A Socially Assistive Robot to Facilitate and Assess Exercise Goals

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***Abstract*—Older adults generally engage in less physical activities than other age groups. Such lack of exercise may increase the risk of developing chronic degenerative diseases associated with aging. The objective of our research is to develop an autonomous socially assistive robot, Leia, to facilitate and assess exercise sessions with older adults. The robot is able to uniquely monitor the performance of users by using the Goal Attainment Scale (GAS) to determine if they are meeting their health goals. This information can be used by occupational therapists to design appropriate interventions. In this paper, we present the design of the robot's architecture including its autonomous GAS calculator module. Preliminary system performance tests are also presented with healthy adults. Results show that the robot has good perceived usability, is easy to use, and will not require much training.**

***Index Terms*—Socially Assistive Robots, Older Adults, Exercising, Autonomous Monitoring of Health Goals**

I. Introduction

OLDER adults are generally less physically active than younger adults due to the decrease of mobility caused by aging and fear of accidents. The lack of exercising can increase the risk of developing chronic degenerative diseases associated with age, such as cardiovascular disease, type 2 diabetes, obesity, or osteoporosis [1]. Furthermore, regular exercise can provide mental and psychosocial benefits, such as better sense of well-being and the reduction of symptoms associated with anxiety or depression [2]. The U.S. Department of Health and Human Services recommends at least 2.5 hours of exercise per week for all age groups [3].

The objective of this research is to develop an autonomous socially assistive robot that can facilitate and assess exercise sessions with individuals. This work expands our previous research on developing socially assistive robots to help older adults with activities of daily living such as meal preparation [4], [5], eating [6] and cognitive stimulating interventions including games such as Bingo [7] and Trivia [8].

Robotic exercise coaches have been recently developed [9]–[14], but they have not yet incorporated capabilities to autonomously evaluate a user's progression towards health goals, which is the focus of our work here. Namely, our research focuses on developing the socially assistive robot Leia, Fig. 1, that can uniquely evaluate a user's health by utilizing the Goal Attainment Scale (GAS). GAS is a measurement used in occupational therapy for assessing a person's progress towards personalized goals (i.e., goal achievement), providing occupational therapists (OTs) with information to propose timely and appropriate interventions [15]. GAS has been used to evaluate progress in therapy sessions with children and mobile robots [16] or robot arms [17], and for psychogeriatric care with the seal-like robot Paro [18]. However in all these cases the GAS score was calculated manually after the interactions using human-based observations. The challenge of incorporating GAS for use directly by a social robot is the autonomous detection of observable user behaviors to determine the attainment of a health goal. In this paper, we address this challenge by incorporating exercise goals that a robot can track while it is coaching exercise sessions. In particular, we focus on arm strengthening exercises, where GAS is used autonomously by the robot to determine whether the user is progressing through these exercises.

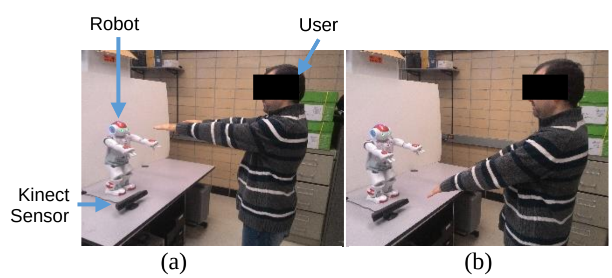

Fig. 1. Leia guiding a user during an exercise session, with the user performing (a) a complete front arm raise pose and (b) a partial front arm raise pose.

II. Socially Assistive Robots for Exercise Facilitation

Previous research has investigated the use of socially assistive robots for both rehabilitation [9]–[11] and exercise coaching [12]–[14].

