Self-Feeding Robot for Elder People and Parkinson's Patients in Meal Supporting

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***Abstract*—Self-feeding robot is a smart assistive device for Parkinson's patients and people who cannot feed themselves. The self-feeding robot includes 3 main parts: rotate tray, 2 Degree of Freedom (DoF) grip arm, remote control. This device configuration not only provides an efficient and easiest way to manufacture but also spreading out more devices with affordable price. Besides, to help patients on their activities and improve metabolism better with nutritional diets, eating recommendation with the supporting of machine learning could enhance the ability of analyzed patient's nutritional consumption and give out diet recommendation directly instead of doctor advisor. The goal of this research was to employ a portable device to make disabled people who cannot eat by themselves now could have previously been served at meals completely or partially independent. With an independent manipulator, a rotate food tray easily control by only 2 simple buttons, highly integrated smart recommendation based on medical index and lightweight plastic fiber, self-feeding robot namely Feedbot is full of hopefully presented for handicapped person eating individuals not only particularly for Parkinson patients but also elderly and disable who have trouble in feeding their meals. Feedbot operated autonomously and wirelessly transferred meal records and relevant information to the software controlling in a mobile device. Furthermore, the reporting system can analyze data and suggest daily meals based on nutritional standards categories. Finally, Feedbot is a user-centered design product which allows to controlling robot's grip and food tray rotates followed the need of user and the user's height based on human anthropology.**

***Index Terms*—FeedBot, self-feeding, 2-DoF robot, manipulator, human anthropology**

I. Introduction

Nowadays, the development of modern technology has brought a more convenient life. According to statistics of United Nations Population Division, the world population's life expectancy is increasing, but birth rates are decreasing, hence the number of elderly people is increasing, and some individuals are unable to care for themselves because they are too weak. From several perspectives, the lives of handicapped persons and their families remain difficult. Parkinson's disease patients are classic examples of persons who are unable to care for themselves. Furthermore, according to a national forecast for 2025, many elderly individuals have Parkinson's disease, and they are quite concerned about bothering others in order to care for them. [1]. Many older adults struggle to do even the most basic daily chores. Machines and robots are currently being developed to assist the elderly and those with upper limb impairments or dysfunctions in regaining independence in one of the most routine and time-consuming daily activities [2]. Especially, eating is a basic need that they are eager to meet. In the twenty-first century, highly healthcare need of modern society requires a combination of many fields of technology like mechanical, electronic, internet of things and also artificial intelligence. The majority of these devices are used for supervising health indicators like heartbeat rate, blood pressure but less device for helping disable in eating, thus, supporting meal research devices was studied and released in recent years [3-9]. Although 6 DoF mechanical arm like human hand is complex due to the task it performed [5] and some is much easier for specific unique task [3, 4, 6, 7], all these indicators are now flexible and efficient with the need for update patient support and medical recorded process. The majority of individuals living in long-term healthcare services were being grown as number of the elderly population rises that healthcare system would be significantly impacted by the rapid demands of requirement. Elderly people frequently have health concerns that demand more assistance from family members or care workers in settings such as homes, nursing homes, or hospitals and update the newest status of patient in the medical record by cloud is importance than ever.

In this study, a robot manipulator named FeedBot (feeding based on robot) is developed for improving self-feeding and meal nutrition management in a variety of settings in nursing home and hospital depending on their characteristics and feeding demands. It allows users to eat independently at mealtimes and can also select their favorite dish after food has been prepared. The proposal robot evolves a manipulator robot arm, a single spoon for getting food from the three rotate bowls. The user scoops food from the bowls into a tray using the manipulator while keeping the spoon in the mouth [10]. FeedBot has a compact and portable size which is suitable for working on a flat table or any kinds of constrain horizontal surface. Users can easily operate FeedBot with the basic controlling interface by pressing and holding buttons of the remote control which allowed the user to feed oneself using a remote control or third company device. The

Manuscript received October 14, 2021; revised January 20, 2022.

