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Interaction Concepts for an Adaptable Dementia Therapy Robot

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***Abstract*—Due to demographic change, an increase in dementia patients in nursing homes is predicted. The prevention and treatment of dementia patients is time-consuming because the therapy must be individually tailored to the patient's state of health. As a result of the cost pressure in nursing homes and the shortage of nursing staff, this poses challenges for the nursing area. The use of therapy robots can help to overcome these challenges and strengthen the resilience of elderly people. Previous research has shown that the therapeutic exercises ball throwing, high-five games, and strength exercises are suitable to be supervised and executed by a dementia robot. Essential for the performance and acceptance of such a dementia robot is its interaction capability. Therefore, an adaptive, optimizing, real-time and knowledge based interaction system for the mentioned therapy exercises was researched. This classifies the dementia degree using fuzzy logic and adjusts the exercise parameters with evolutionary algorithms according to the therapy goal. For this purpose, the expert knowledge of caregivers was first collected using a knowledge acquisition and formalized into a knowledge base with a hybrid inference mechanism. A first prototype of the interaction system has already been tested in a real-time robot simulation. After transferring the knowledge-based interaction system to the real dementia robot, it will be evaluated in a test person study.**

Keywords—robotics, dementia, human robot interaction, fuzzy logic, evolutionary algorithm

I. Introduction

In the World Population Prospects 2022, the United Nations projects an increase in the population over 65 from 9.7% in 2022 to 16.4% in 2050 [14]. This recent demographic trend also means an increase in seniors living in nursing homes and an increasing number of people with age-related diseases such as dementia. In the process, 152 million cases of dementia are expected worldwide by 2050 [13]. Both dementia prevention and dementia care require time-intensive and highly individualized care in the form of specific therapies. Maintaining an appropriate quality of care will pose an enormous challenge to the care sector in the future, as personnel is currently being cut wherever possible as a result of cost pressure in nursing homes [7]. The corona pandemic and related hygiene regulations posed additional challenges to the nursing industry [9]. For this reason, a large number of investigations has already been carried out in recent years, looking for support for nursing staff in the form of robot technology. In particular, the question of how the staff can be relieved by the use of a robot was asked.

The need for research lies on the one hand in increasing the capabilities of robots, especially with regard to a safe mode of operation in human-robot collaboration. On the other hand, not only the performance of a robot, but also the interaction ability is decisive whether an elderly person accepts a robot or not [17]. Dementia prevention and care emerged in preliminary work as an area of application that places high demands on nursing staff and constitutes a large and important part of daily care. There is still no adequate support in the form of efficient care robots. In order to relieve the nursing staff, the aim of this work is to explore a dementia robot with a knowledge based interaction system, which can perform three concrete therapy exercises in the form of physical training with the nursing home resident and constantly adapts to the health status. The research question is: Can a haptic dementia robot for the therapy exercises ball throwing, high-five game and strength exercise adapt to the patient's health status in real time through the expert knowledge of the caregivers?

II. State of the Art

The previous research serves as a basis for the development of a dementia robot. Both the understanding of the fundamentals from nursing and the technical fundamentals must be considered. First, the necessary AI concepts for the interaction system are explained and the state of research on existing care robots is described. Afterwards, an overview of the nursing basics and dementia therapies is presented, which describes the important aspects from a nursing perspective. Finally, the last chapter summarizes and evaluates the feasibility of the research project.

A. Knowledge Representation Basics

Fuzzy Logic is a software theory developed by Zadeh that makes it possible to mathematize human behavior. Natural language fuzzy variables are specified as so-called fuzzy sets in membership functions. Fuzzy rules model case-related relationships between variables and are evaluated via an inference mechanism. The evaluation can be done for example with the MIN-MAX method. The condition part of the rule converts the input values into fuzzy variables. The conditions are linked using fuzzy logic operators such as AND and OR. In the condition of a rule, input variables are compared with sensor values. Depending on the degree of fulfillment of the conditions, output variables are then assigned values in the action part of the rule. An output variable is converted back to a crisp value, for example, using the centroid method [22]. During the back transformation, the center of area (COA) is determined.

