Extending an Open Source Hardware Agri-Robot with Simulation and Plant Re-identification

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Abstract. Previous work constructed an open source hardware (OSH) agri-robot platform for swarming agriculture research. We summarise recent developments from the community on this platform as a case study of how an OSH project can develop. The original platform has been extended by contributions of a simulation package and a vision-based plant-re-identification system used as a target for blockchain-based food assurance. Gaining new participants in OSH projects requires explicit instructions on how to contribute. The system hardware and software is open-sourced at *https://github.com/Harry-Rogers/PiCar* as part of this publication. We invite others to get involved and extend the platform.

1. INTRODUCTION

Open source hardware (OSH) [1] is becoming increasingly available for researchers to design and test new ideas without the need to develop their own system from scratch [9]. Agricultural robotics does poorly in this domain, as most groups still build their own incompatible hardware then struggle to reproduce each other's work [8, 14]. OSH needs new community members to join and extend projects to ensure a high rate of research development is achieved [10].

Our previous robot platform [15] is an OSH system that was devised to allow researchers and practical agrihackers, with minimal cost and complexity, to develop ideas and research within the agri-robotics domain. The original OSH system is shown in Fig.1. This small-scale OSH system has recently been developed by two new researchers in different directions, which we have now merged into the system. Dawson [7] has contributed a realistic simulation package enabling large swarm tests to be run in simulation rather than in the field. Clawson [6] has added vision-based plant re-identification to enhance the localisation accuracy of the GNSS system, and also as a target platform for blockchain based food assurance. Without the availability of OSH both contributions would not have been possible due to time, cost and integration constraints.

The remainder of this article is organised as follows: in section 2 we survey the related work in OSH, in section 3 we summarise the original platform of our robot, in section 4 we present the first contribution to the project, in section 5 we present the second contribution to the project. In section 6 we discuss how the contribution in section 5 enhances the previous work and adds novelty in food assurance. In section 7 and 8 we identify potential future work and conclusions.

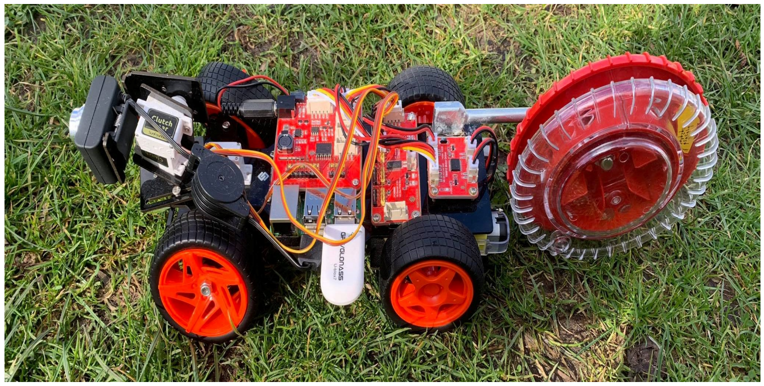

Fig. 1: Original physical OSH robot seeding system from [15].

2. RELATED WORK

OSH has been explored across a wide variety of robotic domains such as education and teaching [4] and laboratory environments [13]. In [4], the authors include both hardware and software much like [15] and is also swarm based through its low cost. [16] adds to the educational domain with both Open Source Software (OSS) and OSH. Here, the authors consider the use of only open source boards, which is now possible due to the maturing of the OSH ecosystem.

Relatively few OSH robotic systems as part of the agri domain have been developed, especially for mobile applications. Systems such as [3], is based around plant science and is a stationary test bed for monitoring and reporting about the plants that it can see and measure. A similar proposal to [3] is [12]. The difference being that [12] can be deployed in an in-field environment, but its use case is primarily as a data collection system. More recently, within precision agriculture, the Internet of Things (IoT) is developing using OSH coupled with OSS but is limited by the incompatibility of platforms [12].

[17] much like previously mentioned systems is static and is targeted towards laboratory testing. [3] offers an interesting additional component of an irrigation system that extends but does not build upon previous OSH. Additionally, [17] also provides an open source repository which adds further value to OSH and OSS projects. However, this project has not been added too since it was created and demonstrates one of the key challenges within OSH robotics.

Where the definition of free and OSS is well defined [18], the definition of OSH is still considered fuzzy [5]. Organisations such as RISC-V have significantly moved the ecosystem forwards through open instruction set architectures. Although the inherent need to have hardware manufacturer involvement can create knowledge exchange challenges, as improvements in the design are not inherent as they would be in software based systems [2,11]. The trajectory of OSH in the agri domain has historically been in the sensory and the non mobile domain. Fully OSH mobile systems are not often seen. Limitations and challenges identified in other OSH projects is the lack of a clear documentation and unclear route to contribution, with most OSH systems created and then forgotten. This is perhaps because a large majority of OSH projects that are resource constrained or have specific aims with limited bandwidth for broader development.

3. ORIGINAL BASE PLATFORM

The original system was designed for automated seed planting and seed location logging. It consists of a Raspberry Pi 3 model B+ and a Sunfounder Raspberry Pi Smart Video Robot Car Kit V2.0. A commercial off the shelf (COTS) seed dispenser and GNSS module have been added to the kit to complete the functionality for the system. The system can manually be driven or can be tasked to travel pose to pose between two predetermined points using a Dubins Path. Tests have been completed and can be found in the original paper [15]. At the time of writing this seems to be the first and only OSH agri-robot with seed planting. The original paper aimed to create a low cost system that was a test bed to be extended and developed in the agri domain.

