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Manipulability and Kinematic Analysis of a Home Service Robot Aimed for Floor Tasks

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Abstract : This paper presents the design and kinematic analysis of a home service robot that is aimed for performing not only table tasks but also floor tasks. The robot has a structure of a mobile manipulator that has two wheels and two arms. One typical design of the robot is to have long arms to reach objects on the floor with ease. The robot is beneficial to homes where people live on the floor. The robot is required to perform cleaning the floor, picking up objects, and arranging them on the floor. For such a given floor task, the manipulability of the designated robot arms is analyzed through kinematics.

Keywords : Home service robot, kinematic analysis, manipulability.

1. Introduction

Recently, a paradigm of robotic research direction is shifting from industrial robots to service robots since the need for industrial robots depends upon the economy of automobile industries. It seems that the number of automobile industries is saturated and automobile companies are even required to merge into one.

However, research on service robots become active and outcomes are enormously expected. One of main streams of service robot research is the category of home robots. Robot technologies and consumer electronics are merged together to develop home service robots. One typical home service robot is a cleaning robot, Roomba.

There are several reasons for Roomba to be successful in the consumer electronics market. The first reason is the affordable price. Consumers can buy cleaning robots as a gift and expect more fun rather than cleaning qualities. The second reason is simple function. Roomba has only one function to clean up dirt on the floor or carpet. The last reason is the simple and compact design. Roomba has solid and simple design of a circular shape.

However, the ultimate goal of home service robots is to serve humans in various aspects, not only cleaning home but also performing other tasks such as making foods, delivering and picking up objects, entertaining humans, and educating children. Since other tasks require sophisticated manipulation, home service robots are required to have both mobility and manipulability. This leads to the active research on developing mobile manipulator-typed home service robots in home environment.

Twendy-one is developed to help humans by providing foods in home environment. The task of serving foods is demonstrated [1]. Although practicality of serving humans is not complete yet, the feasibility of using a mobile manipulator as a home service robot has been proved. Another popular home service robot is the laundry robot that arranges clothes by folding. Precise folding tasks are done based on images obtained by cameras.

Commercial home service robots including personal robot series are introduced by Willow Garage [2]. PR2 by Willow Garage has performed various services including delivering drinks to humans.

All of aforementioned home service robots are designed to provide services to humans at a table level, which means that robots are designed to access objects on the table. This limits the workspace of the robot as above the table.

However, many people live on the floor as well as work on the table. Specially, most of Koreans are living and sleeping on the floor so that they spend most of time on the floor. This requires robots to perform tasks on the floor as well as on the table.

To satisfy the concept that the robot is required to reach objects on the floor, several designed specifications are presented. Firstly, the waist of the robot can be stretched. Secondly, two arms of the robot can be sled up and down to cover both table and floor tasks. Thirdly, the robot has a waist sliding mechanism to balance when the end-effector has a load.

Based on the design concept, kinematics analysis is performed and a real robot has been implemented. The conceptual schematic design is shown in Fig. 1. Although the design is not completely presented, the major concept can be easily figured out.

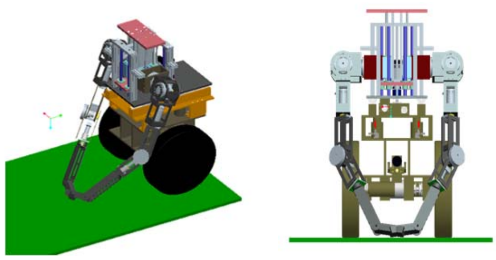
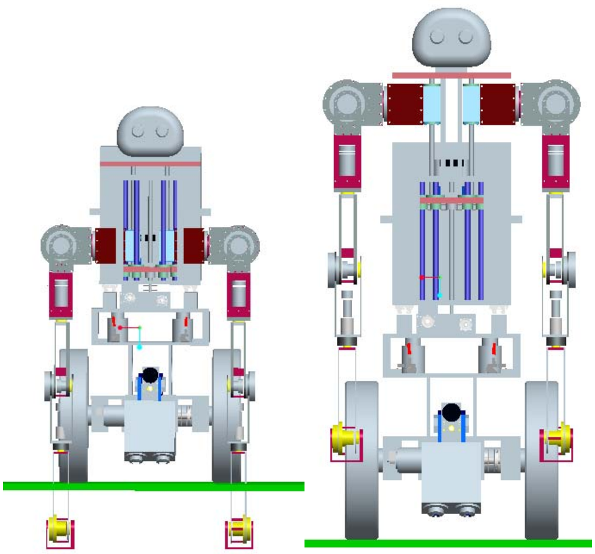


Fig. 1 Concept of a home service robot for floor task

In this paper, as an extension of the previous home service robot [3], the robot is equipped with another joint. The addition of another joint requires a new kinematic analysis. Simulation studies are conducted to confirm the kinematic analysis and its manipulability.

