An IoT-based Common Platform Integrating Robots and Virtual Characters for High Performance and Cybersecurity

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***Abstract*—Two humanoid robots are developed. Both robots are human-like in appearance though one is more human-like than the other. A virtual human with human-like appearance is also developed. Various similar functionalities and interaction modalities for the robots and the virtual human are developed. Various technologies are incorporated with them to make them intelligent and autonomous. A common platform in the form of an internet of things (IoT) is developed that can integrate the robots and the virtual human for their real-world collaboration. Then, the collaboration between each robot and the virtual human is separately implemented via the common platform based on some control algorithms for finding a hidden object in a homely environment. The collaboration between the robot and the virtual human is evaluated. The status of cybersecurity in the IoT is briefly analyzed. The results show that the collaboration is satisfactory in various terms, which justify their social integration in the form of an IoT. Two robots with different appearance are actually used to investigate the effects of anthropomorphism on the interaction. The results can help employ artificial intelligent agents of heterogeneous realities to perform real-world tasks through their cooperation in the form of IoT that can provide high performance and cybersecurity.**

Keywords—humanoid robot, virtual human, autonomy, artificial intelligence, internet of things, multi-agent system, cybersecurity

I. INTRODUCTION

Social robots are proposed for many activities in societies performed for humans [1]-[5]. These robots may have been developed with attributes and aptitudes similar to their human counterparts. However, in many cases, they may not be as similar as humans in their appearance, e.g. the vehicle robot [3] and the penguin robot [6]. Their social applications are still limited probably due to their incompetence in performance and the improper tradeoff between their performance and physical appearance [1]-[6].

On the other hand, virtual humans are software-based human-looking animated characters. Like social robots, virtual humans can be built with human-like abilities. They may have varying level of autonomy [7]-[8]. Currently, virtual humans are used for many purposes such as serving as virtual advertiser, sales person, virtual student and trainee, virtual tutor, virtual patient, virtual recreational agent, virtual host, virtual employee, virtual guide/help desk, virtual expert, etc. They are used for many other purposes such as virtual fashion display, virtual human factor analysis, virtual psychotherapy, virtual anatomy education, biomedical-related research (e.g., virtual embryos, virtual hearts, virtual blood and lungs), etc. [9]-[12]. However, it is still not well-known how to use the virtual humans to perform real-world physical activities.

One can observe that social robots and virtual humans exhibit many common features, and thus these two artificial agents of heterogeneous realities may collaborate with humans separately to execute real-world tasks, and also collaborate with each other to perform the real-world tasks for humans. However, such cooperation is not observed, except a few preliminary initiatives [13]-[14], [23]-[24]. The initiatives are basic lacking suitable control methods and strategies, artificial intelligence, technological development and experimental results to justify the effectiveness of their individual and collaborative performance. Especially, it is quite unknown how the two artificial characters of heterogeneous realities can be integrated to collaborate together. It is realized that a common platform implemented in the form of internet of things (IoT) can integrate them for performing the proposed real-world collaborative tasks [19]-[20]. If so, then the overall performance of the collaboration as well as cybersecurity in their networks are of great importance [28]-[29]. However, nothing can be observed in the literature regarding these issues except the preliminary initiatives taken in [23], [24]. Again, in [23], [24], only one robot was integrated with the virtual human through the common platform though evaluation of the platform using multiple robots can provide better insights about the platform and justify its generality. The issue of cybersecurity was never mentioned in [23], [24].

As an extension of the previous works in [23]-[24], the objective of this paper is to integrate two social robots and a virtual human through a common platform to form an IoT so that each robot can cooperate with the virtual human separately to perform a real-world social task such as searching for a hidden or missing object in a homely social environment. Then, the performance of their collaboration is evaluated, and the strength of cybersecurity in their networks is superficially investigated.

II. DEVELOPING THE ROBOTS AND THE VIRTUAL HUMAN

The social (humanoid) robots and the virtual human need to be developed and integrated in such ways that they are well-connected and enriched with necessary intelligence, capabilities and scope to interact with each other. These are the requirements for their integration in the form of an IoT-the Internet of Things, or more specifically the Internet of Robotic Things (IoT-R) [19]-[20]. The requirements are also discussed in details in [1-6], [15-21], [23]-[24].