doi: 10.18178/ijmerr.11.4.241-247

nutrition of the meal is recorded by software via wireless connection; as a result, the assistant or doctor has portion control in the meal and may change it as needed. The self-feeding analyzed data is being evaluated in hospital as well as through nursing home surveys. The results suggest of self-feeding system is a viable alternative for assisting independence in self-feeding based on financial balance and nutritional intake based on machine learning does relevant analysis and automatic control via the Internet of Things (IoT). A simple design was set five goals including reasonable price; easy to create and also common in use; application of artificial intelligence for meal recommendation and finally capable of supervising nutrient absorption. The

II. MECHANICAL CONFIGURATION

A. Fundamentals of Feeding Device

In the eating culture of the Asian countries, a daily meal conclude four type of food known as starch, main dished or stir-fry and soup. All of food served in separated dish, each person uses chopstick to grip and contain for their own bowl. Observing the daily meals of Asian families as well as in the health care centers for the elders or disabilities, bowls are commonly used in meals unlike European using plate and fork. The characteristics of the bowl are hemispherical shape, with a circular at the bottom of the bowl to constrain it on the flat surface. Usually, the daily meal bowl has 12 cm in diameter and the volume of about 250 ml. According to the report of Vietnamese National Institute of Nutrition, the number of calories required for the body for people over 50 years of age is from 2000 kcal for men, while for women is about 1600 kcal (apply for people who do not work much). Meanwhile, the nutrition of daily meal has to include adequate and diverse food groups known as carbohydrates, protein, fat, vitamins and minerals, for the elderly people, a balanced diet is much importance for recover the health while the organ functions were weakened due to aging. Feedbot converted and recorded the number of calories that the body can receive from the meal based on quantitative ingredient was on the bowl of 250 ml after each spoon of food served for user. With the above diet, to be sum of user can receive 570kcal per meal. Each day, the user can receive about 1700 kcal. Depend on the personal health index of the person, the caregiver can adjust the amount of food to suit the patient' status. Thus, with three bowls on the food tray not only can provide 3 type of complete food for the meal but also ensure enough calories for the patient at each meal and help caregiver could evaluate patient care process.

B. Initial Design Concepts

In this section, user-centered design has been created by 3 concepts. In the first concept, shown in Fig. 1a, the device includes two main parts: the independent manipulator grip and the rotate food tray. The meal tray is half-spherical in design, with sections for storing foods and the ability to turn around the center. The manipulated grip has two degrees of freedom which have been attached to a platform, and the bowl inside the tray can be removable for changing ingredients throughout the meal and simply washed. The second idea for the concept shown in Fig. 1b, the food tray was individually designed and separated from the device which the arm of 4 degrees of freedom is attached to the constrain base, the more of DoF (4 DoFs) means much more complicated singularity calculate than the two DoFs. Finally, for the third concept, a device consists of two manipulators shown as Fig. 1c which the food tray was separated from the two manipulators. The two manipulators has picked up and dropped food from the food tray before putting into the mouth. Concept of designs had to be lightweight, optimal and applicable for all uses especially disable also easy to elderly. Mention to the third concept (Fig. 1c), it uses a clamp for taking food from tray and gives it to second manipulator, the second manipulator uses a spoon to transfer food to the recipient that is required precise in manufacture design and spending long time to transfer food, moreover, food can fall due to food was moving from long distance.

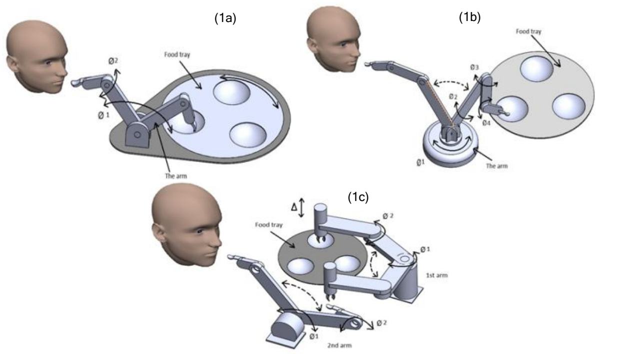

Figure 1. Mechanical configuration concepts for design.

The study aims to a simple design to assist patient supporting for their eating on their own for simplicity and lowest cost. Thus, the first concept shown in Figure 1a had met the requirement which shown the most optimal and most effective than the other ones. Feeding manipulator and a food tray are designed in the same base to make the system smaller and more neatness. It also brings convenience to all kind users and control by caregivers could simply place food on the tray and placed the appliance on the flat table as possible for the patient eating support. The use of the arm has two degrees of freedom making the device simpler to calculate and control, and also reduce the cost of equipment [3-4].

