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Passive Non-Prehensile Manipulation on Helix Path Based on Mechanical Intelligence

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Abstract**—**Object manipulation techniques in robotics can be categorized in two major groups including manipulation with grasp and manipulation without grasp. The original aim of this paper is to develop an object manipulation method where in addition to being grasp-less, the manipulation task is done in a passive approach. In this method, linear and angular positions of the object are changed and its manipulation path is controlled. The manipulation path is a helix track with constant radius and incline. The method presented in this paper proposes a system which has not the actuator and the active controller. So this system requires a passive mechanical intelligence to convey the object from the status of the source along the specified path to the goal state. This intelligent is created based on utilizing the geometry of the system components. A general set up for the components of the system is considered to satisfy the required conditions. Then after kinematical analysis, detailed dimensions and geometry of the mechanism is obtained. The kinematical results are verified by simulation in ADAMS**.**

Keywords—Mechanical intelligence, Object manipulation, Passive mechanism, Passive non-prehensile manipulation.

I. Introduction

OBJECT manipulation is an essential task in industries. The object manipulation can be a part of a complicated task such as assembly or it can be desirable by itself. In the literature, two categories of object manipulation techniques can be recognized including manipulation with grasp and manipulation without grasp. In manipulation with grasp, the object is held down by robot hand and is then it is moved to goal configuration while relative motion between object and hand is zero. In grasp-less manipulation, the object is manipulated by maneuvers like pushing [1], pulling [2], sliding [3], juggling [4] etc. Grasp-less manipulation approach has some advantages and some disadvantages over manipulation with grasp. When different tasks are not expected from the mechanism, manipulation task is not complicated and simplicity and cost are most important factors, grasp-less manipulation is preferred. Because advantages of grasp-less manipulation include minimalism in mechanism, reduction in cost, opportunity of object transfer out of robot's workspace, elimination of need for compliance control and finger coordination in establishing of stable grasp, possibility of doing tasks with more DOF (Degrees of Freedom) than the DOF of the robot and exploiting geometry and dynamics of the environment in performing the manipulation [5].

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As a matter of fact, grasp-less manipulation is the most common approach in the nature. There in another manipulation approach in nature that leads to energy saving mechanisms and simpler systems. That is passive manipulation which means manipulation without actuator and active controllers. Flowing the river down the mountains to the sea, rolling hedgehog down hills and sliding penguins from iceberg are some interesting examples of passive grasp-less manipulation in nature. Rivers can manipulation very large volume of water without the use of actuator or active controller from an initial position to the target position. In this type of manipulation the initial position is higher than the target position. This problem is most main characteristics of this type of manipulation. Thus the manipulation mechanism by passive control the natural forces transforms gravity force to the driving force necessary and enough for manipulation.

As it is mentioned earlier, in this kind of manipulation the mechanism is simplified but versatility of motion is decreased. In all of above examples the only motion generation force is gravity and there is no active controller. Also we can see that rivers have routes with variety shapes. This means that the manipulation mechanism in this example has ability manipulation objects in curved and indirect paths. From this it can be concluded that such mechanisms has a kind of intelligent for control manipulation path. It seems to be possible utilizing this intelligence for to take ideas in artificial systems.

This paper introduces a system of nature-inspired methods, which is composed of two components. The first component is the manipulated object and the second one is platform wherein the object is manipulated. Furthermore the intelligence required to conduct object in a tortuous path its put on geometry of the object and it dynamic interaction with the platform. Thus a special form is considered for the object and a helix path is introduced as manipulation path. This the object can by dynamic interaction with platform manipulations on the predetermined path without grasp and passive. In this system due to smooth motion and avoid wasting energy, collision between the object and any side wall must be elimination.

The one of the earlier and well-known researches in the grasp-less manipulation is related to part feeding studies where an object is manipulated by a single DOF manipulator on a moving conveyer [6], [7]. Lynch and Mason claimed that SCARA manipulator can be substituted by a simple manipulator and programmable conveyor belts with a simple constant velocity replaced. Then another mechanism was introduced [8] which in that object manipulation is done on a conveyor belt by the arm two degrees of freedom with a rotational joint and a prismatic joint. Thus it be possible, to manipulation an object in three-dimensional on a conveyor belt that it speed is constant.

Manipulation by juggling is other approach in grasp-less manipulation. This approach is conceptually similar to part feeding approach except that the conveyer is replaced by gravity force [9]. Akbarimajd and Nili Ahmadabadi have employed two 3-DoF manipulators (one as throwing manipulator and the other as catching one) to gain full control over object configuration [10]. They used free-flight time as a free parameter in motion planning of manipulators. Using consecutive juggling by 1_DoF manipulators, one can manipulate an object do a desired configuration. In [11] this issue is proved and forward and backward throws are planned for manipulation of a cubic object.