2. Schematic Design

The robot is a mobile manipulator that has two wheels to navigate on the plane and two arms to handle objects. Each arm has six degrees-of-freedom as shown in Fig. 2.



(a) Before waist-stretched (b) After waist-stretched

Fig. 2 Home service robot

3. Kinematic Analysis

1. Forward kinematics

To analyze the kinematics of the robot arms, coordinates are assigned to each arm as shown in Fig. 3. Based on the coordinate configuration, we list D-H parameters for each arm as Table 1.

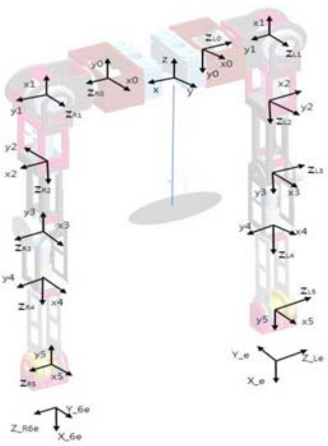


Fig. 3 Coordinates

Table 1. D-H parameters.

	Right Arm				Left Arm			
	θ_i	α_i	a_i	d_i	θ_i	α_i	a_i	d_i
0	$\theta_0\ (\frac{\pi}{2})$ fixed value	$\frac{\pi}{2}$	0	0	$\theta_0\ (\frac{\pi}{2})$ fixed value	$-\frac{\pi}{2}$	0	0
1	$\theta_1\ (\frac{\pi}{2})$	$\frac{\pi}{2}$	0	$d_1(264)$	$\theta_1(-\frac{\pi}{2})$	$-\frac{\pi}{2}$	0	$d_1(264)$
2	$\theta_2\ (\frac{\pi}{2})$	$-\frac{\pi}{2}$	0	0	$\theta_2(-\frac{\pi}{2})$	$\frac{\pi}{2}$	0	0
3	$\theta_3(-\frac{\pi}{2})$	$-\frac{\pi}{2}$	0	$d_3(420)$	$\theta_3(-\frac{\pi}{2})$	$\frac{\pi}{2}$	0	$d_3(420)$
4	$\theta_4\ (0)$	$\frac{\pi}{2}$	0	0	$\theta_4\ (0)$	$-\frac{\pi}{2}$	0	0
5	$\theta_5\ (0)$	$-\frac{\pi}{2}$	0	$d_5(426)$	$\theta_5\ (0)$	$-\frac{\pi}{2}$	0	$d_5(426)$
6	$\theta_6(-\frac{\pi}{2})$	0	$a_6(60)$	0	$\theta_6(-\frac{\pi}{2})$	0	$a_6(60)$	0

The forward kinematics can be obtained straightforward from D-H parameters in Table 1. However, inverse kinematic solutions are not easily obtained due to the typical arm structure of the robot.

2. Inverse kinematics

Our robot arm in Fig. 4 has a different structure from conventional 6 DOF arms. Inverse kinematic solutions cannot be obtained with ease.

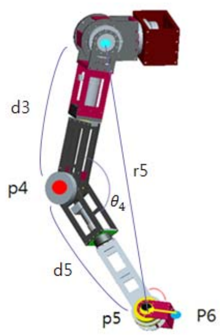


Fig. 4. Right arm configuration

Known at the end-effector position, p_6 , we have

$$p_5 = p_6 - a_6 n \tag{1}$$

Since we know the position, p_5 , r_5 is given. Then θ_4 can be calculated as

$$\theta_4 = a\tan(\frac{S_4}{C_4}) \tag{2}$$

where $C_4 = (d_3^2 + d_5^2 - r_5^2)/(2d_3d_5)$ $S_4 = \sqrt{(1-C_4^2)}$, $r_5 = \sqrt{(p_{5x}-d_1)^2 + p_{5y}{}^2 + p_{5z}{}^2}$.

To solve other joints, we have constraints due to joint 3 that leads to many solutions.

Our proposal here is to use the ratio of movements in the x axis as shown in Fig. 5. Then we can easily calculate p_{4x} so that we can obtain θ_2 .

$$\theta_2 = \frac{\pi}{2} - a\sin(\frac{p_{4x}-d_1}{d_3}) \tag{3}$$

where $p_{4x}=(p_{5x}-d_1)(\frac{d_3}{d_3+d_5})+d_1$.