A. Social Humanoid Robots

Two humanoid social robots were developed-a NAO robot (http://www.aldebaran-robotics.com/en/) and an R-50 model realistic walking Robokind humanoid robot developed by Hanson Robokind (www.hansonrobokind.com) [22]-[24]. To enable the robots interact with the virtual human, they were made intelligent, autonomous and social by enriching them with various social functions and attributes. Some emotional expressions were added in the robots, e.g., happiness, sadness, relaxation, pride, concentration, etc. [30]. They were enabled to speak (from text to speech), and perceive the environment using various sensors, e.g. video, audio, proprioception. They were also enabled to make decisions based on some adaptive rules combined with archived information. Finally, they were able to perform some actions such as movement, walking, pointing act something, etc. [23]-[24].

B. The Virtual Human

A realistic intelligent 3D virtual human was developed on the open source character animation platform "Smartbody" (http://smartbody.ict.usc.edu/). The Smartbody was used for the control and animation. The character model was created following standard art/modelling methods based on the joints and skeleton requirements for the character mentioned in the Smartbody system. Then, it was exported out using Maya 3D animation software (http://www.autodesk.com/). The Ogre (http://www.ogre3d.org/) was used for graphical rendering. The character was based on the Behavioral Mark-up Language (BML) realization engine that could transform the BML descriptions into real-time animations. The anthropomorphic data for the virtual human such as walking/running velocity, joint angles, whole body dimensions, kinematics, etc. were decided by taking inspiration from that of real-human, which can be treated as the biomimetic approach [22].The virtual character was enabled to blend different animations smoothly in real time. In addition, the one on one mapping could also be performed using the Microsoft Kinect (Kinect SDK 1.5). The virtual human was enabled to mimic real humans in terms of whole body motions and facial emotional expressions [30]. The virtual human was displayed in a large screen [23]-[24].

Various technologies related to artificial intelligence, sound processing, animation and rendering, cognitive modeling, image processing, speech and gesture recognition, etc. were incorporated with it to make it autonomous and intelligent. Like the robot, it was enabled to perceive the environment, make decisions based on some adaptive rules combined with archived information. It was also enabled with some basic functions like the robot [23], [24].

Note that the selected two humanoid robots and the virtual human were similar in their functions and features such as emotions, expressions, autonomy, intelligence, perceptual and decision making abilities, etc. [22]-[23]. However, the robots existed physically but the virtual human could be viewed in the screen only.

C. The IoT-based Common Platform

An IoT in the form of a common communication platform (network) for the robots and the virtual human was developed [19]-[20], [23]. The architecture of the platform is shown in Fig.1. The proposed common platform should be sufficient to animate both the robots and the virtual human separately and in collaboration between a robot and the virtual human. To do so, as the system architecture shows, the name of the agent (NAO, Robokind, or virtual human) was needed to be specified in the command script (the client server). Then, the called function API appropriate for the selected agent was to be executed from the relevant control server. The main objectives of this common platform were to ease the software development, reduce software development requirements, and ensure high cybersecurity in the common platform IoT network. The cybersecurity could be understood in various terms reflecting the performance of standard cybersecurity protocols. The term cybersecurity may mean the information security in the agent network, protection of the agents from threats, and defenses to the network, agents and information [28]-[29]. The cybersecurity and collaboration performance may be complementary, may depend on each other, and may be impacted by the performance of the IoT-based common platform [19]-[20].

III. EXPERIMENT

In order to implement the multimodal social interactions between the intelligent virtual human and the intelligent social robots for a selected real-world task of searching for a hidden object, ten rectangular-shape boxes of similar dimensions and appearance were kept in a room, as shown in Fig. 2. Five of the boxes were kept randomly on a table in the left side of the room, and the remaining boxes were put randomly on a couch in the right side. An object that was a small-size doll was hidden in any of the ten boxes by the experimenter during the experiment. The virtual human was seen in the screen (P2), and the robot was to stand in front of the screen (P1), as Fig.2 shows. The gap between the hidden object and the screen (P2) was almost equal to the distance between the hidden object and the robot (P1).

