s) at refill event
Fill station coordinates

Find:
A new mission

Such that:
The tractor triggering the event visits a fill station immediately
Path cost is minimized for all tractors

Figure 2. Replanning events.

Given:
Current location of all tractor(s)
List of orchard blocks to be sprayed

Find:
A mission

Such that:
Path cost is minimized for all tractors

Figure 3. Mission planning.

1.3 Related Work

Agricultural production has to meet the nutritional demands of the world while operating within strict economic boundaries and attempting to minimize environmental impact. One approach to maintain high field productivity and increase nutrient efficiency is called precision agriculture. Precision agriculture uses the state-of-the-art technology combined with knowledge-intensive field management to adapt field operations to local variations in crop and soil conditions. Yields are not only harvested but also mapped; fertilizers, chemicals, and herbicides are distributed according to local demand, new techniques like remote sensing are used, and information technology supports decision-making. A more detailed explanation of precision agriculture can be found in [1].

While precision agriculture has revolutionized the agriculture industry and changed the way farmers work, a new area of interest has recently emerged which could revolutionize today's industry by leaps and bounds over precision agriculture and could possibly save farmers billions of dollars and thousands of hours in the field. This new area of interest is fully autonomous agricultural systems that are capable of performing