Design of a demonstration space, the "Living Lab," for monitoring daily activities in the older adult and the assessment of assistive technologies

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Abstract. In this study, we designed and constructed a demonstration space, Living Lab, with specifications that can simulate daily life in a typical house or small nursing home. The basic concept is to provide a living space equipped with an entrance, living room, dining room, kitchen, bathroom and restroom within which the typical daily activities of an elderly individual can be evaluated. To safeguard against falls, the living space contains a suspension system. The size of the restroom and bathroom can be changed as required to simulate either the home or the nursing home environment. The Living Lab can also be used for training as part of a rehabilitation program prior to discharge from hospital, and also serves as a safe place to demonstrate new nursing-care devices and robots as they are developed.

Keywords: Life space, Life scenario, Suspension device, Outdoor activity, Motion analysis

1. INTRODUCTION

The shortage of nursing care personnel due to an increase in the proportion of the elderly population and a declining birthrate has become an urgent and critical issue not only in Japan but also worldwide. In response to a super-low birthrate and an aging society, a new way of caring for the elderly needs to be developed; one solution to this problem is the introduction and standardization of robot technology and information and communication technology (ICT) in the nursing care field [1, 2]. We believe that this will improve the quality of nursing care and reduce or prevent the worsening of care conditions, and therefore that it is time for robots to play a more significant role.

Table. 1 Conceptual design of a model room for evaluating daily life activities.

Area	Basic concept	
	Design	***Objective***
Indoors	Provide life spaces (entrance, living room, dining room, kitchen, bedroom, washroom, bathroom, restroom)	Simulate the home environment
	Make the sizes of restroom and bathroom adjustable	Simulate nursing home
Outdoors	Provide stairs and slopes, as well as various flooring materials	Simulate outdoor activity
Both	Provide spaces where subjects can safely perform activities of daily living	Ensure safety

The term "living lab" is used as a network for interaction between scientists and older adults to improve quality of life [3], while in other literature the term is used as a vehicle for demonstrating fall prevention [4]. Groups such as the European Network of Living Labs (ENoLL) that collaborate in a broader sense have also used the term [5]. In our work, we use "Living Lab" to describe a model space that we use to simulate daily life and also as a place for rehabilitation. The purpose is to clarify the support needed to make the lives of older adults more comfortable. Here, we have built on our previous empirical studies [6, 7] by designing and constructing a Living Lab with specifications that can simulate daily life in an ordinary house or a small nursing care facility. A

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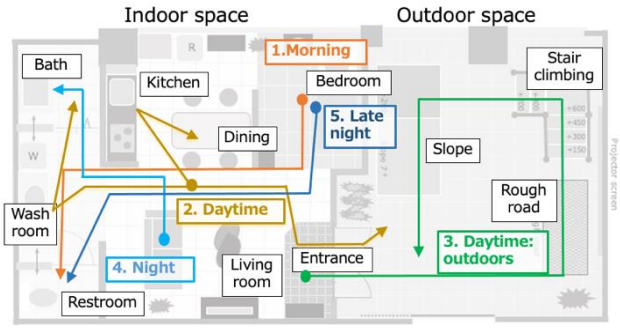


Fig. 1 A study area for the realization of various life scenarios: the Living Lab. By considering scenarios that start from a specific location, a range of behavior associated with everyday living can be observed and assessed.

specific aim is to verify the effectiveness of robots for assisting daily life in a setting that matches as far as possible the normal scenarios of the target individual.

2. METHODS

2.1. Conceptual design of a model space for validation of assistive technologies in daily life

The concept for the design of the model space was to simulate both a home and a nursing home. As shown in Table 1, this provides an ordinary life space equipped with a living room, dining room, kitchen, washroom, bathroom and restroom as well as an outdoor space (Fig. 1).

