DESIGN OF A MULTIPLE-USER INTELLIGENT FEEDING ROBOT FOR ELDERLY AND DISABLED PEOPLE

Homeyra Pourmohammadali
Dept. of Mechanical Eng.
University of Waterloo
Canada

Jonathan Kofman
Dept. of Systems Design Eng.
University of Waterloo
Canada

Amir Khajepour
Dept. of Mechanical Eng.
University of Waterloo
Canada

ABSTRACT

Many feeding systems have been developed for disabled users; however, all have been designed for use with only a single user at a time. Little effort to design a multiple-user feeding system has been made. The aim of this research is to develop a machine to feed multiple elderly people dining all together at the same time on at four-seat tables. A robotic system has been designed based on senior's characteristics and their feeding needs, determined through observations of seniors at a nursing home. In such institutions, the limited number of staff compared to number of dependent elderly makes managing to respond to their needs very challenging during the restricted time allocated for eating. Assignment of a single feeding device to four people may reduce the number and consequent costs of machines and caregivers. Since the eating procedure is not fast, the idle state of the robot during one user's chewing and swallowing can be allocated for feeding another person sitting at the same table. The proposed system uses a 6-DOF serial articulated robot in the center of a four-seat table along with a specifically designed food tray to feed one to four people. It employs a vision system interface to perform recognition of food, forks, spoons and cups. The feeding system is simulated to evaluate the design before prototyping and real-time testing.

INTRODUCTION

The growing number of elderly in institutional living increases the necessity of designing new assistive devices for elderly in residences. The desire to feed elderly and those with upper limb disabilities has captured the minds of many researchers and designers for decades. The desire to provide a neater, safer and more comfortable eating environment with the least dependence on nurses, caregivers and family members has been the major motivation of research in feeding devices, Simple electromechanical or mechanical machines [1-11] to complicated intelligent systems [12-23], have been designed toward providing user independence in Activities of Daily Living (ADL). Some simple assistive feeding devices such as: Eatery [3], Action Arm [4], Ball Bearing Feeder [5], and Stable Slide [6] are purely mechanical and human-powered. However, others such as My Spoon [7], Beeson feeder [3], Neater Eater [8], Assistive dining device [5], Automatic Feeding device [5], Electric self-feeder [5], Mila One-step electrical feeder [10], and Winsford feeder [11] all take advantage of electro-mechanical systems. The limited control of the users of elector-mechanical feeders and recent advances in robotic-related technology has led designers to apply more intelligence in assistive feeding systems [12]. Handy 1 [13, 14], ISAC (Intelligent Soft Arm Control) [15- 17], Eater assist [18-20], robot for bedridden elderly people [21-23] and assistive robot hand [24] are intelligent robots designed for disabled users. However, to date almost all of the proposed feeding systems have been single-user devices. Little effort to design a multiple-user system has been made. In senior and nursing homes, where many elderly people dine together at four-seat tables, a machine that is capable of simultaneously feeding multiple users would be advantageous, as the meal time, as well as the number of staff in these institutions is limited. As elderly people are usually slow in eating, the idle state of a feeding device during one user's chewing and swallowing can be allocated for feeding another person sitting at the same table. The assignment of one feeding device to four people could potentially reduce the number of machines and nurses/caregivers used in feeding, as well as their associated costs.

In this paper, a multiple-user feeding robot for elderly has been designed based on users' characteristics and requirements determined through observations of seniors at a nursing home. The studies have resulted in the design of a food tray, selection of an appropriate robot, and a suitable user interface to facilitate the interaction of the user with the robot. The robot with the desired characteristics and requirements has been designed and simulated on computer. A vision system for recognition of various types of solid food has been tested.

OBSERVATIONS

The main objectives of the observations were to: *a)* determine the types of potential users of a new feeding machine b) determine the users needs, *c)* understand the user's behaviour and physical and mental capabilities, *d)* investigate problems that hinder eating or make it messy or lengthy, *e)* determine design constraints and features, *f)* inspect types of food served, and utensils and methods used to handle each food while eating, and *g)* obtain feedback from caregivers on the feasibility of possible user-system interfaces. The observations were carried out at a senior nursing home, the Village of Winston Park, Kitchener, ON, Canada. About 95 people, mostly 65 years of age and over, in both regular and special care units were observed during meal time. Since the focus of this design was to help those elderly with limited physical ability, the characteristics of the elderly with cognitive problems in a special care unit were not considered as the users' behavior was not consistent. The observation found that about 40% of this population was totally dependent on caregivers because of either no control on their head and neck, severe head tremor, or swallowing/chewing problems. Among the remaining 60%, more than 40% had hand tremor, lack of strength in grasping the utensil, or severe joint pain. They also had difficulties in directing the utensils toward the mouth. More than 40% could not cut or scoop food. About 12% of them used lipped plates with dividers for easier scooping. For each user, 3- 4 different kinds of food and dessert, and 2- 4 cups were used. About 40% to 60% of the foods were already cut into pieces and about 32% of the foods were pureed. Eating was considered fast if the operation of putting the spoon or fork into the mouth was between 4 to 6 seconds, and was slow if it required more than 10 seconds. More than 43% of the people were slow or very slow in eating. According to the caregiver's opinion, at the present time, there are many people who can benefit from being assisted by a multiple-user feeding device in their environment.