In the first condition, the virtual human assisted the NAO to search for the object. Here, the virtual human is treated as the assistant agent and the NAO is the assisted agent. The virtual human was enabled to instruct the robot about the correct location of the object hidden in any of the 10 boxes. To do so, ten most appropriate instruction methods for the 10 locations of the 10 boxes were developed and properly preset for the virtual human in the programming script (client). The virtual human was pre-taught about the correct location of the target box via the programming script. For example, assume that in an experiment trial, the virtual human assisted the robot to find out the object that was hidden in a box closest to the screen (P2). The related pre-developed program was run and the virtual human could instruct the robot to find out the object based on the instruction method preset for that particular location. The instruction methods included speeches, gestures, emotions, facial and body expressions and actions of the agents [23]-[24]. The social attributes were used by the agents to make their interactions more human-like and natural [22].

In the second condition, the opposite was considered. The robot was enabled to assist the virtual human search for the hidden object. The robot is the assistant agent and the virtual human is the assisted agent. The robot was pre-taught the correct location of the hidden object via the programming script. The instruction methods for the robot were almost same as that used for the virtual human, as described earlier. The virtual human was enabled to recognize the gesture of the robot and immediately determine the correct location of the box containing the hidden object. The virtual human turned towards the box, moved towards the target location (up to the limit of the screen), looked at and pointed at the target box, and then spelled out "the object is inside that box". Then, the experimenter opened the pointed box and checked whether the hidden object was actually found there [23]-[24].

In total, 80 separate trials were to conduct: (i) 20 trials for the virtual human to assist the NAO robot (called the virtual human-NAO robot interaction/collaboration), (ii) 20 trials for the virtual human to assist the Robokind robot (virtual human-Robokind robot), (iii) 20 trials for the NAO robot to assist the virtual human (NAO robot-virtual human), and (iv) 20 trials for the Robokind robot to assist the virtual human (Robokind robot-virtual human). In each trial, a human observer needed to subjectively evaluate the attributes and performance of the assistant agent using a five point Likert scale (1 was the worst, 5 was the best) [31]. There were 20 human observers recruited to participate in the experimental trials. The attributes of the assistant agent were expressed in a few terms such as agent's anthropomorphism, embodiment, quality of gesture and actions, and stability (may relate to cybersecurity), etc. [28]

The performance of the assistant agent were expressed in a few terms: (i) level of cooperation towards the assisted agent, (ii) clarity of the instructions for the assisted agent, (iii) effectiveness of the instructions for the assisted agent, (iv) level of difficulty or criticality faced by the assisted agent in finding the object (score 1 was assigned for the most difficult, and 5 was assigned for the least difficult/easiest), and (v) level of potential long-term social companionship between the agents. The experimenter recorded the time taken by the assisted agent to find out the hidden object. Note that the best performance of the assistant agent occurred if the assisted agent found out the correct box containing the hidden object within the shortest possible time based on the instructions of the assistant agent. The experimenter also recorded whether the assisted agent was successful to correctly find out the hidden object based on the instructions of the assistant agent. Note that these performance criteria were empirically selected because it was assumed that the selected criteria would be sufficient to describe the performance of the assistant agent used in the experiment. However, more relevant criteria could enhance the effectiveness of the performance assessment.

