Hole Detection Strategies Based on Force/Torque Sensors

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***Abstract*—Hole detection is one of the most common tasks in robotic field. In the absence of a correct hole identification strategy, the robot working time to complete the assembly process can increase greatly. This paper presents an hole detection algorithm based on the use of force/torque sensors. Different spiral trajectories have been tested in order to evaluate the best strategy according to the initial positions of the peg with respect to the hole.**

***Index Terms*—hole detection, F/T sensor, peg-in-hole**

I. Introduction

Since child humans have always been able to easily perform the task of inserting an object into a hole. They possess several cognitive skills that help them carrying out this task, some of these skills are: the view that helps to identify the position and shape of the peg and hole; motor skills to move and orient the peg; perceptive abilities that allow human beings to feel the different forces and then judge whether the peg is on the surface or it touches a part of the hole. A robot can be equipped or programmed to possess these skills. A camera can be mounted for vision, a controller for motor skills and a force sensor to sense the forces being exerted. These forces are data that can be recorded by the robot joints. In most cases, machine vision is one of the best strategies for positioning an object on a desired place, but it cannot be used in particular environments, especially in those where there are variations in brightness that make visual systems completely useless. Moreover, although it is possible to use machine vision, the field of view of the camera is often too close to the goal, thus generating calibration and resolution errors.

Hole detection represents a widespread task for industrial manipulators which often suffer from some of the issues described above. In previous years, several studies were carried out, many of which refer to the problem of peg-in-hole assembly [1]–[4].

In this paper, a two-step approach is proposed for a serial robotic arm to complete a hole detection task. The real time information coming from the force/torque sensor (F/T sensor), attached on the end-effector of the manipulator, provide feedbacks which guide position and orientation adjustment, in combination with a random research method through spiral motion for the identification of the hole.

II. Hole Detection Strategy

Figure 1 shows the four possible alignment conditions before insertion can begin. From left to right we have Line Contact, One-Point Contact, Two-Points Contact and Three-Points Contact, respectively. Many of the methods used for peg-in-hole insertion focus more on the insertion stage assuming the pin and hole are already aligned. In this paper we focus on the condition shown in Fig.1(a).

The robotic arm depicted in Fig.2 is assigned the task of taking a cylinder, moving it from one floor to another, also trying to center the hole at the first attempt. This task can be accomplished in four steps [5]:

- phase 1 the robot is in the initial position;
- phase 2 the robot grabs the cylinder from the first surface and moves it to the second surface;
- phase 3 the cylinder moves on the surface of the second surface, searching for the hole;
- phase 4 the cylinder is inserted into the hole.

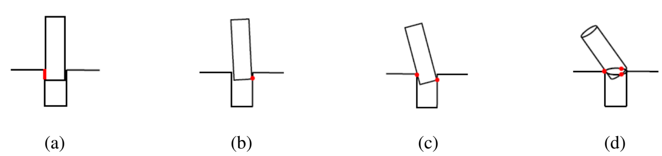


Fig. 1: Four alignment conditions between peg and hole: (a) Line Contact; (b) One-Point Contact; (c)Two-Points Contact; (d) Three-Points Contact.

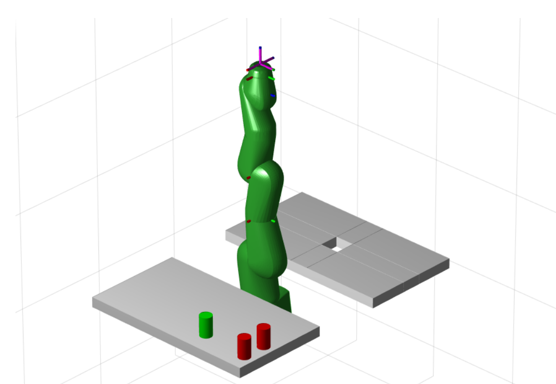


Fig. 2: Robot arm and workspace.

