# Meal Support System with Spoon Using Laser Range Finder and Manipulator

Yutaro Ohshima, Yuichi Kobayashi, Toru Kaneko
Department of Mechanical Engineering, Shizuoka University
3-5-1 Johoku, Naka-ku, Hamamatsu-shi, Shizuoka 432-8561, Japan
{f0130018, tykobay, tmtkane}@ipc.shizuoka.ac.jp

Atsushi Yamashita and Hajime Asama
Department of Precision Engineering, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
{yamashita, asama}@robot.t.u-tokyo.ac.jp

## Abstract

*This paper presents an autonomous meal support robot system that can handle non-rigid solid food. The robot system is equipped with a laser range finder (LRF) and a manipulator holding a spoon. The LRF measures the 3D coordinates of surface points belonging to food on a plate. Then the robot determines the position of food surface to scoop, and the manipulator moves according to the calculated trajectory. The system has an advantage that preparation of food cutting in bite-size is not required. The proposed scooping control was implemented and verified in experiment with two kinds of non-rigid solid foods. It was shown that the robot can scoop foods for the most part with high success rate.*

## 1. Introduction

People who have upper limb disabilities cannot take a meal by themselves. They require helpers to put food to their mouths during the meal. However, in the aging societies, often the number of helpers is not enough for handicapped people in hospitals or care homes. This problem will be relieved by providing meal support systems which do not require a help of a caregiver. If the above people use the meal support system, they can enjoy the meal freely, in favorite order, without a help of other people. Another benefit of an autonomous meal support system is that it can provide care workers with efficiency and reduce waiting time of people who require care for eating. Furthermore, the fact that eating meal by themselves with a robot may make those people energetic to live and encourages them to lead self-supporting lives. Therefore, meal support systems which enable handicapped people to take a meal by themselves are gathering more attention [1].

Recently, many experiments have been conducted aiming to reduce inconveniences of human activity by use of robotic systems. For example, there are manipulator robots for daily life [2, 3]. However, it is difficult to eat meal with tableware by using those versatile manipulators. Thus, it is more practical to develop robot systems specific to meal support.

Meal support systems have been developed and are already in practical use such as “My spoon” [1, 4, 5], “Bestic” [6] and Meal-assistance robot [7]. My spoon consists of a 5-DoF manipulator that has a fork and a spoon on its hand tip, a joystick and a tray. A user of My spoon controls the manipulator by the joystick and moves its hand tip near to the meal on the tray. When the user pushes the button, the manipulator grasps the meal using fork and spoon. Then the manipulator carries meal to the user’s mouth. Bestic consists of a manipulator equipped with a spoon, a plate and foot buttons (or a joystick). Bestic scoops up the meal using the spoon and the plate’s verge. In addition to buttons or joystick, Bestic user can control it with only one button by combination of a turn table and constant manipulator action. The meal support system proposed by Kobayashi [8] also uses a turn table and constant action by a manipulator equipped with a spoon. Meal-assistance robot presented in [7] pushes out the food from a feeder to the spoon and carries the spoon to the user’s mouth.

In order to use My spoon and meal-assistance robot [7], however, it is necessary to cut foods in bite-size in advance. On the other hand, Bestic and [8] do not consider the shape and position of foods and cannot recognize the remnants of scooping.

Meal support systems using chopsticks are also proposed. Koshizaki and Masuda [9] described effectiveness of chopsticks as tableware and developed a meal assistance robot using chopsticks with force sensor. They proposed

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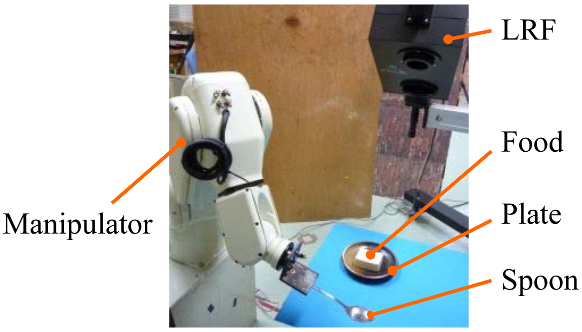



Figure 1. System setup.

