MANIPULATOR OPERATING WITH THE TWO-FINGER GRIP FOR FRAGILE CYLINDERS

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Abstract: *There is an analogy of the equilibrium of a robot on a cylinder for the problems of transfer by a manipulator of a rough cylinder or for robot which legs suspension points are on the cylinder surface. For the cases of one, two and three supporting points the motion equations are different. The difference between the grip and walking robot is in the sign of inequalities due to unilateral constraint. Two supporting points can be on one diameter in the cylinder base. Or because of friction on the opposite sides of the robot center of mass or giving in the dynamics, point C. The analogy is oscillations in the vicinity of the stable equilibrium one cylinder on another. The cylinder lies on one finger rectangular to it, of the hand of a humanoid robot, adheres to the end of the other finger. Similarly holds a glass.*

Key words: *Two-finger grasp, Coulomb friction.*

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This Publication has to be referred as: Golubev, Y[ury] & Melkumova, E[lena] V[adimovna] (2019). Manipulator Operating with the Two-finger Grip for Fragile Cylinders, Chapter 34 in DAAAM International Scientific Book 2019, pp.385-392, B. Katalinic (Ed.), Published by DAAAM International, ISBN 978-3-902734-24-2, ISSN 1726-9687, Vienna, Austria
DOI: 10.2507/daaam.scibook.2019.34

1. Introduction

The problem of the distribution of bipedal reactions was studied in this work. For walking robot depending on the position of the fulcrum on the outer surface of the inclined rough non-holding cylinder taking into account reactions along its axis. This task arose as a development of similar studies to move the walking apparatus horizontally the plane [1].

The first step in the study of a similar problem was made N.E.Zhukovsky. In [2], he investigated equilibrium solid in the plane in the presence of friction.

Movement of a six-legged walking apparatus in quasistatic mode planes are investigated in the work of D.E. Okhotsimsky and Yu.F. Golubev [1], using the following criterion static stability of the apparatus. Walking apparatus, leaning on horizontal plane, statically stable in some moment of time if and only if the vertical projection of its center of mass on the supporting surface lies strictly inside the support polygon corresponding to this moment. A natural question arises, what do they look like similar criteria for other surfaces. Including criterion of non-rollover of the robot.

In the work [3] Yu.F. Golubev and I.G. Kolpakova using linear methods programmers have developed an iterative algorithm for distribution of reactions at randomly located points support walking machine. Later, F.L. Chernousko in work [4] cited a series of statements about the conditions of guaranteed equilibrium of the body on rough plane. Study of the organization of the movement of the octopus walking apparatus special design designed for movement in pipes in the presence of friction was carried out in the works [5], [6].

In [7] investigated the conditions of static stability walking robot on a perfect inner surface horizontal cylinder. In [8] the problem was considered for a rough horizontal cylinder, provided that there are no components of the reactions along the generatrix of the cylinder.

The proposed work continues the study begun by [9], where the problem was considered for a rough horizontal cylinder taking into account reactions along its axis.

The results of solving the equilibrium problem solid under the action of three forces applied to equilibrium biped walking robot on the outer surface of a rough inclined non-holding cylinder. The first contains the statement of the problem. In the second the conditions of equilibrium of a robot under the action of two forces in application to the equilibrium problem of a robot based only on one of the legs. The third is devoted to the balance of the robot, leaning on two legs. The fourth discusses two geometrical equilibrium conditions for a robot based on two legs on top hat.

In this paper, we consider the problem of curved object grasping by the fingers of the robot-manipulator. For example we discussed a three legged humanoid robot with pair of five arms fingers or a monkey-robot with twenty arms and legs fingers. The robot can hold the object by one and grasp by two fingers. An object grasping problem is equivalent to the problem of the walking robot with n legs. Consider a grasp with m fingers. Each finger contacts an object in one foothold.

There is an analogy of this problem to the problem of walking robot dynamics on one-side constraint.