The mobile robots can be utilized for non-prehensile objects manipulation [12]. Another method is to use the array of distributed manipulators. The purpose of this method is that by the number of the actuators that are independently controlled the object be manipulated correctly.

The idea of using passive mechanisms in robotics has been probably initiated by works of McGeer where he inspired from rotation of rimless wagon wheel to design his passive dynamic walkers [13]. The idea of passive manipulation, however, was firstly introduced in [14]. In said work the concept of "Passive Dynamic Object Manipulation" PDOM poses. The four major characteristics of passive systems listed and three examples of proposed method is described.

II. Definition and Analysis

A. Problem Definition

We consider object manipulation path a spiral around a circular cylinder with radius R. spiral tangent line at all points has the constant slope β_0 in relation to tangent horizontal line to cylinder. Also, a cylindrical coordinate system where the axis Z_0 is coincided with the axis of the assumed cylinder is considered. The origin of this frame can be anywhere cylinder shaft said. The axis of θ=0 of Recent frame passes motion starting point of the object on the path. This frame is shown with O_0 (Fig. 1).

Only the gravitational force is exerted on the object to move it and for to adapt object path on the predetermined path, there is no active controller. Also, inactive controllers such as side walls that to impact them it influences the object can on the predetermined path moves to create a complex in motion and loss of energy. Then geometrical form and other characteristics the platform and the manipulated object must get passive mechanical intelligence for to control the path of the object without creation any impact. The platform is considered in the form of a surface corresponding to predetermined path. This area will have a fixed width W_0. Also, the slope of the surface in the radial direction is zero. Fig. 2 shows the surface defined.

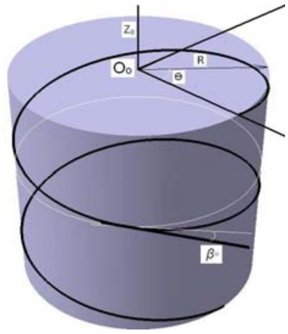

Fig. 1 The helix path

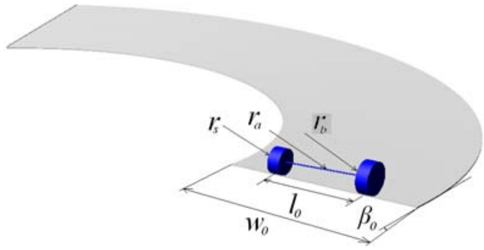

Fig. 2 A helix surface with the located object on it

Now we should design appropriate object in such a way that it can travel on the aforementioned platforms. The proposed object is composed of a pair of wheels with different radiuses that are connected together by an axle. This setup is interesting because it can be used as wheels of passively driven vehicle (for example a wagon). In the rest of this paper we refer to this setup as ***object***. Masses of the small and big wheels are assumed to be m_{ws} and m_{wb} respectively and mass of the axle is neglected; then total mass of the object will be $M' = m_{ws} + m_{wb}$. The radius of the small and big wheels are assumed to be r_{ws} and r_{wb} respectively (see Fig. 2). The axle is connected to the center points of wheels and the projection of center to center distance of wheels on platform is L_0. The radius of axle is r_a.

The aim of this paper is to analyze kinematics of motion of the object and obtain traveled path. We assume that there no slippage and the motion is perfect rolling. Also, the range of motion will be assumed $0 \le \theta \le \frac{\pi}{2}$. Obviously the motion and path will be related to parameters of the object and slop of the platform. Then motion and path planning of the object can be achieved by appropriately selection of the parameters of the mechanism. In the rest of paper we will address these points in more details.

B. Kinematical Analysis

Fig. 3 shows free body diagram of the object at starting motion.

To study motion of the object, we considered right handed coordinates frame O_{XYZ} for the object in such a way that its origin O is located in the object Center of Gravity (COG), X axis is parallel with the projection of center to center distance of wheels on platform and Z axis is normal to the surface. This frame, called "*path-based frame*" in this paper, moves with the object and X axis always remains parallel to the projection of center to center distance of wheels on platform. Another frame o_{xyz} is considered parallel to O_{XYZ} such that its origin o is located at the bottom of the smaller wheel. Coordinated of object COG in o_{xyz} is given by $(\bar{x}, \bar{y}, \bar{z})$. N_{ws} and N_{wb} are normal forces applied from the surface to the wheels. f_{ws} and f_{wb} are friction forces.