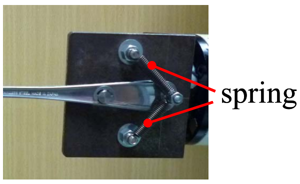



Figure 2. Mechanical compliance.

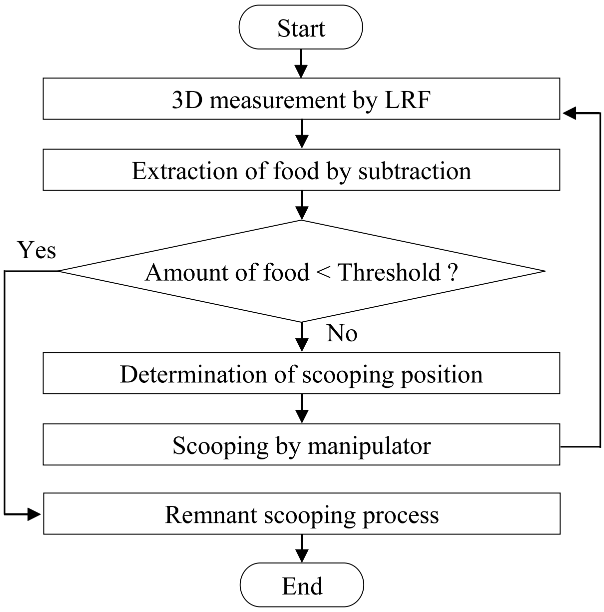



Figure 3. Work flow for scooping.

methods of foods handling such as food division/assembly. Doi *et al.* [10] developed electric chopsticks which can open and shut automatically with a joystick for people who can move their shoulders and elbows but not their hands. However, helpers generally use spoons in hospitals or care homes. Therefore, we pursue to widen applicability of a spoon and propose a meal support system with a spoon.

In this paper, we propose a meal support system that can scoop up non-rigid solid foods automatically. The advantage of our system is that preparation of foods cutting in bite-size is not required. Hereby, meal preparation time is reduced and cost of forming food into special figure can be cut. Additionally, our system can get the information of a shape and orientation of foods using LRF (Laser Range Finder). Sometimes it is enough to scoop up foods with constant manipulator action like [6, 8]. However if foods are non-rigid and fragile, it is favorable to scoop up foods according to its shape and position. We experimented with soybean curd (tofu) and custard pudding as the typical non-rigid solid foods. Effectiveness of the proposed scooping control will be verified in the experiment.

## 2. Outline of autonomous scooping

In this section, the outline of the proposed robot system and its strategy of scooping are described.

### 2.1. Meal support robot system

The system setup is shown in Fig. 1. There are an LRF fixed above food on a plate, a manipulator, a spoon attached at the tip of manipulator and food on a plate. In order to reduce the noise with measurement, a plate and a table that lack luster are used. A plate is not fixed on a table, which implies that the plate might move slightly by each scooping motion. The LRF and manipulator are connected to a PC. The LRF sends 3D point data to PC. The command sent from PC to manipulator provides trajectories of the tip of the manipulator. Two springs are attached between the spoon and the hand tip, as depicted in Fig. 2. This mechanical compliance can soften the force between spoon and plate.

