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# A Feasibility Study of a Data-Driven Human-Robot Conversational Interface for Reminiscence Therapy

Nathalia Céspedes<sup>1</sup>, Anne Hsu<sup>1</sup>, Janelle M. Jones<sup>2</sup>, Ildar Farkhatdinov<sup>1,3</sup>

**Abstract**—Social Assistive Robotics are widely used in health-care to improve conventional treatments and increase patient engagement. Reminiscence Therapy (RT) is one application where social robots can be incorporated. RT is commonly used with people living with dementia, and it aims to evoke users’ memories and stimulate cognitive functioning using nostalgic materials. This paper presents a feasibility study of a data-driven human-robot conversational interface for reminiscing sessions. Ten healthy participants were recruited to evaluate the usability of the interface, user engagement and interaction perception. The results showed that most of the participants followed the conversation, and half of them contributed highly (i.e., interaction/speaking time >51.54%) during the interaction with the robot. Participants perceived the system as being able to generate context-relevant dialogue.

## I. INTRODUCTION

Dementia is a syndrome where there is a deterioration in cognitive functioning (i.e., mental processes involved in the acquisition of knowledge, information management and reasoning) beyond what is expected in normal ageing [1]. Around 55 million people worldwide are diagnosed with this condition [2], [3]. At present, there is no cure for dementia. However, pharmacological and non-pharmacological treatments can help to reduce symptoms and improve the quality of life of people living with dementia (PLWD) [4]. Reminiscence Therapy (RT) is one of the most popular psycho-social non-pharmacological interventions. RT is based on the evocation of past events using nostalgic materials (e.g., photos, music, videos) [5]. This treatment is based on the premise that remote memory remains intact until the later stages of dementia [5], [6], and is used as a way of communicating with PLWD. A diverse number of studies have shown the benefits of RT. Some of the important outcomes include the decrease of negative side-effects such as, depression, aggression and anxiety [7]; higher patient adaptation towards to the present time and life satisfaction [8], [9], and improvements in cognitive performance [10].

Although RT is a promising intervention, many outstanding challenges remain regarding its scalability and efficacy. First, dementia is a growing disease. There is an expected shortage of healthcare staff who are able to support the

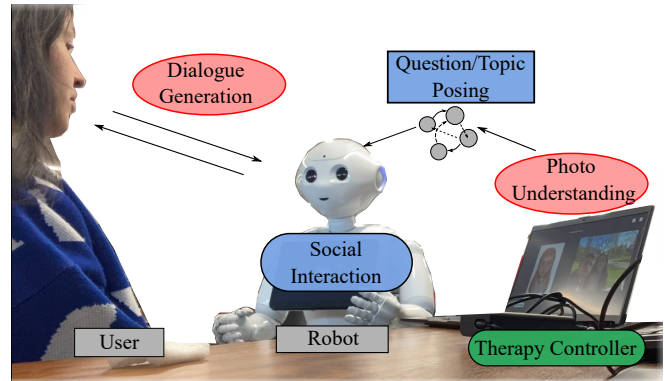


Fig. 1. Human-Robot Conversational interface setup for Dementia Reminiscence Therapy. *User Understanding Module* functions are represented by the red-colored circles, *Social Interaction Module* by the blue-colored circles and *Therapy Controller Module* by the green circles.

demand for RT therapy [11], [12]. Second, the lack of PLWD’s engagement with RT can negatively affect the outcomes of the therapy [13], [14]. Third, there is a need for more understanding of how to assess RT engagement, and how engagement measures are linked to psycho-social effects and outcomes [15]. These challenges can be overcome with technology-based solutions that allow for the practical delivery of RT to a greater number of people [16], as well as contribute to increased engagement and personalisation [17]. Some examples are, Computer Interactive Reminiscence and Conversation Aid (CIRCA) [18] which is able to support RT by creating a natural and relaxing interaction environment, and the system presented by Wu et al. [19], that uses a social robot that guides an RT session supported by intelligent interaction implemented with Convolutional Neural Networks and a Knowledge Graph.

The above-mentioned works have explored the use of technology in RT, mainly focusing on the development of this tools. However, there has been limited work into assessment methods to measure user engagement towards the technology. This paper presents the development of a data-driven human-robot interface (see Figure 1), and a feasibility study with healthy participants in a reminiscence session, where the assessment of verbal engagement and user’s perception is presented. The paper is organised as follows. In Section II, applications of technology in RT are presented. Section III presents the system architecture (e.g., software modules and robot’s interaction). In Section IV the methodology carried out to assess the interface is explained. Finally, Section V and Section VI discuss the results and the conclusions observed

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during the experiments.