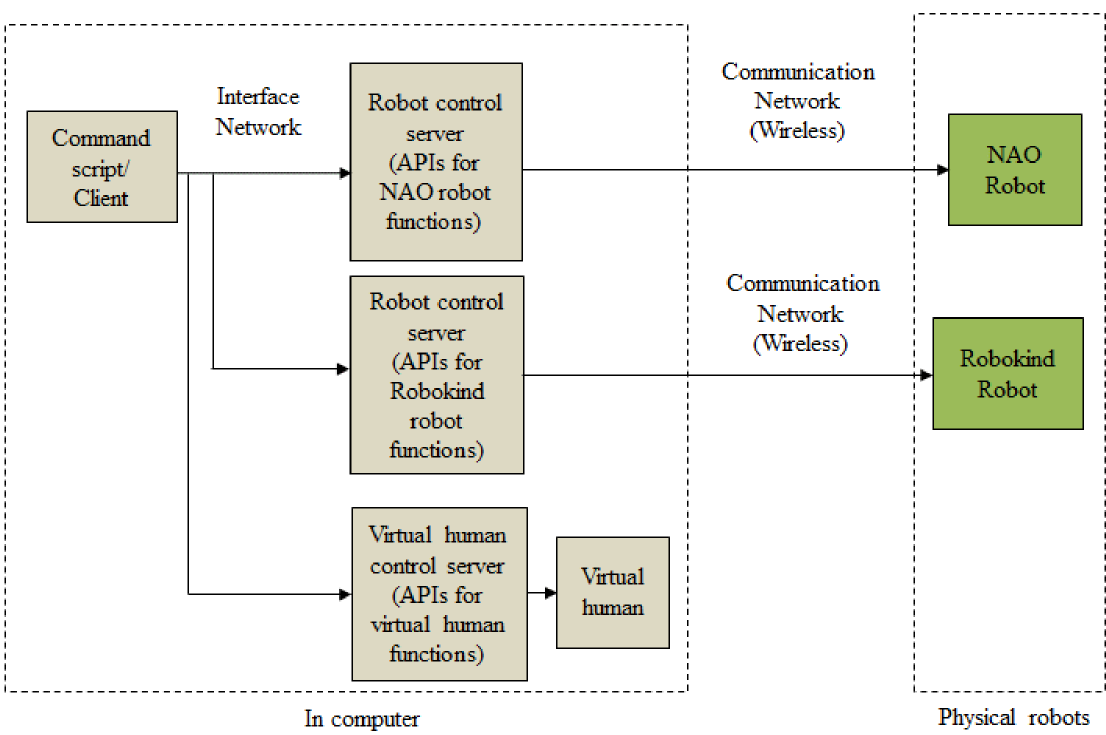

Fig.1. The common communication platform (network) in the form of internet of robotic things (IoT-R) integrating the robots and the virtual human.

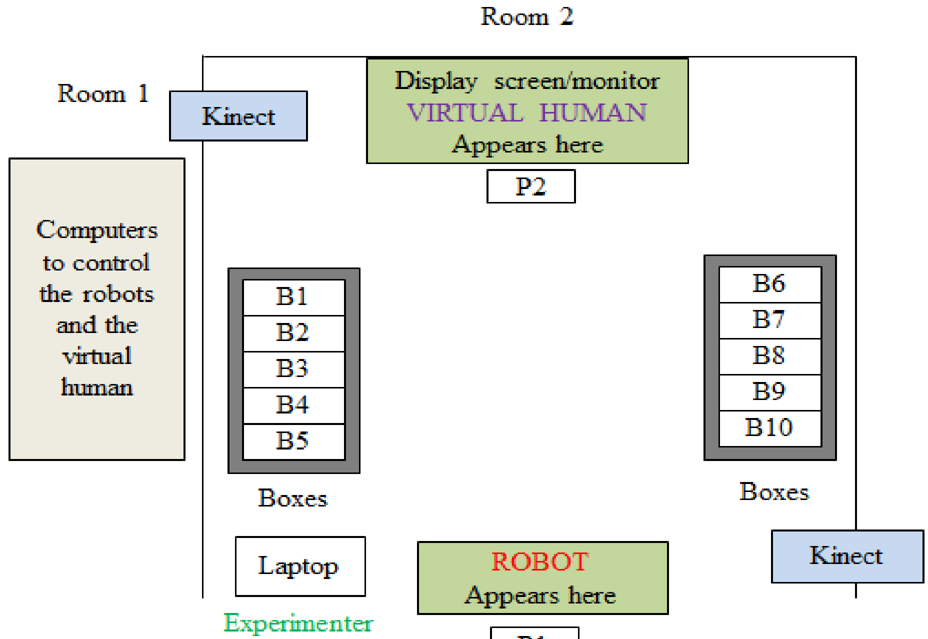

Fig.2. The experimental setup for real-world collaboration between a robot and a virtual human for searching for the hidden object.

IV. EXPERIMENTAL RESULTS AND ANALYSES

The evaluation results for the assistant agent's attributes and performance in assisting the assisted agent are shown in Fig.3 and Fig.4 respectively. The mean time taken by the assisted agent for the interactions is shown in Fig.5. The accuracy of the assisted agent in finding out the hidden object is shown in Fig.6. Note that in each figure for each interaction (e.g., virtual human-NAO robot), the first and the second agent indicates the assistant and the assisted agent respectively.