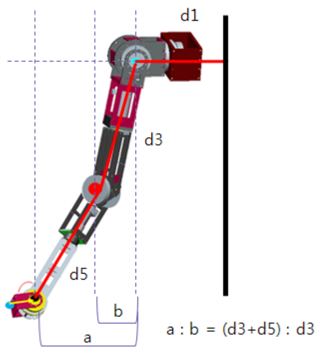


Fig. 5. Constraint condition

θ_3 can be found as

$$\theta_3 = a\tan(\frac{S_3}{C_3}) \tag{4}$$

where $C_3=(p_{6x}-d_1-d_3C_2-d_5C_2C_4)/(d_5S_2S_4)$, $S_3=\sqrt{(1-C_3^2)}$.

θ_1 can be found as

$$\theta_1 = a\tan(\frac{S_1}{C_1}) \tag{5}$$

where $C_1=(k_1p_{5z}+k_2p_{5y})/(k_1^2+k_2^2)$, $S_1=(p_{5z}-k_1C_1)/k_2$, and $k_1=d_5S_3S_4$, $k_2=d_5S_4C_2C_3-d_6C_4S_2-d_3S_2$.

To find θ_6,

$$\theta_6 = a\tan(\frac{S_6}{C_6}) \tag{6}$$

where $C_6=(a_6^2+d_5^2-r_6^2)/(2d_5a_6)$, $S_6=\sqrt{(1-C_6^2)}$, $r_6=\sqrt{(p_{6x}-p_{4x})^2+(p_{6y}-p_{4y})^2(p_{6z}-p_{4z})^2}$, $p_{4y}=-d_3C_1S_2$, $p_{4z}=-d_3S_1S_2$.

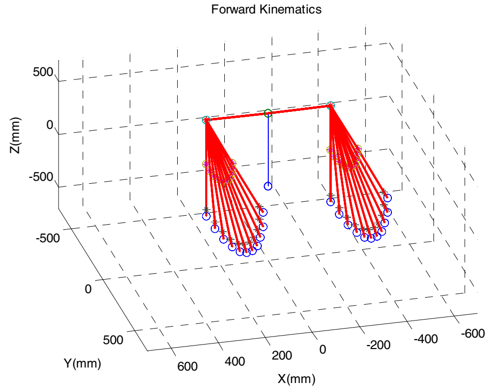
Finally, for θ_5, we have

$$\theta_5 = a\sin(\frac{M_x-A_xM_y}{A_xN_y+B_x}) \tag{7}$$

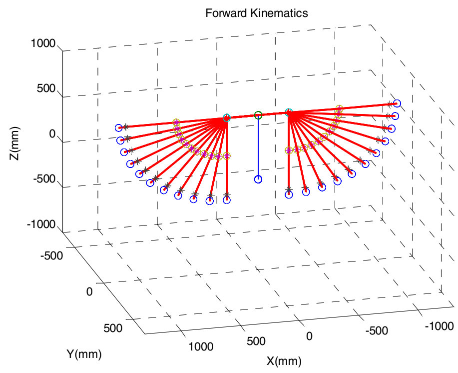
where $M_x=-(p_{6x}-k_{6x})/(a_6C_6)$, $M_y=-(p_{6y}-k_{6y})/(A_ya_6C_6)$, $A_x=C_2S_4-C_3C_4S_2$, $A_y=C_4(S_1S_3-C_0C_1C_2)-C_1S_2S_4$, $B_x=S_2S_3$, $B_y=C_3S_1+C_1C_2S_3$, $k_{6x}=d_1+d_5D_x+d_3C_2-a_6S_6D_x$, $k_{6y}=(a_7S_6-d_5)(S_4(S_1S_3-C_1C_3C_4)-C_1C_4S_2)-d_3C_1S_2$, $D_x=C_2C_4+C_3S_4S_2$, $N_y=-(B_y/A_y)$.

3. Simulation

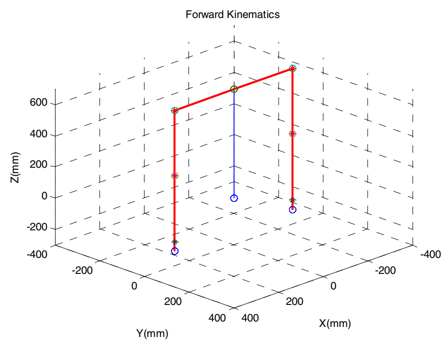
Based on the kinematics derived from D-H parameters, simulations are performed to confirm forward and inverse kinematics. Fig. 6 shows the forward and inverse kinematics of each joint. We see that inverse kinematic solutions are well matched with the forward kinematics.