For example, in [9], the humanoid robot QTrobot was designed to guide people with limited motion through upper-limb exercise sessions. The robot facilitated the activity using body language via its arms and head, and facial expressions

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through emoji-like pictograms displayed on a monitor used for its face. Exercise monitoring was achieved by tracking a ball held by the patient. The ball position was detected by a camera using color segmentation. To motivate the patient, the robot would provide positive affirmations (e.g. "well done") while smiling. A comparison with four healthy volunteers performing the exercise with QTrobot and without it was conducted. A post-test questionnaire based on the Intrinsic Motivation Inventory was given to the participants. The results showed that the participants felt more motivated when doing the exercise with the robot.

In [10], The Nao humanoid robot was proposed for upper-arm rehabilitation of people with partial loss of upper extremity functionality. The robot was able to demonstrate upper-limb exercises and communicate using speech. No user studies were presented. The Nao robot was also used in [11] to autonomously guide children through physiotherapy. It used the Microsoft Kinect 3D sensor to track the child's body joints and monitor the exercise. The robot would ask a child to mimic its postures. If the child performs the correct posture, the LEDs around the robot's eyes turned green and a *ka-ching* sound was played to indicate success. Otherwise, if the child performed the wrong posture, the LEDs became red and it would ask the child to again mimic its posture. Experiments were conducted with 117 healthy schoolchildren. A self-reported questionnaire and video analysis was used to evaluate children's behaviors. The results demonstrated that the participants enjoyed the interaction and were motivated and engaged. Sessions with three children with disabilities (two of with obstetric brachial plexus palsy, and one with cerebral palsy) showed that although they all reported that the interaction was fun and productive, they found them too long and would not take the robot home.

In [12], a Nao robot was used to guide older adults to perform both upper and lower limb exercises. Body joints were tracked using an Asus Xtion sensor in order to monitor movements. While monitoring the exercises, the robot would give verbal positive feedback (e.g. "You are really good") if the correct movements were being performed, or verbal corrective feedback to adjust, for example, speed (e.g. "please, speed up"), or amplitude (e.g. "raise your right arm as much as you can"). To provide a game-like interaction, the robot tracked the percentage of correct movements and used it as a score for the exercise session. User studies with 12 elderly participants were conducted. A post-test questionnaire showed that the majority accepted the robot as a tutor, enjoyed the exercise and robot interaction sessions, but less than half considered it as a friend.

In [13], the mobile robotic platform "HOBBIT" was used to guide people through upper-limbs exercises using the Microsoft Kinect sensor to detect the user's body joints. It used a tablet to display a video of a person showing the desired body movements and also the movements the person was doing as detected by the Kinect. Eighteen older adults were given a HOBBIT to use at home for three weeks. From those, 17 tried the fitness function and recognized it as an important feature, and they enjoyed the exercise sessions, with some mentioning that their level of exercise increased after using the robot.

In [14], the Double mobile robot platform was used to provide exercise instructions also using a tablet and Kinect sensor to track user movements. During exercising, Double would provide a visual feedback such as an idle face, a happy/approving face, or an angry/disapproving face. Double was tested with 17 adults. Questionnaire results showed that the participants agreed that the robot made the exercising sessions more fun and would encourage them to exercise daily.

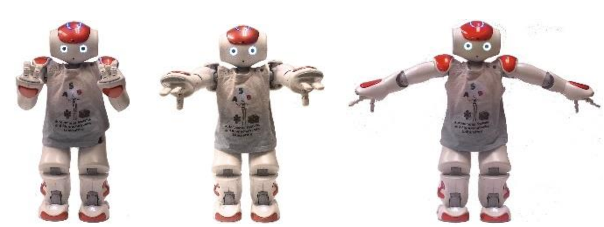
A. *Summary of Related Work*

Most of the aforementioned robots tracked body movements to verify if users were correctly implementing a specific exercise [11]–[14]. Only in [12] the overall performance during the full exercise was considered. Namely, a numeric score representing the percentage of correct movements was determined to create a game-like interaction to motivate the user.

To the authors' knowledge no approach has been used to monitor performance to provide health evaluation. Therefore, in this work, we uniquely incorporate an autonomous procedure based on GAS for a robot exercise coach to quantitatively evaluate how users are progressing towards their individual exercising goals. This information can be used by OTs to make an informed decision to suggest alternative interventions or exercises for the robot to implement.

