

# An Intervening Ethical Governor for a robot mediator in patient-caregiver relationship: Implementation and Evaluation

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**Abstract**— A robot mediator can enhance the quality of patient care in a health care context. Patients with Parkinson’s disease can experience difficulties in precisely expressing their emotions due to the loss of control of their facial musculature, leading to their stigmatization by caregivers. To remedy this challenge, a robot mediator can be inserted into a patient-caregiver relationship. In this context, it is essential to handle the ethical issues of neglect to ensure human dignity. In an earlier paper [19], we proposed an intervening ethical governor (IEG) model, which enables a robot to ethically intervene in a situation where patients or caregivers go across accepted ethical boundaries. In this paper, we show how the IEG model can be implemented and applied in a real robotics system. In addition, by conducting interviews with the target population (adults 60 years of age or older), we evaluate the current intervention rules in the model, discuss potential improvements to the model, and consider uses of the model in real clinical contexts.

## I. INTRODUCTION

The use of robotic technology is rapidly growing in our society in various contexts. Among others, the healthcare industry has been revolutionized by the successful implementation of robotic technology [1]. For example, not only is robotic surgery widely available [2, 3], but robots also improve the quality of patient care, such as the use of robot assistants in hospitals [4].

Today, more than 10 million people suffer from Parkinson’s disease (PD) worldwide and around 1 million Americans have been diagnosed with PD [5, 6]. Robotic technologies have been developed and are used to help PD patients and caregivers. However, most technologies to date are focused on the benefits related to PD patients’ physical rehabilitation [7]. For example, by using robotic training, PD patients can prevent or delay their loss of motor control [8].

Distinct from previous research, we focus on the role of robots in improving the quality of people’s interactions and relationships with each other. For example, therapeutic robots are widely used to help children with autism in their social development [9, 10]. The PARO robot provides emotional support for the elderly in nursing homes or people

traumatized by crises, leading to an improvement in people’s social relationships [11, 12]. More recently, the Zora social robot has been tested for seniors’ and children’s healthcare use in Europe. Results show that Zora enhances many socialization issues with the elderly and with autistic children [13]. In ways similar to how these therapeutic/social robots are used, we aim to improve the quality of PD patients’ everyday life and their relationship with their caregivers by using robotic technologies.

When interacting with caregivers, patients with PD experience challenges due to declining control over their musculature. In particular, since patients experience the loss of control of their facial muscles, they frequently cannot express their emotions or nuances in their faces. As a result, PD patients often can have blank expressions when they are interacting with other people (facial masking) [14, 15].

Facial expression is one of the essential cues in conveying people’s emotions and feelings in human-to-human communication. Therefore, PD patients’ facial masking can cause caregivers to misunderstand patients during their interactions. For this reason, the quality of PD patients and caregivers’ relationships can worsen, and as a result, stigmatization between a caregiver and a patient can arise [14, 16].

To assist in remedying this problem, a robot mediator can be used to assist in the relationship between PD patients and their caregivers. In this five-year, NSF-funded study (a collaborative interdisciplinary effort with Tufts University), we develop a robot mediator that can reduce the communication gap and uphold the dignity of early-stage PD patients that exhibit expressive masks during stigmatizing interactions with their caregivers [17].

The robot mediator’s architecture consists of two new components, which are the ethical adaptor and the intervening ethical governor. The ethical adaptor models the relationship between the patient and caregiver and uses this model to recognize stigmatization by recognizing discordance between their moral emotional states. An ethical adaptor model has been proposed and developed in our lab and has been presented elsewhere [18]. In particular, indignity arises when a patient experiences shame or embarrassment but the caregiver cannot respond with a sufficient level of empathy. In the ethical adaptor model, a robot mediator detects these gaps between the patient’s shame and the caregiver’s empathy and generates an appropriate robot action using kinesic nonverbal cues.