### 2.2. Overview of scooping strategy

The work flow for scooping is shown in Fig. 3. Before scooping work, the calibration of coordinate transformation between LRF and manipulator is conducted following the method using quaternions [11]. The first step in the flow is 3D measurement of a food using LRF. This measurement by LRF is executed before each scooping motion. The obtained set of 3D points includes those corresponding to the plate. By subtracting points of the plate measured in advance, points corresponding to the food are extracted as shown in Fig. 4. Here, as a preprocessing for subtracting, alignment of measured points and points of plate is executed . This alignment process is executed after each measurement. With the food points, the position to insert the spoon in food is determined by the proposed algorithm described in the next section. After scooping up of food with the spoon, measurement using LRF is executed again for the next scooping motion. After subtraction process, the total amount of remaining food is estimated. If the estimated

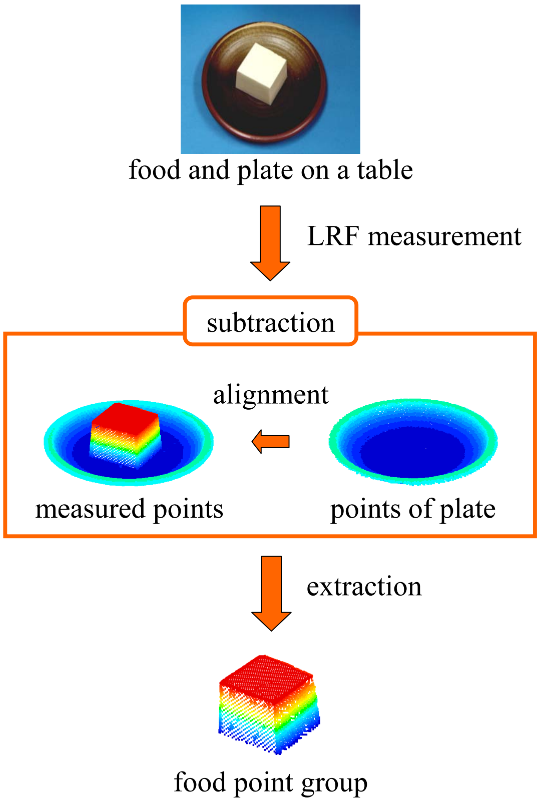



Figure 4. Subtraction process.

amount is smaller than a threshold, the robot switches to the remnant scooping process. If there is no food on plate, the robot terminates the task.

## 3. Scooping procedure

In this section, the scooping procedure for the non-rigid and loaf shape food such as tofu (soybean curd) is described. In this paper the proposed method described in section 3.1–3.3 is called ordinary scooping. Also the proposed method described in section 3.4 is called remnant scooping.

### 3.1. Parameters for ordinary scooping

Before executing food scooping, setting up of three parameters is required. Two parameters are related to the size of scooping food, the width and the height. The depth of scooping is calculated according to the height of food on plate. The last parameter is the diameter of a circle which defines trajectory of the spoon (see Fig. 7). Food can be scooped up by moving the spoon along that circle osculating the spoon.

### 3.2. Determination of scooping position

In order to realize successful scooping, determination of a scooping position of the food is very important. The following is the proposed algorithm to determine a scooping position when the food is put on a shallow plate.

1. The measured 3D points of the food are divided into three groups depending on their heights (z coordinates), where the xyz coordinate system is set so that the x-y plane is parallel to the horizontal surface of the table. Since the measurement is executed toward x axis direction, the opposite side of food is not measured. Then, each point belonging to the highest point group is assigned to either of two groups, one for top surface points and the other for side surface points. Then, each point belonging to the highest point group is assigned to either of two groups, one for top surface points and the other for side surface points as followings. Let coordinates of point $i$ in the highest point group be denoted by $(x_i, y_i, z_i)$. Point $i$ is regarded as a top surface point if the following holds:

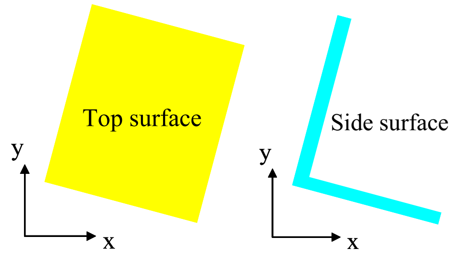
   $$(z_j - z_i) > h, \ \forall j \text{ s.t. } \| [x_i, y_i] - [x_j, y_j] \| < r \quad (1)$$

   where $h$ and $r$ $(h, r > 0)$ are threshold values. Otherwise, point $i$ is regarded as a side surface point. These top and side surface points are used for determination of scooping position. In a case of food whose shape is hemispherical or conical, almost all points of the highest point group are regarded as top surface points, resulting in insufficient number of side surface points. In such a case, points belonging to the second highest point group are regarded as side surface points.