C. Kinematics of Robot

Depend on the design requirement as well as the research object, relevant configuration consist of arm which has two degrees of freedom and one degree of freedom for the rotatory tray. The kinematics of robot supports the control of movements of arm as well as tray to grasp and feed the food to users like as Fig. 2. Both solutions of forward and inverse are based on the Denavit - Hatenberg method with parameters shown in Table I. Two transpose matrices from the reference axis had replaced the D-H parameters in the matrix (1):

$$ {}^{n}T_{n+1} = \begin{bmatrix} c\theta_{n+1} & -s\theta_{n+1}c\alpha_{n+1} & s\theta_{n+1}s\alpha_{n+1} & a_{n+1}c\theta_{n+1} \\ s\theta_{n+1} & c\theta_{n+1}c\alpha_{n+1} & -c\theta_{n+1}s\alpha_{n+1} & a_{n+1}s\theta_{n+1} \\ 0 & s\alpha_{n+1} & c\alpha_{n+1} & d_{n+1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1) $$

According to Eq.1, rotated angle of first rotating pillows and rotating pillows 2 are performed by equation (2) and (3), respectively:

$$ {}^{0}T_{1} = \begin{bmatrix} \cos\theta 1 & -\sin\theta 1 & 0 & l1.\cos\theta 1 \\ \sin\theta 1 & \cos\theta 1 & 0 & l1.\sin\theta 1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

$$ {}^{1}\mathrm{T}_{2} = \begin{bmatrix} -\sin\theta 2 & -\cos\theta 2 & 0 & -l2.\sin\theta 2 \\ \cos\theta 2 & -\sin\theta 2 & 0 & l2.\cos\theta 2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

The position of the origin of the operation of the arm relative to the origin (z_0, x_0) can be determined by multiplying the two matrices ${}^{0}T_{1}$ and ${}^{1}T_{2}$.

TABLE I. THE DENAVIT – HARTENBERG PARAMETERS

#	l	α	d	θ	Variable
1	l_1	0	0	θ_1	θ_1
2	l_2	0	0	$\theta_2 + \pi/2$	θ_2

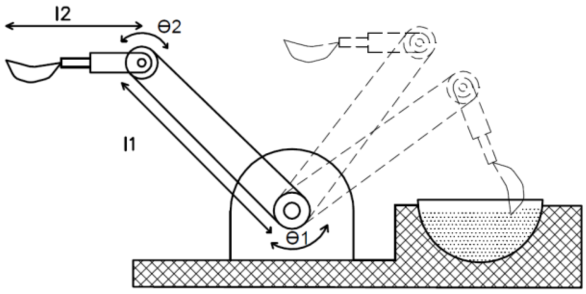

Figure 2. The workspace of FeedBot.

$$ {}^{0}T_{2} = \begin{bmatrix} -\mathrm{s}_{12} & -c_{12} & 0 & l_1.\mathrm{c}_1 - l_2.\mathrm{s}_{12} \\ c_{12} & -\mathrm{s}_{12} & 0 & l_1.\mathrm{s}_1 + l_2.\mathrm{c}_{12} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4) $$

The coordinate is defined with below equations.

$$ P_x = l_1.\cos\theta_1 - l_2.\sin(\theta_1 + \theta_2) \quad (5) $$

$$ P_y = l_1.\sin\theta_1 + l_2.\cos(\theta_1 + \theta_2) \quad (6) $$

$$ P_z = 0 \quad (7) $$

From above equations, the velocity matrix can determine with Jacobian matrix.

$$ \boldsymbol{v} = \begin{bmatrix} \dot{p}_x \\ \dot{p}_y \end{bmatrix} = J \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} $$

$$ = \begin{bmatrix} -l_1 \sin\theta_1 - l_2 \cos(\theta_1 + \theta_2) & -l_2 \cos(\theta_1 + \theta_2) \\ l_1.\cos\theta_1 - l_2.\sin(\theta_1 + \theta_2) & -l_2.\sin(\theta_1 + \theta_2) \end{bmatrix} \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} \quad (8) $$