The second part of the robot mediator’s architecture is the intervening ethical governor (IEG), which can be used in more extreme situations. Stigmatization is highly related to

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ethical issues, and the maintenance of dignity is essential in our development of a robot mediator. For this purpose, we developed the IEG model that enables a robot to observe whether patients or caregivers crossed accepted ethical boundaries. When any one of a set of ethical rules is broken, the robotic intermediary intervenes with both nonverbal and verbal responses in an effort to restore a normal patient-caregiver relationship. The model for the IEG and its architecture were presented in earlier research [19]. that enables a robot to ethically intervene.

In this paper, we present the implementation details, based on the previous IEG model. By applying this model to a humanoid robot, we simulate multiple intervention situations and confirm the application of the interventions at the right time and in the right manner. As an evaluation method, we recorded intervention interactions and ran a formal interview study, where we presented the simulation videos to our target population (people who are aged 60 years or older) and asked questions with respect to the robots actions and the appropriateness of its responses. Based on the interview results, we evaluated the IEG model and obtained feedback on how to improve the current intervention rules and behaviors for further trials.

## II. INTERVENING ETHICAL GOVERNOR

We briefly reintroduce IEG architecture [19] in this section. IEG is a component of a robot architecture that enables a robot to determine how and when to intervene if unacceptable human-to-human interaction boundaries are crossed. As illustrated in Figure 1, perceptual data and previous case knowledge about the patient and the caregiver are encoded and then recalled by the evidence reasoning model. By sharing this information with the rule application module, it is determined whether any of the rules encoding the acceptable social norms have been broken. Once any rule violations have been triggered, the intervening ethical governor generates the appropriate corresponding intervention action, so the robot mediator can promptly intervene in the patient-caregiver relationship.

Intervention rules are the key component in this IEG architecture and are the data structures that encode the intervention procedures. In developing the system, several rules for robot intervention were defined based on evidence drawn from the medical literature [20, 21, 22]. Currently, two

prohibition rules and two obligation rules were predefined

TABLE I. PRE-DEFINED INTERVENTION RULES IN IEG

Rules	Description
Angry (yelling) prohibition	Yelling is one signal of the patient's excess of emotion. Especially, it shows the angry emotion of the patient and it is required to be controlled by the caregiver or the robot mediator by intervening in the situation.
Quiet prohibition	If the patient is too quiet, it is difficult to establish a good communication bond between the patient and caregiver. To remedy the withdrawn patient's status, intervention is required.
Stay obligation	It is the patient's obligation to stay in therapy until the end of the session. Therefore, if the patient tries to leave the room prematurely it should be detected and an intervention generated.
Safety-first obligation	It is an essential obligation to maintain the safety in therapy. Therefore, any situation that can cause risk should be detected and an intervention generated.

according to the literatures. These rules have also been reviewed and modified by the PD expert from Tufts University we are collaborating with. The two prohibition rules are "angry" and "quiet" prohibitions, and the two obligation rules are "stay in the room" and "safety-first" rules. Brief descriptions of these rules are presented in Table 1. The detailed data structure and computation formalization for each rule are described in the previous paper [19]. For this paper, we describe a procedure used to evaluate these predefined intervention rules, simulating four situations where these rules are fired, so that the robot generates appropriate restorative actions.

To implement this IEG architecture on the robotic system, we use multiple sensors. First, "angry" and "quiet" prohibitions are detected by the volume of voices. In addition, the "safety-first" rule in our scenario requires a speech recognition process. For this purpose, we use an external audio sensor (microphone) with speech recognition method. In implementing this part, we use Sphinx4, an open source speech recognition library [23]. Using the external audio sensor and Sphinx4 API, IEG can detect human speech and volume, which are used to trigger "angry," "quiet," and "safety-first" rules. In the current implementation, microphones are used as the external audio sensor and detect the caregiver's and patient's audio data. If the audio volumes are over (or less than) the threshold volume, they are determined as violations of the "angry" or "quiet" rules. The threshold volumes and times are determined empirically by the experimenter in the current version.

