Improving Resilience in the Elderly Through Robot-Assisted Dementia Therapy

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Abstract
The number of older people with dementia has been steadily increasing for years. Physical and mental fitness is a supporting pillar for increasing resilience with regard to dementia. Therefore, older people should perform exercises as often as possible and in a targeted manner to prevent and treat dementia. Due to high cost pressures and staff shortages, there are limited caregivers available to supervise these exercises. Therefore, it is necessary to explore a dementia robot that can be used by elderly people to perform dementia therapy exercises alone at home, without a rigid schedule. In consultation with caregivers, ball games, high-five games, and strength exercises were identified as realistic exercises. The robot should include an adaptive interaction system that controls the design and sequence of the exercises in such a way that the patient receives the best possible individual support. For the realization of this knowledge-based system, initial parts of the nursing staff's expertise were acquired and formalized in five nursing facilities. Based on this, a metric was derived which, after a classification of the patient's daily performance, allows an appropriate adjustment of the degree of difficulty of the exercises. The formalization of knowledge will now be discussed, verified, and detailed with nursing experts from science and practice. After completion of this knowledge acquisition, the interaction system will be implemented and prototypically transferred to a mobile robot. Subsequently, the dementia robot will be evaluated in a test person study with regard to its performance and its acceptance.

Keywords: Resilience, Robotic, Dementia, Fuzzy Logic, HMI

Introduction

The UN's 2019 world population forecast predicts a drastic increase in the number of people over 65 in the coming years (United Nations, 2019). The fact that demographic change is also steadily increasing the number of seniors living in nursing homes can already be observed and will continue to increase in the next years (Graf, 2018). Physical and mental fitness is very important for building resilience to dementia. The prevention and treatment of dementia in the elderly therefore requires time-intensive care by nurses, which must be tailored to the health of the individual. In order to provide the best possible care for nursing home residents, certain standards of care must be met. These include specific care and nursing for age-related conditions such as dementia, assuming an adequate number of employed nursing staff with competent expertise (Korecic, 2013). Maintaining adequate quality of care will be an enormous challenge for the nursing sector in the future, as currently staff is being reduced wherever possible due to cost pressures in nursing homes (Graf, 2018). In addition, the COVID-19 pandemic has created additional challenges for the nursing sector due to hygiene regulations.

For these reasons, intensive research has been conducted for several years on how to reduce the workload of caregivers through the use of care robots and how robots can be used to promote the mental and physical development of older people. The acceptance of robots by the elderly depends not only on the performance of the robots, but also to a large extent on their ability to interact. For this reason, numerous research projects on the topic of care robots have been conducted in recent years and a large number of findings have been obtained. Within the research, dementia stands out as a special application area that places high demands on caregivers and for which there is not yet adequate support in the form of high-performance care robots.

The care of dementia patients is very complex and requires elaborate and time-intensive care. Due to the high incidence of dementia in nursing homes, care measures are already very much focused on the therapy and prevention of the clinical picture (Radenbach, 2017). Current care robots for dementia patients mainly provide supportive functions in the area of loneliness prevention and entertainment, but not for therapies with haptic exercises that are regularly performed by caregivers alone with dementia patients (Chang et al., 2013). This results in an urgent need and a high potential use for a caregiver robot that supports dementia care with appropriate haptic exercises. Ball throwing, high-five games, and strength exercises have been identified as haptic exercises that can be performed by an autonomous mobile robot given the current state of the art. Such a dementia robot relieves the burden on caregivers, as patients can practice independently with the robot. For patients, the dementia robot offers the advantage of being able to exercise flexibly and without a rigid schedule, both in the nursing home and individually at home.

The usefulness and acceptance of such a dementia robot depends largely on its ability to interact. Therefore, the long-term goal of the research presented here is to develop a knowledge-based interaction system for a dementia robot that adaptively optimizes the robot to the patient's current performance ability and therapy goal in the aforementioned haptic applications. The interaction system is intended to utilize the specific expertise and many years of practical experience of the nursing staff. Therefore, for the realization of the interaction system, it is necessary to collect the expert knowledge of the nursing staff through knowledge acquisition and then formalize it in order to be able to integrate it into a knowledge-based system. Therefore, the research question of this thesis is: In which tasks of dementia therapy can a current nursing robot support the nursing staff and which information-based interaction concepts are necessary for this purpose?