4. PHYSICAL SIMULATION

Dawson [7] has contributed a 3D simulated model of the platform by working from the original OSH CAD files and importing them into the Gazebo simulator. Work was done in collaboration with the original designers to obtain approximate weights of subcomponents and friction coefficients for the wheels to produce enough realism to enable simulations of swarms of many robots driving together in fields. Fig.2 shows the final iteration Dawson took to complete the model development. This work extends the original base platform in a new direction that would not have been possible without open hardware designs, schematics and bill of material (BOM). This extension enhances the previous work by enabling low cost design iteration and environment simulation to take place.

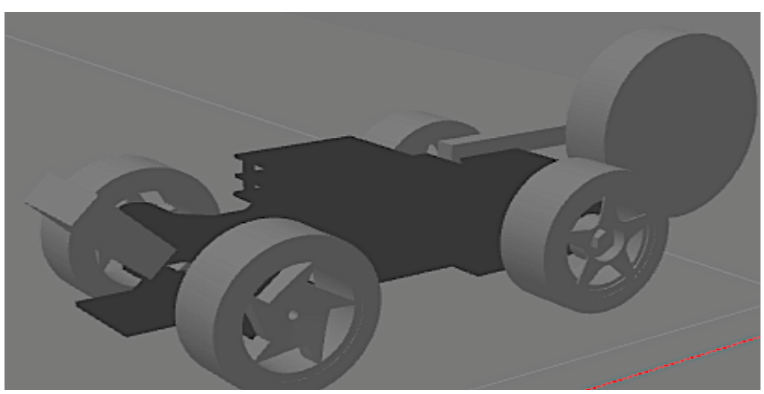

Fig. 2: Final simulation of base platform seeding OSH robot. Taken from [7].

5. PLANT RE-IDENTIFICATION AND LOCALISATION

In-field plant re-identification is the problem of matching a previously seen plant with a currently seen plant over long periods of times. It is a prerequisite for many agri-robotics tasks but is difficult because the resolution of cheap, OSH-friendly GNSS is only around 200mm which is not sufficient. While Real Time Kinematic (RTK) systems can in theory reach 20mm, they are too expensive for most OSH makers and can be inconsistent. Clawson [6] extended the original base seeding platform with a machine vision module which extracts ORB features from in field stones, determined by approximate GNSS position, and matches them using RANSAC to previously seen images. The implementation results suggested that re-ID and improved localisation are possible, within Lincolnshire fields which have many small, irregular shaped stones which are useful landmarks at this scale, as in Fig.3. Due to the modular design of the base platform the required addition of a Arducam 5MP mini camera module was fast and easy and was the reason this platform was chosen to deploy this project.

Fig. 3: ORB feature matching and RANSAC alignment of a previously seen stone to a new image of the same stone. Stone width is approx. 100mm. Taken from [6].

6. EXTENDING OSH INTO FOOD ASSURANCE

Clawson [6] used the plant-re-identification system discussed in section 5 as a first farm step towards "seed to store" food assurance targeted on blockchain technology. In assurance, the supermarket customer would like to scan a product and see its entire supply chain history, including images of its daily growth on the farm. For example, this may provide evidence that it has been grown organically. Due to blockchain data storage constraints, this research demonstrated how a distributed file storage system, IPFS, was employed using blockchain as a notarisation agent. Deploying this concept onto the OSH base seeding platform ensured minimal integration complexities and a reduced overall system cost.

7. FUTURE DEVELOPMENTS

Future developments for this project would target improving the overall system by enhancing base platform modularisation as well as providing new branches for this platform to grow research from. This section will explore both software and hardware ideas that could be developed.

7.1 Software

Software development and enhancement could take multiple routes. The easiest approach for new researchers to contribute to the project is to use simulation. Development on ROS or ROS2 would be greatly appreciated, as this is open source and a de facto standard for robotics. Using simulations, new navigation algorithms could be developed. Seed planting could also be researched considering real world conditions such as wind, rain and travelling speed causing bouncing from planted seeds. Other aspects such as robot vision could also be advanced for swarm identification of weeds for instance. This would involve lighter weight algorithms to match the base system Raspberry Pi module.

7.2 Hardware

One of the problems with the original base model as an OSH development is that acquiring parts takes time and can be delayed by a number of factors. One solution, although not optimal, is to 3D print the chassis and enhance the planting system with 3D printed elements. The base model Raspberry Pi module is not certified OSH, but Arduino boards are. Implementing OSH boards could be explored to minimise the system costs as well as ensure a full OSH philosophy. Further, a more robust method for localisation with GNSS modules, akin to RTK GNSS could be introduced. Design developments targeting ingress protection so support physical testing across a variety of in-field environments is also welcome.

8. DISCUSSION AND CONCLUSION

The goal of the original OSH [15] was to plant seeds and to build a community around the platform. The end goal being to grow the system in many new directions. This has now become a reality as new contributors have joined with simulation and vision contributions. The first new members in any open source project are usually the hardest to gain, and lessons were learnt during this process. Specifically, the need for OSH projects to have explicit and clear instructions on how to contribute for young researchers that are gaining experience in OSH.

The contributions shown in section 4 and 5 demonstrated that a simple base platform can quickly be built upon and result in several new directions of welcome research that were unexpected by the original developer. This was possible because of the reduced costs and complexity that the OSH platform provided.

9. ACKNOWLEDGEMENT

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