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Robot magic show: human–robot interaction

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Abstract

The use of robots in performance arts is increasing. But, it is hard for robots to cope with unexpected circumstances during a performance, and it is almost impossible for robots to act fully autonomously in such situations. IROS-HAC is a new challenge in robotics research and a new opportunity for cross-disciplinary collaborative research. In this paper, we describe a practical method for generating different personalities of a robot entertainer. The personalities are created by selecting speech or gestures from a set of options. The selection uses roulette wheel selection to select answers that are more closely aligned with the desired personality. In particular, we focus on a robot magician, as a good magic show includes good interaction with the audience and it may also include other robots and performers. The magician with a variety of personalities increased the audience immersion and appreciation and maintained the audience's interest. The magic show was awarded first prize in the competition for a comprehensive evaluation of technology, story, and performance. This paper contains both the research methodology and a critical evaluation of our research.

1 Introduction

With the development of robot technology and artificial intelligence (AI), robots for various purposes have emerged and the environment where robots and people live together has been gradually expanded. In this situation, human–robot interaction (HRI) is mentioned as an important research field because of the increased demand for smart technologies for supporting the coexistence of humans and robots. HRI is defined as a technology that allows the robot to communicate and collaborate with humans by judging the user's intention and performing appropriate responses and actions. The HRI field is divided into perception, cognition, and expression. Perception is the process by which a robot collects data on human behavior, emotion, etc. through sensors. Cognition is a mechanism that converts the information obtained by the perception into information that the robot can understand and determines the tasks, behaviors, and emotions that the robot should perform. Expression refers to the methods for conveying the robot's intention to humans by using various methods such as the simulation of emotions and behaviors by the robot. The robot can interact with people through perception, cognition, and expression (Soegaard & Dam, 2013).

Each year, the *IEEE International Conference on Intelligent Robots and Systems* (IROS) organizes a series of competitions to showcase the current state of various important robot technologies for other roboticists, hobbyists, and the general public (Moon *et al.,* 2017; Baltes *et al.,* 2018). The theme of *IROS2018 Humanoid robot Application Challenge (HAC) – Robot Magic* is robot magic, where actors, audiences, and robots interact with each other. The robot magic show, which is the live performance like a musical and a play, should take into account many factors, such as the script, motions, and the background music. Participants do not have any restrictions (magic tools, sound effects, the number of

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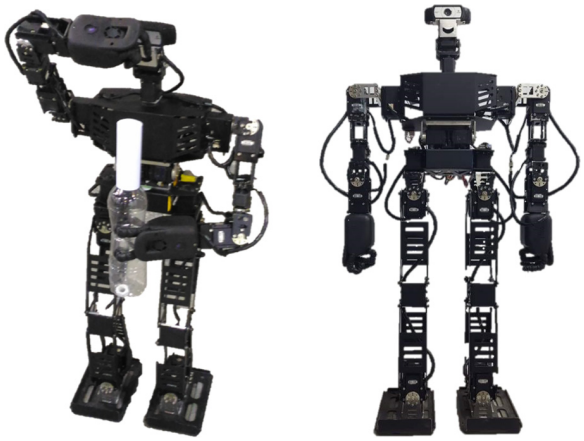


Figure 1 Magician: Robinion

participants, scenario, etc.) except that the team should perform a magic show, involving a humanoid robot. People may think of the magic trick analyzed as a simple performance to be implemented using a humanoid robot, but the process of preparing and conducting the magic show is not as simple as it sounds. This is because the magic show includes *the interaction between the audience and performers*.

This study analyzed our first-place *Robinion*'s magic show in IROS2018-HAC[1]. The theme of the *Robinion*'s magic show is failure and success. The audience gets to interact in the process of communication with the performers while watching the magic show. The relationship between the objects in which the interaction occurs is subdivided into five categories. In addition, we focused on the development of the unpredictable HRI, which comes in the form of various speech acts by our humanoid robot that are selected using a roulette wheel algorithm in our magic shows. Our humanoid robot can select from 39 350 different dialogues and 32 motions based on personality vectors at 10 selection points in each magic show. Even if the audience watch the same trick more than once, the audience is not likely to be bored. So, a variety of interactions are possible between performers (our humanoid robot and participants) and the audience.

In Section 2, we describe the hardware and software system of our magician humanoid robot and explain some of the important design choices. Section 3 describes the composition and tricks of the magic show. We describe the speech act algorithm of our robot magician based on personality vectors in Section 4. In Section 5, we show the analysis of the HRI that appeared in the magic show. We discuss the result of *Robinion*'s magic show in IROS2018-HAC in Section 6. Finally, we mention our conclusion and future work about the magic show in Section 7.

2 Humanoid robot

This section describes the hardware and software systems of our magician humanoid robot (*Robinion*) (Figure 1). *Robinion*'s mechanical structure is based on previous humanoid's developments and experiences of our team, which has been named ZSTT since 2010. *Robinion* is a teen-sized[2] autonomous humanoid robot which serves as a research and competition platform used for walking using omnidirectional gaits, controlling motion algorithms, and participating in the *IROS Humanoid Robot Application Challenge - Robot Magic* (IROS-HAC), *FIRA Hurocup*, and *Robocup Humanoid league* competitions (Baltes *et al.,* 2017).