Fig.3 shows that the attributes of the virtual human were evaluated as almost the same for the virtual human-NAO robot and virtual human-Robokind robot interactions. It seems to be logical because the same assistant agent (virtual human) assisted different assisted agents (NAO and Robokind robots). Evaluation scores on anthropomorphism, embodiments, and gesture and action increased for the NAO robot-virtual human interaction. It might happen because the NAO was a human-looking physical robot, but the virtual human being software-based did not exist physically. The evaluation scores on these criteria further increased for the Robokind robot-virtual human interaction. This might happen because the Robokind robot was more human-looking in appearance than the NAO [22]. It indicates that the physical appearance of the assistant agents can influence human's acceptance of agents' gesture, action, embodiment and anthropomorphism even if the agents are controlled via a common platform based on similar functions, interaction modalities, intelligence and autonomy. However, stability of the robots as the assistant agents was evaluated as lower than that of the virtual human probably due to the reason that the robots exist physically and thus are much more influenced by the physical disturbances such as the floor quality (when move), obstacles, etc., accidents such as sudden fall, hardware issues such as motor heat, noises, etc. [23]-[24].

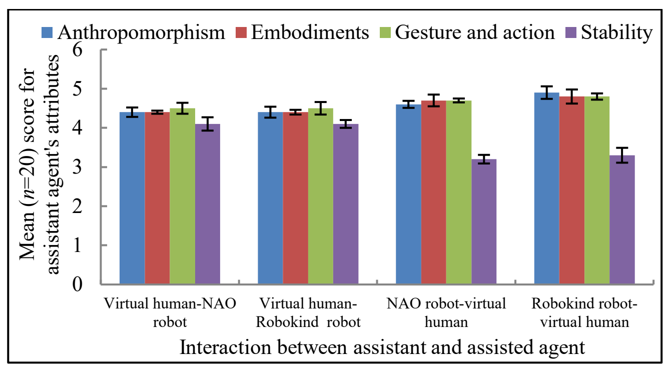

Fig.3. Evaluation results of assistant agent's attributes for various interactions.

Fig.4 shows that the performance of the virtual human as the assistant agent was evaluated as almost the same for the virtual human-NAO robot and virtual human-Robokind robot interactions. It seems to be logical because the same assistant agent (virtual human) assisted different assisted agents (NAO and Robokind robots). The evaluation scores on performance increased for the NAO robot-virtual human interaction. It might happen because the NAO was a physical robot, but the virtual human did not exist physically. The evaluation scores further increased for the Robokind robot-virtual human interaction probably due to the reason that the Robokind was more human-looking than the NAO. It further indicates that physical appearance of the assistant agent can influence human acceptance of agent performance even when the agents are controlled through a common platform based on similar functions, interaction modes, intelligence and autonomy. This also indicates that attributes of the assistant agents may be related to their performance as perceived by humans. The results also indicate that the attributes and the performance of the agents were satisfactory [23]-[24].

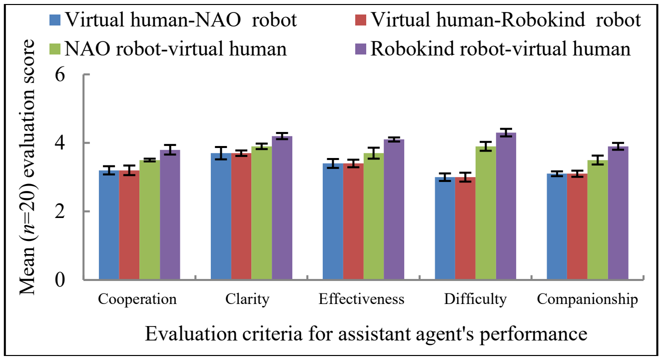

Fig.4.Evaluation results of assistant agent's performance for various interactions.

Fig.5 shows that the virtual human (assisted agent) took the lowest amount of time to find out the hidden object based on the instructions of the robots. This can indicate that the robots performed better as the assistant agents than the virtual human. This result is consistent with the findings found earlier. Here, the robots took longer time as the assisted agents to find out the object. However, the assistant agent (virtual human) might not be solely responsible for this situation because the floor quality, motor temperature, etc. might make the robots slow.

Fig.6 shows that the assisted agents in all trials were able to accurately find out the hidden object based on the instructions of the assistant agents. The results thus clearly indicate that the interactions between the robot and the virtual human for the real-world task were satisfactory, and hence their integration in the form of an IoT was also successful [19]-[20].