2.2. Demonstration scenarios

Possible daily activities associated with each location in the Living Lab were prepared as scenarios and appropriate equipment was installed. We derived relevant scenarios from events that take place in the morning, daytime and nighttime in the home and nursing-home environments, and found that some activities were common to both environments (Table 2). Typical scenarios include a series of activities from waking up to washing and toileting, or taking a bath. When imitating the home, scenarios around the kitchen and clothes washing were considered important, while in the nursing home, where a more intensive care regime was required, scenarios including caregiver assistance were considered important. When we hypothetically placed the scenarios in the Living Lab as shown in Fig. 1, we found that it was possible to conduct wide range of activities in the room apart from long-distance travel. Here we give some sample scenarios.

Sample scenarios

Morning: indoor activities beginning in the bed room

- The subject gets up, walks from the bed to the closet to obtain a change of clothes, then performs dressing and toileting activities.

Daytime: indoor activities around the living room

- The subject sits on a sofa, becomes aware that the water is boiling in the kitchen, so he/she hurries to turn off the heat/electricity.

Table. 2 Selection of scenarios that simulate daily living at home and at a nursing home

	At home	*At nursing home*
Morning	Morning preparations (getting up, changing clothes, dressing, toileting[a])	Same as on the left
Daytime (indoor activities around the living room)	Meal and medication management	Same as on the left
	Cooking in the kitchen[a]	Meeting with family
	Washing[a] and drying clothes	Handicraft
	Dealing with a courier	Events
Daytime (outdoor activities)	Travel outside the home (shopping, strolling)	Same as on the left
	Stair climbing, walking on rough surfaces, gardening	Gardening, shopping, taking a walk
Evening	Bathing[a]	Same as on the left
	Getting ready for bed (medication → changing clothes → going to bed)	Same as on the left
Late night	Toileting[a] at night	Same as on the left

a. A water supply was not available for the kitchen, restroom or bathroom, which might limit some scenarios associated with these areas.

- The bell rings and a courier arrives, so the subject gets up from the sofa and goes to the entrance, signs for the parcel and returns with it to the living space.
- The family comes to visit, the subject goes to the entrance in a wheelchair and greets them.

Daytime: outdoor activities

- The subject goes out through the entrance and into the garden, and waters the plants with a hose.
- The subject climbs the steps and when the subject reaches the top, he/she is about to stumble and fall.

Evening: indoor activities

- The subject is in the bathtub, but finds it difficult to get up and get out.
- The subject takes his/her usual medicine, brushes his/her teeth, changes into his/her pajamas and goes to bed.

Late night: indoor activities beginning in the bedroom

- The subject wakes up in the middle of the night, turns on the light, and uses the walker to go to the bathroom.

2.3. Particular design points

The Living Lab was designed with many points in mind so as not to interfere with the subjects' activity, which is indicated by numbers refer to activities and letters refer to equipment in Fig. 2 and Table 3, respectively.

Table. 3 Features of each scenario implemented in the Living Lab.

	Indoor	***Outdoor***
Activity-based equipment	1. Provide sufficient space besides the bathtub for caregiving activities	5. Training on stair risers and ramps
	2. Match the type of the chair with that normally used by the subject	6. Projection of scenery and background on wall surface
	3. Adjust table height to suit the subject's preference and needs	7. Challenge with several types of rough surface (slippery tile, stone, etc.) or simulate a pedestrian crossing
	4. Secure space for a wheelchair; side wall can be moved to enable verification	
Equipment-based activities	A. Wall height, about 1 m, and fenestration of some interior walls	D. Play with pets, enjoy the garden, or simulate gardening activities
	B. Daily activities starting from the living room with sofa and TV	
	C. Ability to meet couriers across boundary stile	

2.4. Development of a study area for safe practice

In the Living Lab, a fall prevention device (Yorisoi Robot[1], Sanyo Homes Corp., Osaka, Japan) that uses a suspension system has been made available almost everywhere within the main living space to ensure safety. Fig. 3 shows a partial rail arrangement and a photograph of the actual system. After detecting acceleration due to a fall, the system immediately applies the brake, and the subject is slowly lowered to the floor, which is expected to prevent any trauma caused by the fall.

2.5. Motion analysis of daily life activities

To measure the stability, accuracy and proficiency of movements and activities associated with daily life, the Living Lab was equipped with a markerless motion-capture (mocap) system, Theia 3D[2] (Theia Markerless, Inc., Kingston Ontario, Canada), whose measurements should not interfere with the subject's activities. For the analysis, 10 video cameras (SONY digital still camera, DSC-RX0M2[3]) were installed around the bedroom as shown in Fig. 4A.