2. Main result

The kinetic moment of the robot relative to the point O is considered. In order for the given motion to be realized, the reactions $\tilde{\mathbf{R}}_i$ at n support points must satisfy the following kinetostatic equations [1]:

$$\sum_i \tilde{\mathbf{R}}_i = -\tilde{\mathbf{\Phi}}, \quad \sum_i \tilde{\mathbf{r}}_i \times \tilde{\mathbf{R}}_i = -\tilde{\mathbf{M}}, \quad i = 1, \dots, n, \quad (1)$$

where $\tilde{\mathbf{R}}_i$ are the reaction components, $\tilde{\mathbf{r}}_i$ are the radius vectors of the pivot points, $\tilde{\mathbf{\Phi}}$ is the sum of the d'Alembert forces of inertia and external active forces, $\tilde{\mathbf{M}}$ is the sum of the moments of d'Alembert inertia forces and the moments of external active forces relative to the fixed point O .

Assuming that $\tilde{\mathbf{\Phi}}$ is orthogonal $\tilde{\mathbf{M}}$, we obtain: [8] that the system $\{\tilde{\mathbf{\Phi}}, \tilde{\mathbf{M}}\}$ can be also used at the point C

$$\tilde{\mathbf{r}}_C \times \tilde{\mathbf{\Phi}} = \tilde{\mathbf{M}}, \quad \mathbf{r}_C = -\frac{\tilde{\mathbf{M}} \times \tilde{\mathbf{\Phi}}}{\tilde{\mathbf{\Phi}}^2}, \quad \tilde{\mathbf{\Phi}} = |\tilde{\mathbf{\Phi}}|,$$

where $\mathbf{r}_C$ is the vector $\mathbf{OC}$, and C corresponds to point at which the resultant of the reactions is acting.

Further problem of reactions distribution $\tilde{\mathbf{R}}_i$ in some fixed point of time is investigated by the proposal that force $\tilde{\mathbf{\Phi}}$ is acting at the point C and force moment there is zero. Motion equations (1) for finding reactions of walking robot body arms and legs prescribed motion can be transformed [10]:

$$\sum_i \tilde{\mathbf{R}}_i = -\tilde{\mathbf{\Phi}}, \quad \sum_i \tilde{\mathbf{r}}_i \times \tilde{\mathbf{R}}_i = -\tilde{\mathbf{r}}_C \times \tilde{\mathbf{\Phi}}. \quad (23)$$

We restrict ourselves to the case when $\tilde{\mathbf{\Phi}} \neq 0$. We bring the system $\{\tilde{\mathbf{\Phi}}, \tilde{\mathbf{M}}\}$ to the resultant at a point [2]. The point C will also be the point of application of the resultant reactions. For example, a point C may be the center of mass of a transported object.

Next, we consider the problem of the distribution of reactions $\tilde{\mathbf{R}}_i$ along the fulcrum at some fixed point C .

Fig. 1. Inclined cylinder.

Let the robot support points be located on the surface of a rough straight circular cylinder with a dry friction coefficient k , Fig. 1. And the axis of the cylinder is the angle α with the vector $\tilde{\Phi}$. In the case of two points of support, the model is supplemented by the introduction of the turning friction moment at the contact points. For three points of support, we restrict ourselves to the consideration of dry friction. The results apply to the case of sliding of support points with Amonton-Coulomb friction.

The kinetostatic equations are supplemented by inequalities responsible for getting reactions into the corresponding friction cones. The first group of inequalities is a consequence of the fact that the cylinder is an uncontrollable surface. When an object is captured internally, the scalar product of the reaction to the main normal to the surface at the fulcrum should be non-negative: $\tilde{N}_i = \tilde{\mathbf{R}}_i \cdot \mathbf{e}_i^y \geq 0$, where $\mathbf{e}_i^y$ is the external normal to the cylinder surface at the i -th fulcrum. With external capture, these inequalities are reversed.