For the values of P_x, P_y from the dynamic problem of the robot, inverse kinematics was calculated to find the positions of the rotation angles of the matches to any coordinate in the workspace of Robot. Sum of squares P_x, P_y is implemented for the purpose of simplifying the calculation equations. Then find the angle value θ_2 is:

$$ p_x^2 + p_y^2 = l_2^2 + l_1^2 - 2 l_1 l_2 s_2 $$
$$ \Rightarrow \theta_2 = \arctan\left(\frac{s_2}{\pm\sqrt{1 - s_2^2}}\right) \quad (9) $$

For each of the values θ_2, trigonometric formulas and rearrange is changed like as (10):

$$ \begin{bmatrix} l_1 - l_2 s_2 & -l_2 c_2 \\ l_2 c_2 & l_1 - l_2 s_2 \end{bmatrix} \begin{bmatrix} c_1 \\ s_1 \end{bmatrix} = \begin{bmatrix} p_x \\ p_y \end{bmatrix} \quad (10) $$

Values of $\sin\theta_1$ and $\cos\theta_1$ is defined by using Cramer formula.

III. DESIGN THE ELECTRICAL SYSTEM

Diagram circuit block of the device can be divided into three main parts: Supply part; Control part; Communication part. In this study, a remote monitoring system was being created for an appliance utilizing an Android-based Smartphone app (Fig. 3). In comparison to comparable systems, the suggested system does not require a dedicated server PC and provides a communication interface to monitor and manage the device with more than merely switching capabilities. The signal from this monitoring system makes use of wireless communication, including Bluetooth and WIFI transmission. The nutrient statistics of the meal are displayed, as well as the storage ratings. Initially, the data is transmitted by Feedbot via Bluetooth transmission, and the smartphone app receives it to analyze and display on charts all of the nutrients that the user had eaten, based on the list of nutrients provided by the assistant and the data received by robot, and the result of this analysis is stored in the smart phone's memory. That implies the assistant is responsible for entering the nutrient list of a meal into a smartphone app. Second, the web server is linked to a database through the use of the smartphone, and the nutritional data from the meal is saved in the database. Smart phone has pushed up the develop progress of cloud and IoT which mobile app built for Feedbot has some functions as set up a program follows routine meal (include time, scoop, nutrient…), in the mode setting for Feedbot, caregiver could find the data of meal was shown and storage during the meals for each spoon was served. Furthermore, the mobile app has functioned allowed to controlling Feedbot via internet and monitor meal used camera attached on the platform.

IV. Control and Communication

A. Control of System

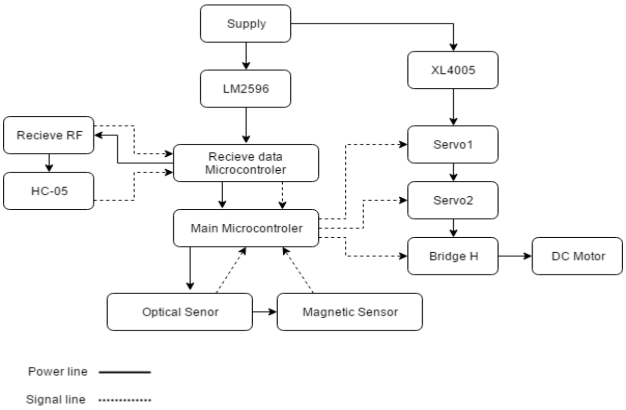

Figure 3. Diagram circuit block of the FeedBot.

The structure of the control system is a device that is programmed for the operating cycle and then receives the command from the control device via the RF signal that is also programmed as required to control those cycles. Besides, there are two Android and window applications to control the device remotely and set up modes for more efficient working as well as automatic mode settings for the device without pressing the button of the user. After receiving the signal from the control device or applications through the microcontroller which has a function to receive data, the central microcontroller outputs the pulse to control the two servomotors and outputs the pulse for H-bridge to control DC motors operate the program has been installed matching with each command from the application.

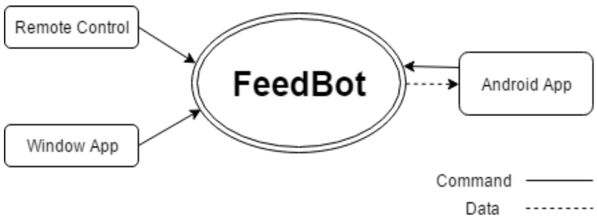

Figure 4. The overall block diagram of the system.

