A Study on the DOA, Accuracy and Facial Impact of Food Assist Robot for the Elderly and the Disabled

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***Abstract*—Industrial robots were operated in an independent environment and did not expose humans to direct danger. However, since the operation environment of robots such as human care and collaboration has changed recently, safety and performance of this robot are inevitably important. Therefore, in this study, we studied the care robots among the service robots that collaborate with humans collectively. First, we presented the autonomy judgment index of robots as an indicator for human risk management. In addition, we presented a method to determine the accuracy of motion through food assist robots among care robots. In order to prove this experimentally, the impact level limit was set and suggested through the collision test of the human face region.**

It is thought that this result can be provided as a valid indicator for developers and robot evaluators by identifying the degree of human injury in the development of care robot in the future.

***Index Terms*—care robot, risk management, DOA (Degree of Autonomy), food assist robot, motion accuracy, human injury**

I. Introduction

Ensuring the safety of people, assets and the environment is a necessary and difficult challenge for robots that work or service in close proximity to people. In general, when personal support robots are used in home and public environments, robots cannot respond to risk situations immediately and appropriately. In particular, problems arise when people come into contact with people who are not familiar with robotics, including children and the elderly. In particular, safety is a more important issue when personal support robots are in close contact with people to improve their quality of life [1], [2].

So far, robot manufacturers have carried out risk assessments to ensure safety by referring to the safety standards of machinery, ISO 12100 and ISO 13849-1. Given the nature of service robots that are autonomous in movement and interacting in close proximity to humans, there is a problem. To solve this problem, ISO 13482 has been enacted, which defines the safety requirements of personal support robots. As international standards for safety requirements for personal support robots are enacted, overseas markets such as Europe, China, Japan, and the Middle East require certification based on international standards [3], [4].

However, as with other industries, the lack of experience, evaluation processes, and measurement techniques has arisen in robotic test certification. In particular, the lack of safety of care robots, the most closely related human beings, can lead to death. Therefore, it is necessary to establish a safety verification process for care robots and to develop test measurement technology [5], [6].

Therefore, this article describes how to evaluate DOA of care robot among personal support robots. In addition, take a food assist robot among CARE robots as an example and explain the accuracy of movement and the degree of human injury, which are the most important parameters that can lead to a safety accident.

II. Materials and Methods

A. DOA (Degree of Autonomy)

The personal support robots studied in this study are shown in Fig. 1.

The ability to perform an intended task based on current state and sensing without human intervention is called autonomy. We should judge this, but ISO 8373, KS B 7301 and MFDS Guidelines, which are currently proposed as the basis for autonomy judgment, are very difficult and specific to judge autonomy through actual test evaluation.

First, Table I describes the grounds for judging the degree of autonomy of the newly proposed robot. Autonomy 0~2 is first executed by human operation, autonomy 3~5 is operated by sensing robot first.

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Autonomy is judged by early human intervention. In addition, autonomy from 6 to 9 is determined according to the working level of the robot. In addition, Table II describes the evaluation of the robot according to the autonomy evaluation as verification items and verification methods. It should be undertaken with risk assessment and risk reduction in accordance with ISO 13482 and ISO 13489-1 [7]-[9].

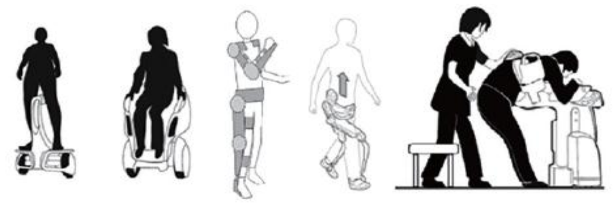

Figure 1. Personal support robot – care robot.