There are several ways to detect a human's absence for the "stay in the room" obligation. As an initial implementation, we use a camera sensor, so the system can detect and track human faces. In other words, when the patient's face is continuously undetected more than the threshold time (i.e., the time to absence the tracked patient's face is over the threshold), the robot can trigger the "stay" obligation to be fired. For facial recognition and tracking, we use OpenCV, an open source computer vision library [24]. Alternatively, a sensor in the chair could also be used in the future.

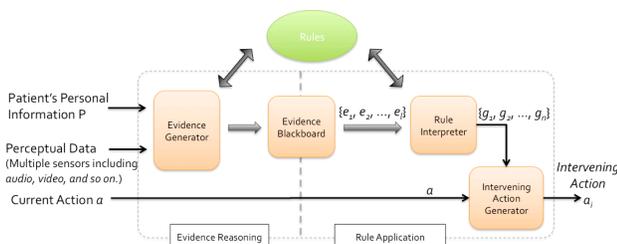


Figure 1. Intervening Ethical Governor Architecture



**Figure 2. Perceptual data monitoring interface for the IEG; facial detecting and tracking from the vision sensor (left) and audio detection from the microphone (right)**

Figure 2 shows the simple monitoring interface for the IEG’s sensory data. As explained above, current intervening rules are determined by encoding the perceptual data of both video and audio. The incoming perceptual data are plotted in this monitoring interface, and users can not only monitor these data but also empirically change the necessary thresholds for each rule.

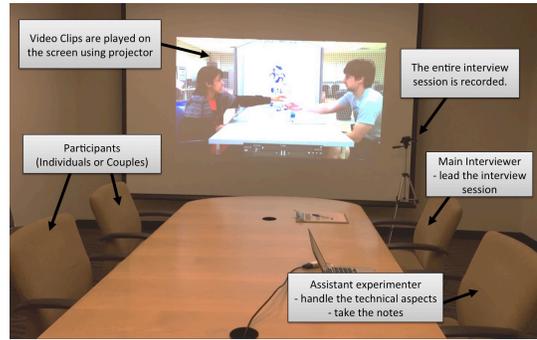
Finally, intervention actions are implemented and applied to NAO robotic systems. Verbal and nonverbal perceptual cues and actions for each intervention action have been described earlier [19], and these behaviors are implemented in the robotic system using NAOqi APIs [25]. The implemented verbal and nonverbal cues for each intervention action are also illustrated in the video scripts (more details in Table 2).

### III. EVALUATION METHODS

Conducting a human-robot interaction study by involving people in a real clinical situation is challenging. Especially, IEG triggers intervening actions when human’s dignity becomes threatened due to other’s inappropriate behavior. However, it would be particularly challenging from an ethical perspective to have patients or caregivers display inappropriate behaviors toward the others in any structured or systematic way to test our system. Therefore, we conducted standardized open-ended interviews as qualitative research [26]. In the study, we show multiple simulated videos to the participants, where a robot performs the intervening actions based on the scenarios, and evaluate the system by getting their feedback during an interview/discussion session.

We recruited three individuals and three couples as interview participants. Therefore, we interviewed nine people in total who are aged 60 years or older. The number of participants (9 people) is determined according to the literature [27], which suggests that at least six participants are required in a qualitative health study. This number has also been reviewed and confirmed by a PD expert with prior experiences with qualitative research in health care settings. Couples mean two individuals who know each other very well (in our case, husband and wife). Couples are involved in this study since they can generally discuss and share opinions interactively together, resulting in the potential deeper discussions in the interview study [26, 27].

Participants are invited to the interview session in a conference room at Georgia Tech (Figure 3). The study room has a door for privacy along with a table and chairs to seat a circle of up to 5 people. A video projector and screen are



**Figure 3. Experimental Setup: Interview room**



**Figure 4. Screenshots of simulation video. Left person plays the role of caregiver and right person plays the role of patient; A robot mediator is placed alongside them.**

used for the study. It is confirmed beforehand that everyone can see the monitor or projector screen from his or her position. The interviewer leads the interview session. All interview sessions are recorded. The assistant experimenter handles the technical aspects and also take notes if necessary.