Related Work

In order to answer the research question specifically, a broad understanding of the scientific basis and prior work on dementia care, dementia robots, and knowledge acquisition in the medical field is required. Therefore, the current state of research in the literature is summarized and evaluated below.

Dementia Care Terms

Activities of Daily Living is an indicator used to assess a person's ability to care for themselves. There is a significant correlation between the cognitive fluctuations of affected dementia patients with the decrease of the ADL indicator (Edemekong et al., 2017). There are a variety of promising therapeutic methods for the prevention and treatment of dementia in nursing homes. Gesundheit in Bewegung 2.0, (GiB 2.0), is a research and development project of the Kärnten University of Applied Sciences, based on a systematic compilation of international scientific results. The scientific evaluation of the program shows a significant effect on the mobility of the test persons in the area of social and communication behavior as well as on activities in everyday life (Gebhard & Schmid, 2017). In addition to GiB 2.0, another non-pharmacological treatment exists for people with dementia. MAKS is a multi-component therapy consisting of a motor, everyday practical, cognitive and social module (Gräßl, 2019). The results of a cluster randomized controlled, single-blind study over six months regarding the success of a MAKS therapy show that, on average, the outcome measures "cognitive abilities", "practical abilities" and "practical daily living skills" stabilized (Straubmeier et al., 2017).

Robotic in Dementia Care

Robotics is advancing rapidly in the medical field. Driven by technical progress in sensor technology, there are now various forms of interaction between humans and robots. A basic distinction can be made between three forms (Bendel, 2018). In nursing robotics, human-robot collaboration is predominantly used, in which the human works directly with the robot. For this purpose, safety standards are defined in the form of a precise definition of the workspaces. The intersection of the robot's workspace and the worker's workspace is the shared workspace (Thiemermann, 2004). Mostly, autonomous mobile robots are used that take over tasks independently and execute them fault-tolerantly. To do this, they use a range of skills which they can apply in a targeted manner when carrying out tasks (Hertzberg, Lingemann & Nüchter, 2012).

Looking at the operating concepts of existing care robots in dementia care, different interaction classes with individual benefits and deficits emerge. A basic distinction is made between natural user interfaces and computer interfaces. In general, well-known dementia robots such as Paro, Pepper, Mario and Nao offer the common Natural User Interfaces speech, facial expressions, gestures, biosignals and haptics, which can occur in different combinations (Bendel, 2018) (Chang et al., 2013) (Sather et al., 2021) (Mannion, 2020). Sensors and screens are used as the basic computer interfaces. The exact form of the respective interaction class varies depending on the specific use and application of the robot. Overall, however, no fine-grained concepts for situationally appropriate haptic use in dementia care can be observed in existing care robots. The research focuses on the realization of applications with simple haptic feedback to patients without the targeted use of specific expert knowledge. However, for efficient operation, an application-specific, User Center Design is absolutely necessary (Schweiger, 2018).

Transferable Therapy Exercises

Science-based non-medicinal dementia therapies such as MAKS and GiB 2.0 ensure health gains as long as human caregivers use them. Because some activities are very community-based and often involve highly unpredictable processes, certain therapy exercises are currently more transferable to a robot than others. Training concepts in which nursing home residents exercise motor skills, cognition, coordination and strength not only achieve health benefits, but can be very well realized by robots. Pushing and pulling are important exercises for successful therapy. Elastic bands are often used for this purpose. Instead of the bands, the robot can be used as a training partner. Essential interaction concepts of care robots are haptics, gestures, speech and facial expressions. Overall, the three categories of ball games, coordination exercises and strength exercises are very well suited for transfer to a care robot (Schweiger, 2021).

Figure 1 shows how the exercises can be performed with a dementia robot instead of a caregiver as a partner. In the ball throwing game, the dementia patient has to catch a ball that is thrown to him by the robot. In the high-five game, the dementia robot claps the hands of the dementia patient with a musical background. In the strength exercise, the patient pushes or pulls on the robot arm.

