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Towards an artificial vision-robotic system for tomato identification

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Abstract: In the present paper we developed a simple and affordable vision-based robotic system for the identification of the Euclidean position of red spheres that emulate ripe tomatoes. This is done by using a RGB-D sensor in a fixed position, together with a 5 DOF manipulator. To detect the tomato the sensor considers it as a red blob and then it calculates its center using a point cloud map. The position of the red blob is mapped to the manipulator reference frame using the homogeneous transformation matrix from the camera to the manipulator. The position of the sphere is sent through a micro-controller to drive the manipulator, with the purpose of reaching the sphere's position. Experimental results of the vision-based robotic system are provided, and the system accuracy obtained in localizing and touching the interest object demonstrate to be highly effective, reaching an accuracy of 10/10 in identification and touching the object in ideal environment.

Keywords: Artificial vision, fruit detection, fruit localization, robotic system

1. INTRODUCTION

Protected crops are a great opportunity to obtain high quality and production rates in profitable crops, such as cucumber, tomato, lettuce, pepper, among others. Therefore, many different types of machinery and technology have been intended for this type of systems, e.g., sowing, transplanting, watering, environmental automated control, etc. However, the available equipment for green production did not fulfill the specific demand of specialized devices, where a high level of automation and autonomous systems can operate in the production site.

The evolution of robotic systems can help to develop greenhouse repetitive tasks in autonomous way, see Comba et al. (2010). Moreover, autonomous robots can be developed for crop's surveillance, picking tasks, to make highly precision chemical treatments and precision fertilization.

Despite the fact that several researches have been conducted based on robotics, automation, artificial vision, and artificial intelligence for application in agricultural systems, more than twenty years have passed between the first publications and now, were many papers have been published, see Kassler (2001), Belforte et al. (2006), Comba et al. (2010). Nowadays, the improvement in communication technology, in faster and affordable cameras, in servo-motors and in cheaper and smaller control devices, are allowed the design of simple and reasonable priced servo-mechanisms. In general, accesible robotic systems to navigate between the crops (as much in outdoor conditions as in greenhouses), to do surveillance, crop manipulation and harvesting tasks, making this a big research and development opportunity area.

2. RELATED WORK FOR TOMATO CROP

Tomato *(Lycopersicon esculentum Mill)* is one of the most important crops in the world. It is used in both fresh form and in processed products, Mehdizadeh et al. (2013). Regarding produced hectare, it occupies the second place after the potato, and as processed product is considered the first one worldwide, Mehdizadeh et al. (2013). Since harvesting represents up to 50 % of the total production (Japanesse Robotic Society (1996)), several autonomous robotics systems have been developed to harvest it. In Corell et al. (2009) a novel and a complete distributed autonomous gardening system is developed, where the garden consists of a mesh of robots and plants. The gardening robots are mobile manipulators with an eye-in-hand camera, and are capable of locating plants in the garden, watering them, and locating and grasping fruit. In Liang et al. (2010), the authors developed a motion planning approach for tomato harvesting manipulators with 7 DOF, and they proved their proposed algorithm only by simulation and considering that the tomato position is known. In Arefi et al. (2011), the authors developed a segmentation algorithm for recognition and localization of ripe tomato based on machine vision, which was proved by using 110 color images of tomato under greenhouse's lighting condition. In Nezhad et al. (2011), the authors developed a manufactured tomato picking vision machine using OpenCV. Wand et al. (2012) designed a tomato harvesting robot based on a mobile platform, a 4 DOF manipulator, a vision system together with an end effector and a cutter tool, the authors only provide simulations of the electromechanical system. In Chen et al. (2015) the authors developed a vision cognition framework for a

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tomato harvesting humanoid robot based on geometrical and physical reasoning. Their vision approach is based in two RGB-D sensors, one installed in the humanoid's head and the other on the hand. These authors used the upper body of HRP-2 humanoid robot and a VMAX omnidirectional mobile platform, which has 7 DOF on each hand and 2 DOF on the head. Moreover, in their proposed vision approach, they modeled the fruit in one branch to estimate the pedicel direction of each fruit and as well as the remaining stable crops in a branch, with respect to the gravity and interaction forces from near elements. Finally, in Gongal et al. (2015) the authors present a review of several methods for fruit localization using different types of sensors, features, and classifications. They also mentioned that use color as a feature for detection improves up to a range of 80 to 85 % the detection accuracy. Among their conclusions they recommended to use a Kinect® like sensor and calculate the depth of the object in order to approach a manipulator for harvesting purposes.