If no command is received from the application, the device can still operate in the default mode and is controlled by the control device via RF signal. At the end of the meal, the device will send the collected meal data to the application to determine the number of times, the dish has been eaten, the meal's time was eaten and combined with the nutritional data entered by the user over the application to calculate nutritional content and draw a chart. The overall block diagram of the system was shown in Fig. 4.

The program sets two joints of the manipulator to original location: reset the angle value of 2 RC motor if two joints are not in the original location. The value of the angle was reduced to move the arm to the original location. Program is set the initial position for the tray: If the first dish's position is different from the original be installed position, the tray would rotate to the correct position and stop by using the optical switch, reset the counting times of each dish. The arm was moved from the initial position to the position of feeding, with different types of food such as rice, porridge, soup, the scoop would being had different angle which could enhance the ability of assessment of meal during self-feeding [10]. For setting angle of arm, feed-bot control has been installed on the android or computer application for more optimal of feeding and mode different from each food to limit food to fall out and then move and bring food to feeding position. At the same time calculate the number of times of each dish. Program shakes the spoon to limit food to fall out when feeding: depending on the type of food that after feeding, the spoon would shake with different angles so that the food stuck outside the spoon falls down the dish and not to fall out when the arm moves up to feeding. However, if not installed what the type of food, the spoon would shake with default mode make sure the liquid stable and not fall a single drop. When receiving an auto-feeding signal with delay time after each times feeding and food type, the device will send the signal to start the meal on the android application to start calculating time to eat and arm will start automatically feeding by the number of times each dish received each time will be delay A period of time for the elder to eat because the time each person eating will be different, this time will depend on the user entered on android application. After setting the auto mode, the device would automatically be feeding the food until times of each dish equal zero, automatically return home position and send meal data as well as signal to finish the meal to android application. The main program: reads data from the microcontroller received RF signal to receive data from the remote control and control the device operating in the default mode.

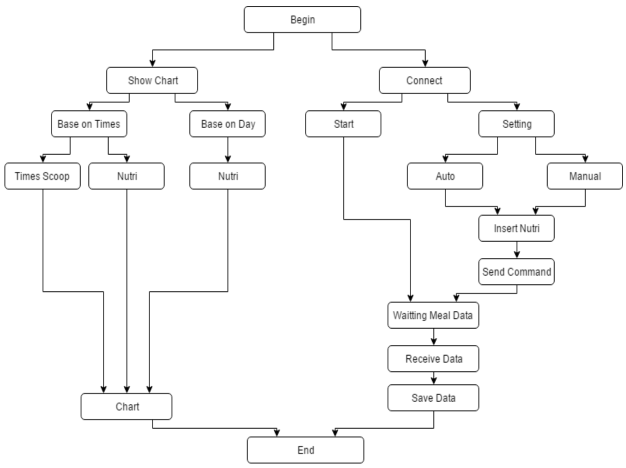

Figure 5. Mobile application flowchart.

Receiving data from the Bluetooth module to receive data from the android application and the computer to set advanced modes as well as run automatically and send meal data to the application for statistics, charting and counting time of a meal. First, the program receives a signal from RF or Bluetooth. After that checking which mode is requiring and saves this mode. Next step, the program checks the feeding position has been set yet if this position was set the program will go to the next step. Otherwise, check this step again, the next step would not performed until this position was set. After the feeding position was set, the program will send “Start” to android application.