TABLE I. EVALUATION METHOD OF DOA

	Sensing	Start working	Operation	Alarm	Restore	Work Level
0	x	①H	H	x	x	Work (Human intervention O)
1	x	①H	R	x	x	
2	R	①H	R	x	x	
3	①R	R	R	x	x	Work (Human intervention X)
4	①R	R	R	R	x	
5	①R	R	R	R	FR	
6	R	R	R	R	FR	Plan+Work
7	R	R	R	R	FR	Plan+Work +Environment
8	R	R	R	R	FR	Plan+Work +Environment +Risk detect
9	R	R	R	R	FR	Plan+Work +Environment +Risk detect +Restore

※ H : Human, R : Robot, FR : Feedback Restore

TABLE II. VERIFICATION METHOD OF ROBOT

CODE	VERIFICATION ITEM	VERIFICATION METHOD
A	INSPECTION	Visual inspection
B	TEST	Performance test
C	MEASUREMENT	Measurement comparison test
D	OBSERVATION	Observation during operation
E	INSPECTION	Structure review including specifications
F	S/W	Structure review for S/W
G	RISK MANAGEMENT	Review for risk analysis table
H	DOCUMENT	Review for related document

B. Accuracy of Motion

There are several ways to measure the motion accuracy of the robot. In particular, since the care robot can pose a danger to the human body when the accuracy is not reliable, the operation accuracy is a very important parameter. There are several methods which are used for characterizing robot performance in accordance with ISO 9283 [10]. These methods are classified as follows:

1) Positioning test probe methods
2) Path comparison methods
3) Trilateration methods
4) Polar coordinate measuring methods
5) Triangulation method
6) Inertial measuring method
7) Coordinate measuring methods
8) Path drawing method

We used the single laser tracking method, one of the path drawing method techniques. This test method is used when several assumptions are prioritized

The assumption is as follows.

First, only position (or orientation) tan be measured in pose characteristics testing. And, Path characteristics (linear or circular) tan be measured only along restricted.

Robot performance testing is defined in ISO 9283. This standard is setting different performance criteria for industrial robot and suggesting test procedures in order to obtain appropriate parameter values. The aim of this standard is providing technical information to help users to select the most convenient robot for their purposes. Care robots with manipulator functions can also use this standard. His standard defines important principles based on the path, and then different appearances will be seen to evaluate them. These principles are approximate accuracy of the path, absolute accuracy of the path repetition ability of the path rapidness specifications and corner variable.

Accuracy represents the deviation from the average of the arrival positions when approaching the command position in the same direction. This is expressed as a formula:

Positioning accuracy:

$$\mathrm{A}P_P = \sqrt{(\bar{x}-x_c)^2 + (\bar{y}-y_c)^2 + (\bar{z}-z_c)^2}$$

$\bar{x}, \overline{y, \bar{z}}$: Coordinates of a cluster of points obtained by repeating the same pose n times

x_c, y_c, z_c: Coordinates of the command pose

x_j, y_j, z_j : The coordinate of the jth arrival pose

Iteration accuracy indicates how close to each other the position reached after n iterations of the same instruction in the same direction.

Position repeat precision:

$$\bar{I} = \frac{1}{n}\sum_{j=1}^{n} I_j$$

$$I_j = \sqrt{(x_j-\bar{x})^2 + (y_j-\bar{y})^2 + (z_c-\bar{z})^2}$$

$$S_I = \sqrt{\frac{\sum_{j=1}^{n}(I_j - \bar{I})^2}{n-1}}$$

Distance accuracy is expressed as positioning and direction deviation between the command distance and the average of the execution distance.

Distance accuracy:

$$\mathrm{A}D_p = \bar{D} - D_c$$

$$\bar{D} = \frac{1}{n}\sum_{j=1}^{n} D_j$$

$$D_j = |P_{1j} - P_{2j}|$$

$$= \sqrt{(x_{1j} - x_{2j})^2 + (y_{1j} - y_{1j})^2 + (z_{1j} - z_{2j})^2}$$

$$D_c = |P_{c1} - P_{c2}|$$

$$= \sqrt{(x_{c1} - x_{c2})^2 + (y_{c1} - y_{c2})^2 + (z_{c1} - z_{c2})^2}$$

x_{c1}, y_{c1}, z_{c1} : P_{c1} coordinates used in robot controller
x_{c2}, y_{c2}, z_{c2} : P_{c2} coordinates used in robot controller
x_{1j}, y_{1j}, z_{1j} : P_{1j} coordinate
x_{2j}, y_{2j}, z_{2j} : P_{2j} coordinate
n : number of times

Finally, repeatability is expressed as a closeness of agreement between multiple reach distances repeated in the same direction n times for the same command distance.