The robot system is divided into three parts: the perception controller (PCR) that recognizes objects and controls the robot's behavior, the motion controller (MCR) that controls servo motors and calculates kinematics for various motions, and thirdly the sensor controller (SCR) which reads sensors such as an inertial measurement unit (IMU), a force sensing resistor, and so on for closed-loop (feedback) control

[1] A video of the live performance can be found at https://www.youtube.com/watch?v=36n26CNH-JY
[2] https://www.robocup.org/leagues/30

Table 1 Robinion specification

Items	Description
Name	Robinion
Height	85 cm
Weight	7.5 kg
d.f.	41 (10 in legs, 1 in torso, 8 in arms, 20 in hands, 2 in the head)
Actuators	MX-106, RX-64, MX-28, AX-12
Sensor	6-axis IMU
Camera	C930e
Perception controller	Lattepanda (Intel Atom z8350)
Motion controller	OpenCM9.04 (Cortex-M3)
Sensor controller	OpenCM9.04 (Cortex-M3)
Walking speed	20 cm s^{-1}

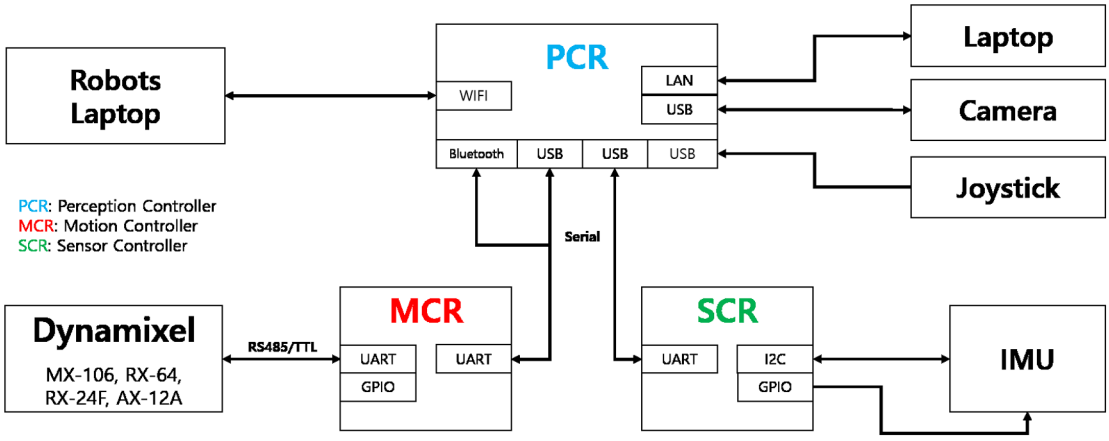


Figure 2 Block diagram of our humanoid robot

(Figure 2). The MCR is composed of: a *Cortex-M3* board, smart actuators which are part of the *Robotis Dynamixel* series, and serial communication devices (*USB, Bluetooth*) for exchanging motion data with the PCR. The MCR computes inverse and forward kinematics in real time. In order to have a sense of stability in the robot, the SCR reads IMU information along six axes and measures the sensor input data in order to calculate the output data (yaw, pitch, roll angles). The PCR periodically exchanges information with two other nodes to which it is connected: the MCR and the SCR (Yang *et al.,* 2019). The PCR gets frames from the camera and then tries to detect objects such as a television, buttons, a hand, and fingers in the sketchbook at the magic show. The humanoid robot is connected to the laptop via virtual network computing for programming and debugging via *WiFi and LAN*. The user can manipulate the robot with a joystick to test whether motions of the robot work properly on various grounds and environments.

2.1 Hardware system

The specifications of our magician robot are shown in Table 1. The humanoid robot is 85 cm tall and weighs 7.5 kg. The robot has 41 degrees of freedom (d.f.): five in each leg, one in the torso, four in each arm, ten in each hand, and two in the head.

The robot frame is manufactured using flat aluminium sheets (1.5T, 2T, and 3T) and is cut by a CNC machine. All joints are equipped with smart servo motors chosen from the *Robotis Dynamixel MX, RX, DX, AX, and XL* series. *MX-106* servos are used in the legs and arms, and RX-64 servos are used in the

Figure 3 Robinion's manipulator

hip and the arms, and *AX-12* servos are used in the neck. For better noise resistance, we use an *RS-485* bus to communicate with the actuators in a star topology except for motors in the neck and hands.

We used the RH2D which is a special gripper made by Seed Robotics for the magic show (Figure 3). The RH2D Manipulator is a tendon-based, under-actuated unit with tendon tension equalization, in a compact and lightweight form. The manipulator grasps objects with a force control which is based on sensing electric current in the motor. At just 144.5 mm long, about 200 g, it is a great option for kid-size and teen-size humanoid robots. The RH2D has 10 d.f.: one is wrist rotation and the others are a thumb flexion and index fingers flexion which are a combined actuation with tendon tension equalization. The RH2D features a magnetic finger detachment system that protects finger joints in the event of impacts. The RH2D uses *Dyneema* (a Kevlar fiber) tendons for maximum reliability (Seed Robotics, 2019).