3. RESULTS

3.1. Specification of the Living Lab

The completed Living Lab meets the following specifications (Fig. 1):

i. The entrance is equipped with a wheelchair-sized tiled floor and stile to allow shoes to be put on and taken off, and the door is designed to allow the suspension system to pass through.

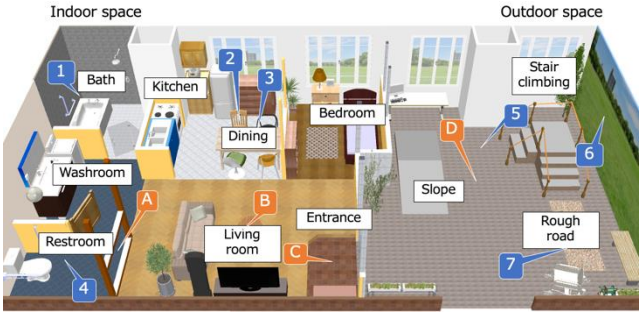


Fig. 2 Three-dimensional representation of the Living Lab, which aims to put various scenarios into practice. Points relating to several activities and associated equipment are indicated in the figure by numbers and alphabetical characters, respectively, as described in Table 3.

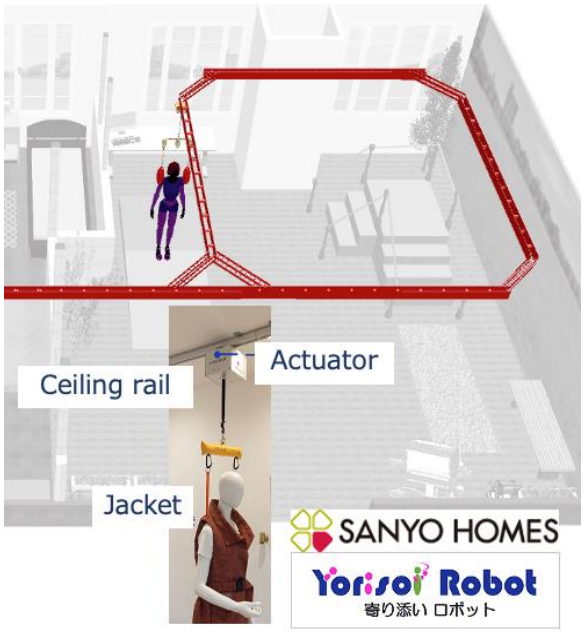


Fig. 3 A suspension system, "Yorisoi Robot," distributed throughout the main living space of the Living Lab.

ii. For the living room, the layout and equipment were selected so that the occupant can sit on the sofa, operate the TV, and use the table even when wearing the jacket of the suspension system.
iii. The dining room layout and equipment selection allows the user to carry food from the kitchen to the table, and eat and drink while seated in a chair using the jacket.
iv. For the kitchen, a sink, stove, and other equipment were selected to allow for food preparation and cooking while wearing the jacket.
v. The bedroom is equipped with space for getting in and out of bed, changing clothes, and putting on and taking off the jacket of the suspension, as well as space for a wheelchair or walker.
vi. Toilets are equipped with a toilet bowl, toilet seat, and toilet paper holder, and sufficient space to allow toileting activities.

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[1] Sanyo Homes homepage: https://www.sanyohomes.co.jp/life_support/yorisoi_robot/

[2] Theia Markerless, Inc. homepage: https://www.theiamarkerless.ca/

[3] Sony Group Corp. homepage: https://www.sony.jp/cyber-shot/products/DSC-RX0M2/