## II. RELATED WORK

With the growing challenges in dementia care, researchers have proposed technology solutions to improve conventional treatments and support people with dementia and health/social care staff. Information and communication technology, social assistive robotics and virtual reality (VR) are the most common approaches.

### A. Technology for Reminiscence Therapy (RT)

Gowans et al. [20], a multimedia conversational aid for RT was presented. Their application integrated a touch-screen system that prompts different multimedia materials (e.g., family photographs, food pictures, events images and music) and was used to promote the dialogue between clinicians and people with dementia. The application facilitated the interaction by reducing the number of direct questions, and therefore, creating a relaxed environment to talk. After using the system, it was observed that people with dementia engaged more during RT leading to an improved mental state.

Reminiscence therapy challenges have also been addressed with the use of VR and haptic interaction. For example, Tominari et al. [21], built a VR experience where a traditional Japanese house was recreated for people to remember things from their past and tap into their long-term memory. The participants used the system for eight weeks. The results demonstrated a positive impact on patient's quality of life and well-being.

### B. Social Assistive Robotics and Reminiscence Therapy (RT)

Among the many methods in which technology can support RT, socially assistive robotics has the advantage of promoting social interaction naturally due to embodiment (physical presence). For instance, Kim et al. [22] and Kidd et al. [23], compared the influence of social agents in the user's perception depending on the physical presence level. The results demonstrated that the users showed increased confidence and engagement towards the social agents when there was an embodied physical presence.

Tapus et al. [24], developed an adaptive system focused on dementia treatment. The system used gamified music therapy to increase the patient's cognitive and social skills. The game consisted of recognizing songs played by the robot pushing certain buttons located on a board. The game's difficulty and the robot behaviours (e.g., robot's dialogue and movements) changed according to the user's performance. In this way, the learning and adaptation systems allowed PLWD to maximize their performance during the therapy. The system was evaluated with 4 participants that belonged to a living care facility for 6 months. The results suggested that participants could sustain attention to the music (i.e., on average 20 minutes for participants diagnosed with mild impairment dementia, 14 minutes for participants diagnosed with moderate impairment and 10 for severe impairment), and the recognition time and incorrectness decreased. The system adapted its game

settings according to PLWD impairment level, and therefore, increase their session engagement.

Within the EU MARIO project [25], an image-based reminiscence application was developed. The project implemented a *reminiscence ontology*, in charge of representing person's biographic information along with their association with persons, places and life events. An *authoring tool*, allowed family members and caregivers to update and manage the reminiscence ontology. However, the usability of the system was not evaluated in further stages. Similarly, Wu et al. [19] developed an interactive questioning system for robot-assisted reminiscence. The main contributions of the study included the development of a data-driven algorithm for event recognition in images, a concept interference model (i.e., a model in charge of creating appropriate topics for the robot, considering the observable entities in the images), and an end-to-end robotic system to perform the interaction. Results showed that the system was able to generate coherent question-related dialogue based on the user's photo and had the potential to guide the recall of memories. However, the study was only evaluated in healthy users, and some limitations regarding the conversational procedures (i.e., errors in event recognition and conversation flow) were reported.

The limitations of the previous work include the lack of objective metrics to assess types and levels of interaction with socially assistive robotics, and the effects of these interactions. In particular, the engagement between dementia users and social robots. Hence, this paper presents a Human-Robot Conversational interface for reminiscence therapy, where the development of cognitive architecture and a preliminary assessment of the engagement is addressed.

## III. DATA-DRIVEN HUMAN-ROBOT INTERFACE

We designed a human-robot interface based on a conversational approach that can be used to support people with dementia during RT (see Figure 1). The software components that are described below are represented by a cognitive architecture divided into three modules: (i) *User Understanding Module*, (ii) *Social Interaction Module* and (iii) *Therapy Controller Module*.

### A. User Understanding Module

Reminiscence therapy uses nostalgic materials to trigger memories in the elderly and it is based on a conversational method. This requires the ability to analyse photo content and also recognise when the user is speaking. Thus, this module is in charge of preparing the system to engage with the user (i.e., analysing photo content and voice dynamics calibration). First, the *photo analysis* is implemented using the OpenCV Deep Neural Network library and the COCO (Common Object in Context) image large-base dataset. The outcomes of the analysis are used to build the conversation around the photo based on context-related topics. For example, if a face is recognized, the "Who?" topic will be triggered and the social robot will start generating questions around the faces recognized (the topics and questions generator is carried out in the *Social Interaction Module*).