Let write the vector $\mathbf{r}_i = \tilde{\mathbf{r}}_i / \rho = (x_i, y_i, z_i)$, in the cylinder coordinate: $\mathbf{r}_i = (x_i, -\sin \varphi_i, \cos \varphi_i)$, normal $\mathbf{e}_i^y = (0, -\sin \varphi_i, \cos \varphi_i)$, and the vector $\mathbf{N}_i = \tilde{\mathbf{N}}_i / \tilde{\Phi} = (0, -N_i \sin \varphi_i, N_i \cos \varphi_i)$, where φ_i is the angles between axis Oz and cylinder normal $\mathbf{e}_i^y$. We define $\mathbf{e}_x$ as the unitary vector in the Ox axis, while the vector $\mathbf{e}_i^t = (0, \cos \varphi_i, \sin \varphi_i)$ as the tangential to the cylinder. Then the tangential reaction component: $\mathbf{F}_i = \tilde{\mathbf{F}}_i / \tilde{\Phi} = (F_i^x, F_i^{yz} \cos \varphi_i, F_i^{yz} \sin \varphi_i)$, where $F_i^x = \mathbf{F}_i \cdot \mathbf{e}_x$, $F_i^{yz} = \mathbf{F}_i \cdot \mathbf{e}_i^t$, the reaction vector $\mathbf{R}_i = \tilde{\mathbf{R}}_i / \tilde{\Phi} = (R_i^x, R_i^y, R_i^z)$, center mass vector $\mathbf{r}_C = \tilde{\mathbf{r}}_C / \rho = (x_C, y_C, z_C)$.

We further define the supporting points the coordinate differences along the cylinder, and angles difference: $\Delta x = x_2 - x_1$, $\Delta \varphi = \varphi_2 - \varphi_1$. We then project system (2) onto the axes $Oxyz$. For arbitrary surface we find that the second equation of (2) (corresponding to the angular momentum) has the skew-symmetric matrix with respect to the component R_i^x [11]. These are two independent equations, while the third equation corresponds to the restriction of the point C to the plane containing the two supporting points. As a result, the system (2) yields five independent equation and a restriction:

$$\begin{aligned} R_1^x &= -R_2^x + \sin \alpha, \quad R_1^y = -R_2^y, \quad R_1^z = -R_2^z + \cos \alpha, \\ (z_1 - z_2)R_1^x + (x_2 - x_1)(R_1^z - \cos \alpha) &= (z_C - z_2)\sin \alpha, \end{aligned}$$

$$(y_2 - y_1)R_1^x - (x_2 - x_1)R_1^y = (y_2 - y_c)\sin\alpha,$$

$$\operatorname{tg}\alpha = \frac{(x_2 - x_1)(\sin\varphi_2 + y_c) + (x_c - x_2)(\sin\varphi_2 - \sin\varphi_1)}{z_c(\sin\varphi_2 - \sin\varphi_1) + \sin(\varphi_1 - \varphi_2) + y_c(\cos\varphi_2 - \cos\varphi_1)}.$$

If $p = R_2^x - R_1^x$, then from (3):

$$R_1^x = (p + \sin\alpha)/2, \quad R_2^x = (\sin\alpha - p)/2,$$

$$R_1^y = \frac{p(y_2 - y_1)}{2(x_2 - x_1)} + \frac{2(y_c - y_2) + y_2 - y_1}{2(x_2 - x_1)}\sin\alpha,$$

$$R_2^y = \frac{p(y_1 - y_2)}{2(x_2 - x_1)} + \frac{2(y_2 - y_c) + y_1 - y_2}{2(x_2 - x_1)}\sin\alpha,$$

$$R_1^x = \frac{2(x_2 - x_c)\cos\alpha + p(z_2 - z_1)}{2(x_2 - x_1)} + \frac{2(z_c - z_2) + z_2 - z_1}{2(x_2 - x_1)}\sin\alpha,$$

$$R_2^x = \frac{2(x_c - x_1)\cos\alpha - p(z_2 - z_1)}{2(x_2 - x_1)} + \frac{2(z_2 - z_c) + z_1 - z_2}{2(x_2 - x_1)}\sin\alpha,$$

$$\operatorname{tg}\alpha = \frac{(x_2 - x_1)(\sin\varphi_2 + y_c) + (x_c - x_2)(\sin\varphi_2 - \sin\varphi_1)}{z_c(\sin\varphi_2 - \sin\varphi_1) + \sin(\varphi_1 - \varphi_2) + y_c(\cos\varphi_2 - \cos\varphi_1)}.$$

If the number of contact points $n + m$ is even, and they are pairwise located at coincident points on opposite sides of a surface of almost zero thickness, then the indicated inequalities are satisfied.