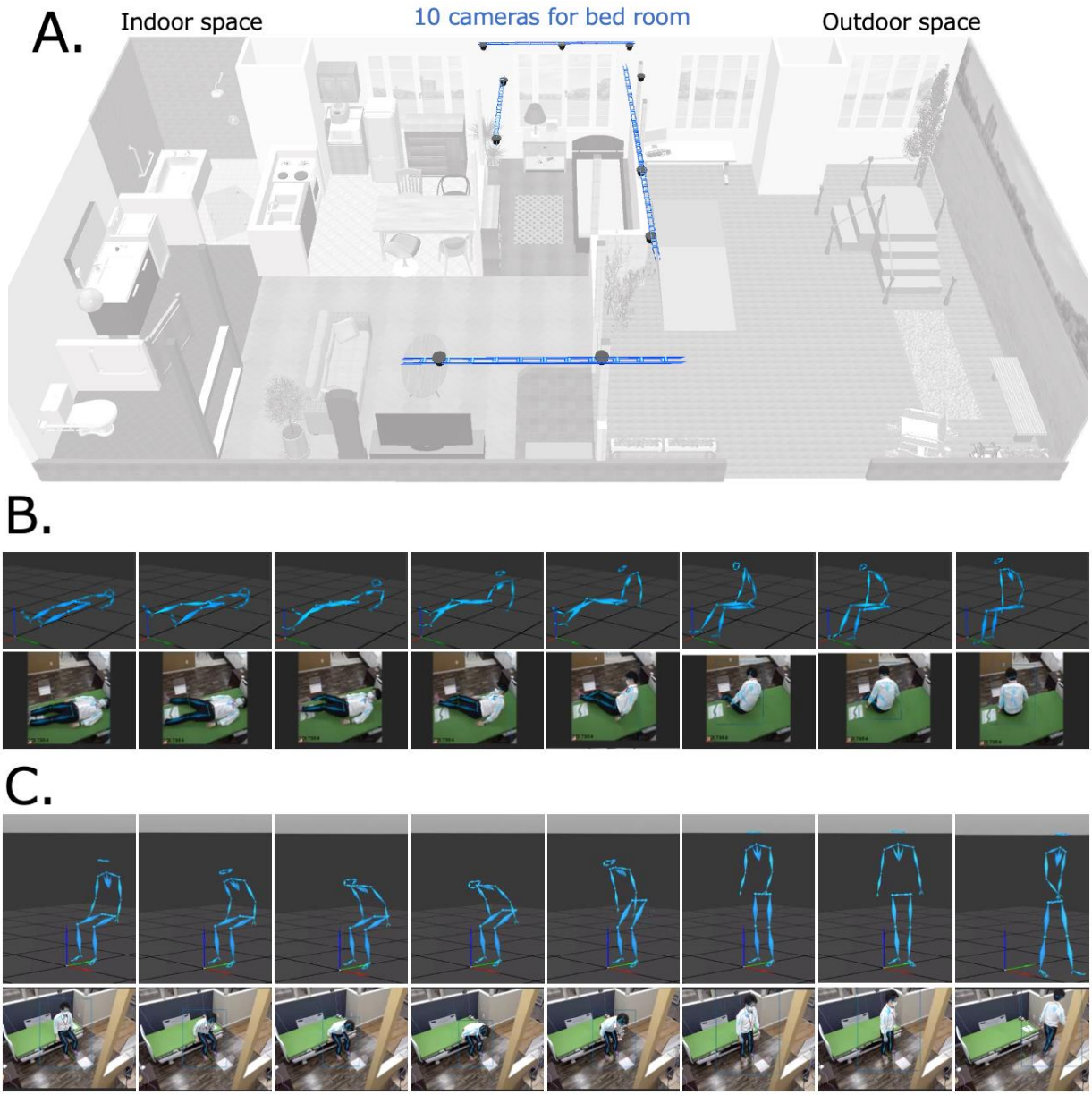


Fig. 4 Markerless motion analysis system. The location of the 10 video cameras in the bedroom is shown in A. Two series of video images and corresponding stick pictures produced by the markerless motion-capture system are shown. B, A subject getting up from the bed; C, A subject getting up from the bed and walking away.

vii. The washrooms has a washbasin and a washing machine to simulate face washing, clothes washing, dressing, and undressing.

viii. The bathroom is equipped with a bath unit, and sufficient space to allow bathing while wearing the jacket of the suspension system.