Distance repeat precision:

$$\mathrm{RD} = \pm 3\sqrt{\frac{\sum_{j=1}^{n}(D_j - \bar{D})^2}{n-1}}$$

$$RD_x = \pm 3\sqrt{\frac{\sum_{j=1}^{n}(D_{xj} - \overline{D_x})^2}{n-1}}$$

$$RD_y = \pm 3\sqrt{\frac{\sum_{j=1}^{n}(D_{yj} - \overline{D_y})^2}{n-1}}$$

$$RD_z = \pm 3\sqrt{\frac{\sum_{j=1}^{n}(D_{zj} - \overline{D_z})^2}{n-1}}$$

As a result, the error rate of these four parameters is closely related to the degree of human injury. If the error rate of these parameters is minimized, human injury can also be minimized.

C. Facial Impact Test

This modelling is based on the notion that for a given contact scenario between a robot and operator, the body contact region and the contact area are known, and the energy transfer can be modified by adjusting the robot velocity at the point of contact. Although this research was performed using state-of-the-art testing techniques, the values shown here are the result of a single study in a subject area that has not been the basis of extensive research. There is anticipation that additional studies will be conducted in the future that could result in modification of these values. Testing was conducted using 10 healthy adult test subjects on 7 specific facial region, and for each of the facial region, pressure and force limits for dynamic contact were established evaluating onset of pain thresholds. The maximum permissible pressure values shown here represent the 75th percentile of the range of recorded values for a specific facial region [11], [12].

They are defined as the physical quantity corresponding to when pressures applied to the specific body area create a sensation corresponding to the onset of pain. Peak pressures are based on averages with a resolution size of 1 mm2, The study results are based on a test apparatus using a flat (1,4 x 1,4) cm (metal) test surface with 2 mm radius on all four edges. For each body region, the maximum permissible energy transfer can be calculated as a function of the maximum force or maximum pressure values [13], [14].

Once the energy transfer limit value for the contact scenario is established, it can be used to identify the maximum speed at which the robot would be able to move through the collaborative workspace, while maintaining potential pressure and force values below the threshold limits, if contact between the collaborative robot system and operator were to occur [15], [16].

The assumption behind the derivation of the speed limit for the contact is to equate the spring energy of the human body region to the total kinetic energy in the centre-of-mass coordinates, assuming fully inelastic contact.

III. Results

A. DOA Evaluation

In addition to the care robot, Table I can be applied to all existing robots. If a person operates a robot, the DOA is divided into 1 and 2. For example, if a person first starts a robot and the robot simply works on it, its DOA is 1. DOA 1 has sensing, but if you simply work on it without feedback, the robot's DOA is 2. Starting from DOA 3, the robots operate by themselves through sensing functions. If the robot works by itself and performs its work, its DOA is 3. In DOA3, the robot's DOA is 4 if it has the ability to consistently provide feedback about its performance. In DOA4, the robot's DOA is 5 if it can self-repair of the wrongly performed task through the constant feedback of task performance. This is the robot's DOA that we're talking about in general. From this next stage, the concept of artificial intelligence is combined. DOA 6 is equipped with the concept of artificial intelligence, where the robots themselves plan and carry out their work. In DOA 6, it is DOA 7 to change or plan the work and carry out the work according to the change of environmental factors. In DOA 7, it is DOA 8 that detects risks, plans work on its own, and takes action. In DOA 8, DOA 9 is a self-healing feature that requires repairs from any risks while performing work.

B. *Accuracy of Motion Test*

The food assistant robot used OBI, a US product. The process of robot movement to measure the accuracy and precision of a food assist robot is shown in Fig. 2. The test was carried out 30 times and measured only when the success rate was determined by the user after the test. In addition, for the sake of accuracy, the plates were measured when they were not moving with 10 N force applied in various directions. Table III shows the test conditions for the position and precision of the food assist robot. We considered the test conditions at 0% and 100% load on the tableware for data accuracy. We also used a laser reflector attached to the tableware and a radar tracker to track it for accurate testing. As a result, under the same test conditions, the accuracy and precision of the Table IV were obtained.