Likewise, if a place is recognized, the “Where?” topic will be triggered and specific questions will be asked about the location. However, if the system does not recognize the place, face or an object of interest, general questions will be asked. Figure 2 demonstrates topics generation based on a photo.

Additionally, a *Voice Activity Detector (VAD)*<sup>1</sup> system was integrated to analyze the user’s voice during the conversation. Note that the current system does not perform full speech-recognition. Instead, we simply record the whether the user or robot was speaking, and the length of time that the user speaks. While we have some speech recognition of commands used to control the flow of the interface, we are not generally processing the semantic content of user’s utterances. With this measurement two metrics were assessed: (i) dialogue dynamics (i.e., when the user is talking and when the robot is generation a question), and (ii) *the duration of user’s answer*.

### B. Social Interaction Module

The main aim of the *Social Interaction Module* is to integrate a social robot in the RT environment. Following the results of the studies presented in previous sections, where the importance of physical embodiment is mentioned, a Pepper Robot was used as the social agent. To promote natural interaction, the Pepper Robot needs to demonstrate socio-cognitive skills. Thus, two sub-modules were developed: (i) the verbal interaction module aimed at managing the question/topic generation system, and (ii) the non-verbal interaction module in charge of running the robot’s body gestures and behaviours.

Figure 2 shows the question and topic generation system. The dialogue is created according to the data extracted in the *User Interaction Module*, triggering different topics (i.e., “who”, “where” and “when”). As the system does not understand the user’s speech, the questions are mutually exclusive, which means the robot will pose questions that avoid incoherence during the dialogue. Thus, most of the questions are closed-domain (i.e., “yes” or “no” answers). However, open questions are also included. The questions<sup>2</sup> proposed within the interface are chosen from those commonly used during reminiscence therapy [26], [27], and are meant to stimulate memory.

The non-verbal behaviours include the robot’s body movements to generate expressions during the conversation<sup>3</sup>. A face tracking service was also used to follow the user’s head, and to enhance the interaction.

### C. Therapy Controller Module

This module comprises the Graphical User Interface (GUI), where the therapy flow can be controlled. For in-

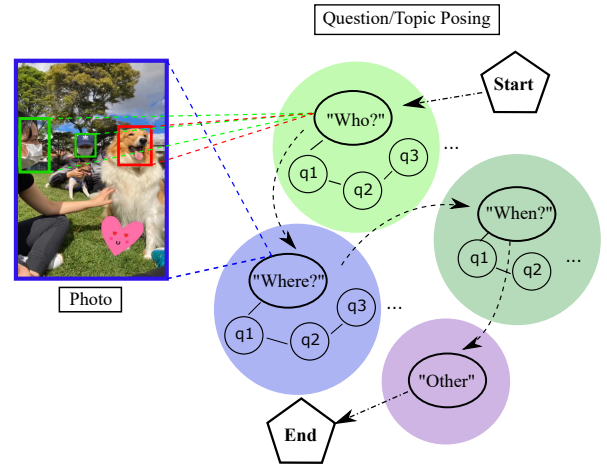


Fig. 2. Topic and Question generation system for Dementia RT. The diagram represents one example of the dialogue flow where the topic “Who” is activated first. However, the dialogue could take random order.

stance, the health/social care staff can register the patient’s data, configure the robot settings and run the interface.

## IV. EXPERIMENTAL SETUP

This feasibility study was performed with the purpose of assessing three different aspects: (i) the functionality of the interface (e.g., running flow, smoothness in the robot’s behaviours execution, etc), (ii) the user’s perceptions, and (iii) verbal engagement using the dialogue dynamics.

### A. Participants

A total of 10 participants, age:  $25.5 \pm 2.38$  (mean  $\pm$  st.dev.); 8 females, 2 males, were recruited. All participants were healthy adults without vulnerable conditions. Healthy participants were considered in this study as the primary goal was to evaluate the technical aspects of the proposed robotic system. The participants received a £10 Amazon voucher as a compensation for their time.

