Kinematic Analysis of Novel Assistive Robot for Self-Feeding

Prof. Vikram Kapila, Angad Boralkar, Mitravarun Anand

Original Work of Won-Kyung Song and Jongbae Kim

***Abstract*— The aim of our paper is to perform kinematic analysis on the Assistive Robot for Self-Feeding, developed by Won-Kyung Song and Jongbae Kim, at the Korea National Rehabilitation Research Institute, Korea National Rehabilitation Center, to verify the results of the workspace. This can be utilized further to develop applications that require a similar robot to solve various disability-specific assistive technologies.**

I. INTRODUCTION

The design of assistive robots to help with self-feeding depends strongly on the specific culture of the user. Korean food, like most Asian food, consists chiefly of boiled rice, soup, and side dishes [1]. The procedure of having a meal is as follows: the user eats the boiled rice first and then the side dishes. These steps are performed repetitively. Boiled rice sticks together very well after cooking. Handling this sticky boiled rice can be problematic. In addition, Asian soup includes meat, noodles, and various vegetables, thus the existing feeding robots find it difficult to handle such foods. In the Assistive Robot for Self-Feeding (ARSF), the system with a food tray is located on a table. The robotic arm picks up food and then moves it to a user's mouth. These tasks are divided into two steps: one is picking up the food and the other is moving the food to the user's mouth. Two arms can be used to perform the above two tasks, respectively. This system varies widely from other self-feeding robots such as Handy-1, My Spoon Partner, etc., in its ability to handle complex food items, by using a dual-arm configuration.

II.PRINCIPLE

The robot consists of two separate arms, to control the gripper and the spoon independently. A spoon-arm has two degrees of freedom (DOF) to transfer food on the spoon without changing the orientation of the spoon. A grab-arm includes a three-DOF SCARA joint for the planar motion, a one-DOF prismatic joint for the up and down motion, and a gripper. The feeding robot uses a microcontroller unit to control a spoon-arm and a grab-arm. There is also a small-sized PC with a touch screen to enable the user to enjoy entertainment and to test various kinds of user interfaces. During mealtime, a user wants to enjoy multimedia such as movies or music. In addition, the small-sized PC has a Windows operating system, and we can effectively add assistive devices for human computer interaction, i.e., switches, a joystick, and bio-signal interface devices.

III. CONFIGURATIONS

The microcontroller unit allows a user or a caregiver to select the following: operation modes (automatic/semiautomatic/manual mode), the shape and size of a container, the location of the mouth, the robot's speed, the time to stay in front of the mouth, and so on. Depending on the types of food, a user also selects the divided grasping region in each container and the grab strength of the gripper of the grab-arm. Our system will can select the above parameters. A user can save the parameters of various kinds of food. We expect that in a community, different members will be able to exchange their robots effectively by exchanging their individual parameters via the Internet. The grasping regions of boiled rice in a bowl could be defined in 3D space because the bowl should be over 50 mm in height.

Dual-arm configuration

A dual-arm robotic system is applied in accordance with an original design concept. If a caregiver prepares food, users can eat the food based on their intentions. A grab-arm picks up the desired food on a food container, and the arm releases the food on the spoon of a spoon-arm. The spoon-arm moves the spoon to the user's mouth. Then the user can eat the food on the spoon

Single-arm configuration

A spoon-arm could be used independently without a grab-arm. The caregiver manually picks up the food on a tray and puts the food on the spoon of a spoon- arm. The next step is like that of the dual-arm robotic arm. A caregiver only provides a user with food when the spoon is empty in the home position. From the perspective of the caregiver, he or she can reduce the amount of time needed to check or wait while the user is chewing. From the perspective of the user, the food can be eaten when he or she wants to eat. Although a user may have difficulty choosing food in an automatic manner, he or she can chew the food sufficiently without considering the next spoon serving from a caregiver. From an economical point of view, the single-arm configuration has a lower cost in comparison with the dual-arm configuration. Applying a spoon-arm has advantages in facilities such as hospitals or nursing homes. One caregiver supports more than one consumer. That means one caregiver can serve food on the spoons of multiple users' spoon-arms in turn. This configuration is especially useful if the labor cost of a caregiver is not high, as in developing countries.

IV. KINEMATICS

Joint Configuration diagram for the complete robot can be drawn by breaking down the system into two distinct manipulators, shown as follows.