For each study, individuals and couples are interviewed, where the interview includes a maximum of two participants at the same time. In the interview, participants are asked to watch five video clips and discuss each situation (details on video clips in subsection A). After showing each video, the interviewer asks questions related to the situation and the robot’s intervention actions (details on interview scripts in subsection B).

#### A. Simulation Videos

The video clips<sup>1</sup> simulate the interactions between two people; one person plays a patient and another plays a caregiver. We recruited two graduate students from the lab and trained them to perform the role of a patient and a caregiver (Figure 4).

In the simulation scenario, the patient performs a simple medication-sorting task and the caregiver interacts with the patient. This task has been selected as the primary scenario since pill-sorting is a general daily activities for PD patients. Due to tremor (shaking) in hand, this task can sometimes be challenging to the PD patients and it leads to frustration

<sup>1</sup> The simulation videos are available in the following links:  
[http://www.cc.gatech.edu/ai/robot-lab/nri/videos/IEG\\_basic.m4v](http://www.cc.gatech.edu/ai/robot-lab/nri/videos/IEG_basic.m4v)  
[http://www.cc.gatech.edu/ai/robot-lab/nri/videos/IEG\\_interventions.mov](http://www.cc.gatech.edu/ai/robot-lab/nri/videos/IEG_interventions.mov)

TABLE II. FIVE SIMULATION SCENARIOS; ONE BASIC “PERFECT” SCENARIO (NO INTERVENTION; DEVELOPED BY A PD EXPERT) AND FOUR INTERVENTION SCENARIOS (REVIEWED BY A PD EXPERT)  
P: PATIENT, CP: CARE PARTNER, R: ROBOT MEDIATOR

<p><u>Basic “Perfect” Scenario</u> CP: We’re going to sort medications Monday and Tuesday. Should we read the prescription label and find the directions for taking this medication? P: Okay, so this label says take one at each meal, and at bedtime. CP: Yeah, that’s right. Okay, let’s use this medication organizer the occupational therapist gave us. ... You can get started, I’ll be here if you need any help. P: I think I get it. [Patient opens the bottle/organizer and sort the medication correctly.] ... CP: That’s great, perfect!</p>
<p><u>Prohibition 1. Angry (yelling)</u> P: Ah, I can’t open the bottle. CP: Okay, but can you try one more time? P: [Patient is yelling] No, I said I can’t open it! → <i>Robot Detects patient’s yelling using volume sensor.</i> R: I understand. Let’s calm down a little bit! [With calm down hand /body gesture.]</p>
<p><u>Prohibition 2. Quiet/Withdrawn</u> P: [Patient doesn’t say anything during the entire session] → <i>Robot detects patient’s withdrawn using volume sensor.</i> R: You look so quiet today! [With pointing gesture and head turns to the patient.]</p>
<p><u>Obligation 1. Stay-in-the-room</u> P: [Patient stands up and turns his body to the door.] → <i>Robot detects patient’s leave via camera sensor.</i> R: The session is not yet finished! Please come back! [with waving hand gesture.]</p>
<p><u>Obligation 2. Safety-first</u> P: Okay, it says take two on an empty stomach, once a day. → <i>Robot recognizes the pill name from the chart.</i> R: The previous records say he had a reaction. I think it’s not safe. [with warning hand gesture]</p>

feeling and rarely some inappropriate reactions [28]. In the scenario, these unexpected/inappropriate behaviors arise in patient-caregiver interaction, and so a robot mediator intervenes in the situation to remedy the difficulty arising in their relationship.