### B. Variables

Two parameters of the dialogue dynamics were measured: *adjacency pairs* and *user verbal interaction*. The percentage for both metrics was calculated as follows:

- *Adjacency pairs* ( $AP_{[\%]}$ ): Two utterances by two speakers with minimal overlap or gap between them (i.e., question-answer pairs).
- *Interaction times*: Represented by the *User Verbal Interaction* ( $UVI_{[\%]}$ ) (i.e., the time of the user’s answer after a social robot request), and *Robot Interaction* ( $RI_{[\%]}$ ) (i.e., the time used by the robot to make verbal and non-verbal interventions).

These metrics were used as indicators of the user’s verbal engagement during the experiment [28], [29]. For instance, if the user is engaging in the conversation with the robot, it is expected that longer answers and greater number of adjacency pairs occur.

Additionally, a user experience questionnaire was applied to measure the participant’s perception. Several studies

<sup>1</sup><https://webrtc.org/>

<sup>2</sup>For example, “What is the name of the people/person in the photo?”, “Are they your relatives or friends?”, “Do you remember when/where this photo was taken?”

<sup>3</sup>For the non-verbal behaviors, the NAOqi ALAnimatedSpeech module and the annotated text was used. These modules, allow to use predefined behaviors of the robot as “enthusiastic”, “saying hi”, “Explain”, among others

highlighted the benefits of using the Subjective Assessment of Speech System Interfaces (SASSI) to understand and measure comprehensively experience [30], [31], [32]. The SASSI questionnaire includes a wide range of factors related to user experience and evaluated with Likert scales. These factors are categorized into six main indicators:

- *Response Accuracy*: Whether the system recognizes the user input correctly, and thus gives answers relevant to the user’s expectations.
- *Likeability*: The user’s opinion regarding the system and the feelings (affect) towards the interface.
- *Cognitive Demand*: The user’s perceived level and experience of effort required to engage with the interface.
- *Annoyance*: User perception of their interaction with the interface in terms of being repetitive/boring/irritating.
- *Habitability*: The extent to which the user understands the system (i.e., knows what to do and knows what the system is doing).
- *Speed*: This measurement represents the speed of the system.

Finally, one close question and three open questions were added to the questionnaire: “*Did you enjoy the interaction with the robot?*”, “*What was the aspect that you enjoyed the most during the interaction?*”, “*Is there anything you did not like about the interaction with the robot?*”, “*What would you recommend to improve the interaction with the robot?*”

### C. Experimental Procedure

Before the reminiscence session started, two meaningful photos of each participant were collected. The photos were uploaded and displayed through the GUI. The participants selected the photo they wanted to talk about. Then, the system performed the image analysis to build the conversation. During the session, the data were recorded and stored in the database. At the end of the experiment participants were asked to fill in the SASSI questionnaire and the informed consent. This study was approved by the University’s Ethics of Research Committee reference QMERC20.488.

## V. RESULTS

Dialogue dynamics and SASSI questionnaires were applied to understand user verbal engagement and perception towards the RT interface.

To explain the results, an example of the verbal interaction between a user and the robot is shown in the Figure 3. Red lines represent the robot’s behaviours triggered during the interactions and the blue signal corresponds to the participant’s voice activity (1: activation, 0: deactivation). Each robot event is recorded with a label to identify the type of interaction (e.g., greetings - highlighted in orange boxes, open/close questions per each conversational topic, not hearing, etc) and to further analyze the user’s verbal engagement (e.g., answer duration and adjacency pairs as shown in Figure 3).

The number of robot events generated depended on the data from the photos extracted by the *User Understanding*

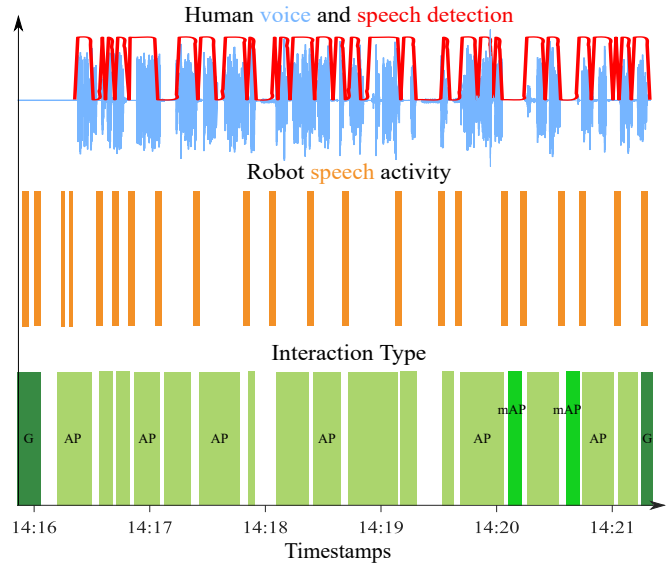


Fig. 3. Example of a user’s voice dynamics during the reminiscence session with the social robot. The labels in the Interaction Type graphic represent the Adjacency Pairs (AP) and Missed Adjacency Pairs (mAP).