3.2. Design feature of the Living Lab.

We designed the space so as not to interfere with the daily activity of each subject. This resulted in a number of features, which are presented below and are labelled with numbers and alphabetical characters in Figure 2 and Table 3.

Space provided for daily life activities

Indoors:

1. To provide sufficient space beside the bathtub for caregiving activities, the wall in front of the bathtub slides to increase the available area.
2. To match the type of chair normally used by the subject, four different types of chair are installed.
3. The height of the dining table can be adjusted to suit the individual needs of each subject.
4. To secure sufficient space for a wheelchair and caregiving, the side wall of the restroom can be moved.

Outdoors:

5. A set of stairs with 15 and 20 cm tread heights and a 1/12 (7%) slope is provided for training or exercise.
6. A projection screen along one wall allows demonstrations of outdoor scenery, including interactions with the cityscape.

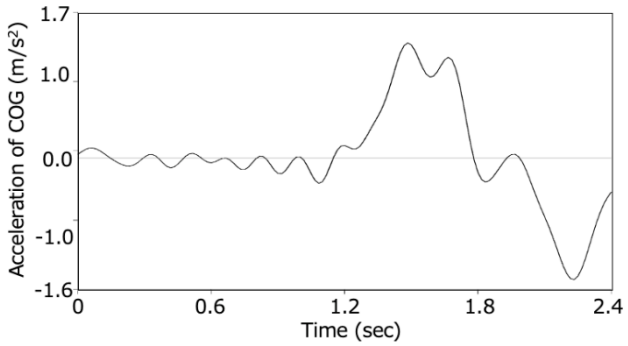


Fig. 5 Analysis of acceleration during daily activities. The vertical acceleration of the center of gravity (COG) during the standing up motion from the bed shown in Figure 4C.

7. Various surfaces (slippery tile, rough stone, etc.) or matting with a pedestrian crossing are provided for training purposes.

Equipment provided
Indoors:

A. To reduce blind spots for video capture, the wall height is set at 110 cm, and the restroom wall is fenestrated.
B. For daily activities starting in the living room, a sofa and television are provided for relaxation.
C. To simulate putting on and taking off shoes, going outside or meeting couriers, the entrance has a stile (11cm height) like a Japanese house.

Outdoors:

D. To simulate outdoor activities such as gardening, walking, shopping, crossing the road and so on, a relatively large space is available.

3.3. Markerless motion capture system

Using the video cameras placed around the bedroom (Fig. 4A), we performed motion analysis. Without bedding, it was possible to analyze the subject’s posture when getting up (Fig. 4B) using the mocap system. All aspects of getting up from the lying position could be observed clearly, as were the movements involved in getting up and walking away from the bed (Fig. 4C). The bone-frame connecting each joint, measured and calculated in three dimensions by the Theia3D software, was shown in upper column of Figs. 4B and 4C. This allows parameters such as the time taken, and the individual’s stability and smoothness of movement. As a result, the vertical acceleration of center of gravity (COG) in motion of standing up from the bed was analyzed (Fig. 5). The data obtained with Theia3D was exported to Visual3D[1] (C-Motion Inc., Germantown, MD, USA) and analyzed to calculate the gravitational acceleration in the vertical directions. Positive and negative accelerations were observed during the rising motion.

3.4. Realization of the demonstration spaces

A panoramic view of the Living Lab, together with the equipment and facilities provided, is shown in Fig. 6. The rails of the suspension system run throughout the demonstration space, including the restroom, bathroom, kitchen, bedroom, living room and the entrance to the outdoor area (shown as red lines). At the entrance, there is a stile like in a normal Japanese house (not shown in the figure), and subjects can change their footwear. All aisles are large enough for wheelchairs. Several video cameras are placed around the bedroom for motion analysis. A markerless motion-capture system can be used to analyze the subject's movements on the bed, stability on getting up from the bed, and posture when starting to walk.

4. DISCUSSION

4.1. Role of the Living Lab

The Living Lab was designed to simulate daily life. It can be used for training as part of the rehabilitation process after hospitalization due to a disability or before discharge, or as a place to safely demonstrate new nursing care devices or robots as they are developed.