B. Communication between Users and FeedBot

General diagram of app works as shown in Fig. 5. Two main modes of operation by mobile application are data retrieval for drawing nutrition charts and device connection modes for advanced settings for operation modes as well as enter nutritional value meals and data be collected from the device, saved in the smart phone’s memory. In the monitoring mode, there are options such as nutrition charts for times of each dish, time of the meal, the nutritional value of each meal or daily nutritional value statistics. In advanced settings mode, there will be a set type of food for each dish and automatic feeding, sending a command to set up the device then counting the time to finishing and receiving meal data from device sent up. The user can set 2 modes: manual and automation. In the manual mode, the user can choose the radio button on the screen to set the type of food type on each dish, including rice, porridge, and soup. The second mode as automatic mode, the user can choose the type of food on a typical food item, enter times of each food on the number of time item and the time has to wait for the next times. Besides, the user can send the nutrition of each food to monitor device. This value combines with times of spoon to calculate nutrition of the meal (can be ignored). The user can also send a command to the device and wait for device send data, times of spoon to application and calculate the nutrition of the meal. At the end of the meal, the application will receive the number of times each food is eaten. If the meal is entered the nutrition, the nutrient content is calculated and charted. The chart will be drawn a base on nutrition or times of each food and show time of meal on this page. Data was saved by date or meals to form the history of the time of meal and nutrition of meal by meal or day to monitor health.

V. Experiments and Discussions

This study aims to implement a framework to feed elderly people based on their features and dietary demands as determined by observations at a nursing home; moreover, the ingesting time and nutrition intake are monitored by a nutrients management tool for caretakers (Fig. 6). The majority of those who remained had hand tremors, joint discomfort, or a lack of hand muscular power, making utensil handling and coordination difficulties, as well as the eating process untidy and time-consuming.

Figure 6. FeedBot in designed model and developement of reality.

TABLE II. Technical Parameter of Feedbot

Feedbot	
General size	408 x 367 x 390 mm
Weight	1.0 Kg
Power supplier	9VDC
Manipulator	
Number of DoF	02
Actuator	RC motor
Speed of actuators	0.52 rad/s
Power	5VDC, 10A
Consuming power	6W
Index tray	
Number of DoF	01
Actuator	DC motor
Speed of index tray	0.9 rad/s
Consuming power	5W
Joystick	
Size	110x65x30mm
Weight	100g
Power	Pin 9VDC
Consuming power	0.4W

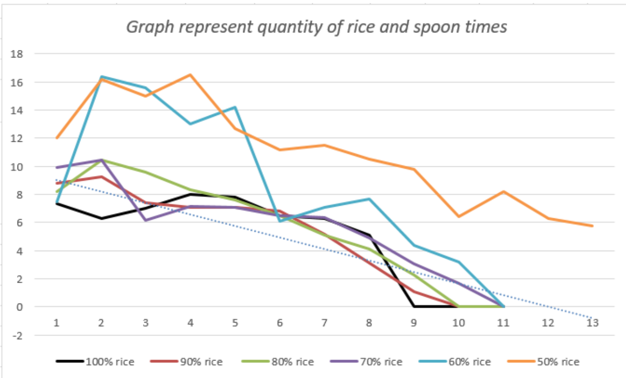

Figure 7. Graph represents the quantity of rice and picked times.

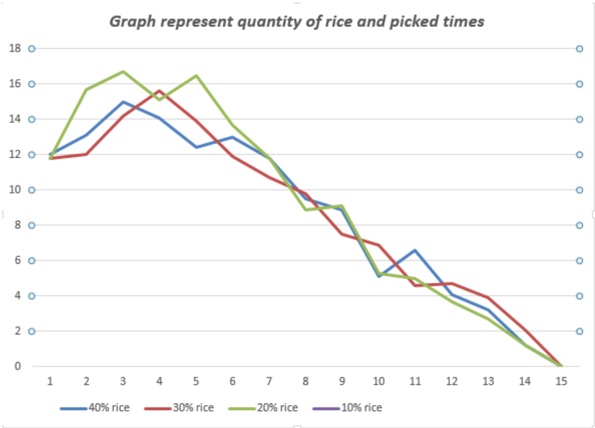

Figure 8. Graph represents the quantity of rice porridge and scoop times.

Furthermore, more than 40% of the elderly were very slow in eating-related to chewing and swallowing issues and the majority of the remainder were slow in scooping and guiding utensils toward their mouths. As a result, with the restricted number of staff members available, one nurse could attend to a maximum of two diners at the same time and handle the requirements of all senior customers. However, due to the short time allotted for each meal and the constant advancement of the seniors' infirmities, mealtime was extremely difficult. According to the caretakers, many seniors in such situations would benefit from a machine that can feed many people at the same time. Eating is a time-consuming process with elderly and disable, the idle state of the robot during one user's chewing and swallowing time can be used to feed another person sitting at the same table. Also, since the seniors dined together at a specific time at several four-seat tables, it would be ideal to assign one feeding device to a maximum of four people in such institutions in order to dramatically reduce the number, and consequent costs, of machines and nurses or caregivers. The observations and research led to the design of a meal tray, as well as the selection of an appropriate robot and application user interface. Supporting elderly with eating process, the suggested system employs a 2-DoF manipulator and an index rotated food tray with three bowls. The characteristics of a self-feeding system are shown in Table II.