*Module*. For instance, if the user provided a photo where not only faces but animals were recognized, the dialogue generated by the robot in the “Who?” topic was longer compared to situations where only faces were recognized in photos. The dialogue generation is limited by the possible objects recognized by the algorithm and the size of the questions database.

Figure 4 presents the outcomes of the verbal engagement for each participant. As it can be seen, the adjacency pairs percentage ( $AP_{[\%]}$ ) is greater than 74% in all cases, with 18 pairs in average per conversation. This result indicates that at least 74% of the questions posed by the robot were answered by the user, suggesting an acceptable level of verbal engagement during the conversation.

Figure 4 shows the interaction measurements ( $UVI_{[\%]}$  and  $RI_{[\%]}$ ) during RT. These measurements provide a better insight into the counterparts’ contribution to the dialogue. Half of the participants contributed proportionally to the robot interaction (e.g.,  $P_1, P_2, P_3, P_9$  and  $P_{10}$ ), with an average of participation of 51.54%. Other participants,  $P_4, P_5, P_6, P_7$  and  $P_8$ , participated less (26.98%) during the RT session. These results are related to the participants’ verbal engagement during the dialogue. It was observed that participants that engaged more in the dialogue tended to use more open answers<sup>4</sup> rather than close answers.<sup>5</sup>

The SASSI questionnaire was administered at the end of the session to understand the user’s perception towards the interaction with the robot. Figure 5, presents the results for each construct. In the case of *Response Accuracy*, 54.16% of the users agree/strongly agree that the system recognized the voice input correctly. Similarly, the outcomes regarding

<sup>4</sup>Longer answers that contain greater information or description about what was asked by the robot.

<sup>5</sup>Short answers of the type “Yes”, “No”, “I cannot recall”, or similar.



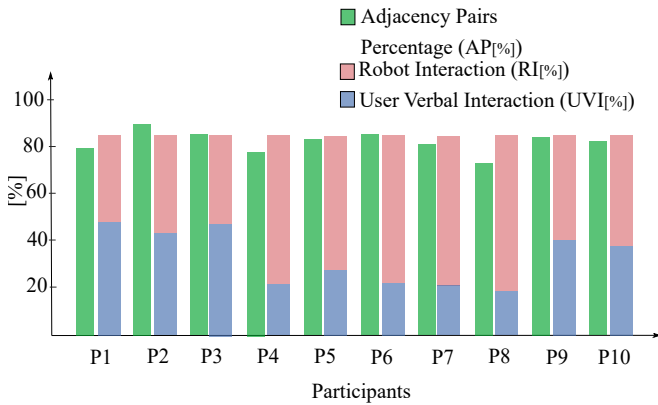


Fig. 4. Verbal engagement results. Adjacency pairs and user/robot intervention percentage.

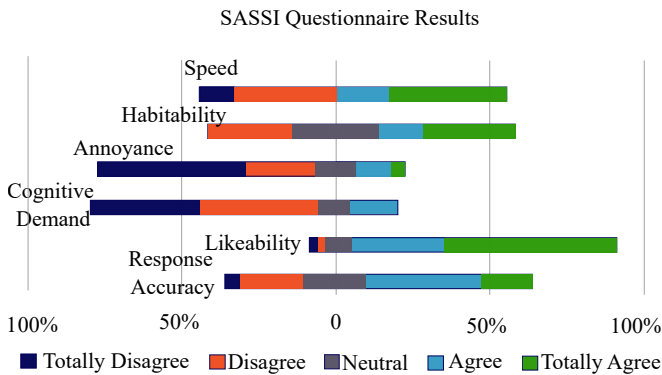


Fig. 5. SASSI questionnaire results per each construct.

the *Speed* show that 55.5% of the users consider that the conversation was fluid and the robot commented or answer quickly. On the other hand, more than 70% of the users agreed that the system does not require a high *Cognitive Demand* or they did not feel *Annoyed* by the system. In terms of *Likeability*, 86.1% of the users perceive the system as useful, pleasant and enjoy overall interacting with the robot. The *Habitability* construct shows that only 27.7% of the participants struggled with understanding the system.