Our humanoid has three controllers which are the PCR, the MCR, and the SCR. We use *Lattepanda* as the PCR which is used for vision and decision-making. *Lattepanda* is also used for computation, with a 1.44 GHz Intel Atom z8350 quad core processor, 4 GB RAM, and 64 GB embedded multi-media card. *Lattepanda* has several communication interfaces which are *USB2.0/3.0, SPI, I2C, UART, Bluetooth, HDMI, WIFI, and Ethernet*. In addition to the PCR, one *Robotis OpenCM9.04* board is used to maintain a high-frequency serial communication link with the servo motors as the MCR. The MCR controls the smart actuator *Dynamixel* series for moving the robot and communicates network data using *FT232/Bluetooth* with the PCR. Furthermore, the SCR uses the other *OpenCM9.04* board with IMU integrated three-axes accelerators and three-axes gyroscopes as sensors for direction estimation and feedback control of walking gaits.

2.2 Software system

Our software system is implemented with *Python* and *Qt* (Figure 4). Most robotic software systems are only compatible with a single OS, but our software systems can be installed on *Windows, Linux*, and *MacOS*. In our system, we used *PocketSphinx* for speech recognition, *OpenCV* for image processing, *Pyttsx* (Text To Speech) for speaking the written words, and *Pyserial* for serial communication with our humanoid robot: the MCR and the SCR.

When the humanoid robot shows magic tricks to the audience, we need to prepare a lot of information such as the scenario, the humanoid's motions and the music in each scene, the magic tricks, and so forth. We can control the motion and dialogue of each scene individually, control the music while the robot is in a magic show, and control it when using image processing in the robot magic show. In addition, our software has such versatility that not only can it be used in robotic magic shows but it can also be used in various robot competitions such as *FIRA* and *Robocup*.

There are three parts in the software system: image processing, a speech act selection, and the communication with the MCR and the SCR (Figure 5). As mentioned before, the PCR, which is connected with other nodes, periodically exchanges information between the MCR and the SCR. The PCR gets frames from the camera and then tries to detect objects such as the sketchbook, the television, the button, and the finger. During the magic trick where the robot's camera looks at the sketchbook's drawing of a television and sees a real video, many processes are involved in the PCR. The block diagram of Figure 5 illustrates