III. Leia the Exercise Coach Robot

Leia can facilitate a number of different arm exercises, including fly (side raise), front raise, and biceps curl, as shown in Fig. 2. These exercises were chosen as they can strengthen shoulder and upper arm muscles [19], and can be performed while both standing and sitting, allowing users with mobility restrictions to partake in the exercises.



(a) (b) (c)

Fig. 2. Leia performing three exercises: (a) biceps curl; (b) front raise; (c) fly.

Leia uses a combination of body language and speech to autonomously interact with the user. Before asking the user to undertake each exercise, Leia first asks if the user is feeling fatigued or is in pain, and will not partake in the exercises if the user raises his/her hand to indicate that he/she is not feeling well. Leia also instructs the user to stop exercising whenever he/she feels tired or pain during a session. During an exercise routine, the user's arm poses are monitored and tracked. These recorded arm poses are then used to calculate the goal achievements using GAS.

The proposed architecture for our autonomous robot exercise coach is comprised of three modules: Exercise Monitoring, Interaction Module, and GAS Calculator, Fig. 3. Each module is discussed in more detail below.

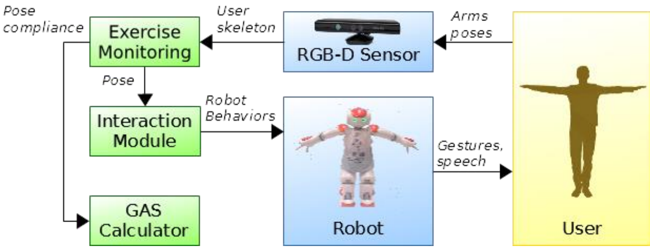


Fig. 3. Exercise Facilitation Architecture.

A. *Exercise Monitoring*

The Exercise Monitoring module detects if the user is performing the requested arm poses using the upper body joints. The Microsoft Kinect 3D sensor is used with OpenNI and NITE [20] to detect the spatial positions (*x*, *y*, *z*) of the shoulder, elbow, and wrist joints of each arm for exercise monitoring. A *k*-Nearest Neighbors (*k*-NN) classifier was trained to classify seven arm poses: the initial/resting pose; the complete pose for each of the three exercises; and a partial pose for each of the three exercises, where both arm poses are below the complete pose, as in Fig. 1(b). Two volunteers (one male and one female) recorded one session for each exercise. From the recorded sessions, 140 samples of the seven arm poses (20 per arm pose) were used to train the *k*-NN classifier. The classifier achieved an accuracy of 93% when compared to a human expert coder.

B. *Interaction Module*

The Interaction Module uses a Finite State Machine, Fig. 4, to determine the corresponding robot behaviors, based on the exercise goals and user inputs. At the beginning, Leia greets the user and explains the exercise interaction. Then, Leia shows each exercise set and asks the user to imitate it for *n* number of repetitions. After the user finishes the repetitions for each set, Leia congratulates the user and asks him/her to rest for thirty seconds before the next exercise in order to avoid potential overexertion. After resting, Leia asks if the user wants to do another exercise. If the user accepts, Leia continues the exercise session. If the user refuses, Leia skips that exercise. After performing all the exercises, Leia congratulates the user and says farewell. Detailed examples of the robot's behaviors are presented in Table I.