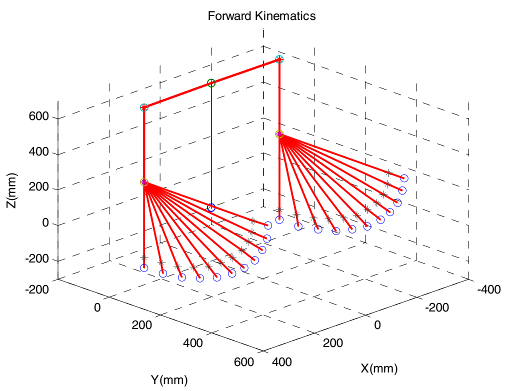
(a) First joint



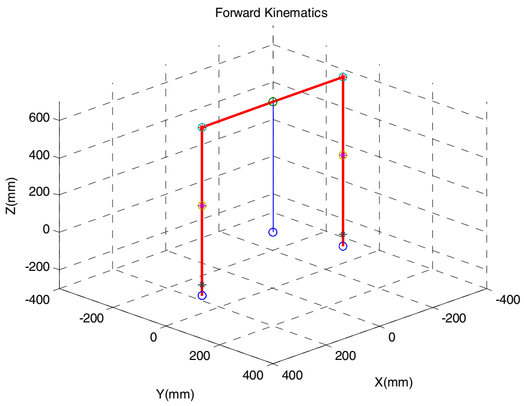
(b) Second joint



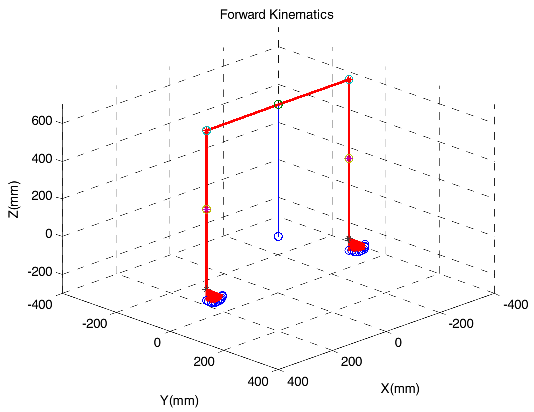
(c) Third joint



(d) Forth joint



(e) Fifth joint



(f) Sixth joint
Fig. 6 Forward and inverse kinematics

Fig. 7 shows the real robot. The last joint is newly attached for floor tasks.

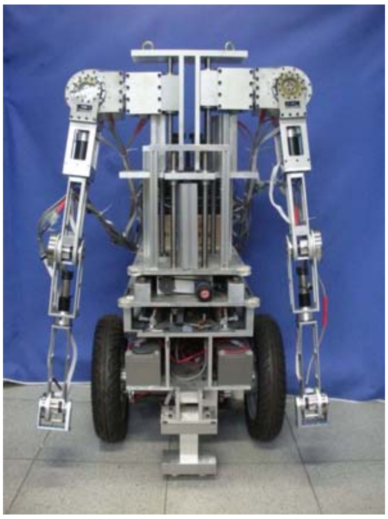


Fig. 7 Home service robot

4. Manipulability

The manipulability is commonly used to measure the effectiveness of a manipulator[4-7]. Manipulability ellipsoid is used to represent the manipulability of the robot on a three dimensional space. For a given floor task of the manipulator, the manipulability is analyzed. The velocity rate on the 3D space is confirmed through the analysis of the manipulability ellipsoid as shown in Fig. 8.

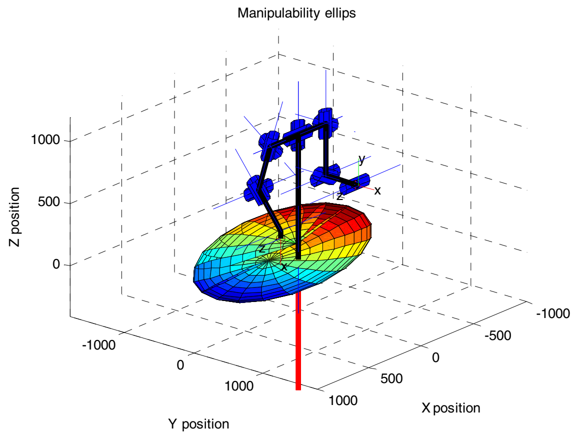


Fig. 8 Manipulability Analysis

5. Conclusion

In this paper, a mobile manipulator for floor tasks is presented and developed. The mobile manipulator is built for service in home environment so that two arms are designed long to reach an object on the floor. To check the feasibility, the kinematic analysis of manipulator arms is introduced. Simulation studies are carried out to confirm the analysis of work space and manipulability for a typical floor cleaning task through kinematics. Experimental verification is an on-going research topic.

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