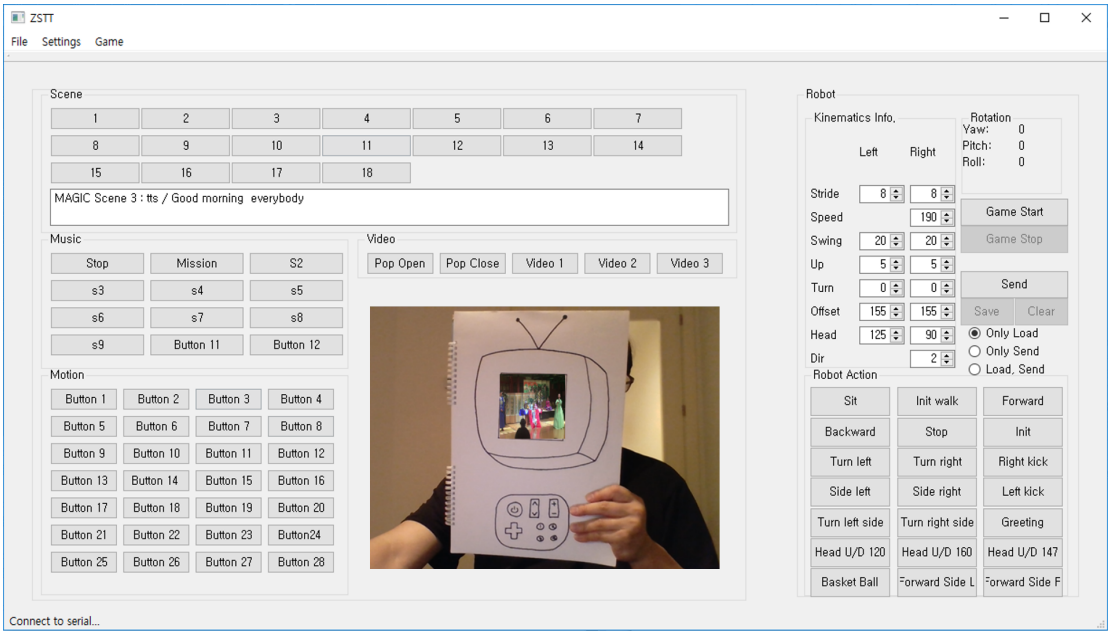


Figure 4 Robinion software system

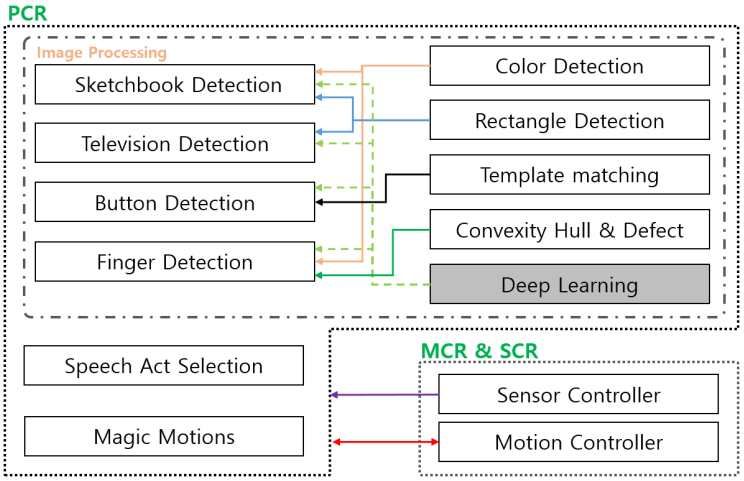


Figure 5 Block diagram of software

the functions of the PCR and the relations between it and the MCR & SCR. First, the PCR uses color and rectangle detection to detect the sketchbook. It also uses rectangle detection in order to detect the television. Then, it matches a template image of, for example, the 'on' button with the same button in the sketchbook drawing. Color detection and a convexity hull & defect system are then both used in order to detect the person's finger when he/she 'presses' the button on the sketchbook drawing. There is also the speech act selection function in which we can choose different dialogues for the robot in each show, depending on metrics that we decide such as how political, humorous, and aggressive we want the robot to sound. The SCR periodically sends IMU data (roll, pitch, and yaw) to the PCR for the balance of the robot. The PCR determines the motion command based on object detection and IMU data and then sends it to the robot.

Up until the last competition, we have been able to detect objects such as the sketchbook, the television, the button, and the finger using the template matching, convexity hull, convexity defect, and color-based methods. However, the system based on color detection is too unstable to receive color information, which is heavily influenced by ambient light. For this reason, we are developing our vision system

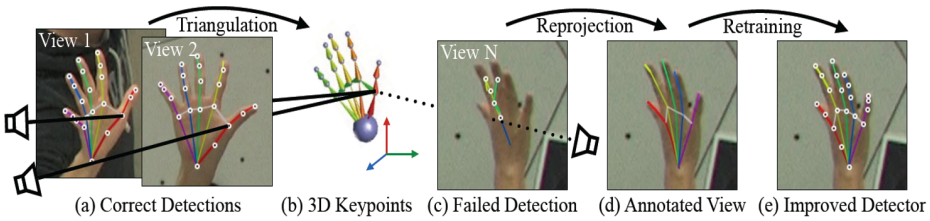


Figure 6 Multi-view bootstrapping made by Carnegie Mellon University Perceptual Computing Lab

Figure 7 A scene of Robinion's magic show

based on Deep Learning for detecting objects and improving performance. Our new software system which detects hands and finger is based on *Carnegie Mellon University (CMU) Perceptual Computing Lab*'s key point detection of hand and face along with the body (Figure 6) (Simon *et al.,* 2017).

3 Robot magic show

Humans have long enjoyed the clever trickery that comes from a good magic show. Magicians have been a source of entertainment for many centuries, with the ability to play on human bias and perception to create an entertaining experience (Morris *et al.,* 2018a, 2018b). The Humanoid Robot Magic Show is the continuation of the humanoid robot application challenge which started in 2011. The idea of the humanoid application challenges in the IROS competition was to create a competition which allowed teams more creative freedom to express themselves than other standard robot competitions do (Baltes, 2018). In 2018, the theme of the humanoid application challenge was robot magic. In order to participate in the robot magic show, researchers are required to perform various roles such as a developer, an actor, a writer, a producer, and others. The use of a humanoid robot is either as a magician, an assistant, and/or as a prop during the performance of a magic trick. Most participating teams set up a humanoid robot as a magician and the human appears as an (amateur) actor in the magic show (Figure 7). The humanoid robot needs to have various interactions such as speech, speech recognition, emotional expression, image processing, manipulation of the objects, and trickery of the audience in order to act as a magician. The Robot Magic Show, which requires such a variety of interactions, is a remarkably new and unique attempt in robotics. In addition, the magic show is an interdisciplinary research area that can collaborate with various fields such as engineering for developing humanoid robots, science for making magic trick tools, literature for writing a script, music for selecting a background music and sound effects, and performance art.

3.1 The purpose of our magic show

Everyone in the world experiences a lot of challenges and failures while living. Team *ZSTT-NTNU* has participated in various humanoid robotics competitions with *Robinion* every year for 7 yr and has experienced many failures and successes after many challenges. Getting results with the humanoid robot requires a lot of patience. We thought the results of the work, which the humanoid robot and our team made together, constituted true 'robot magic' (this was the official theme of the IROS2018-HAC). Because all the results that are both failures and successes of the events that took place with the humanoid robot and the team are meaningful, we have learnt from the process of repeatedly trying without giving up, even if the result of the challenge has been unsatisfactory. Based on this experience, we told the story of the team and the humanoid robot's challenges, failures, and successes in the *Robinion*'s Magic Show.

At first, *Robinion* hesitates to move, as opposed to *Jaesik* (human) who dances when the magic show begins. *Jaesik* urges *Robinion* to start the magic show, but *Robinion* confesses with frustration that he has not finished preparing the magic show. In addition, the easy magic trick that *Robinion* tries fails twice. For the audience expecting a perfect magic show, *Robinion*'s magic show may be considered a failed magic show. However, *Robinion*'s mistake is intentional. *Jaesik* does not advise or reprimand *Robinion*, who is frustrated by the magic show, which he says he failed due to the pressure of the performance. Instead of reprimanding, *Jaesik* gives *Robinion* the hope of remembering moments of success in the past. *Robinion* finally succeeds in the third attempt, after promising to succeed.