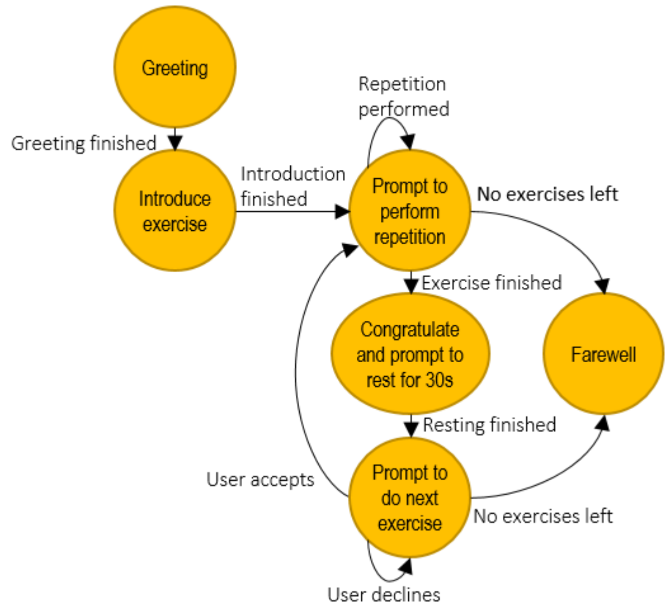


Fig. 4. Finite State Machine of the Interaction Module.

C. *GAS Calculator*

This module converts the pose compliance from the Exercise Monitoring into GAS scores. We define the goal as performing arm exercises with the correct poses and with the appropriate number of repetitions, and the observable behavior as the poses achieved by the user. In GAS, each goal has five possible outcomes [15]: -2, much less than expected; -1, less than expected; 0, expected outcome; +1, better than expected; +2, much better than expected. These outcomes are presented in Table II, where n_1 is the less-than-expected number of total repetitions, n_2 is the expected number of total repetitions, and

TABLE I
EXAMPLE OF ROBOT BEHAVIORS AND SPEECH FOR EACH STATE.

State	Non-Verbal Behavior	Speech Example
Greeting	Waves and bows to the user	"Hi there! My name is Leia, your personal exercise coach. I will help you to do three different exercises"
Introduce exercise	Performs the poses for the given arm exercise	"The three exercises we are going to do are Biceps curl… Front raise…and Fly. Each exercise has *n* repetitions. If you are tired, just stop doing the exercise at any time. Don't force yourself."
Prompt to perform repetition	Performs the poses for the given arm exercise	"Let's get started. Repeat the movement after me. One. Two. Three. Four… Do you want to keep going?"
Congratulate and prompt to rest for 30s	Nods and claps.	"Congratulations, you are doing fantastic! Let's rest for thirty seconds before doing the next exercise."
Prompt to do next exercise	Performs the poses for the given arm exercise	"The next exercise is Front raise. This is how you do it. Do you want to do this exercise now?"
Farewell	Nods and claps, bows and then waves goodbye to the user.	"Congratulations, you finished your exercises for the day. I am glad I could be of assistance. I hope I see you again soon. By for now."

n_3 is the better-than-expected number of total repetitions. The values for n can be set by therapists for each individual.

TABLE II
GAS FOR PERFORMING ARM EXERCISES.

Score	Predicted Attainment
-2	Did not complete at least n_1 repetitions
-1	Completed n_1 repetitions with partial and complete poses
0	Completed at least n_2 repetitions with complete poses
+1	Completed n_3 repetitions with a mixture of partial and complete poses
+2	Completed n_3 repetitions with complete poses

Leia computes one GAS score for each exercise, x_j, $j = \{1,2,3\}$. Once the scores are calculated, the simplified T-Score [15] is computed:

$$T = 50 + C_x \sum x_j, \quad (1)$$

where C_x is a coefficient dependent on the number of scores. For three scores (one per exercise), C_x=4.56 [15].

IV. EXPERIMENTS

We conducted a preliminary experiment with 10 healthy adults to test system performance prior to interaction with older adults. The participants stood between 1.5-2 m from the robot. The U.S. National Institute of Aging (NIA) [19] recommends older adults start with a total of 8 exercise repetitions, and then increase repetitions to 10-15 over time. Therefore, we used $n_2 = 8$ as the expected number of repetitions, and $n_3 = 12$ (approximately between 10 and 15) as the better-than-expected number of repetitions. The less-than-expected number of repetitions was defined as $n_1 = 1$.