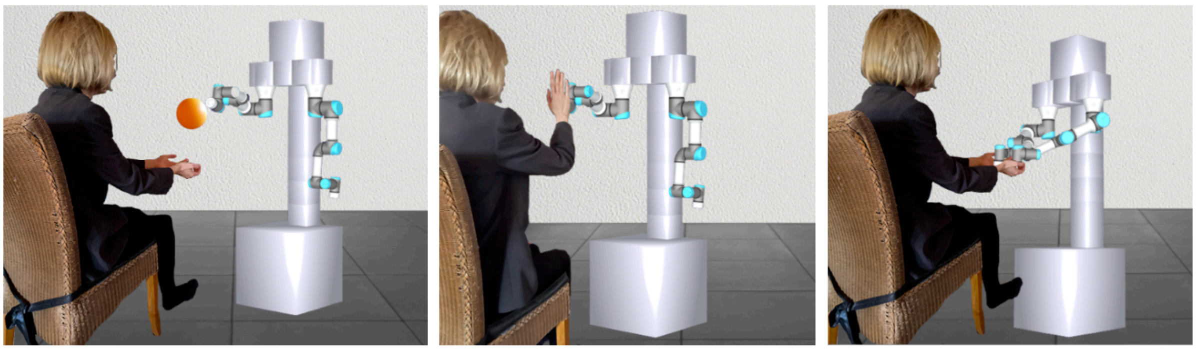

Figure 1: Exercises Dementia Robot

Summary

Currently, however, there is no dementia robot that can perform haptic therapy exercises such as ball games, coordination games and strength exercises together with the patient. Consequently, there is no knowledge-based interaction system that uses the knowledge of the caregivers specifically for these exercises. Furthermore, there is no scientific research so far on which knowledge is used in detail for the mentioned exercises and how to formalize it with regard to a knowledge-based interaction system for a dementia robot. Finally, there has not yet been a study that uses user-centered design to evaluate an appropriate interaction system together with caregivers and patients.

Method

To realize a knowledge-based interaction system for a dementia robot, the specific expertise of caregivers on the mentioned exercises ball throwing, high-five games and strength exercises has to be acquired. The knowledge acquisition is done in two steps, the Knowledge Collection and the Knowledge Modeling. The resulting interaction classes form the basis for building a knowledge-based planning system that plans in real time the actions of the dementia robot during the execution of one of these exercises and passes them on to the actuator for execution.

Knowledge Collection

For knowledge acquisition, on the one hand, the relevant methods of knowledge acquisition for expert systems must be used. Since this is a knowledge-based interaction system, appropriate user experience design methods are also used. So far, expert knowledge has been collected in a total of five regional nursing homes using the methods of Contextual Inquiry and expert interviews. The focus was primarily to capture the small but typical tricks that caregivers use with impaired patients to achieve successful therapeutic progress.

Expert Interviews. First, interviews were conducted. The survey method expert interview belongs to the qualitative methods of social research and is a special form of the guided interview (Blöbaum et al., 2016). For this interview, five experts with in-depth knowledge of dementia care from five different nursing homes in the Regensburg area were recruited and interviewed for one hour. The interview guide was created using the SPSS method (Helfferich, 2014). The expertise that was identified included especially the partly fine granular changes in the difficulty level of the exercises, in order to achieve therapeutic success as effectively as possible. The method captured a broad body of knowledge that was first documented and evaluated and then formalized into concrete interaction classes and heuristics.

Contextual Inquiries. After the interviews, an initial observation was conducted in the natural context of application through the Contextual Inquiry method. The three-hour observation of caregivers performing dementia exercises provided a realistic assessment of the actual interactions between patient and caregiver. An additional post discussion with the competent nurse could concretize unclear procedures in the specific handling of a person suffering from dementia during the exercises. The evaluation of the qualitative data from contextual inquiries and interviews was based on empirical methods. To this end, Bryman's four stages of qualitative analysis were used to identify correlations and orders of factors of particular relevance (Hinrichs et al., 2017).

Knowledge Modeling

The knowledge collected about each nurse is hardly characterized by precise measurements of specific patient responses and actions. Instead, patients are summarily assigned characteristics as a consequence of their behavior, which describe their performance in natural language. These terms also play a central role in both the caregivers' classification of the degree of dementia and the adaptation of exercise design. Therefore, it is necessary to capture these terms in the course of a knowledge acquisition and to represent their meaning. Fuzzy logic is already used to describe medical contexts (Ozsahin, 2020). Downstream neural networks can be used to realize classifiers that are capable of learning (Gayathri, 2018).