We can think of the meaning of the belief that, even though mistakes and failures can be made and repeated, there is a great benefit in continuing the challenge without giving up. *Robinion* hands a bouquet to *Jaesik*, saying that he has been grateful for the constant love for the last 6 yr. *Robinion*'s magic show asks everyone '*what is real success*' in the human–robot relationship.

3.2 Structure of Robinion's magic show

We contacted the magician named *Seungchan Guk* (EPIC entertainment, Korea) at the *Education Robot Center* in *National Taiwan Normal University* in January 2018 to consult magic tricks while preparing the 2018 Robot Magic Show. It was not difficult to identify and follow the magic tricks online, but we judged that we needed advice from a professional with experience. First, we talked to the magician about the range movements that the humanoid robot can perform, and we wrote the story of the magic show with the magician. In order not to focus solely on the implementation of the magic tricks or the technical research, we needed a special story for the magic show. We completed the story of the human–robot relationship, its failures and its successes, with which to deliver to the audience. *Robinion*'s magic show took about 8 minutes when it was performed as a narrative play, and the technical research presentation took about 5 minutes. The magic tricks were composed of a bottle & marble & needle, a flying strand of silk, and a sketchbook with nine pieces of music: five pieces of background music and four sound effects. The *Robinion* magic show is a stage art composed of *Performer, Play, and Audience* (Figure 8). The first element, *Performer*, is our humanoid robot as the main actor, *Jaesik* as an assistant 1, *Greene* as an assistant 2, and some unspecified members of the audience as an assistant 3. The *Play* consists of 16 scenes. The last element, *Audience*, does not limit anyone from being able to participate, including the participants and judges of the magic show, who can sit or stand and watch freely.

The stage is open on the right and left sides (there are no barricades or curtains); there are two tables, a projector, and a screen on the stage. If the trick is easily exposed, the participant should pay attention to the installation so that the audience and the judges will not notice during the preparation time after the previous team's presentation. In addition, we modified the movement of the performer several times during the preparation of the competition because the performer might block the projector during the performance. In order to allow the audience to focus on the magic show, some brilliant visual effects that we had originally planned with images & video were deleted, and the humanoid robot's motion, dialogue, and music were controlled in real time, away from the stage.

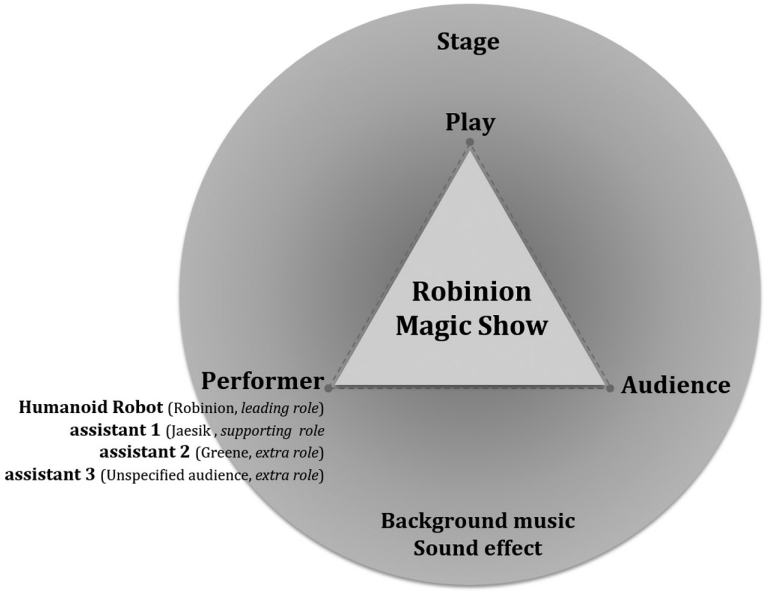


Figure 8 Structure of Robinion's magic show

3.3 Magic tricks

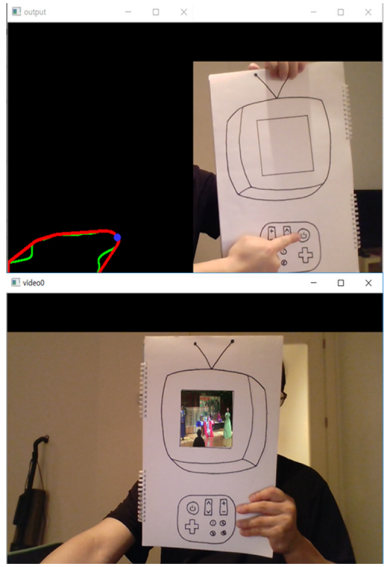
IROS2018 HAC-Robot Magic was a stage magic which was held on an open stage (as-mentioned above). The magic show of team *ZSTT-NTNU* consisted of three tricks (Table 2), and it proceeded with some magic tools, as well as through the interaction of the participant, our humanoid robot, and the audience through DC motor control, image processing, and manipulation of the objects.