Leia instructed participants that each exercise set (one set per exercise) had 8 repetitions, but they could do up to 12 repetitions. The rest session of 30 seconds was between each exercise set. Participants could stop the exercise set at any point.

A. GAS Results

Table III shows the GAS T-scores autonomously generated by the robot for each user at the end of the exercise session. These values are obtained by computing the scores using Table II and Eq. (1). A T-score lower than 50 indicates that the exercise goal was not being met, whereas a T-score equal to 50 indicates expected goal achievement, and a T-score higher than 50 indicates that the goal achievement is better than expected.

Two users achieved the expected goal (*T*=50), while the other eight performed better than expected (*T*>50). This result was anticipated, as all ten participants were healthy and able to perform the amount of repetitions. Therefore, we were able to verify that our designed GAS and T-Score calculations are reliable.

In the case of the two participants who scored *T*=50, a long-term interaction with Leia would provide important health information. If T increases, it would mean that the robot is able to improve their goals towards physical activities; whereas if T does not change, it would mean that the robot is able to maintain their physical conditioning. In the event where T decreases, it could suggest that they may be affected by some health problems. In such a case, a healthcare provider could evaluate the T-score progression and use that information to make an informed decision regarding health intervention.

The T-Score computed by Leia could be especially beneficial for older adults. Not only can the robot monitor goal attainment over time and determine positive or negative changes, but as previously mentioned the score can be shared with caregivers and OT. This would provide reliable data for these healthcare professionals, enabling them to better evaluate their clients' progression towards their goals related to physical activities and to suggest alternative interventions if necessary.

B. Usability Study

After interacting with the robot, the participants were asked to complete a 5-point Likert System Usability Scale (SUS) [21] to determine their perceptions of the robot system's usability. The ten SUS questions are presented in Table IV. Average user score [21] is determined by:

$$2.5 \times (\sum_{k=0}^{4}(q_{2k+1} - 1) + \sum_{k=1}^{5}(5 - q_{2k})), \quad (2)$$

TABLE III
GAS T-SCORES.

Participant	1	2	3	4	5	6	7	8	9	10
T-Scores	59.1	77.4	72.8	68.3	77.4	50.0	50.0	63.7	59.1	59.1

TABLE IV
SUS QUESTIONNAIRE RESULTS.

#	Question	Average result (q_k)	SD (σ)
1	I think that I would like to use this system frequently.	3.5	1.4
2	I found the system unnecessarily complex.	1.5	0.7
3	I thought the system was easy to use.	4.6	0.7
4	I think that I would need the support of a technical person to be able to use this system.	1.9	1.0
5	I found the various functions in this system were well integrated.	4.1	1.0
6	I thought there was too much inconsistency in this system.	1.7	1.1
7	I would imagine that most people would learn to use this system very quickly.	4.8	0.4
8	I found the system very cumbersome to use.	1.4	0.7
9	I felt very confident using the system.	4.0	0.8
10	I needed to learn a lot of things before I could get going with this system.	1.5	1.0

where q_K is the average result across all users for question k, $k = \{1, \ldots, 10\}$. The system achieved an average SUS score of 82.5 (σ = 14.9), which represents "good usability". In particular, the participants found the system easy to use (q_3 = 4.6) and would not require much training (q_7 = 4.8).

V. Conclusions

In this paper, we presented the design of the Leia robot as an autonomous exercise coach to be used with older adults. The robot uniquely and autonomously is able to utilize the GAS to determine if users are meeting their exercise goal requirements. This information can also be provided to healthcare professionals such as OTs.

We present a preliminary study to investigate system performance. Results showed that our GAS design was able to reliably identify that participants were able to achieve their desired goals. Furthermore, they found the robot easy to use without much training. Our future work consists of designing long-term experiments with older adults living in our partner long-term care facilities in order to evaluate if using GAS the robot is able to improve user exercise performance, while also investigating the acceptance of the robot and the adoption of our autonomous GAS calculator by healthcare providers. The older adults and/or their caregivers will be able to adapt the exercises to user needs through an app we will develop for the robot.

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