Therefore, Fuzzy Logic is used as a description method for describing the expert knowledge in the form of a taxonomy. In particular, for each term mentioned, a linguistic variable is defined to which different linguistic values can be assigned. Each linguistic value is thereby described by a membership function, which describes both the underlying, sharp physical size, and their fuzziness. The fuzziness here arises predominantly from knowledge elicitation with different caregivers. From the natural language assessment of patient behavior, nurses assign each patient a natural language dementia level and an individualized exercise routine. Applied to knowledge acquisition, this means that the linguistic variables describing the patient's behavior are assigned a linguistic value for the degree of dementia and the robot's follow-up responses. The mapping is thereby specified as fuzzy rules.

Results

Interaction System

The results show that the execution of the identified dementia therapies in the form of group therapies is a compromise for all participants. Since the health status of a dementia patient can vary greatly and even fluctuate depending on the day, group therapy often over- and underchallenges patients and is only just right for a fraction of patients at that moment. The fun factor suffers as a result, and health promotion is not optimized in the process. Caregivers therefore often conduct additional individual therapies, which are, however, very time-consuming. The usefulness of the robot with a knowledge-based interaction system, with which the patient can practice independently and individually, is underlined by this aspect. Overall, it was possible to gather extensive expert knowledge on how to deal with dementia patients with different levels of performance during dementia therapies.

Knowledge Modeling. The knowledge of the nursing staff for the implementation of these exercises in the context of dementia therapies consists, on the one hand of professional school knowledge acquired in the context of specific training. On the other hand, the nursing staff also have a broad wealth of experience for the individual implementation of dementia therapies. In order to be able to develop a knowledge-based interaction system for a dementia robot, this expert knowledge of the caregiver must be transferred to the robot. For this purpose, a taxonomy with heuristics serves as a basis in which this knowledge is modeled in a fine-granular way. The expert knowledge is structured into seven levels in the taxonomy. The upper levels specify the therapy framework with the three identified dementia exercises and the exercise goals. Each specific exercise improves targeted disease-related limitations through specific manipulated variables. The lower levels of the taxonomy map the specific variation variables and variation values. Figure 2 shows a section of the four lowest levels. Building on this factual knowledge, caregivers have a variety of tips and tricks on how to vary the individual variables between exercises to gradually adjust the level of difficulty with respect to the therapy goal. This knowledge has been modeled in the form of rules. For example, one of these rules is shown in Figure 3.