Robinion tries a marble and a bottle magic trick that was to put the marble in the correct position of the plastic bottle before the first magic trick: a flying silk magic trick. Before showing the magic trick, the participant confirms that it is impossible to put a marble in the plastic bottle, which has a lid screwed on it, and no hole on the top of the bottle. *Robinion* can proceed quickly on the first magic attempt because it is very simple, but it is not easy to calculate the kinematics and Centre of Mass (CoM) of a robot when the robot moves its arm to grasp the bottle and drop the marble into the correct position. If the robot performs the motion of the magic trick, the center of gravity of the robot changes. Therefore, the robot controls its balance through CoM analysis and feedback control of the SCR. The robot failed several times when we were practicing because the servo motor has a little bit of backlash. We were able to calculate the robots exact arm position through various kinematic iterations when the robot grasps the plastic bottle, grasps the marble, and throws the marble to the bottle.

The first magic trick was made up of a flying silk trick that used a DC motor, wire, cloth, and guide mount made by 3D printer. Our humanoid robot asks the assistant to wipe sweat off his forehead because he says the first the marble and the bottle magic attempt failed because of the sweat. At this time, the assistant tries to wipe the sweat off the cloth, but the cloth is blown away by the flying silk magic trick (Figure 9). We should use a wire of the same color as the background and encourage people to focus on our humanoid robot and the cloth because the wire can be seen if the wire color contrasts with the background color.

The sketchbook magic (Figure 10) consists of using image processing to play a video on a television which has been drawn on a sketchbook. Our software gets frames from the camera in the *Robinion*'s head and then detects objects: the sketchbook, the television, the button, and the finger in this magic trick. The assistant shows the sketchbook drawing of a television to our magician robot after the second marble and bottle magic trick fails. First, our software finds the sketchbook using color detection. For detecting the sketchbook, we convert the RGB color space to an LAB color space. The LAB color space is designed to approximate human vision. It aspires to perceptual uniformity, and its L component closely matches human perception of lightness. Then, we set the sketchbook as the region of interest. It also uses

Table 2 Magic tricks

Magic tricks	**Flying silk**	**Sketchbook**	**Bottle & Marble**
Image			
Magic tools	DC motor, wire, cloth,Guide mount	Sketchbook	Needle, fishing line

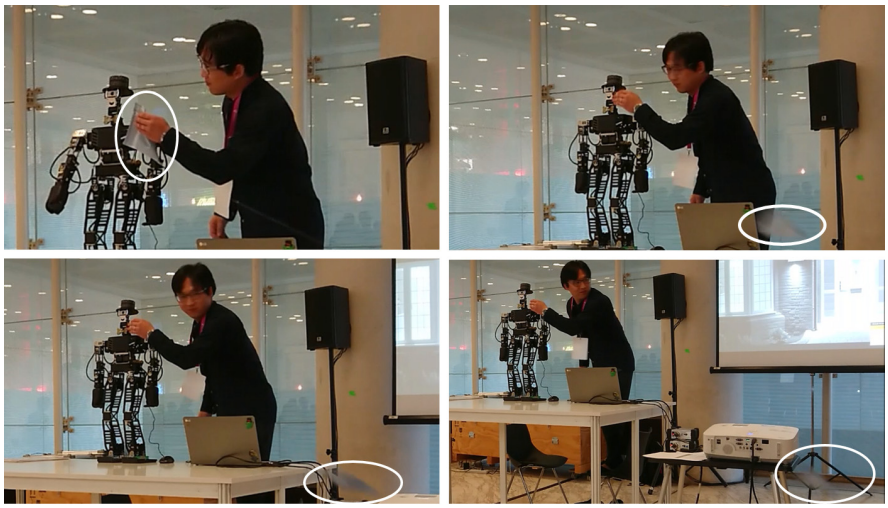


Figure 9 Flying silk magic trick

Figure 10 Sketchbook magic trick using image processing

rectangle detection in order to detect the television. After detecting the television, the software calculates an angle of television. Color detection and a convexity hull & defect system are then both used in order to detect the person's finger when he/she 'presses' the button on the sketchbook drawing. Then, it matches a template image of the 'on' button with the same button in the sketchbook drawing. Then, the ''*Robinion Diary*'' video will be broadcast inside the television in our software while calculating the angle of the television.

The last magic trick was made up of a needle, a wire, a marble, and a plastic bottle. The magic was to put the marble in the plastic bottle without the hole on the top of the bottle (Figure 11) (Yang *et al.,* 2019). The audience thinks that there are hidden magic trick devices in the plastic bottle due to two failures. There is small a hole in the plastic bottle where the lid can be inserted and a needle with fishing line is inserted in the hole. There is the marble between the needle and the lid. This magic trick is that the assistant pulls the fishing line attached to the needle, and then drops the marble inside the plastic bottle. The assistant does not give the humanoid robot the marble in the third the marble and the bottle magic trick because we will use the marble inside the bottle. When the assistant pulls the fishing line from behind the robot, the marble fall into the plastic bottle and the the assistant gives the audience and the judges the bottle for checking the magic trick. Almost everyone cannot find a pinhole, so the magic trick ends up successfully.