1. For the Gripper Manipulator:

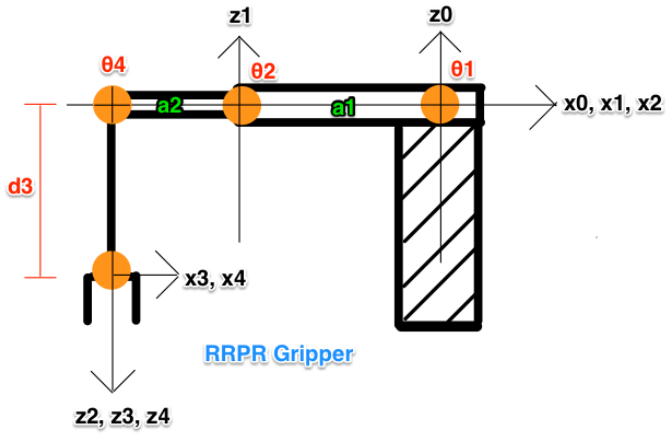


Fig.: Gripper Manipulator Configuration.

Link	a_i	α_i	d_i	Θ_i
1	a_1	0	0	Θ_1*
2	a_2	180°	0	Θ_2*
3	0	0	d_3*	0
4	0	0	0	Θ_4*

Table: DH Table – Gripper Manipulator.

$$ {}^{0}T_{4} = \begin{bmatrix} c12c4 + s12s4 & -c12s4 + s12c4 & 0 & a1c1 + a2c12 \\ s12c4 - c12s4 & -s12s4 - c12c4 & 0 & a1s1 + a2s12 \\ 0 & 0 & -1 & -d3 - d4 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Fig.: Transformation Matrix – Gripper Manipulator.

Forward Kinematics:

$P_x = a_1 \cos\theta_1 + a_2 \cos(\theta_1+\theta_2)$
$P_y = a_1 \sin\theta_1 + a_2 \sin(\theta_1+\theta_2)$
$P_z = -d_3 - d_4$

Inverse Kinematics:

$\theta_1 = \text{atan2}(O_x, O_y) - \text{atan2}(a_1 + a_2\cos\theta_2, a_2\sin\theta_2)$
$\theta_2 = \text{atan2}(\cos\theta_2, \pm(\sqrt{1-\cos\theta_2}))$
$\theta_4 = \theta_1 + \theta_2 - \text{atan2}(a_1+a_2\cos\theta_2, a_2\sin\theta_2)$
$d_3 = O_z + d_4$

2. For the Spoon Manipulator:

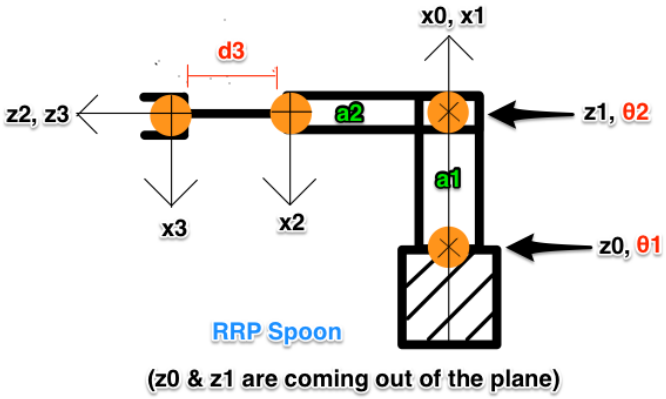


Fig. 2: Spoon Manipulator Configuration.

Link	a_i	α_i	d_i	Θ_i
1	a_1	0	0	Θ_1*
2	a_2	90°	0	Θ_2*
3	0	0	d_3*	0

Table: DH Table – Spoon Manipulator.

$$ {}^{0}T_{3} = \begin{bmatrix} c12 - s12 & -c1s2 + s1c2 & 0 & a2c12 + a2s12 + a1c1 \\ s1c2 + c1s2 & -s12 + c12 & 0 & a2s12 + a1s1 \\ 0 & 0 & 1 & d1 + d2 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

Fig.: Transformation Matrix – Spoon Manipulator.

