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Current Developments in Automated Citrus Harvesting

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Abstract. *The area of intelligent automated citrus harvesting has become a renewed area of research in recent years. The renewed interest is a result of increased economic demand for better solutions for selective automated citrus harvesting than are currently available by purely mechanical harvesters. Throughout this paper the main challenges facing intelligent automated citrus harvesting are addressed: fruit detection and robotic harvesting. The area of fruit detection is discussed, and incorporates the important properties of citrus that can be used for detection. Robotic harvesting is covered, and involves the discussion of the main mechanical design needs as well as the use of visual servoing for the control of the robotic harvester. A description of our proposed intelligent citrus harvesting system as well as our current prototype is presented.*

Keywords. Harvesting, harvester, picking, fruit, citrus, oranges, image processing, machine vision, real time, automated, mechanical, visual servoing, gripper, robot, robotic

Introduction

Strictly mechanical harvesting systems that are currently being operated work on the idea of shaking or knocking the fruit out of the tree. The two basic designs are the canopy shaker and the trunk shaker. The trunk shaker based systems attempt to remove the fruit from the tree by simply shaking or vibrating the trunk of the tree and allowing the induced vibrations and oscillations to cause the fruit to fall out of the tree. Canopy shaker systems, see figure 1, typically use larger rotating drums with protruding "fingers" that are inserted into the tree's canopy. The rotating fingers allow for better shaking of the canopy than the trunk shakers alone.

Figure 1. Canopy Shaker Design for Mechanical Citrus Harvester[1]

However, the main problem with these strictly mechanical harvesters is that citrus typically have a strong attachment between the tree branch and the fruit. Thus it may require a large amount of shaking before the fruit can be harvested which can cause several problems. The first is that the shaker system may cause physical damage to the tree, such as bark removal and broken branches. Second, and most importantly, the fruit has a high probability of being damaged by either the shaker system or falling out of the tree, and thus mechanical shakers systems are typically only used for juice quality fruit. Though fruit used for the making of juice is a large part of the citrus market there is still a large percentage of citrus that is sold as fresh market fruit, which cannot be damaged in any way. Due to these problems a better and more intelligent citrus harvesting system is needed.

Earlier attempts in the 1980's and early 1990's showed promising research efforts in creating viable automated "intelligent" citrus harvesting systems. The focus of most research efforts has been to design a harvesting system that can replicate the precision of a human harvester while achieving the efficiency and decreased labor of the purely mechanical harvesters. The basic design used for an intelligent automated citrus harvesting system typically consists of a vision system for the detection of fruit and a robotic manipulator for the harvesting of the fruit. The difficulty of this approach involve the natural complexity of the harvesting environment, which requires sophisticated vision algorithms to help discern the fruit from the branches and leaves of the tree under varying weather and lighting conditions. The robotic manipulator must be able to remove the fruit as quickly as possible with out damage to the fruit or the tree despite the fruit's location relative to the tree's canopy.

Due to the limitation in technology and monetary funding no single harvesting system was designed that could provide a sufficient harvesting efficiency to make the system economically

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feasible. The most promising efforts were made through the French and Spanish EUREKA project named CITRUS, which was initiated in 1988, IVIA (2004). The project involved both French and Spanish research and development institutions and companies. The project was able to demonstrate satisfactory operation by 1997. The system achieved harvest rates up to 80% for fruit on specially adapted trees, but could only manage 60-65% harvesting rate on standard trees. The project was suspended in 1997 due to several factors, including the inability to fully adapt the system to commercial groves, excessive system costs, and lack of funding.

In this paper the most important problems in designing an intelligent automated citrus harvester will be presented. We cover in detail the problems of fruit detection using machine vision, the design of the robotic system, and finally how the vision and the robotic system need to be coupled in order to provide the needed robustness and precision to make an automated harvester economically feasible.

Fruit Detection

One of the most important components of an intelligent automated citrus harvesting system is the detection of the fruit. The robotic system can only harvest the fruit that has been detected, and thus it is vitally important that the fruit detection system be both accurate and robust. Many different properties can be used to detect citrus from its natural environment, but a successful detection strategy will need to use several different properties depending on the harvesting situation.

Color

The most obvious property of citrus is its color. Many different researchers such as Parrish (1977), Tutle (1983), Sites (1985), Rabatel (1988), Harrell (1989, 1990, 1990), Grasso (1996), Levi (1988), Weeks (1999), Plebe (2001), and Bulanon (2001) have used color-based vision for their research efforts. The toughest obstacle faced when looking for a certain color is the variations in color due to many different factors. Oranges, for example, may be less ripe and take on a more yellowish color rather than the typical "orange" color, and others may have been affected by weather or disease and may take on more of a brownish color. Therefore, the color detection algorithm must be able to detect these different shades of color.

Another problem that can arise with color detection is lighting. Without the proper lighting the color of the fruit can vary greatly. The main contributing factor to lighting of a harvesting scene is sunlight. The amount of sunlight that is available as a result of cloud cover and the sun's angle with the harvesting scene can cause significant variances in how the harvesting scene appears. Figure 2 shows the same scene under two different sunlight conditions. Figure 2 (a) is the result of indirect sunlight, as may be experienced on a cloudy day. The resulting image captured by the camera is very uniform in brightness across the entire image, and provides consistent coloring of the leaves and fruit. Figure 2 (b) is the result of direct sunlight on the harvesting scene. The direct sunlight causes a drastic change in brightness across the scene, and both the leaves and fruit can take on very different shades or hues of color.