Fig. 2. Regions of parameters for which the problem of the distribution of reactions has a solution.

The second group of inequalities is the condition that the tangent components of the reactions are limited by the limiting value of the Coulomb dry friction. Those. kinetostatic [3] equations are supplemented by quadratic inequalities responsible for getting reactions into the corresponding friction cones. As soon as the modules of the tangent reactions exceed the limit value, slipping of the foot or finger relative to the surface occurs. These are quadratic inequalities with respect to the parameter p , where p is the difference of the reaction components along the axis of the cylinder, E which coincides and does not depend on α the coefficient p of squared. Note that for an arbitrary surface, the structure and properties of these inequalities are preserved, Fig. 2.

When the robot moves, a change occurs in the one-support and two-support [4] phases. Let $n = 1$. The desired condition for the existence of motion is that the reaction at a single point of support must be equal to the force $\tilde{\Phi}$ modulo, and the reference

point C is located on a straight line along the force $\tilde{\Phi}$ passing through the point. Moreover, the slope of the line of action of the force $\tilde{\Phi}$ to the normal should not exceed the angle of friction.

Let $n = 2$. For the bi-support phase, the robot configurations are considered symmetrical with respect to point C along and across the axis of the cylinder. At $x_2 = -x_1$, $\varphi_2 = -\varphi_1$, for angles $\alpha = 0$ and, $\alpha = \pi/4$, below, fig. 3. charts are given for areas $E < 0$ and $E \geq 0$. These graphs supplement and summarize the results obtained [5], [6].

Fig. 3. Symmetrical along the axis of the cylinder configuration of the robot.

For robot finger configurations symmetrical about a point C along the axis of the cylinder, three cases with a non-negative coefficient E are considered for the distance x between the point C and the reference points: 0,9, 1 and 1,1 for ρ and k equal 1, α from 0 to π (all 14 different values of the angle of the cylinder) [7], [8]. Areas of existence of a solution to the problem of the distribution of reactions on the plane of two angles corresponding to the projections of the support points on the base of the cylinder and three-dimensional regions complementary to the indicated plane of the applied point C are constructed. When: $\alpha: 0$, $x: 1$ the area consists of three separately located connected subdomains.

On the plane of the angles, each of a pair of parallel lines corresponds to a support in the diametrical plane of the cylinder containing the point C. Between these lines is a connected area. It contains a straight line segment corresponding to equal angles, the robot rests from above, on a straight line parallel to the axis of the cylinder, satisfying the restriction on deviations from the direction of the force. The indicated segment on the graphs disappears when x equal to 0,9 for α equal to $\pi/4$, and when increasing x , later, when $4\pi/9$ [9], [10]. This corresponds to the fact that the cylinder begins to slide in the grip of the robot with two fulcrum. Valid areas for $\alpha = \pi/3$; $x = 1,1$ built in works [12], [13].

The results obtained in [4], [5] for a walking robot with two support points have an analogy for gripping with two support points of a holding cylinder.

3. Conclusion

The robot can hold an object with an arbitrary surface, such as a cylinder, with one finger from the inside or outside, so that the center of mass of the surface is located, respectively, below or above the contact point. Moreover, the slope of the line of action of the force to the normal should not exceed the angle of friction.

The grip can hold the cylinder with two fingers located on the same diameter. And with fingers located on opposite sides of the thin surface of the object at matching points.

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5. Acknowledgements

Many thanks to colleagues N.N.Bolotnik, A.M.I.Krivtsov, E.I.Kugushev and V.E.Prynichnikov for advices.