3. MAIN CONTRIBUTION

In this paper we propose the development of a simple and affordable vision-based robotic system, for the identification of the Euclidean position of red spheres that emulate a ripe tomato. This is done by using a RGB-D sensor on a fixed position together with a 5 DOF manipulator. Our proposed system detects the tomato by considering it as a red blob, and calculate its center using a point cloud map. The position of the red blob is mapped to the manipulator reference frame using the homogeneous transformation matrix from the camera to the manipulator. The position of the sphere is sent to a micro-controller to drive the manipulator with the end of reaching the sphere position.

The work is organized as follows: In Section 4 the kinematic model of the manipulator is provided together with the imaging processing description. In section 5 some experimental results are showed, and in Section 6 some conclusions are provided.

4. KINEMATIC MODEL AND IMAGE PROCESSING

4.1 Kinematic model

According to Siciliano et al. (1996), kinematics is the study of the mathematics of motion without considering the forces that affect motion and deals with the geometric relationships that govern a robotic system. It consists on the translation and rotation of the reference frames on which each articulation moves in. In this work a 5 DOF manipulator with rigid rotational joints that consists of 6 HiTEC servomotors and 3 aluminum links is considered and it is depicted in Fig. 1.

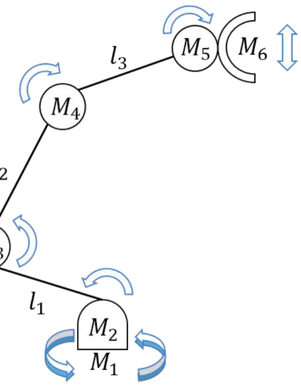

Fig. 1. 5 DOF manipulator, showing the actuators (M) and the links (L).

Where:

- l_1: link 1 (12cm)
- l_2: link 2 (17.5cm)
- l_3: link 3 (23cm)
- $M_{1,2}$: Servomotor HS-755HB
- $M_{3,4}$: Servomotor HS-5685MH
- $M_{5,6}$: Servomotor HS-422

And its kinematic chain is showed in Table 1. With:

Table 1. Manipulator Kinematic Chain

HTM	t(x)	t(y)	t(z)	R(x)	R(y)	R(z)
1	–	–	–	–	–	$\frac{\pi}{2} - q_1$
2	–	–	–	$-\frac{\pi}{2}$	–	$-q_2$
3	12	–	–	–	–	$-\frac{\pi}{2} - \frac{\pi}{4} + q_3$
4	17.5	–	–	–	–	$\frac{\pi}{2} + \frac{\pi}{4} - q_4$
5	23	–	–	–	–	$\frac{\pi}{2} - q_5$

- HTM : Homogeneous Transformation Matrix.
- $t(\alpha)$: translation vector between two reference frames over the α axis in cm.
- $R(\alpha)$: Rotation matrix between two reference frames over the α axis in radians.

Knowing that the equation of the forward kinematics is given by:

$$x = f(q) \quad (1)$$

where x represents de 3D position of the final effector, we can make use of the information in Table 1 to re-write system 1 in explicit form as:

$$\begin{aligned}
T_0 &= I_4 \\
T_1^0 &= T_0 R_z\left(\frac{\pi}{2} - q_1\right) \\
T_2^0 &= T_1^0 R_x\left(\frac{-\pi}{2}\right) R_z\left(-q_2\right) \\
T_3^0 &= T_2^0 T_x(12) R_z\left(\frac{-\pi}{2} - \frac{\pi}{4} + q_3\right) \\
T_4^0 &= T_3^0 T_x(17.5) R_z\left(\frac{\pi}{2} + \frac{\pi}{4} - q_4\right) \\
T_5^0 &= T_4^0 T_x(23) R_y\left(\frac{\pi}{2}\right) R_z\left(\frac{\pi}{2} - q_5\right)
\end{aligned} \quad (2)$$

and $x = T_5^0(1..3, 4)$.

For the artificial vision system, a RGB-D sensor mounted on a fixed position was used (see Fig. 2). The camera