Evolutionary algorithms are optimization methods, which are oriented on the emergence of living beings and can be used to solve corresponding optimization problems [2]. They use the biological concepts of selection, reproduction and mutation. Reproduction forms a new generation of living beings and, in the simplest case, can be done by cloning. Mutation constantly creates new candidate solutions that are again different from their parents. Using a quality function, selection is used to determine which are the best solution candidates to reproduce again. Once a minimum quality has been reached, the processes terminate at a suboptimum [21].

B. Dementia Care

In nursing homes, a variety of promising therapy methods exist for the prevention and treatment of dementia. Gesundheit in Bewegung 2.0 (GiB 2.0) is a research project of the Karnten¨ University of Applied Sciences whose scientific evaluation showed a significant effect on the mobility of the test persons. Successes were achieved in the areas of social and communication behavior and activities of daily living [6]. In addition to GiB 2.0, another non-pharmacological dementia treatment exists. MAKS is a multi-component therapy consisting of a motor, everyday practical, cognitive and social module [8]. The results of a study show that on average the target variables cognitive abilities and everyday practical abilities could be stabilized using MAKS [18]. The five nursing homes surveyed in the Regensburg area execute several exercises from these therapies. However, the exact models are not implemented, as this would be too expensive and too time-consuming. The efficient and popular exercises ball throwing, high-five game and strength exercise can be transferred to a robot, as emerged from the preliminary work [16]. The exercises are very often performed as group therapies. This has advantages such as saving time, but is always a compromise for the individual, as the exercise cannot be precisely adapted to their individual state of health. Due to changing demographics, caregivers' time for individual therapy, will likely continue to decrease in the coming years. This also means that patients will be over- or underchallenged during community exercises. In addition, dementia patients want to remain in their familiar home environment for as long as possible, but this is often no longer possible because they are dependent on support. Here, too, a suitable dementia robot would strengthen resilience, as patients can also practice alone at home with the robot.

C. Robots in Dementia Care

The identified exercises can be classified as human-robot collaboration, since humans and robots are working in a shared workspace. Of course, the associated safety standards must be taken into account here [19]. Preliminary work has shown that many robotic concepts for care already exist. Lio is an autonomous, friendly companion and consists of a multifunctional arm that assists caregivers and patients in their daily lives [12]. Additionally Paro and Pepper are well known robots that, like many other robots, use common Natural User Interfaces (NUI) such as speech, haptics, facial expressions, gestures and biosignals [4], [15]. In addition to NUIs, the concepts of many care robots make use of classic computer interfaces such as touch panels [16]. Existing robots so far focus a lot on the function of a friendly companion to prevent loneliness [11]. There are also service robots and rehabilitation robots with simple haptic feedback [16]. Particularly advanced software architectures of powerful geriatric robots already exist, such as that of Garmi. This specializes in the field of telemedicine, multimodal interaction and autonomous physical support for seniors at home [20]. Although some robots provide support during exercises, they do not offer a fine-grained concept for the situational use of haptics in dementia care. Moreover, none of these concepts yet draws on the specific expert knowledge and optimizes accordingly. Finally, there is a lack of an application-specific user-centered concept that contributes to increasing efficiency [16]. The three exercises ball throwing, high-five game and strength exercise are suitable for this and are shown in figure 1 [17]. The figure shows how a patient performs the exercises with a robot.

Fig. 1. Exercises.

D. Summary

A powerful robot support for the exercises ball throwing, high-five game and strength exercise from the dementia therapy with the use of the concrete expert knowledge of the caregivers has not been researched yet. For the realization, a knowledge-based interaction system must be researched, which optimizes the exercise execution of the robot according to the health condition of the dementia patient.

III. Knowledge Engineering

Expert knowledge encompasses the entire wealth of experience of the nursing staff on dementia therapies. This includes, above all, the specific response and adaptation of exercise parts, which achieves the greatest possible therapeutic progress. This knowledge was collected using the method of knowledge engineering.