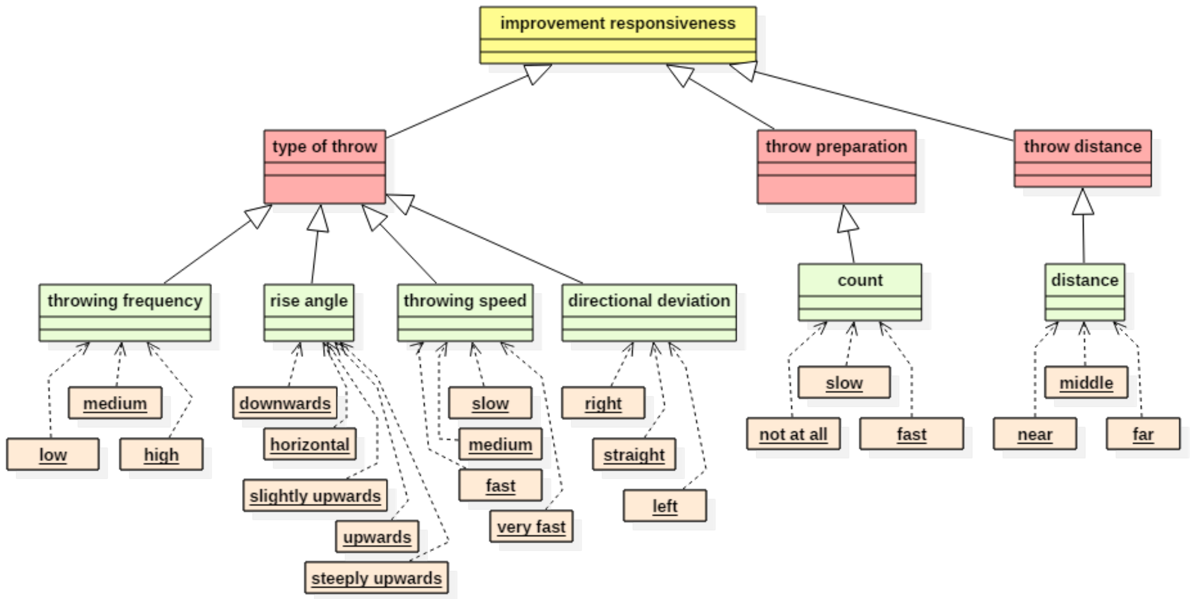

Figure 2: Part of ball throwing taxonomy nurse

Knowledge Formalization. In order to be able to transfer this knowledge to the dementia robot, fuzzy logic was selected as the form of representation for the expert knowledge. This made it possible to formalize summary, natural language descriptions of facts and actions in the form of fuzzy sets and fuzzy rules. This formal specification of expert knowledge can then be evaluated with an adaptive, optimizing real-time planning system. The actions of the plan consist of the associated robot capabilities, which are adjusted to the respective difficulty level of the exercise using the expert knowledge.

Here is an example: to improve the patient's reaction time when throwing a ball, different variation values can be selected to change the difficulty level of the exercise. The variation values of the rise angle, the direction deviation and the throwing speed. In the same way, the degree of dementia is specified as membership functions (see figure 4). The fuzzy rules shown in figure 5 define on the one hand how the concrete values are varied between exercises and thus the adapted behavior of the robot. So, if the patient manages to catch the ball when the directional deviation was performed straight, the rise angle was chosen upwards and the throwing speed was slow, the directional deviation should be set to the right for the next throw to increase the difficulty. On the other hand, the rules also determine the classification of the patient's dementia exercise level. For example, if the rise angle was laid out horizontally, the directional deviation was set to the left, the throwing speed was performed quickly, and the patient was able to catch the ball, then the dementia exercise level in this rule example is classified as "no dementia".

If the patient can safely catch a ball thrown slowly, directly to him, upwards, then in the next exercise I throw the ball slightly to the side.