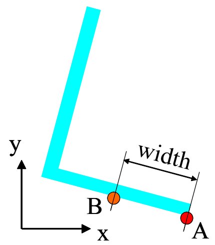
2. The side surface points are projected onto the x-y plane and the followings as shown in Fig. 5(a),(b),(c) are obtained. Point A: the projected point whose y-coordinate is the smallest. Point B: the projected point whose distance between point A is the nearest to the width parameter of scooping. Point C: the middle point on the line segment AB. Line L: the line passing through point C and orthogonal to line AB. Vector **M**: the unit vector along line L and whose x-componet is positive.

3. The top surface points are projected onto the x-y plane and the followings as shown in Fig. 5(d),(e) are obtained. Point D: the projected point whose y-coordinate is the smallest among the points lying in the vicinity of line L. Point E: the projected point that is translated from point D in the direction of vector **M** with the distance equal to the height parameter of scooping.

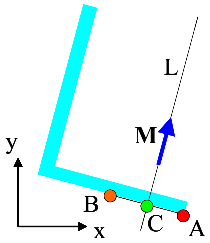
4. By back projection of point E to the top surface point in 3D, this 3D point is determined as the scooping position of the food.



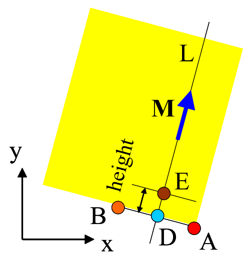

(a) Point group projected on x-y plane.



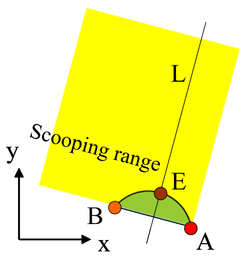

(b) Point A and B.




(c) Point C, line L and vector **M**.




(d) Point D and E.




(e) Scooping range.

Figure 5. Determination of scooping position.

In the case of a second or subsequent scooping, determination of a scooping position is realized by the same algorithm as the first scooping (Fig. 6).

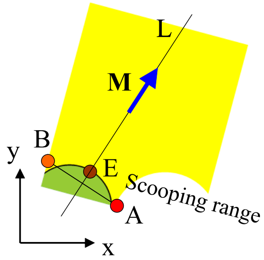



Figure 6. Scooping range in 2nd measurement.

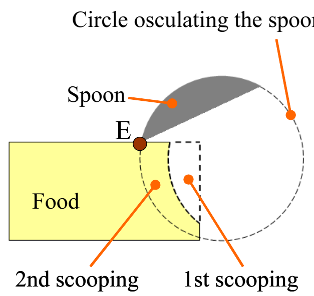



Figure 7. Scooping along osculating circle.

### 3.3. Food scooping along osculating circle

Scooping of the food with the spoon is executed along the osculating circle of spoon. Spoon direction on the x-y plane of manipulator coordinate system is parallel to vector **M** given in section 3.2. The spoon edge is inserted from point E and rotate the spoon around the center of the osculating circle as shown in Fig. 7. The velocity of scooping motion is kept constant.

### 3.4. Remnant scooping

The scooping method mentioned above cannot scoop up a food completely. In order to scoop the remnant food, an additional procedure with a longer stroke along the plate is introduced. Note here that it is more suitable to use a plate whose slope of edge is larger for remnant scooping. In other words, flat plates are not preferred for the scooping. The following is an additional procedure to solve this problem.

