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Design of a Task-Based Modular Re-Configurable Agricultural Robot

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Abstract: This paper presents a new method for designing an optimal harvesting agriculture manipulator. The novelty in our approach is the re-configurability of the robot's joints, i.e., the ability to assemble a given set of joints in a variable order to form different manipulators for different harvesting tasks. This way, we provide the farmer with the ability to change the robot's construction before each harvesting period to achieve maximal use of the robot throughout the year. The efficiency of task-based optimization is demonstrated on apple and tangerine harvesting tasks. The method is shown to improve efficiency in terms of success harvest ratio and harvest time compared with non-reconfigurable robots of the same complexity.

Keywords: Robots, Manipulators, Agriculture, Task-based optimization, Convex optimization

1. INTRODUCTION

The UN projects that the world population will exceed 9 billion by 2050 (UN DESA, 2015). As the population grows, lands for agriculture becomes scarce, making the population's feeding more difficult. One of the biggest problems in agriculture today is the shortage of laborers, as people prefer to work in comfortable jobs rather than in the field. One possible solution to this problem is the use of robotic manipulators. Past research has shown the advantage of using agricultural robots for specific or even niche tasks such as harvesting cucumbers (Van Henten et al. 2009) or sweet peppers (Hemming et al., 2014). However, a significant limitation to this approach is that single, task-oriented robots are capable of performing only a dedicated task that they were designed for. We call such specialty robots "single task targeted robots". Using a robot of this kind leads to poor utilization since the robot is only used during specific periods. For example, an apple-harvesting robot can be used for about one month during an entire year, while for the rest of the year this robot provides no revenue to its owner.

To design a robot capable of performing two, even apparently similar tasks, such as harvesting peaches and harvesting tangerines, a drastically different manipulator structure might be required. Therefore, it should be desired to create a robot capable of completing several tasks. However, integrating many capabilities into a robot will inevitably end up being a "universal robot", which is often complicated and expensive.

In this work, we propose a new approach to design an optimal, task-based agriculture manipulator, which combines simplicity and the ability to compete with a number of different tasks. Moreover, the robot is designed to be re-configurable, i.e., that the joints of the robot can be assembled in a different order. We present the algorithm for developing optimal re-configurable manipulator. To test this concept, we show a proof-of-concept simulation of robotic harvesting on a true models of apple and tangerine trees. For simplicity, we focus on three Degree-of-Freedom (DOF) manipulators with one prismatic (P) and two revolute (R) joints. However, this method can be generalized to deal with more complicated manipulators and on different trees or tasks. The harvesting task was chosen as it is considered to be the most complicated task among agricultural tasks, since it involves both accuracy and large workspace.

An example of such an approach is illustrated in Fig. 1. By using a manipulator with one prismatic and two revolute joint, it might be the case that the PRR (Fig. 1, top) construction deals best with peach harvesting, and RRP provides better results for tangerine harvesting (Fig. 1, bottom). As one can see, a simple rearrangement of joints provides the robot with extended capabilities.

Fig. 1: An illustration of the re-configurability concept to use on a peach harvesting task (top) using a PRR arm, and on a tangerine harvesting task (bottom), using a RRP arm.

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2. RELATED WORK

When designing a robotic manipulator for agricultural tasks there are two general approaches. The first approach is to design and use a universal arm capable of executing many different tasks. This approach will most likely be expensive and complex, thus, not suitable in agriculture (Bloch, et al., 2015). Another approach suggests to use a task-based robot which is designed for a specific task.

2.1 Manipulator optimization

Yang and Chen (2000) proposed an approach to optimize the manipulator based on a cost function that differs between three types of joints: revolute (R), prismatic (P), and passive. The optimization was done using evolutionary algorithm, which optimized both the number of links and the link's parameters. Chocron (2008) also used a genetic algorithm for parameter optimization that was shown to be an NP-complete problem. Ceccarelli and Lanni (2004) introduced an optimization of a 3-DOF robot where the objective was to maximize the workspace without increasing the size of the manipulator itself. The solution was obtained using a Sequential Quadratic Programming (SQP) algorithm. They did not declare tasks for the manipulator but rather focused on increasing the workspace. The optimization parameters that were used were similar to those used by Yang and Chen.