Figure 3: Exercise variation rule

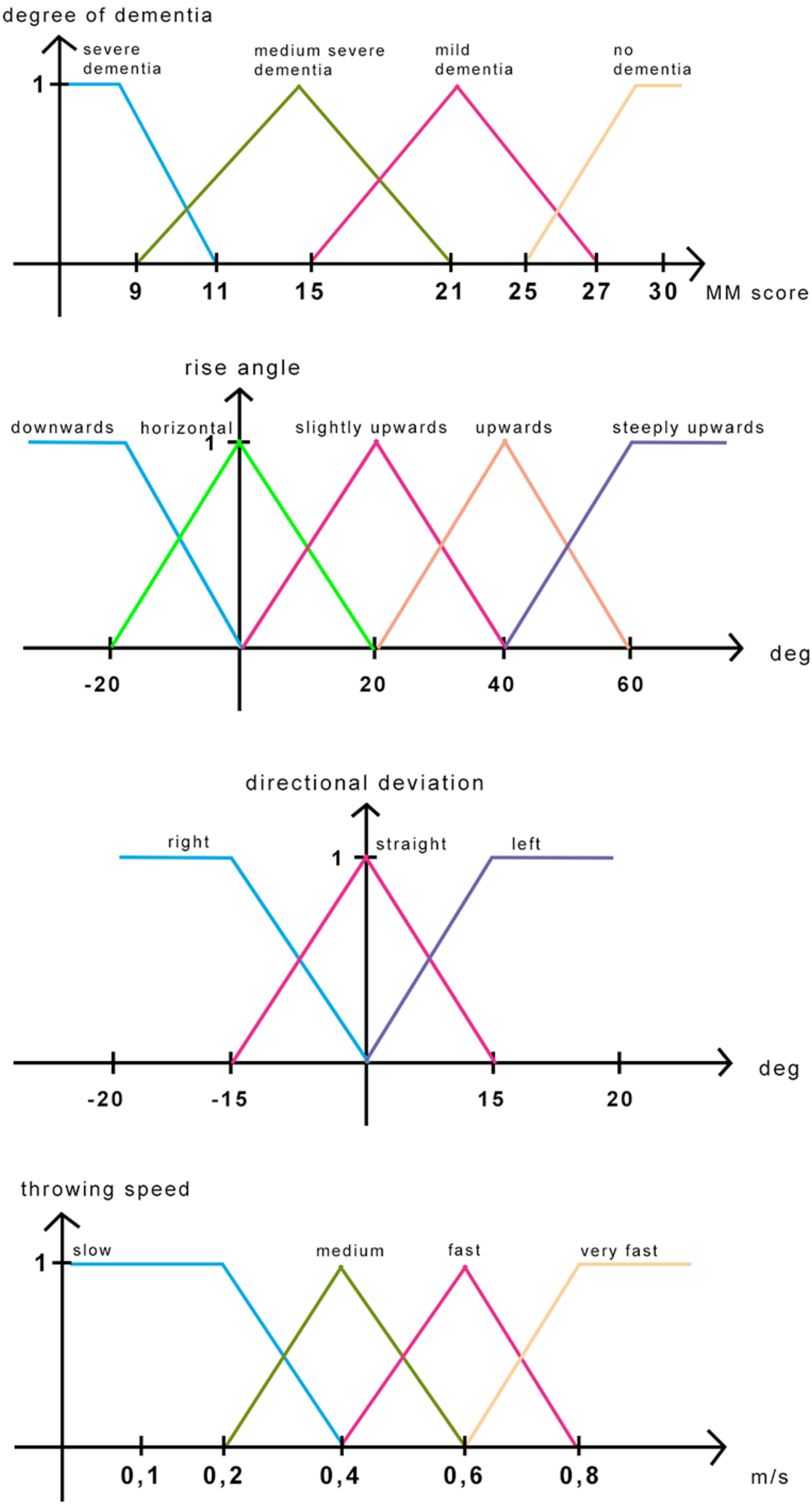

Figure 4: Example membership function

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if      (directional deviation = straight AND
        rise angle = upwards AND
        throwing speed =  slow AND ... AND
        reaction = caught
then    directional deviation = right

if      (rise angle = horizontal AND
        directional deviation = left AND
        throwing speed = fast AND ... AND
        reaction = caught)
then    degree of dementia = no dementia

if      (rise angle = upwards AND
        directional deviation = straight AND
        throwing speed = slow AND ... AND
        reaction = touched)
then    degree of dementia = mild dementia
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Figure 5: Example fuzzy rules

Discussion

The results of the knowledge acquisition show that the nurse's expertise for the exercises is multi-layered and finely granular. The experiential knowledge is largely case-based and is also applied on a case-by-case basis with the help of analogy building. Classification is exercise-based using indicators that are dynamically summarized into a dementia grade. The case-based knowledge is largely applied summarily. In the foreground of the exercises is always the enjoyment of the exercises and only then the success of the therapy. The expert knowledge therefore contains a lot of room for interpretation in the assessment of the patient's current performance. In addition, it contains numerous, fine-grained variation possibilities for the design of the next exercise in each case. Finally, the procedures are not universally applicable, because successful empirical values for one patient do not always lead to the same success for other patients.

Therefore, the interaction system of the dementia robot must be designed in a particularly adaptive way and be able to optimize itself depending on the situation. Therefore, it was important to design the knowledge model in such a way that both the summary classification of the patient and the flexibility of the actions based on it are represented. The specification form with fuzzy logic used for this purpose proved to be suitable. By using the expert knowledge of the caregiver, the dementia robot can act purposefully in a situation-specific context. Compared to other dementia robots, the concept is thus much more specific and concrete. In particular, the robot can not only perform common interactions with Natural User Interfaces and computer interfaces but can also implement the little tricks of a caregiver and interact haptically. This is an added value compared to previous dementia robots, which are also very much designed for specific mental domains such as loneliness.

Limitations

The taxonomy of knowledge acquisition documents so far only the first results from knowledge acquisition. So far, these have also been transferred to fuzzy logic with only a few case studies. In order to be able to explore the detailed expertise of the experts in a fine-granular way, further observations and formalizations must be carried out. Moreover, only the nurses' point of view has been considered so up to now. The patients' assessment of the effectiveness of the exercises has not yet been included. Further methods from user experience design must be used for this purpose.

Conclusion

From the results, it appears that the realization of a caregiver robot to perform the identified therapies of ball games, high-five games, and strength exercises is entirely feasible based on the current state of research. The construction of a taxonomy for modeling the factual knowledge of the nursing staff has proven to be successful. Rule-based description to classify dementia level and variation of actions is appropriate. Formalizing the knowledge using fuzzy logic is possible and provides a good knowledge base for the real-time adaptive planning system.

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