ROBOT AND FOOD TRAY SPECIFICATIONS

Food Tray

Based on the observations, a food tray was designed to hold four plates and cups, and one spoon and fork for each user, as shown in Figure 1. From possible shapes for the tray, the arc-shaped tray was chosen for the following reasons: 1) the robot can be located at the center of the arc to easily feed multiple persons; 2) scooping the food is easier compared to the square and round plate with 3-4 compartments (Figure 2); 3) the food trays can be postioned beside each other with one robot at the center for feeding multiple users (Figure 3); 4) the computations in determining robot position may be reduced. It was assumed that the robot always places the cups, forks, and spoons at the same position and orientation. The spoons and forks have holders to keep them in a predefined position and orientation. All the handles are cylindrical with the same diameter, and angle of 60 deg with respect to the flat bottom of the food tray, to simplify grasping The depth and inside shape of the food sections are specified according to the maximum required volume and the type of food. The design of the deep sloped plate, shown in Figure 1, matches well with the slope of the spoon while reaching food; and it provides a smoother path while the spoon is moving into and out of the food plate. The slope helps the fluid and semi-fluid foods to slide down to the deeper points and makes scooping easier. For foods that should be picked up by a fork, a flat plate is better. Some assumptions for operation are: 1) large solid foods are cut into bite-size pieces, 2) the fluid and semi-fluid foods are poured into the deep sloped plates and the solid foods are placed on the flat plates, 3) the user has control of the neck and head, 4) the user is in an upright position or sitting at an angle that is safe for eating, and 5) the spoon and fork are only used with the deep sloped and flat plates, respectively.

Robot

In order for the robot end-effector to reach any position inside the workspace in any orientation, the manipulator requires a 6-DOF robot. However, the desired system requirements such as type of robot, joints, length of links, workspace, maximum weight, payload and reach, are specified based on the users' characteristics and also on the feeding environment. Some other criteria that affect the decision of selecting this robot are: the desired configuration, dimensions of the table and food tray, the weight of the utensils and foods, and the anthropometric data of an adult in a sitting position [25]. Considering this information, a robot with 6-DOF was selected with the following desired characteristics: 1) it is small and light enough to fit at the center of a four-seat table with a diameter of almost 60 cm, 2) it can lift the weight of a full cup, spoon or fork, 3) it is able to rotate 350-360 deg about its base to be able to feed four different users simultaneously, 4) it is a serial articulated robot to provide a large workspace for multiple-feeding, and 5) the rotation angles of joints and the lengths of links provide a maximum reach between 800- 836 mm. The CRS-A465 robot with 31 kg weight, maximum payload of 2 kg at the end effector, and waist rotation range of -175 to +175 deg has similar characteristics. The robot's maximum reach is 711 mm without the end effector and 864 mm with a standard end-effector (not including the length of the spoon or fork). The three joint axes of the 3-DOF wrist intersect at one point. This has the advantage of providing a closed-form solution for the kinematic and dynamic analysis. A 3D model of the robot, table, and four food trays containing deep and flat plates and four cups for each user were modeled in ADAMS software (MSC Software), as shown in Figure 3.

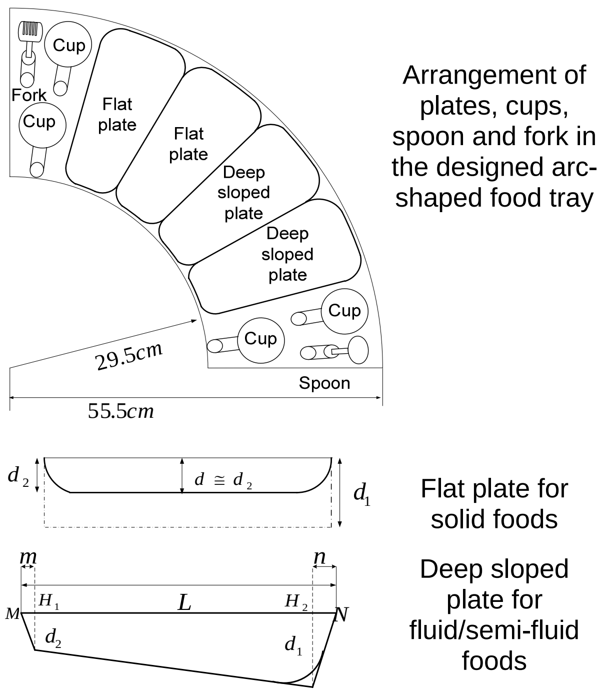

Figure 1. Food tray for each user.