Forward Kinematics:

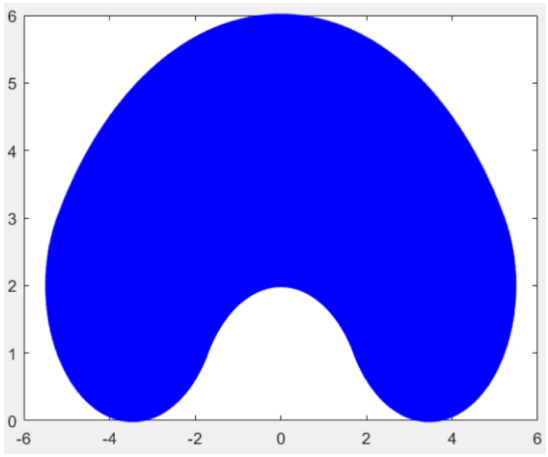
$P_x = a_2\cos(\theta_1 + \theta_2) - a_2\sin(\theta_1 + \theta_2) + a_1\cos\theta_1$
$P_y = a_2\sin\theta_1\cos\theta_2 + a_2\cos\theta_1\sin\theta_2 + a_1\sin\theta_1$
$P_z = d_1 + d_2$

Inverse Kinematics:

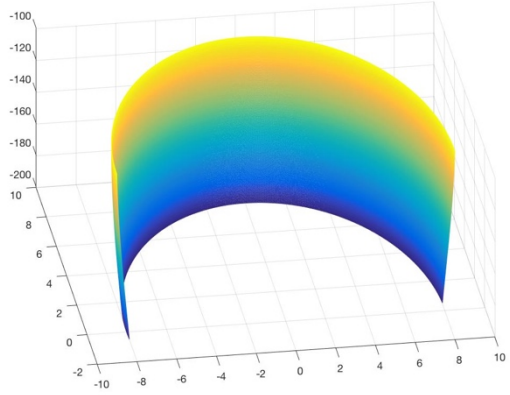
$\theta1 = \text{atan2}(P_y, P_x) \pm \text{atan2}((\sqrt{(P_y^2 + P_x - (a_2\cos\theta_2 + a_1)^2}),$
$a_2\cos\theta_2 + a_1)$
$\theta2 = \text{atan2}(\pm(\sqrt{1-(Px^2 + Py^2 - a_2^2)/2a_1a_2}), (P_x^2+P_y^2-a_2^2)/2a_1a_2)$

V. WORKSPACE

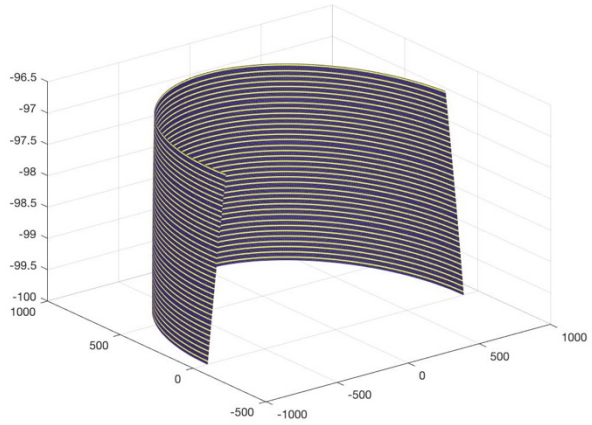
The workspace generated by both the arms have been plotted using MATLAB [3]. The results, as shown below, have been consistent with the results obtained by the original author. The MATLAB commands “linspace” and “mesh” [5] were used to create the following plots, along with the color variable “C” for imparting different colors.