Figure 9. The executed experiments at the nursing house

Rotate tray contains 3 bowls of food served for the meal, because of the tray can rotating so the arm's work just needs to coop the food at only one position. Feeding action is evaluated just need concentrated on two joints of robot arms. It employs a human-robot interface (HRI) to recognize user's face as requirements. An android application tool for a mobile phone was used for monitoring the self-feeding system and simulating the system as well as evaluating its dynamic behavior.

Following the construction of the self-feeding device prototype, we conduct a variety of experiments to establish the device's functionality. Food is utilized with a varied component rate (the density of rice), such as watermelon, rice, and rice porridge. The experiment was presented the findings and performance in the form of graphs in Fig. 7 and 8. Because rice is a dry solid food, the amount of food that the equipment cannot scoop is very large, accounting for around 35% of the original rice volume. The turns are also not in accordance with the rules. In this example, rice porridge in liquid state has little sticking, thus the amount of food falling and remaining on the bowl amounted for 15% of the entire amount of rice porridge originally. Similarly, sliced watermelon has a dimension of 1x1cm, and the surplus food content is roughly 20% of the starting volume. The testing findings indicate that the operational equipment would give excellent results for meals with a density of less than 60% by weight, low adhesion, and solid foods sliced to a maximum size of 1x1 cm. Eating assistance studies with the suggested human interface were carried out in collaboration with an elderly person. The trials were carried out in a nursing home in Ho Chi Minh City, and many regions of Vietnam, which the user is an elder woman sitting wheelchair (Fig. 9). The self-feeding device was placed on a normal table opposite the user. The table's height was changed to match the height of the user's wheelchair. Using her motorized wheelchair, the user approached the table. The evaluation experiments demonstrated that a user can feed the spoon of food and eat the meal using both the automated interface and the caregiver-programmed interface. The majority of people who took part in the tests provided favorable comments, and several were impressed that they were able to eat their chosen meal when they wanted to consume it. The most important function of these devices is feed to the patient; the feeding actions were divided into two-ingredient action which the first action is choosing what kind of food and the second action is feeding action.

VI. Conclusions

The design and develop the self-feeding device was not new in the world, but in Asian countries, it is the first time of cheap, simple, smart and has deeply focus on humanity value. Using this device named FeedBot, the elderly and people with disabilities would be easily independent in their meal, while reducing the burden of caregivers, apply the diet management software help caregivers and doctor have more information about patient's health and disables can be modified the diet to ensure the health of patients. The motivation for the development of the self-feeding device was presented. The design and development resulted in a high integration and a user-oriented design with many interaction possibilities. The self-feeding device with the proposal HRI was designed and developed as well as evaluation experiments was conducted. The self-feeding device is proposed used for people with physical disabilities who have limited arm function as elders and

Parkinson patients. During the design and development of the system, feedback from user provided the great meaning for caregivers, doctors, and nutrition experts. In addition, the experiments carried out to users to test and evaluate the reality of the system. The self-feeding system of affordable price, flexible control, and monitoring system is conceived and developed in this study utilizing an Android-based Smartphone/Tablet. For communication between the remote user and the system, the suggested architecture employs tool-based Web services as an interoperable application layer. To access and control the devices at home, any Android-based Smartphone with built-in Wi-Fi connectivity could well be utilized. In the absence of a Wi-Fi connection, mobile cellular networks can be utilized to access the system.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization and methodology, N.T.T and N.D.X.H; Software, visualization, validation, formal analysis and writing-original draft, N.D.X.H; Writing-review and editing, N.T.T; All authors had approved the final version.

Acknowledgment

This research was supported financially by the Ho Chi Minh City University of Technology and Education, Viet Nam.

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