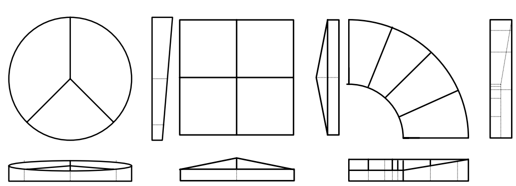

Figure 2. Possible shapes for food tray: circular, square and arc.

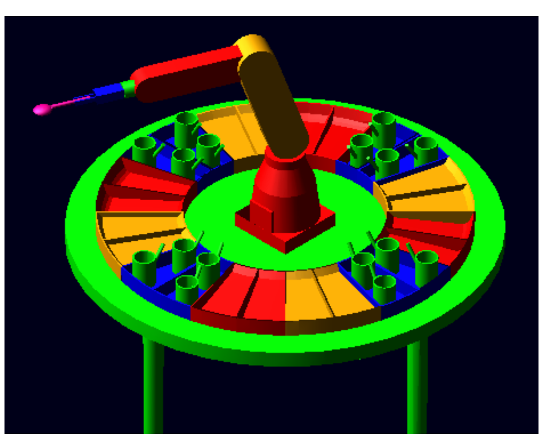

Figure 3. The 3D model of the robot located at the center of the table along with four food trays.

User Interface

The user interface should be applicable in a dining environment that is susceptible to food or drink spills and be usable for the elderly with different upper-limb disabilities. Among available interfaces, simple and reliable switches and buttons should be large enough, with large-print labels for elderly. Touch sensitive panels with no moving parts to wear can be completely sealed and impervious to food and drink spills, with no need for pushing power. Joysticks require power for manipulation and may not be suitable for people who omit stimuli from one side (e.g. stroke patients). Switches activated by chin, head, shoulder, or by biting or blowing into a tube [18-20] can be some alternatives. The feeding robot users can choose their commands on a monitor with the help of a laser pointing device [18-20] attached to the head; however, even minor head tremor may change its accuracy. Vision [17, 19, 24] and voice and speech recognition [17, 24] have already been applied in intelligent systems. However, eye blink, human emotion and intention, body gesture, head and eye movement, biosignals, facial or emotional expression and eye gaze have not yet been used for the purpose of feeding. Some information can be delivered to users in the form of light, signal, sound, animation and graphical images, to warn about unreachable locations, or approaching dangerous situations. Scanning the food tray (with light) [13,14], getting confirmation of receiving the command (for speech synthesis) [24], and command menu display (monitors, CRT displays and GUI) [18-20] could be used.

In general, some of these interfaces may not be suitable for a multiple-user feeding robot in a senior home. The chosen environment is noisy, the voice of elderly may be heard with difficulty, they may not be able to see all the characters or objects in variable lighting conditions; and they may have tremors in their head. For the proposed system, two or more users may issue a command at the same time and since they sit close to each other, differentiating their voices could be a problem. The sound output can likely be applied only in restricted conditions such as by using an earphone. Elderly may not be able to raise their hand properly and hold their fingers or hands in a specific configuration to communicate with the robot by a gesture. Furthermore, training people to assign the correct gesture and expecting them to remember them, would be beyond their abilities. One of the biggest challenges would be training such a population no matter what user interface would be used. Therefore, an interface that needs no or little training is highly preferable.

Vision

Application of vision reduces conflict with the disabilities of the users. A system failure would be caused by the program used, the lighting or background condition, but not from the users. An integrated vision system would be used for recognizing the position of solid food parts inside the flat plate of the food tray, checking the presence of cups and utensils in their places, and tracking the user's mouth. The present design includes two cameras located at the right side of each user, one for capturing food images and one for acquisition of user's face images. The soft food inside the deep sloped plate has no specific shape. As it may not be easily recognizable by image processing, the spoon moves in a predefined smooth path to sweep through the deep section and scoop up the food. A mouth-tracking agent specifies the closest safe point to the user's mouth where the end-effector should stop. The robot responds to commands based on the order they are received. In the case of receiving simultaneous commands, the robot interrupts the previous command only if it is in an idle state or it reaches the maximum waiting time for the other users. The robot changes its speed as necessary and may respond to the users based on a specific predefined priority.

CONCLUSION

Observations of elderly at a senior home were used to determine user needs for the design of a multiple-user feeding system. The anthropometric data of a typical adult user in a sitting position were used to design the robot workspace, table and food tray dimensions and locations. This verified that robot end-effector is able to reach user's mouth and all the points inside the food tray. The selected robot can be replaced with a robot with similar characteristics. In addition to 3D visualization, the virtual model helped in understanding the dynamic behaviour and control of the end-effector position of the robot during operation. At the present time, the developed image processing program is able to recognize and specify the fork insertion points for pieces of cut toast and sandwiches with acceptable accuracy. The current vision system would be integrated with the virtual model to test the capability of the overall system before performing experiments with a real robot.

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