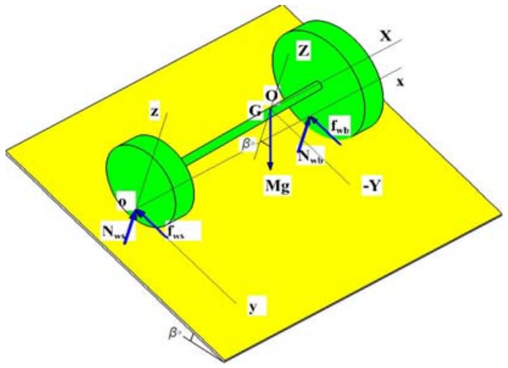

Fig. 3 Free body diagram of the object at starting motion

Apparently, different points of the object have different linear velocities in Y direction and the same angular velocity in X direction. Linear velocities of wheels in y-direction are given as:

$$v_{ws} = \omega_{x0} r_{ws} \Rightarrow a_{ws} = \dot{\omega}_{x0} r_{ws} \tag{1}$$

$$v_{wb} = \omega_{x0} r_{wb} \Rightarrow a_{wb} = \dot{\omega}_{x0} r_{wb} \tag{2}$$

where ω_{x0} denotes angular velocity of the object in x direction. From (1) and (2) we obtain:

$$\dot{\omega}_{x0} = \frac{a_{ws}}{r_{ws}} = \frac{a_{wb}}{r_{wb}} \tag{3}$$

Difference between linear velocities of the wheels is fixed which results in a circular path for the object from the normal point of view of the surface. Let R be the radius of the circular path and z_0 the axis of rotation of the object as it is shown in Fig. 4.

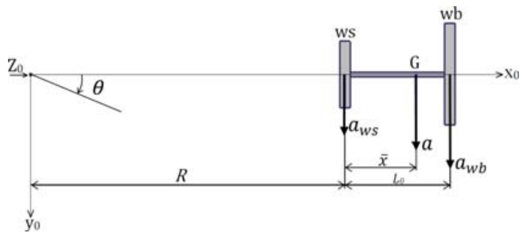

Fig. 4 Display of object motion from the normal point of view

Angular acceleration of the object about z_0 is given as:

$$\dot{\omega}_{z_0} = -\frac{a}{R + \bar{x}} \tag{4}$$

where $\bar{x}$ is *x*-component of CoG of the object in o_{xyz}. Then we obtain linear accelerations of wheels in terms of $\dot{\omega}_{z_0}$ as:

$$a_{ws} = \dot{\omega}_{z_0} R = -\frac{a}{R + \bar{x}} R \tag{5}$$

$$a_{wb} = \dot{\omega}_{z_0} (R + L_0) = -\frac{a}{R + \bar{x}} (R + L_0) \tag{6}$$

Substituting a_{ws} and a_{wb} from (5) and (6) in (3) we obtain radius of the path as:

$$R = \frac{r_{ws} L_0}{r_{wb} - r_{ws}} \tag{7}$$

Relation 7 shows the object motion path is a three-dimensional curve with R constant radius. Then the object motion path on the simple ramp can be a circular path with radius R for center of the small wheel if a simple ramp uses instead helix surface. Also, it is clear that the object path corresponds to the helix surface with R radius.

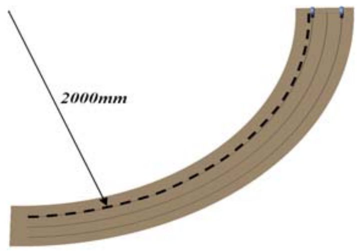

Fig. 5 Evaluation the calculated path with traveled path

III. Simulation and Experiment

To perform simulations, we considered an object with wheels radiuses $r_{ws} = 30$mm and $r_{wb} = 37.5$mm and an axle with radius $r_{ax} = 1.5$mm. The width of wheels is $b = 28$mm and their center to center distance $L_0 = 213$mm. The object is built from steel with density 7975 kg/m^3 and mass of that is 1618 gr. Also, a helix surface at an angle of $\beta_0 = 2.7^0$ was used. The aim of simulations is to verify kinematical equations obtained in (1)-(7). According to parameters of the simulated model we can obtain radius *R* from (7) as $R = 852$mm. This gives the radius of the helix appropriate for this object. The simulations are executed for time duration of 11s. In Fig. 5, target calculated path (given by (7)) is shown by dashed line and the traveled path by the small wheel is shown by solid line.