First, a curved surface equation is fit to the plate model already known so that a normal vector of arbitrary position of the plate can be calculated. A curved surface equation (2) is applied to each plate area divided into adequate number to scoop. A subscript $i$ in Eq. (2) is area number of the plate model. A normal vector $\boldsymbol{n}$ of arbitrary position is calculated by Eq. (3).

$$F_i(x, y, z) = -a_i x^2 - b_i y^2 - c_i xy - d_i x - e_i y - f_i + z \quad (2)$$

$$\boldsymbol{n}_i = \begin{pmatrix} \frac{\partial F_i}{\partial x} & \frac{\partial F_i}{\partial y} & \frac{\partial F_i}{\partial z} \end{pmatrix}^T \quad (3)$$

Second, the vector of moving spoon is determined. After subtraction process described in section 2.2, the CoG (center of gravity) of the measured 3D points of the food is calculated. By projecting CoG of the food and the center of the plate on the x-y plane of the manipulator coordinate system, the vector ($\boldsymbol{p}$ in Fig. 8) which indicates the moving direction of the spoon is obtained. The z axis component of the spoon position is being changed along the plate shape. Spoon angle is not changed between the start point and the center of plate. After passing the center of plate, spoon angle is changed along the plate shape.

Third, the spoon angle is determined. The tangent vector ($\boldsymbol{q}$ in Fig. 8) of the osculating circle using the spoon geometry is obtained. Spoon angle is changed so that vector $\boldsymbol{n}$ and vector $\boldsymbol{q}$ will be orthogonal. This action can put the food on the spoon. To realize this spoon action, it is necessary for the spoon to touch the plate softly, which is enabled by spring insertion described in section 2.1.

## 4. Experiment

In order to verify the effectiveness of the proposed method, an experiment of food scooping by our proposed methods was made with tofu and custard pudding as non-rigid solid foods. Experiments for tofu was made four times with variations of its weight and orientation. Experiment for custard pudding was made three times with the same condition. As to the parameters described in section 3.1, the width and height for scooping are 30mm and 8mm that were determined from the width and depth of the spoon. The diameter of a circle osculating the spoon was set as 30mm from the measuring result of spoon shape using LRF. The scenes of scooping food are shown in Fig. 9 and Fig. 10. In Fig. 10, it can be seen that the manipulator missed to scoop in the sixth motion and a part of pudding dropped down to the table in the eighth motion. About custard pudding, after the robot scooped it, its position might be changed. Its cause was that custard pudding was gooey. However, due to measurement by the LRF at every scooping, the system could handle the change of food position. It can be seen that tofu and custard pudding were mostly scooped. A large portion of non-rigid solid food was scooped by bite-size.

Quantitative evaluation of the proposed scooping is depicted in Table 1. About the items in Table 1, "net" is the initial food weight, "no. of scooping" is the number of scooping actions by the manipulator, "minimum scooped" and "maximum scooped" are the minimum and the maximum weight of food that was scooped at a time using the ordinary method, respectively, "sum of scooped" is the total weight of scooped foods, "scooped ratio" is calculated by $(sum\ of\ scooped\ /\ net) \times 100$.

The average scooped ratio of all trials in Table 1 was 92.7 percent. From this result, food scooping succeeded mostly. On the other hand, remnant scooping was not completely accomplished because some portion of food dropped out of the plate. This was caused by multiple small lumps of remnant food. When there were two small lumps remaining, for example, one lump was pushed out of the plate in the process of scooping the other. One simple solution for this problem is to use a plate with high rim. From the viewpoint of improving scooping strategy, on the other hand, it is required to count the number of remaining clusters to cope with the situation where a food is separated into multiple clusters. It will be also required to choose which cluster to scoop first according to their relative positions.

Another problem is that amount of each scoop was not constant, as can be seen in the values of "minimum scooped" and "maximum scooped" in Table 1. The proposed method considers of an amount of scooping food by parameters described in section 3.1. However, this method was not sufficient to control each amount of scooping. Thus one of our future works is to propose a method that can scoop an arbitrary amount of food and to realize scooping of non-rigid solid food without any loss or final remnant.