Phases 2 and 4 always occur when it is necessary to insert the cylinder into the hole; phase 3 occurs when the cylinder lacks the hole due to, for istance, disturbances, impediments, which make it impossible for the robotic arm to complete its task. Therefore, in this case, it is necessary to identify the new position of the hole through different search strategies. The strategy proposed in this paper consists to move the robot in a spiral path on the second surface. In order to test the proposed hole detection algorithm, three different spirals have been tested: the Archimedean spiral, the logarithmic spiral and the Fermat spiral. We can describe the Archimedean spiral by introducing two parameters: the angular speed ω at which the line rotates around the origin of the spiral A and the speed v at which the point moves on the rotating line. These speeds are constant. Let us consider the period T in which the rotating line makes a whole revolution, as shown in Fig.3. In this case the angular velocity is $\omega = 2\pi/T$. The first segment AB is linked to the velocity v by the relation $AB = vT$ since in a period T the point of the spiral moves from A to B. Using the Cartesian coordinates and choosing the center of the spiral as the origin of the reference system we have the following parametric equations:

$$\begin{cases} x = vt\cos(\omega t) = \frac{a}{T}\cos\left(\frac{2\pi}{T}t\right) \\ y = vt\cos(\omega t) = \frac{a}{T}\sin\left(\frac{2\pi}{T}t\right) \end{cases} \quad (1)$$

where a is the segment AB.

Unlike the Archimedean spiral in which the distance between successive turns of the spiral is a constant, in the logarithmic spiral the distance between successive turns increases in a geometric progression. On the contrary, in the Fermat spiral, also known as parabolic spiral, this distance decreases as it moves away from the centre. In Fig.4 the three different spirals are shown, and the square represents the hole position.

Once the peg is positioned on the working surface, the robot begins to move according to one of the three spirals. If the F/T sensor mounted at the end-effector does not read any value along z axis, it means that the peg has been inserted into the hole. Otherwise, if the force value is not zero, the robot proceeds to follow the spiral trajectory by positioning the peg on the surface at regular intervals.

A. *Experiments*

In order to validate the proposed algorithm, several tests have been performed. The software used to conduct the simulations is the *Robotics System Toolbox* of Matlab. During the simulations, several points have been identified around the hole. When the initial position of the peg is very close to the hole, the Archimedean and logarithmic spirals were able to identify the hole before Fermat's. Sometimes it happened that with Fermat's the robot jumped the position of the hole, not completing the goal. In some simulations it happened that by using the Fermat spiral the robot jumped the position of the hole, not completing the goal. Conversely, when the initial position of the peg was not very close to the hole, the Archimedean and Fermat spirals completed the task before the logarithmic one.

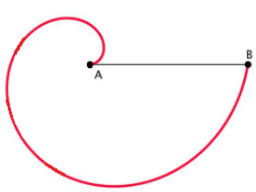
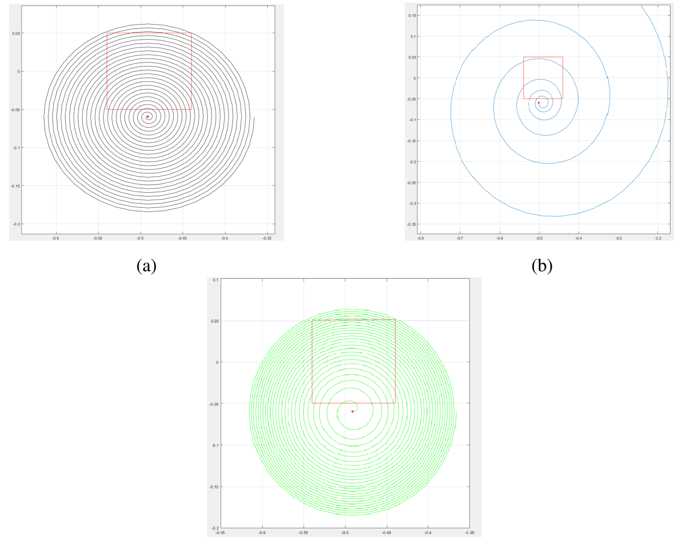


Fig. 3: Archimedean spiral path.



(a) (b) (c)

Fig. 4: The three spirals: (a) Archimedean; (b) Logarithmic; (c)Fermat.

III. Conclusion

In this paper a hole detection strategy based on F/T sensor has been developed. Several tests with three different spiral trajectories have been conducted in order to identify which choice was the best according to the initial distance of the peg from the hole. In most of the tests it has been proved that the Archimedean spiral turns out to be the best compromise for achieving peg-in-hole insertion in the shortest possible time.

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