There are five video clips: 1 basic “perfect” situation; 2 prohibition situations; and 2 obligation situations. Table 2 illustrates essential scripts of each simulation scenarios. The basic “perfect” situation first shows the ideal situation. In other words, the patient performs the medication-sorting task without any trouble and the patient-caregiver relationship remains healthy. PD experts developed this “perfect” scenario based on their observations and experiences with patients as well as consultation with the appropriate literature. In the other four videos, the patient performs behaviors that are prohibited or violates certain obligations with respect to maintaining dignity in the relationship. Those four scenarios were developed based on the intervening rules in IEG. As a result, when the patient shows those behaviors, a robot intervenes to mediate the situation with pre-defined intervention actions. The scripts for these four scenarios have been also reviewed and confirmed by the PD expert.

In the interview, we always show the basic “perfect” scenario first to the participants. Afterwards, the other four videos are played in a random order.

## B. Interview Scripts

The interview is structured around a set of predetermined questions, but the discussion is also free-flowing. The interview consists of three parts, which include pre-interview, main interview, and post-interview parts. In the pre-interview, the interviewer briefly asks about participants’ previous experiences. The questions are about the participant’s prior experiences with caregivers or as a caregiver. In the main interview, we show participants five video clips, in which a robot performs intervening actions based on intervening scenarios, and then ask related questions to get their feedback. This main interview session is structured with open-ended interview questions. Finally, in the post interview, the interviewer asks participants’ overall opinion about the robot system and wrap up the interview.

In the main interview session, participants first watch the basic “perfect” scenario video. By showing this video, the interviewer can confirm whether participants correctly understand the tasks, the roles of actors, the flows of the scenarios, among other things. In addition, prior to showing the videos depicting interventions, the interviewer asks participant to articulate their opinions about situations that could require interventions. (*Interview script: “Can you imagine any kind of ethically inappropriate behaviors that might happen in this scenario?” “Can you think of any frustrating situation that might happen here?” “Do you have any questions or opinions related to this ideal scenario?”*).

After, participants are asked to discuss the four videos depicting robot interventions. The interview procedures and questions for each video clip are similar. After showing each video clip, the interviewer first asks participants to explain how they interpreted it. (*Interview script: “Can you briefly explain why you think a robot mediator intervened in that situation?”*). By asking about and discussing the scenario, we aim to ensure that participants clearly understand the current intervention scenario, as well as, could validate whether the scenario accurately represented the rules of intervention. After confirming participants’ understanding of the scenario, the interviewer asks participants for their opinions about the necessity of the intervention. (*Interview script: “Do you think this kind of intervention is necessary?”*) In addition, feedback about the robot’s behaviors is gathered. (*Interview script: “Do you think the robot’s reaction, I mean intervening action, was appropriate and effective?”*) Participants’ comments and opinions are solicited before proceeding to next clip. For all questions, the interviewer can ask any follow-up questions in response to participants’ answers. If couples participate in the study, the discussion between them is more free-flowing.

## C. Data Gathering and Analysis

This interview study is a semi-structured one, and therefore we gather mostly qualitative data from the participants. As part of the data gathering process, all interview sessions are recorded. For the analysis, the

<i>“Quiet” Intervention Scenario</i>	
Easy to recognize a robot’s intervention from the current scenario?	<input type="checkbox"/> Yes <input type="checkbox"/> No - why? - how to improve?
Necessary Situation to intervene?	<input type="checkbox"/> Yes <input type="checkbox"/> No - why?
A robot’s intervention action appropriate?	<input type="checkbox"/> Yes <input type="checkbox"/> No - why? - how to improve?
Other opinions or comments	

**Figure 5. Sample coding questions for each intervention scenario in the interview-coding sheet**

experimenter watches the recorded interview videos and codes all responses based on an interview-coding sheet. This interview-coding sheet enables the video data to be analyzed in a consistent manner and helps in finding patterns or common opinions among different participants’ responses without any bias. Figure 5 illustrates exemplar questions from the interview-coding sheet. After all interview responses are coded, to validate the coding process, the final data is also compared to the co-experimenter’s notes, which were taken during the interview sessions.