## 5. Conclusion

In this paper, we proposed food scooping strategies (ordinary scooping and remnant scooping) for a meal support system having advantages that preparation of food cutting in bite-size is not required and it can scoop foods according to shape and position of them. High ratio and little remnant food scooping were achieved by experiment. However it is not enough to scoop intended amount of food with the parameters that are proposed in this paper. Another problem is that division of food points into top surface and side surface groups might not work well if surface of food is lumpy. Thus the challenges for the future is proposing a method that can scoop an arbitrary amount of food and raising the ratio of scooped food. Concretely we are building a method that measured points are expressed in voxel and amount of food can be calculated by counting number of voxels.

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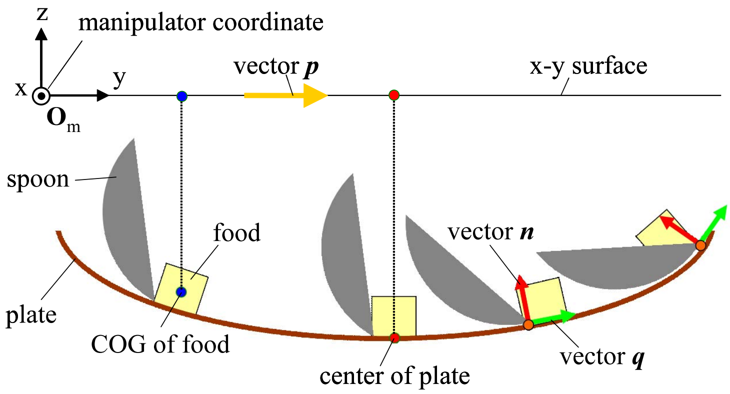


Figure 8. Remnant scooping.

Figure 9. Experiment for tofu.

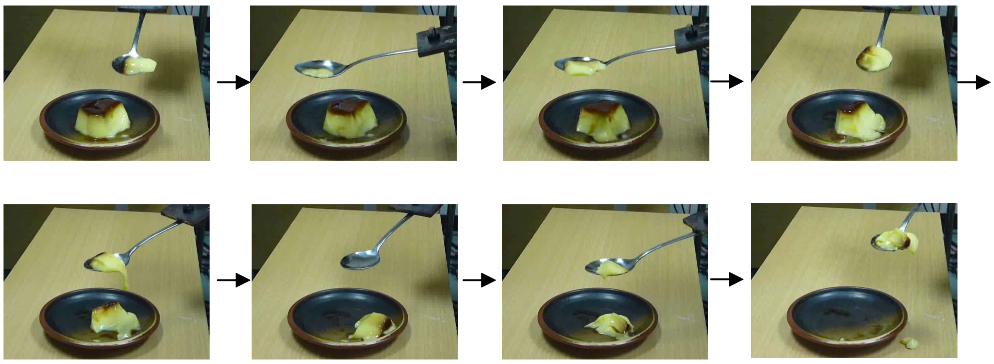

Figure 10. Experiment for custard pudding.

Table 1. Experiment result.

| food | Tofu a | Tofu b | Tofu c | Tofu d | Pudding a | Pudding b | Pudding c |
|---|---|---|---|---|---|---|---|
| net [g] | 48.6 | 47.8 | 63.2 | 62.4 | 66.1 | 67.2 | 67.3 |
| no. of scooping | 9 | 4 | 5 | 6 | 9 | 10 | 8 |
| minimum scooped [g] | 1.8 | 3.5 | 6.5 | 3.9 | 4.6 | 3.0 | 2.7 |
| maximum scooped [g] | 9.0 | 19.2 | 16.9 | 12.5 | 9.3 | 10.9 | 15.4 |
| sum of scooped [g] | 43.7 | 46.8 | 57.7 | 53.6 | 61.2 | 57.2 | 66.1 |
| scooped ratio [%] | 89.8 | 98.0 | 91.4 | 85.8 | 96.3 | 89.5 | 98.2 |

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