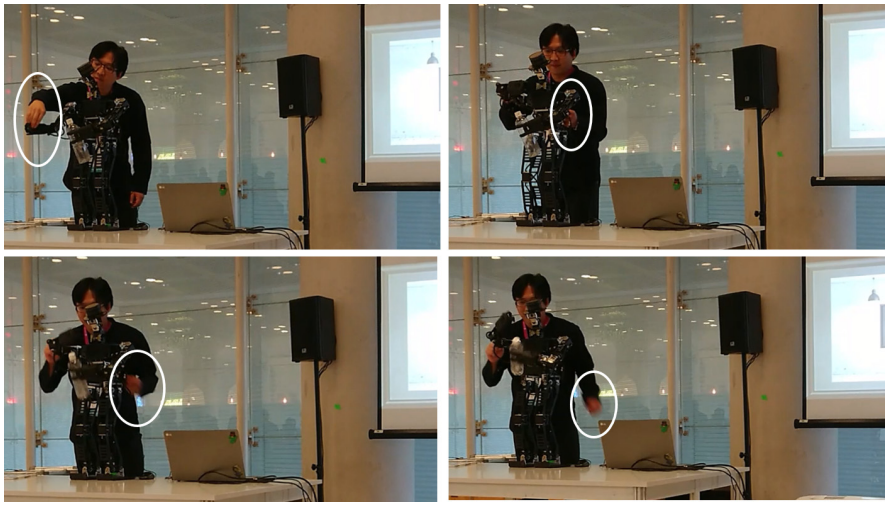


Figure 11 Bottle & marble magic trick with needle

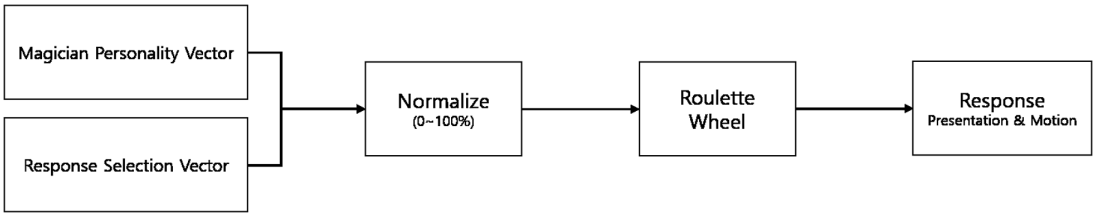


Figure 12 Process of output response (presentation & motions)

4 Robot personalities

The interaction of the magician and the audience is the most important factor in the magic show. A humanoid robot is a more powerful delivery than other types of robots in magic shows that directly interact with humans, and the audience can feel emotions and empathy more effectively because they regard a humanoid robot as a magician just like a human. In the *IROS2018 Humanoid Robotics Application Challenge - Robot Magic*, we set our primary goal as delivering the emotion of the humanoid robot to the audience through magic. To achieve this goal, we developed an algorithm that enables the robot to perform a magic show that is not repeated word-for-word and motion-for-motion each time, but rather, having various different tendencies with which to interact with the audience instead. That way, even if the audience keeps watches the same magic show again, it makes the magic show more interesting because they cannot predict the robot's next line. Users can continue to add even more robot personality traits and different responses. The more robot personality traits and responses there are, the more varied the magic shows the robot can produce will be.

Our humanoid robot can select different responses (motions and presentations) based on personality vectors at 10 selection points in each magic show. The humanoid robot can perform the magic show by selecting about 39 350 dialogues and 32 motions from 10 selection points. The various presentations and motions are determined by magician personality traits, response selections, and a roulette wheel selection algorithm. The dot product result of the Magician personality vector and Response selection vector is normalized and then applied to the roulette wheel algorithm to obtain the response (Figure 12).

We classified the magician personality traits and the response selections into three aspects: humor, aggression, and political. Then, we applied it to the magic show. The speech acts algorithm that we developed has the advantage of showing more various magic shows because the user can add the personality that the user wants at any time. As more personality traits are added, however, the development of our software will become more complex. To solve the complexity, we are developing a new system based on

