Towards a Swarm Robotic System for Autonomous Cereal Harvesting ⋆

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1 Introduction

With the world population predicted to reach 10 billion by the year 2050, there is a pressing need to feed the masses with fewer resources. To achieve this, farmers must make more effective use of their land by reducing waste, increasing yield, and improving sustainability. In order to cope with rising demand, and labour shortages that are leaving crops unharvested, some food producers are turning to robotic automation. However, existing solutions are often so large that they lack precision, resulting in waste; so heavy that they cause serious soil compaction, limiting yield; or prohibitively expensive for small farms.

Swarm robotics [5] is an emerging technology that has the potential to overcome these issues and revolutionise precision agriculture by coordinating fleets of smaller autonomous vehicles to minimise soil damage, increase farming resolution, lower the cost of automation, and provide solutions that are intrinsically safer and more sustainable than large monolithic systems. The benefits of this technology have already been explored in the context of automated seeding as part of the Mobile Agricultural Robot Swarms (MARS) project [2], which used cloud-based path-planning and supervision to manage different fleet sizes, field shapes, and seeding patterns, while preventing collisions and repeated work. In addition, the Swarm Robotics for Agricultural Applications (SAGA) project [1] experimented with fleets of drones for autonomous weed detection, demonstrating that a decentralised system of UAVs could be scaled to different farm sizes without loss of performance.

Here, we propose a novel swarm robotic system for autonomous harvesting of cereal crops such as wheat and barley. We have chosen cereal harvesting as a case study, as cereals are the most cultivated staple crops in the UK [6], and because the task has yet to be automated with small vehicles in a fault-tolerant manner. In contrast to existing agricultural swarm robotic systems, we intend to use small autonomous versions of traditional agricultural vehicles, in an attempt to narrow the skills gap for future end-users.

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Fig. 1. Hands Free Hectare autonomous harvest using a Sampo Rosenlew 130 combine harvester and an Iseki compact tractor retrofitted with GPS autopilot hardware.

2 Autonomous multi-vehicle cereal harvesting

Cereal harvesting is typically carried out using combine harvesters (agricultural vehicles that mechanically separate the grain from the rest of the plant) that drive through fields of crops in a predictable pattern. The harvested grain collects in an on-board tank that must be periodically emptied into the trailers of tractors that drive alongside the harvester, which then transport the grain to a nearby silo. A combine harvester will be forced to stop harvesting when its grain tank becomes full, so multiple unloading tractors and trailers are required to ensure an uninterrupted harvest. Due to changeable weather conditions, there may only be a short time window during which the harvest can be completed, so maximising the rate at which crops are harvested is essential.

Many agricultural vehicles are already semi-autonomous, thanks to auto-steer technology and GPS localisation, and can be programmed to repeatably follow paths defined by virtual waypoints. Centimetre-level accuracy can even be achieved via Real-Time Kinematic (RTK) positioning, through the addition of an on-farm base station. An autonomous cereal harvesting system has recently been prototyped as part of the Hands Free Hectare Project[4] — a two-vehicle system comprising an autonomous tractor that offloads cereals on-the-go from an autonomous combine harvester (shown in Figure 1). These vehicles are significantly smaller and lighter than those typically used on large farms, thus reducing soil compaction and improving sustainability. However, the vehicles are relatively unintelligent — they both follow predefined paths, and their on-board sensors simply bring the system safely to a halt if an obstacle is detected.

[4] http://www.handsfreehectare.com

Path planning for fleets of combine harvesters and unloading tractors is a relatively well-studied subject, and is often modelled as a Vehicle Routing Problem [3] (a generalisation of the travelling salesman problem). The challenge of minimising the time wasted when turning in headlands has also largely been solved [4], and established methods exist for planning efficient field coverage in complex field shapes [8]. Unfortunately, the solutions found using these algorithms can be brittle, as they often assume fixed fleet sizes and static environments, so cannot cope with unexpected events occurring at run-time, such as mechanical failure in one (or more) of the vehicles.

3 A more flexible swarm robotic system

To better cope with such eventualities, we propose a swarm robotic approach to autonomous cereal harvesting that employs local sensing and decentralised control, to achieve a more flexible and scalable system. Farms of the future will require autonomous vehicles with on-board sensors for navigation and obstacle avoidance, as well as the capacity for real-time inter-vehicle communication and coordination, rather than machines that simply follow pre-planned routes. This will enable effective coordination between autonomous combine harvesters and unloading tractors, allowing them to adapt their behaviour in response to changes in system status and the environment.

We envisage automated fleets of small commercial tractors and combine harvesters, similar to systems already used in projects such as Robot Fleets for Highly Effective Agriculture and Forestry Management [7] and Hands Free Hectare, which feature limited storage capacity to minimise vehicle weight and size. Relay chains of autonomous tractors will offload each combine harvester, with multiple autonomous harvester/tractor teams operating on the same farm. The allocation of offloading trailers to harvesters will not be predefined, rather they will be dynamically reallocated in response to changing demand. Harvesters will signal to nearby tractors when their grain tank is reaching capacity and needs unloading, and inter-vehicle communication between unloading tractors will be used to prevent congestion around the harvesters and grain silos.

The proposed swarm robotic harvesting system will first be implemented in the V-REP robot simulator [9], to explore its potential benefits before implementation in hardware. We will evaluate the efficacy of the proposed solution by investigating how parameters of the system affect total harvest time and levels of simulated soil compaction. The system will be parameterised by the grain tank capacity and harvesting rate of the combine harvesters, the trailer size of unloading tractors, the time required to offload grain from one vehicle to another, the speed of the vehicles, and the distance between the farmland and the nearest grain silo. Through a series of simulation studies, we will determine the optimal number of unloading tractors per harvester and storage capacity of the vehicles, such that both soil compaction and harvest time are minimised.

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