Finally, the comments collected through the open questions were positive in general. Most of the participants answer that they enjoyed the interaction with the robot and they highlighted the robot’s capabilities. For example: “*It was a novel experience since I have not interacted with a robot before – it was an interesting experience to have*” ( $P_1$ ), “*I was fascinated by how it generated questions from looking at an image and processing it without consistent manual input*” ( $P_2$ ), “*I enjoyed telling the robot about my photos and it replying very kindly*” ( $P_3$ ), and “*That it asked me about my memories of that places and/or people. And also its voice, it is really calm and nice*” ( $P_8$ ). Participants also commented on the negative aspects of using the interface. Most of the negative comments were related to the speed of the robot when reacting to a user’s input during the conversation: “*It was slow to reply at times so I did not know if it had not heard me, so I repeated myself without*

*being asked*” ( $P_1$ ), and “*The robot found it quite difficult to pick up what I was saying*” ( $P_2$ ). Participants recommended some improvements: “*I suggest it would be important if the robot could try pick up different voices of different accents and different volumes so that it can be used on a variety of people*” ( $P_6$ ), “*More tailored responses to questions according to the emotions communicated during, such as sounding happy when recalling a happy memory*” ( $P_5$ ).

## VI. DISCUSSION

This study presents the architecture for a conversational human-robot interface, and its preliminary assessment in an RT context. Verbal engagement was measured during the session to understand the user’s adherence to this approach. For all participants, *Adjacency Pairs* the question-answers pairs happened 74% of the time during the reminiscing session. This preliminary result suggests that the users were capable of following the conversation built by the robot.

While participants had a high number of adjacency pairs in the experiments, the interaction times provide a more detailed sense of the user’s verbal engagement during the RT session. Some of the participants contributed more during the interaction, using more information to answer the questions posed by the robot. For instance, when the robot asks about recalling memories related to the place/time of the photo, some of the participants elaborated at length and provided more facts when describing the pictures compared to the others who used closed answers. This result could indicate a higher verbal engagement during the interaction with the robot.

Our results suggest that using the measurements to analyze engagement can provide a sense of users’ verbal engagement to the robot application. Given that, one of the current limitations of previous work is the lack of in-depth measurements of technology’s effects on engagement, assessing elements such as, *Adjacency Pairs* and *Interaction times* can be useful for objectively evaluate the engagement metric.

Furthermore, the *Likeability* and *Annoyance* constructs from the SASSI questionnaire shows that the system was positively evaluated by the users. Within the participants’ comments, we found indications that using the images for recalling memories was important. The fact that the robot was able to recognize the context within the photos and build a dialogue around it provides novelty to the interface. Although the robot cannot understand the user’s answers, some participants highlighted the robot’s intelligence in its ability to carry out the dialogue, which was attributed by the question-generation coherence during the interaction.

Regarding the *Speed* of the interface, the participants perceive that the speed could be improved. For example, one of the limitations of a conversational approach was the noise interference during the experiments. Hence, in the future a microphone to reduce the noise will be implemented to improve the conversational dynamics.

Finally, the rest of the constructs *Habitability*, *Cognitive Demand* and *Response Accuracy* were also evaluated positively. These outcomes showed the interface was easy to

understand and the users trust the system. Overall, the results are promising in terms of offering new technology strategy for RT and perform objectively analysis of participant engagement. Additionally, in the cases where the users did not engage highly during the session these two metrics can be used in the future to adapt the robot's behaviors to improve the engagement.

## VII. CONCLUSIONS AND FUTURE WORK

Reminiscence therapy is currently a useful strategy to enhance the quality of life of people with dementia. Recalling past events have been demonstrated to increase positive mood and reduce agitation. This paper presented a data-driven Human-Robot conversational interface for RT. A usability assessment was carried out to understand the system usability in terms of user perception and interface performance. Additionally, the user engagement was measured through the dialogue dynamics.

Regarding the engagement the results showed that although the adjacency pairs were greater than 74% between the participants, the interaction measurement provide a better insight of the participants contribution during the dialogue. As future work these measurements could be used to adapt the robot responses and increase the participants engagement depending on their performance. Critically, the SASSI questionnaire highlighted that participants enjoyed using the interface and the interaction with the robot good was overall. In future work, the system will be improved to enhance the dialogue between the robot and the users. Furthermore, the interface needs to be tested with PLWD in a realistic scenario to have a better understanding of the interface's usability.

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