Both position accuracy and distance accuracy show less than 1% error. As a result of less than 1%, it can be seen that the body impact energy value to be tested next is reliable. As a result of this test, we chose distance accuracy as the most important parameter for paralyzed patients to eat. The accuracy of the distance is also an important parameter, but the precision of the distance is given priority in actual user evaluation. In addition, path accuracy and path traceability were not important parameters for the final meal. However, the accuracy of the path can be used as an indicator for evaluating the performance of the robot, but it was not an important indicator for the evaluation of meal efficiency. Therefore, the accuracy of the route was excluded from this test, and it was also excluded from the evaluation index of the food assist robot. Other types of food assist robot should use this same test conditions.

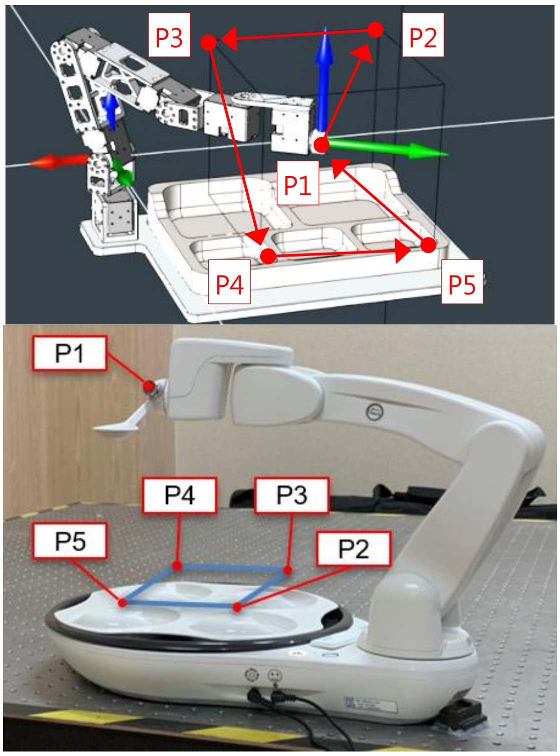

Figure 2. Test path setting: position accuracy, precision.

TABLE III. POSITION AND PRECISION TEST CONDITION

Test item	Load	Speed	Position	Number of cycle
Position accuracy & precision	0%	1 %~100 %	P1-P2-P3-P4-P5	30
Distance accuracy & precision	100 %	100%	P1-P2 & P2-P4	30
Test Picture				

TABLE IV. POSITION AND DISTANCE MEASUREMENT DATA

Test item	P1	P2	P3	P3	P5
Position accuracy	4.05	6.98	8.58	6.38	8.43
Position precision	0.51	0.71	0.70	1.40	0.47
Distance accuracy	0.43				
Distance precision	0.66				

C. *Facial Impact Test*

A premise of a risk assessment for power and force limited food assist robot applications is that incidental contact between parts of the food assist robot and user can occur. For this test, a facial model was created that included seven specific face areas, classified as face areas. The material of the manufactured facial model is a human body silicone material according to IEC 60601-1 5.4. In addition, the size and shape of the facial model is used as the size of the Korean human body size data. The data used were 30 years old and male faces. There are seven measurement locations, forehead, eyes, nose, lips, chin, cheek and neck. The measurement position is indicated by red dot in Fig. 3.

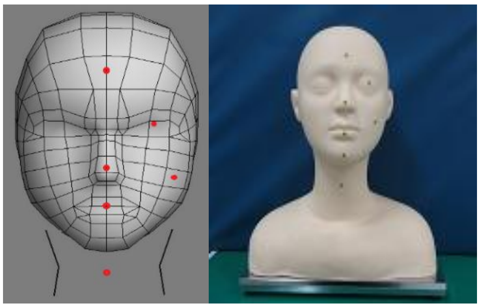

Figure 3. Facial impact test point.

TABLE V. TEST CONDITIONS OF FACIAL IMPACT TEST

Item	Facial hardness & contact impact	
Temp.	(23±2) ℃	
Humidity	(45±3) % R.H.	
Test time	10	
Test subject	Dummy & 5 man	Dummy
Test picture		

TABLE VI. FACIAL IMPACT ENERGY LIMIT

Body region	Transferred energy	Hardness of facial model structure	Hardness of Man face
Forehead	1.25	51.9	44.7
eyelid	0.19	8.1	6.0
nose	0.44	18.5	16.5
cheek	0.69	28.8	25.4
Lips	0.62	26.2	22.3
chin	0.97	40.6	32.1
neck	0.51	21.2	12.8