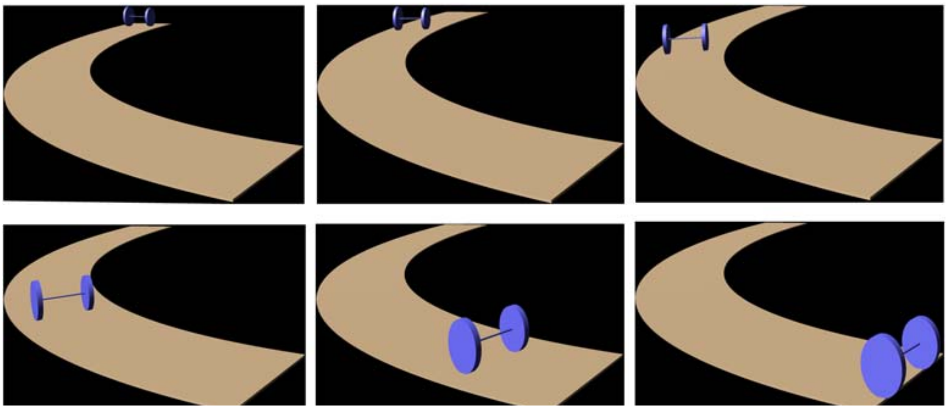

Fig. 6 Initial condition and five other snapshots of the simulation

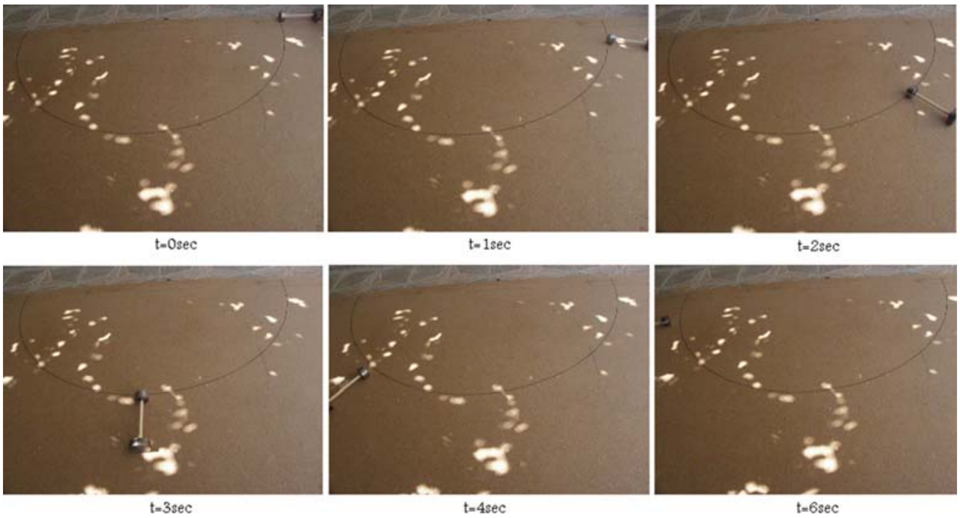

Fig. 7 Six snapshots of the experiments of proposed passive manipulation mechanism

Fig. 6 illustrates initial condition and five other snapshots of the simulation. An equivalent experimental setup was also built to validate the equations (1)-(7) and simulations (see Fig. 7).

This experiment was performed on the simple ramp because the simpler fabrication. Comparing Fig. 6 with Fig. 7 confirms matching of simulations and experiments.

For better evaluation, curve of deviation from the calculated path (given by (7)) and the real travelled path of the object is shown in Fig. 8. In addition, Fig. 8 shows that in the inclined helix, maximum deviation is 18mm which is less the 1% of the calculated path.

IV. Conclusion and Future Directions

This paper shows that we can manipulate a special object in along a helix path without grasp and with the passive and very simple mechanism. The mechanism introduced in this paper can control manipulation path without any actuator or active controller in the form of a helix track. The radius of motion path was obtained by kinematical analysis. (7) shows that the radius of the object path depends only on the characteristics of the geometric object. Simulation and experimental results showed that the obtained model is accurate enough to describe the motion with acceptable level of accuracy.

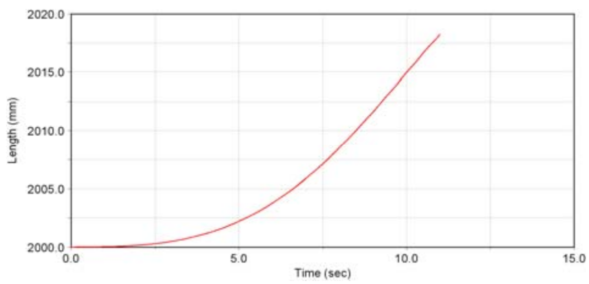

Fig. 8 Curve of deviation from the calculated path

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