With the help of methods from user experience design, expert knowledge could be collected. For this purpose, five experts from five different nursing homes in the Regensburg area were recruited as knowledge sources. A study design specified the methodological procedure. First, guided qualitative expert interviews were conducted over half an hour per meeting to roughly structure the knowledge [1]. Contextual Inquiry is an empirical method of requirements analysis. With its help, the next step was to capture the fine-grained knowledge. Thereby, the nurses were observed in their normal working environment while performing the therapies [5]. To create a natural context and ensure transparency, the presence in the room was kept to a minimum. It was important to capture the small, sometimes subconscious tricks used by the caregivers. Intermediate questions were noted and relevant steps were discussed in the follow-up in order not to disturb the natural flow. Finally, interviews were conducted with dementia patients to better assess the health status of certain dementia degrees. All findings from the knowledge acquisition were transcribed and documented. The evaluation of the results was done by Bryman's four stages of qualitative analysis [3].

The next step was to formalize the knowledge and specify it into a knowledge base. Taxonomies were identified as a suitable form of knowledge representation. In a further cycle, the knowledge base was again verified, expanded and concretized by interviewing the nursing staff. Here, the focus was on the concrete parameters that determine the severity of dementia. The experts were asked to classify the degree of dementia on the basis of concrete case studies in order to be able to check and specify the parameters. A guideline structured the interview.

IV. Interaction System

The result of the knowledge engineering was a detailed specification of the three dementia therapy exercises. The formalized expert knowledge was transformed into a system design for the knowledge-based interaction system and the associated knowledge base was built. Next, hybrid inference mechanisms were designed and implemented. A robot simulation was used to test the system.

A. Knowledge Base

If we look at the resulting knowledge base, we see that the nurses not only possess a wealth of learned school knowledge, but also have a highly developed wealth of experience that they apply specifically. In doing so, they individually adjust the smallest parameters of the exercises in order not to over or underchallenge the patient and to achieve the greatest therapeutic success. This approach does not consist of specific measurements but is a broad natural language explanation from features of the behaviors for classifying the severity and corresponding response. Overall, there were both obvious and unexpected findings. For example, song familiarity plays a crucial role in the high-five game in particular. From a logical point of view, one would assume that the complexity of the melody and the lyrics of the song serve as a correlate of difficulty. The knowledge survey showed that this hardly plays a role for dementia patients. Only the degree of familiarity with a song from earlier times determines whether the patient can sing the song or not. This means that a patient with severe dementia can sing a song with a complex composition which he knows better than a song with an easy composition which he does not know so well.

The Mini Mental Status Test is used in nursing to classify the degree of dementia [10]. The evaluation is divided into four states, where grade 1 means severe dementia and grade 30 means no dementia. This gradation is suitable for classification for the exercises. The results were modeled as a taxonomy, divided into four hierarchical levels. While the upper levels define the therapy framework with the exercises and the exercise targets, the lower levels represent the variation sizes and variation values. The natural language expert knowledge describing the adaptation forms the rules.

Figure 2 shows an exemplary extract of the variation variables and values of the therapy strength exercise. These serve both as variations for execution and as manipulated variables for difficulty adjustment. First, the nurse can decide

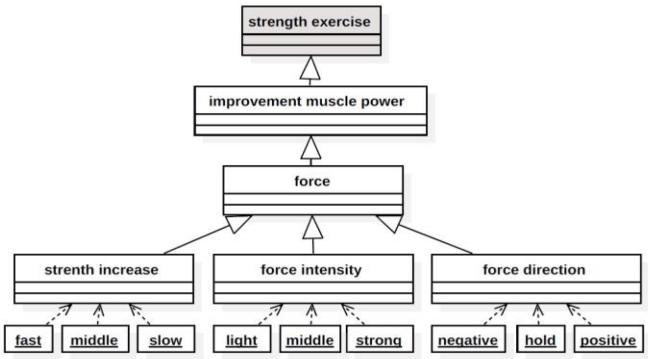

Fig. 2. Excerpt Taxonomy Strength Exercise.

the direction of the force. That is, she pulls, pushes, or holds the partner's force. The strength exercise can be made more difficult or easier by the force intensity. A light, a medium or a strong force can be applied. The speed of the force increase is another control variable for the difficulty. A fast force increase is harder than a slow one. The taxonomy describes the knowledge base using imprecise natural language statements which are specified by fuzzy logic in terms of fuzzy sets with membership functions. Figure 3 shows an example of the fuzzy sets of force intensity, force increase and the degree of dementia with the respective membership functions.