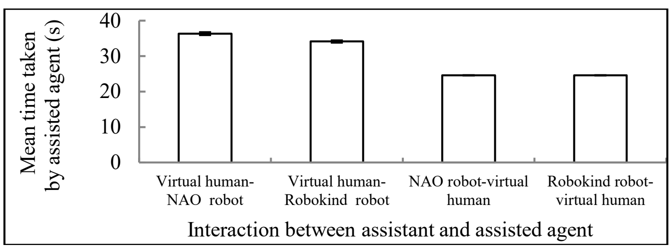

Fig.5. Mean (n=20) time taken by assisted agent for various interactions.

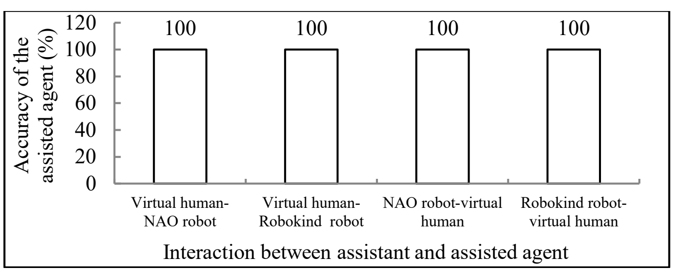

Fig.6. Accuracy (success rate) of assisted agents for various interactions.

In addition to the successful interactions and performance for collaboration between the robot and the virtual human, the cybersecurity in the agent network (IoT) was assessed in various terms based on observations. The observation results in general showed that cybersecurity in terms of information security in agent networks, protection of agents from threats, and defenses to the network, agents and information were satisfactory as no such issues were reported [28]-[29].

V. DISCUSSION

It is true that the interactions between the robot and the virtual human were controlled by the algorithms through the programming script that were not impacted by the appearance or anthropomorphism of the artificial characters. However, the performance of the interactions were evaluated by human observers who might be influenced by the appearance of the characters [1]-[2], [22].

It could be possible to control the interactions between the robot and the virtual human through the application of a joystick controller, a master arm, etc. However, the method that implemented herein seems to be more robust, real-time, flexible, autonomous and intelligent.

The interactions between the robot and the virtual human presented herein are susceptible to disturbances such as sound, noises, etc. The robot could also be affected by the floor quality and floor obstacles (if any). Hence, the cybersecurity issues seem to be very important for the proposed network, which is superficially addressed here, but needs more concentration [28]-[29].

The major limitations of this study were that the robot and the virtual human collaborated based on some preset and prearranged functions with very limited sensor-based real-time autonomous decision-making events. This approach is helpful to understand the possibility and potentials of collaboration between robot and virtual human. However, the individual characters and their integration need to be more intelligent, robust and natural so that the characters are enough autonomous to make real-time decisions to find out the hidden object from any location in the experiment area. Again, even though the presented IoT could integrate at least two robots and one virtual human together, only one robot at a time actually collaborated with the virtual human. Collaboration of several robots and virtual human together in a multi-agent team through the proposed IoT-based platform can further justify the effectiveness of the platform. In addition, the involvement of human user/beneficiary is loosely reflected in the presented scenario. More involvement and interactions with human users may make the collaborative system more useful and user-friendly [34].

VI. CONCLUSIONS AND FUTURE WORKS

Two humanoid social robots and one social virtual human were developed with required similar attributes, functions, interaction modes, capabilities, intelligence, autonomy, control strategies and algorithms, interfacing and communication technologies, sensors, etc. for multimodal social interactions between them for a real-world common task (searching for a hidden object) through a common platform resembling an IoT. The social interactions between them for the social task were evaluated in terms of various attributes and performance criteria. The results showed that the attributes and the performance of the social agents in their interactions were satisfactory, which indicate that the real-world integration of the robot and the virtual human as an IoT was successful. This task-based real-world interaction between the robot and the virtual human is believed to be the first of its kind. The results may empower the virtual agents to interact with their real-world artificial and natural counterparts to perform social tasks for humans or to assist humans in their social tasks.

In the near future, more focus will be put on AI and machine learning-based advanced decision-making algorithms [32]-[33] and control strategies [25]-[27] to control the interactions between the social robot and the virtual human in the form of an IoT, employ advanced technologies to realize the interactions, and also implement the interactions between the robot and the virtual human for other social tasks. Detailed investigation and evaluations on how the common communication platform-based IoT enhances the cybersecurity in the agent network will be conducted and analyzed.

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