In the former case, the Living Lab can be used for training and demonstration of the need to provide assistance in several life scenarios, for example, if the patient has a disability in walking function. In the latter case, where a nursing care robot has been developed and needs to be evaluated, the Living Lab can be set up to match the subject’s daily life scenarios and to verify the effectiveness of the robot in such situations.

In the Living Lab, a range of activities that the subject naturally performs in his/her daily life can be simulated. In the simulation, the subject performs simple daily activities such as getting up, walking, brushing teeth, drying hair, eating and drinking by handling and using objects placed in the living space. By analyzing the subject’s behavior, it is possible to provide advice on support points, support methods or support devices, as applicable. For each daily activity, if there is a failure, it is possible to quantitatively verify the cause of the failure.

One particular feature of this demonstration space is that the fall prevention system allows even the elderly with mobility issues to safely test their daily activities. This feature allows us to propose a demonstration environment not only for able-bodied people, but also for a wide range of people who need assistance. For example, in the rehabilitation of inpatients, use of the fall prevention system may improve the subject's willingness to take on challenges and develop self-efficacy. With such a platform, it will be possible to propose new support methods and conduct demonstration experiments on next-generation daily life assist robots quickly and safely.

Finally, we installed a markerless motion analysis system in the Living Lab and confirmed that basic motion could be analyzed around the bedroom area. Video-based

[1] C-Motion Inc. homepage: https://www.c-motion.com/#visual3d



Fig. 6 Panoramic view of the Living Lab.

markerless motion capture is a user-friendly and widely applicable technology, and has the potential to reduce barriers to the measurement of spatiotemporal gait parameters in clinical and more diverse environments such as the Living Lab. In particular, Theia 3D software is suggested to adequately measure spatiotemporal gait parameters during treadmill use and when walking over conventional ground [8]. As shown in Fig. 5, it is possible to obtain information from the smoothness of body movements and the time taken to perform them about whether the subject is able to perform necessary daily activities and how skilled he/she is in doing so. It could also be used for a variety of other purposes, including assessing rehabilitation outcomes and learning how to use nursing-care robots. In future work, cameras will be placed throughout the Lab to support the analysis of all daily life activities.

4.2. Scenario

In the Living Lab, scenarios that simulate daily life activities and care-giving activities were created as shown in Methods, section 2.2. The subject selects a few scenarios and performs each activity to assess the stability of his/her movements and the effectiveness of the assistive devices or robot. These scenarios are modified according to the subject's level of required care, lifestyle, wishes, etc. to demonstrate daily living activities that are similar to those experienced at home. Scenarios that are appropriate for the subject will be selected and used under the supervision of experts in nursing, caregiving and rehabilitation.

4.3. Limitations

In the Living Lab as currently specified, actual hand washing and bathing activities are limited because there is no water supply. Nevertheless, it is useful to be able to simulate these life activities in an environment that resembles an actual home.

4.4. Future applications

The Living Lab will allow robots and devices in development to be safely tested prior to their introduction into the home or nursing-home environment. We also expect the Living Lab to be used as a demonstration space in which the utility and effectiveness of new robots are assessed and where data can be accumulated to define standards for the International Organization for Standardization (ISO) and other robot standardization projects. In addition, the Living Lab is well positioned to act as a standard demonstration space in which to develop human digital twin technology by facilitating the development of a database of the basic movements of daily life.

5. CONCLUSION

In this study, we designed and developed the Living Lab, an area in which assistive technologies and practices for daily life can be demonstrated and evaluated. The basic concept provides a living space with specifications that can simulate daily life in either a house or a nursing home. Flexibility is built into the design such that, for example, the size of the restroom and bathroom can be changed. Activities in the Living Lab can be performed safely, even with disabled subjects, using a suspension system, which is designed to prevent falls, and can be analyzed by motion capture. This analysis is expected to deliver performance-level notifications and suggestions for future applications and new robots. The Living Lab is a novel demonstration space that can be used for training as part of a rehabilitation program prior to discharge from hospital, and also for the safe assessment of new nursing-care devices or robots.

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