B. Hybrid Inference Concepts

The modeling of the knowledge for the classification of the degree of dementia was modeled case by case in the form of fuzzy rules, based on the linguistic variables of the lowest level of the taxonomy. Each individual rule thus classifies the degree of dementia proportionally thus increasing the maintainability of the knowledge base and allowing additional knowledge to be added flexibly. Figure 4 shows an excerpt from the rule set used to classify the degree of dementia in strength exercise. If the force intensity is mild and the patient's response is deviant force then the dementia grade for the exercise is severe dementia. Conversely, if the applied force is strong and the patient's response is a reasonable force, the patient has mild dementia.

The evaluation of the fuzzy rules is performed in two directions. The forward linkage of the rules classifies the dementia level and the backward linkage infers the exercise parameters from a target dementia level. The MIN-MAX method is used to infer the classification. The classical operators AND/OR as well as scaling operators and addition functions are used. The centroid method is used for defuzzification.

The backward chaining of rules is applied as soon as the degree of dementia has been determined and a new parameter adjustment has to be made. A certain search concept is used and the optimization is performed by evolutionary algorithms. The calculation has to be done after a successful execution of the exercise after which a certain dementia level could be reached. The current parameter set is thus reproduced with a certain number. The clones are subsequently modified by mutating random exercise parameters within a certain variance. The expected degree of dementia can then be calculated for each modified exercise and used as a quality measure for selecting the most appropriate parameter set. Optimization continues in

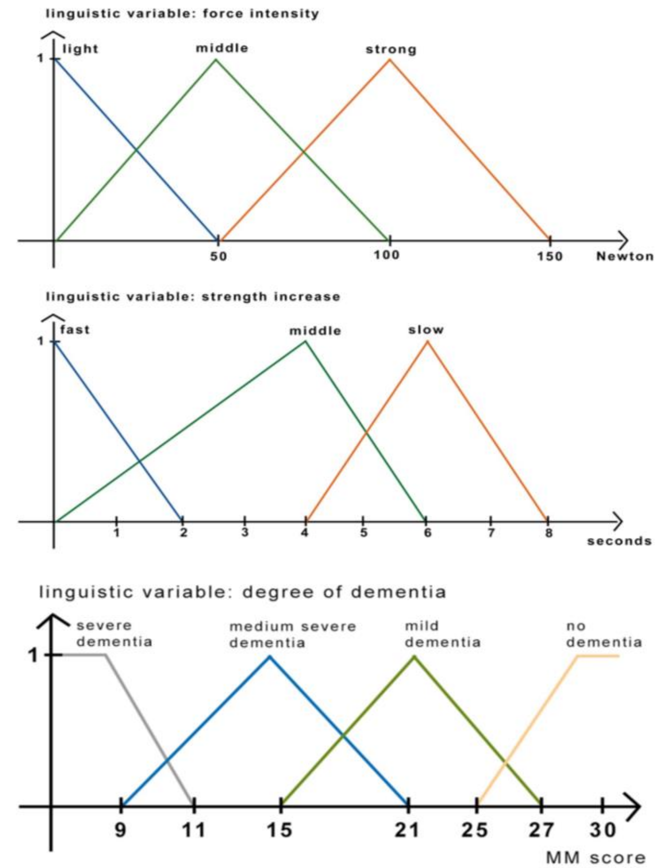

Fig. 3. Excerpt Taxonomy Strength Exercise.

the form of reproduction, mutation, and selection until the specified minimum quality of parameterization is achieved. In exceptional cases where no minimum quality is reached, the best parameter set found is used in order not to interfere with the process. Usually, however, there are several suitable parameter sets that can be used for adaptation.

C. Prototype

IF	forceIntensity	IS	light
AND	reaction	IS	forceDeviation
THEN	degreeOfDementia	IS	severeDementia
IF	forceIntensity	IS	light
AND	reaction	IS	matchingForce
THEN	degreeOfDementia	IS	mediumDementia
IF	forceIntensity	IS	middle
AND	reaction	IS	matchingForce
THEN	degreeOfDementia	IS	severeDementia
IF	forceIntensity	IS	strong
AND	reaction	IS	matchingForce
THEN	degreeOfDementia	IS	lightDementia

Fig. 4. Example Rules in Strength Exercise.