2.2 Manipulator optimization for agriculture

In agriculture, the research for task-dedicated or task-based robot is still at its infancy. Van Henten et al. (2009), proposed a cucumber harvesting robot based on a four-link robot whose first joint is prismatic. The optimization goal for the remaining joints are the Denavit–Hartenberg (DH) parameters (Spong et al, 2006), i.e., the length of the links, the angles between the joints and the specific joint type (R or P). For solving this optimization problem, the authors used the DIRECT non-gradient algorithm.

Schütz et al. (2014), designed a robot for four different tasks: harvesting cucumbers, grapes, peppers, and apples, as well as grape spraying. In their work, the authors described the pepper harvesting as the most complicated task, so the design was done according to this specific task. All other tasks were shown to be completed by the same robot with various levels of success. The robot was designed with two different constructions: one with seven DOF and one with nine DOF, where in both constructions, three DOF were at the end effector, and the other four or six belonged to the manipulator. The same robot structure was the result of the peppers harvester designed by Hemming et al. (2014).

2.3 Re-configurable robots

Schmitz et al. (1988) presented a modular re-configurable robot. This robot, according to authors, is more suitable for less predictable environments. The concept was based on a set of links of different lengths that can be adopted in different orders. In addition, this type of robot is more economical since if one module breaks it can be easily replaced. The two main differences between their work and our current proposed research is that they only included revolute joints and only re-configured the link lengths. We believe that, by adding prismatic joints and allowing changing the order of the revolute and prismatic joints together with the link geometry, we can increase the flexibility of the robot for different tasks. Moreover, we emphasize performing task-based design, presenting an algorithm which provides a polynomial time solution for the reachability of pre-defined fruits on different trees.

3. METHODS

3.1 Re-configurable method overview and assumptions

In this paper, we will describe a simplified proof-of-concept example using three actuator types: two revolute (R) modules and one prismatic module. The links connecting between the actuators (related to the DH parameters) are assumed to be simple and can be constructed of base parts, as shown in Fig. 2. Another assumption is the re-configurability of joints, i.e., one can change the joint's order as well as their geometry (d, a, θ, and α).

3.2 Generating tree models

As an initial step in the optimization, we created tree models in Matlab™ based on real tree measurements. Previous works on tree measurements consist of using a wireless tracked glove while touching the fruit (Arikapudi, 2016), or laser scanning (Gorte and Pfeifer, 2004; Jutila et. al, 2007). Most of them suffer from relative large estimation error (10 cm for the radio signals method, and about 4% for the laser scan method) and assumptions such as performing the measurements while the trees are dormant. Moreover, these methods did not provide an automatic semantic representation of the model (segmenting and "naming" the trunk, branch, or fruit). In our current work, we use a mechanical device, a "digitizer", presented by Bloch (2016), which consists of four passive revolute joints (RRRR) (seen in Fig. 3). The measurement location error is up to 3.5 mm using encoders with resolution of 0.07°, where the tool's position is calculated based on forward kinematics. The digitizer's output are 3D measurements which are used as the foundation for the modelling process of fruit and branches. Fruit were modelled as oriented spheres while branches were modelled as a sequence of cylinders. The ground was modelled as a flat plane. Fig. 4 depicts trees measured by Bloch (2016) consisting of an apple tree (N=65 fruit) and a tangerine tree (N=235 fruit).

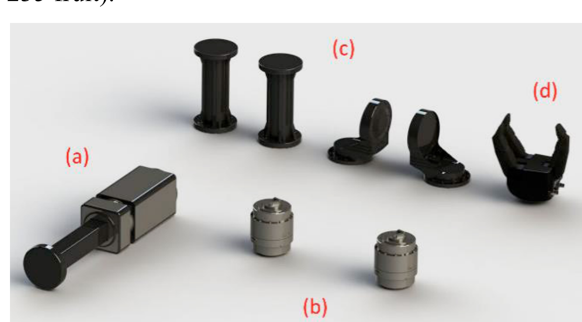

Fig. 2: Base modules for the re-configurable robotic arm. a) prismatic joint, b) two revolute joints, c) link connections – based on the DH parameters, and d) end effector.