#### IV. RESULTS AND DISCUSSIONS

We interviewed three individuals and three couples (six interview sessions with nine participants in total). The average age of the participants is 71.44 (std: 5.54), and more detailed demographics information for each participant is shown in Table 3.

##### A. Safety is most important

All nine participants emphasized that the “safety-first” intervention is not only the most appropriate, but moreover essential for the robot mediator’s IEG model.

*“I think anything to protect the patient is a good thing.”*

*“That’s a high value. That’s appropriate there, because it gives real information, not just commanding.”*

*“I think that’s a good thing.”*

In the post-interview, the interviewer also asked all participants to rank four intervention scenarios from the most to least important. As Table 4 shows, all nine participants answered that the “safety-first” intervention scenario is the most important. They even commented that more safety-related interventions should be considered and added the robot mediator.

##### B. The robot should not command or judge

Participants indicated that the robot’s intervention behavior should be toned down. They agreed that the robot’s speeches and gestures sometimes seem and sound judgmental of patients, which they deemed unacceptable. In addition,

TABLE III. DEOMOGRAPHICS INFORMATION

<b>Individuals (3 participants)</b>
Gender: 1 Male and 2 Females Average age: 77 (std: 3.4668, min: 73, max: 79) Prior experience with robots: Two of them have very limited experience with any robots and one has experience with humanoid robots.
<b>Couples (6 participants in total)</b>
All couples are husband and wife. Average age: 68.66 (std: 4.08, min: 63, max: 73) Prior experience with robots: One participant has experience with industrial robots and all others have very limited or no experience with robots.

TABLE IV. RANK RESULTS FROM SIX INTERVIEW SESSIONS; PARTICIPANTS ARE ASKED TO RANK FOUR INTERVENING SCENARIOS FROM LEAST RULE TO MOST IMPORTANT RULE.

<b>Ranks from individual participants’ sessions</b>
[Least] Stay – Quiet – Angry – Safety-first [Most] [Least] Quiet – Angry & Stay – Safety-first first [Most] [Least] Angry – Stay – Quiet – Safety-first first [Most]
<b>Ranks from couple participants’ sessions</b>
Safety-first is most importance (no ranks for the other rules). Safety-first is most importance (no ranks for the other rules). [Least] Stay – Angry & Quiet – Safety-first [Most]

participants commented that some speech seem to command patients, which they believe the robot mediator should avoid.

*“I think that [commanding] puts the robot in the spot of being in a judgment ... I think it should be more asking such as "how can I help you?" ... But the robot was judging the patient. I don't think that's why we would want the robot.”*

*“He [the patient] should not be criticized for leaving or forgetting to do something by the robot. The caregiver should be more in that position”*

*“If the robot stood there and told me to "please calm down," I'd smack him.”*

*“The robot was instrumental in making him [the patient] relax or not get stressed out... It should not criticize him.”*

Participants’ feedback reflects that a robot should not have the authority to judge patients. Before implementation, we have reviewed the first version of the robot’s intervention behaviors with the PD expert, who similarly pointed out the problem of robot judgment. The expert argued that even caregivers should not judge patients or command them, which can make patients feel as though they are being blamed. According to the expert’s feedback, we have revised the robot’s intervention prior to the current implementation. For example, the original verbal cue for the “Quiet” intervention behavior was “Do you feel bad today?”

However, the PD expert pointed out that that sounds as if the robot is judging the patient, which can result in patients' feeling blamed. In response, it has been toned down to the current version ("You look so quiet today!"). We also modified the original cue for the "Angry" intervention from "Please calm down" to "Let's calm down," which is less commanding and more suggestive. Nevertheless, as the interview feedback shows, participants continued to think that the robot was being judgmental, commanding, and even critical. Based on that feedback, we will once again review the intervention approaches with the PD expert and modify the robot's verbal tones to be more smooth and polite.