The knowledge-based interaction system has already been fully implemented in Java. The quality is still determined randomly or entered interactively. This could already be tested with a simulation environment. The membership functions in the simulation are currently discretized with a resolution of one decimal place and the evolutionary algorithm develops a static clone count for each replicate. With each optimization, the individually determined variance of the mutation of the linguistic variable decreases.

Figure 5 shows the software architecture of the dementia robot. The software consists of two agents that cooperate via a distributed knowledge base. The Interaction Agent implements the knowledge-based interaction system and provides instructions to the Robot Control Agent to perform the particular dementia exercise. The distributed knowledge base is an active blackboard that hierarchically interprets knowledge about trigger methods in real time and thus independently semantically enriches the environmental model.

The interaction agent is structured into a proactive and a reactive layer. A behavior pattern control is implemented on the reactive layer. It enables the modularization of the individual interaction steps into independent behavior patterns. The behavior patterns generate requests that are combined by a resolver into concrete action specifications. Depending on the situation, only a subset of the behavior patterns is active. Behavior patterns that do not contribute to the current interaction situation are deactivated for reasons of efficiency. Which group of behavior patterns is currently active is determined by the proactive level. The proactive layer is implemented as a planning system. During planning, a skeleton plan with concrete actions is adapted. The steps of the skeleton plan are shown graphically as a finite state machine in Figure 5. Most important planned actions of the knowledge-based interaction system are the nodes classify and optimize. In classify, a group of behavioral patterns is active that derives the classification rules shown above to determine the degree of dementia. The behavior pattern group of the optimize node implements the evolutionary algorithm for optimizing the exercise parameters.

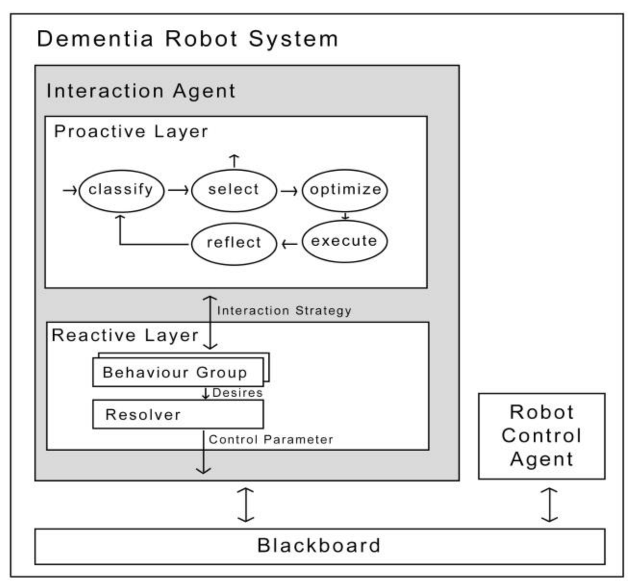

Fig. 5. Interaction System Architecture.

The robot's movements are currently being simulated in real time. In parallel, the real dementia robot is currently being built. The robot is equipped with two Universal Robots UR5 manipulators and can move fully autonomously in space. It has optical sensors for navigation as well as for recognition of the exercise sequence and the patient. Haptic sensors in the manipulators enable the consideration of haptic feedback.

V. Conclusion and Future Work

Knowledge engineering resulted in a detailed knowledge base that was expanded and verified with the help of the caregivers. The knowledge about the three dementia exercises was formalized and modeled in the form of a taxonomy. The transfer into a knowledge-based system is thus ensured. Fuzzy logic is suitable as a form of representation because the linguistic variables can be classified one by one. The classifier of the degree of dementia could be realized and inference mechanisms for evaluating the knowledge could be implemented. The calculation of exercise parameters by evolutionary algorithms with quality function works, but so far depends on the targeted improvement of dementia level. Which exercise parts patients prefer has not been considered yet and still needs research. Robot simulation has already allowed the software to be tested. The real dementia robot is currently being built.

So the research question can be answered positively. In the next step, the interaction system will then be connected with the real dementia robot. After certification of the safety technology, the evaluation of the real robot is to take place. In addition to the performance and practical suitability, the acceptance of the robot will be investigated.

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