(i) Arm with SCARA Manipulator



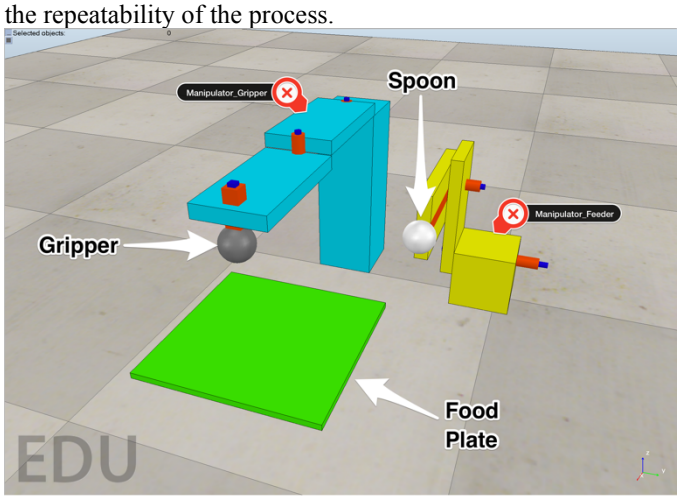
(ii) SCARA Mesh



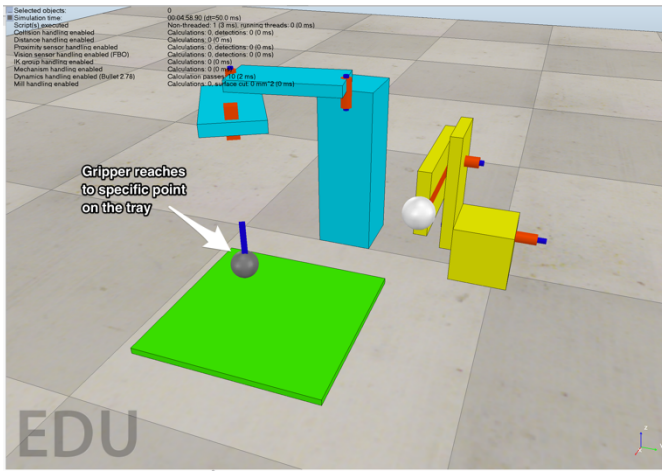
(iii) Arm with Spoon Mesh

VI. SIMULATION

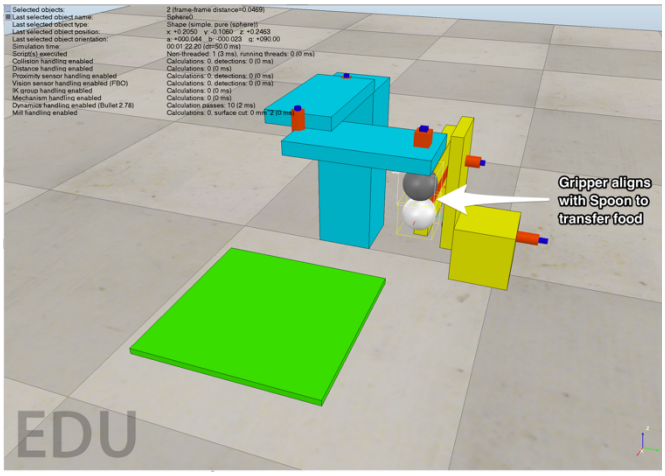
The design of ARSF have been modelled into VREP [4], and with MATLAB as the remote API, the entire system with both the arms and their joint configurations have been simulated to verify the accuracy of the system under consideration, verifying the repeatability of the process.



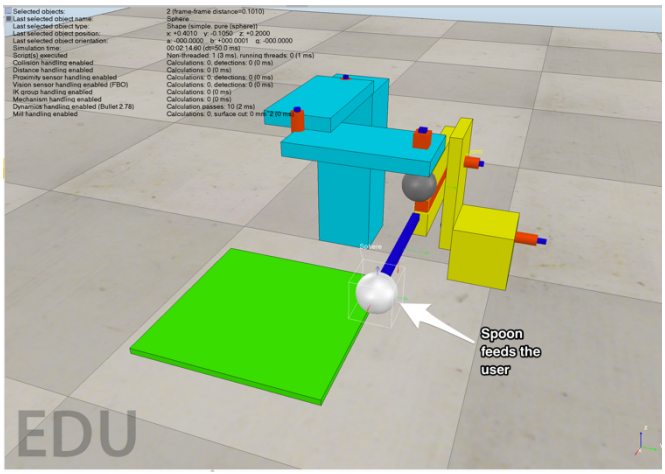
The images below show the simulation snapshots at (three) different instances of time.



Step 1



Step 2



Step 3

VII. CONCLUSION

Kinematic analysis was performed for the ARSF Robot and simulated to verify the efficiency of the device which was rated 2.7 on a scale of 5 by the test users. Major drawbacks that the users felt was the arrangement of the spoon feeder in a frontal plane. A spatial plane approach is preferred. Other complaints included, simpler input system, a less noisy robot and the use of joysticks instead of buttons. Finally, the objective of the kinematic modelling of ARSF is that it can be used for developing similar applications to help the disabled community-expanding the areas of application to a washing/ shaving/teeth cleaning system, as make up applicators, as well as for various art-box prototypes to keep the user feel to be a part of the society.

VIII. ACKNOWLEDGEMENT

The complete credit for developing the Assistive Robot for Self-Feeding goes to Won-Kyung Song and Jongbae Kim at the Korea National Rehabilitation Research Institute, Korea National Rehabilitation Center.

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