### C. *The robot should be a mediator*

Participants expressed that they would accept an interventional robot in the therapeutic and clinical situations presented because it plays the role of mediator. Taking the viewpoint of patients, participants reported that they like the idea of this robot mediator because the caregiver is present while the robot interacts with the patient. They pointed out that if patients, especially older ones, should be with the robot only, then they might feel unsafe. The interview results illustrate that the participants take a more conservative perspective than we had anticipated, and this point should be considered when designing an interactive robot targeting this population (older adults/patients).

### D. *Other Feedback*

Participants described their prior experiences with caregivers' unprofessional or inappropriate behaviors, one of which is blaming patients. For example, if a caretaker could not appropriately manage a task, then a caregiver would say to the patient, "Come on-it's an easy thing!" In the post-interview, one participant described such a situation and argued that this kind of reaction might potentially be intervened by a robot mediator, since it shames and might discourage patients. More extremely, some participants worried that caregivers could abuse patients. To prevent such blame and abuse, participants expressed wanting a robot mediator to play the role of observer and to intervene in and report situations of blame or abuse.

Participants debated the acceptability of the robot's direct reaction to patients. In the current intervention behaviors, the robot mediator directly warns or alerts to patient when something goes wrong, and participants pointed out that such direct reaction could make patients feel ashamed. Instead, they suggested that it would be more appropriate if the robot indicates situations needing intervention to caregivers more subtly so that the caregiver could take actions to remedy the situation.

We also received feedback about the simulation scenarios. Mostly, participants agreed that the current simulation scenarios based on the pill-sorting task are appropriate since this task could be challenging for PD patient (e.g., "safety-first" or "angry" intervening scenarios). However, participants argued that the pill-sorting task is not appropriate for every intervention scenario. For example, the "quiet/withdrawn" situation could be interpreted from the

patient's intense concentration on a task. Instead of the pill-sorting task, other situations such as long-term daily activities at home might be more appropriate to simulate such intervention. Therefore, to be more realistic, it is necessary to find more natural and appropriate situational context for each intervening rule and develop the scenarios separately.

Responses to privacy-related issues were also solicited from several participants during the interview. As they pointed out, to make patients accept the robot mediator, especially in mid- or long-term care, privacy should clearly be confirmed to both patients and caregivers beforehand.

## V. CONCLUSION AND FUTURE WORK

Our previous research introduced an intervening ethical governor, which enables a robot mediator to ethically intervene in PD patient-caregiver interactions. By extension, in this paper, we implemented the architecture and applied it to a real robotic system by integrating external sensors. To run the implemented intervention actions of the robot mediator, we simulated the intervention situations with two players and confirmed the model's operation. Scripts for intervention situations were developed and reviewed by a PD expert, and the simulations were recorded and used in the evaluation. By conducting six interviews with the elderly, we received feedback about the IEG model and evaluated the system. During the interview study, we showed video clips of simulations and asked for participants' feedback concerning the robot's intervention action. Overall, participants agreed upon the benefits of a robot mediator's intervention in the patient-caregiver relationship. There is also criticism and feedback that can help improve our IEG models. For example, it may be valuable to add more intervention rules related to safety and situations of blame/abuse. Participants also pointed out certain inadequate tones in the robot's verbal cues or interaction methods, both of which should also be modified in the model. Based on these interview results and feedback, we aim to improve the robot mediator's intervention rules and actions.

Future instantiations of this research could be improved by making several updates: First of all, as discussed above, the intervention rules should be modified and updated based on the interview feedback. In regard to the implementation, the current version uses people's audio volumes to detect their angry or quiet statuses. By collecting more sensory data (e.g., physiological data), we can expect a robot to be able to detect patients' and caregivers' emotional statuses, and this could potentially improve the accuracy of the robot's intervention. In terms of evaluation, this study only recruited a general population of elderly people. More reviews and feedback from the target population (i.e., caregivers and/or PD patients) should be gathered in future work. For this purpose, by modifying the architecture, we plan to evaluate the model with more extensive reviews, including focus group studies with PD patients and caregivers.

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