Test conditions of facial impact test is shown in Table V. All test conditions are room temperature and the number of tests is 10. In addition, the test was conducted using a human face dummy as shown in Table V. In addition, the hardness of the produced face model is shown in Table VI. And, this table shows the allowable pressure value of the human facial region with respect to the spoon used in the actual meal. These measurements can be important factors in determining the speed, power, and design of a food assist robot. Therefore, in order to prevent the user's risk, the developer should design not to exceed this limit, and the test standard developer should consider the following test results in the care robot test guideline. Biomechanical limits are set forth to prevent biomechanical load initiated by robot motion to create a potential for minor injury to an operator in the event of contact between the operator and the robot. There pressure values can be used to estimate transient pressure and force limits using conservative estimates established by studies. [17]. The transfer energy resulting from hypothetical contact between a robot and human can then be modelled, assuming fully Inelastic contact between the robot and the user and taking into account the payload capacity of the robot and factors associated with the user's body part undergoing contact Once the transfer energy is established, speed limit recommendations for robot motion in the care robot workspace can be established to maintain the transfer energy at a level below a threshold of minor injury to a human in the event of contact between the robot and user in the care robot workspace [18], [19].

The transferred energy transmitted to the face from the impact of the face of the food assist robot is given by the following equation. From this result, the impact energy delivered to the body depends on the hardness of the body. These values can also be used as energy limits for other types of robots as well as care robots, which are food assist robots [20], [21].

$$E = \frac{1}{2}\,kmv^2$$

$$k = \text{facial hardness constant}$$

$$m = \text{mass including food (200g)}$$

v = robot speed 0.4 (m/s)

D. *Reliability Testing for the Test Results*

Robust statistics were used to validate the study results. This statistical methodology lends itself well to testing experimental results and analysis data, having outliers such as repeat test for the same experimental group. The robust validation of position accuracy and precision tests yielded more than 95% reliability at 10 repetitions, with Z-scores of 0.87 and 0.95, respectively. The Z-score for the facial impact test was 0.98 [22].

If the Z-score converges to zero, the confidence level of the test results is greater than 95%. Therefore, test results are very consistent or satisfactory, with levels above 95% confidence. [23], [24].

Table VII shows the Z-score results that guarantee the test results using robust statistics.

TABLE VII. RELIABILITY VERIFICATION THROUGH ROBUST STATISTICS

Parameter	Position accuracy	Position precision	Facial Impact
Number	10	10	10
Z-score	0.87	0.94	0.98

IV. CONCLUSIONS

The following conclusions can be drawn from the First of all, the application of ISO 13482, the safety standard for personal support robots, is not yet specific in the autonomy of robots. Therefore, it is necessary to secure the autonomous judgment index and verification method of personal support robot through this study. The indicators and verification methods we present are not perfect, but they are certainly the most advanced assessment methods to date. What we haven't decided yet is whether we should distinguish autonomy by characteristics and purpose of robots according to industrial structure, or whether we should apply this evaluation method to robots as a whole [25], [26]. This is believed to require further research.

The accuracy part of the robot is a method-by-method selection based on the already developed test standard ISO 9283. However, it is clear that the accuracy of the robot and the impact energy level are closely related to each other, so we must have a minimum margin of error. Only then, the energy impact level indicator can be valid.

In addition, in order to prevent injury to the human face, the accuracy of the user of the robot should be clear, and when this accuracy is prioritized, the energy limit should be considered. This research method can be applied not only to food assist robots, but also to overall care robots. The facial model is a means by which integrators of care robot (: food assist robot) systems can use scientific principles to set appropriate limits associated with risk assessments on power and force limited care robot operations. This is a new field of study and is the subject of ongoing investigation and research. Furthermore, the facial model is presented as a means whereby a robot integrator can apply scientific principles and a standardized approach to considerations pertaining to a risk assessment involving a hypothetical contact situation between a user and a power and force limiting robot.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization, S. Yuk. And I. Moon; methodology, I. Hwang and J. Ryu; software, S. Jung; validation, W. Yu; formal analysis, J. Hwang; investigation, S. Yuk; resources, S. Yuk; data curation, J. Hwang; writing-original draft preparation, S. Yuk; writing—review and editing, I. Moon; visualization, S. Yuk; supervision, S. Yuk; project administration, S. Yuk; funding acquisition, I. Moon.

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