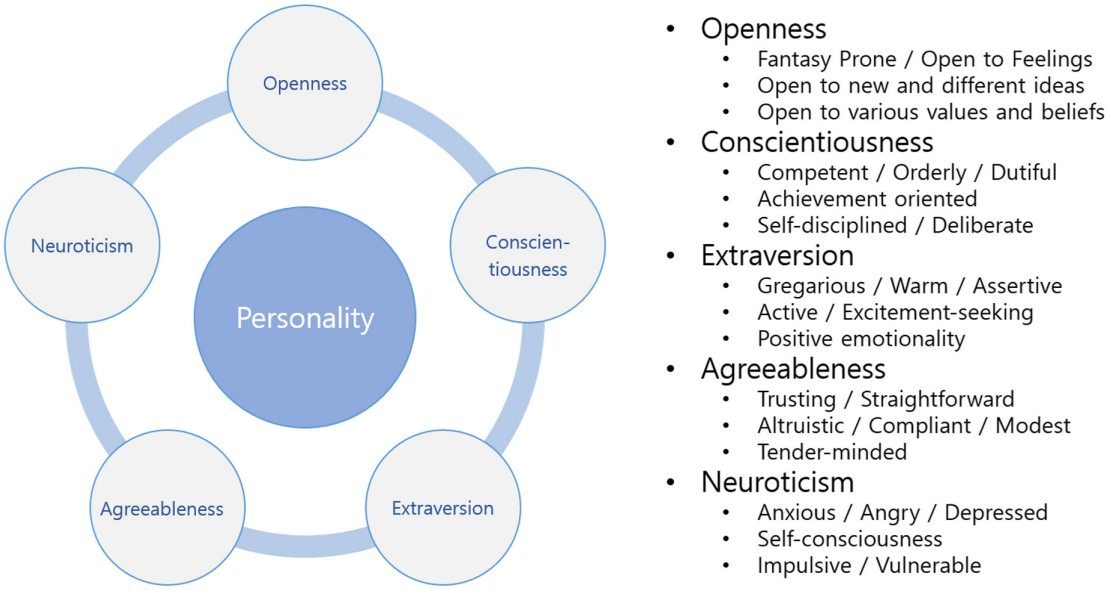


Figure 13 Big five personality traits

the big five personality traits, a model that is condensed by Costa and McCrae (1999) (Figure 13). We are developing user-oriented software by classifying the magician personality traits and response selections within the big five personality traits.

4.1 Magician personality traits

If the magician robot performs the same tricks, presentations, and motions, audience will be bored. The interaction of the audience and the robot magician is the most important factor in the robot magic show, that is why we developed different speech acts based on *Robinion*'s personality and response selections during the magic show in real time. The user sets *Robinion*'s personality based on the Magician Personality Vector (MPV) before starting the magic show. Each property of the vector has a value between 0 and 1. *Robinion* will perform magic shows with different personality traits every time according to how the vector is set up before the start of the magic show. *Robinion* has three personality traits: humor, aggression, political; the magician personality vector is composed of humorous (comedy [0] to serious [1]), aggression (nice [0] to aggressive [1]), and political (neutral [0] to political [1]) (Yang *et al.*, 2019). For example, we can set *Robinion*'s personality vector as shown below.

Magician Personality Vector: [Humor] [Aggression] [Political]

[0.2] [0.9] [0.1]: *Humorous & Aggressive & Neutral Magician*
[0.5] [0.5] [0.5]: *Normal Magician*
[1.0] [1.0] [1.0]: *Serious & Aggressive & Political Magician*

Because of our speech algorithm, even if we set the political personality of the magician to be very high, the audience cannot necessarily predict the next speech act. In this case, however, the magician's political personality will increase the probability that each line of speech he chooses will be at the more political end of the spectrum.

4.2 Response selection

Our magician robot interacts with the assistant and the audience with various responses in the magic show. The Response Selection Vector (RSV) is set to the same properties as the magician personality vector's chosen personality traits. There are various responses for each situation, and if there are more responses, various magic shows are possible. The properties of the response selection vector have a value

between 0 and 1, where 0.5 is neutral. Each vector is expressed as a vector of humor, aggression, and political as with the composition of the magician personality vector (Yang *et al.* 2019). In IROS2018-HAC, we developed 29 different dialogues from 10 selection points to show about 39 350 different magic shows in total.

Response Selection Vector: [Humor] [Aggression] [Political]

Selection point 1:

[0.8] [0.4] [0.0]: *Give me a second. I need some preparation time. 1 or 2 minutes.*
[0.2] [0.9] [0.0]: *Wait! I am not ready. Slow down idiot.*
[0.1] [0.2] [0.0]: *I am nervous. . .*

Selection point 2:

[0.3] [0.5] [0.6]: *Look what happens if you use the same motor for 6 yr.*
[0.2] [0.9] [0.5]: *Jaesik, It's about time you changed my shitty old motor.*
[1.0] [0.5] [0.5]: *It seems my motor is in need of upgrading.*

Selection point 3:

[0.8] [0.1] [0.5]: *I'm sorry Jaesik.*
[0.5] [0.9] [0.9]: *It's all your fault!*
[0.3] [0.5] [0.6]: *You can't teach an old robot new tricks.*

Selection point 4:

[0.0] [0.7] [0.2]: *Don't panic, bro!*
[0.8] [0.8] [0.7]: *You always keep pushing me.*
[1.0] [0.4] [0.5]: *Let me see what I can do.*

Selection point 5:

[0.5] [0.7] [0.5]: *It sounds too quiet.*
[0.3] [0.8] [0.5]: *Come on. Let's make some noise!*
[0.1] [0.3] [0.7]: *Let's do it Gangnam style.*

Selection point 6:

[0.8] [0.5] [0.5]: *Third time lucky. I can do it.*
[1.0] [0.3] [0.5]: *Do you think I can really do it?*
[0.2] [0.7] [0.5]: *The last two times I was just practicing. No more fooling around.*

Selection point 7:

[1.0] [0.5] [0.7]: *Show the judges so that they believe me.*
[0.1] [0.7] [0.8]: *The judges will never believe me! Show them.*
[0.0] [1.0] [0.7]: *Those stupid judges will never know the secret of my trick!*

Selection point 8:

[0.3] [0.9] [0.9]: *That is not a whisky bottle you know.*
[0.3] [1.0] [0.8]: *If you break it, I will kill you.*
[1.0] [0.7] [0.5]: *Handle it carefully.*

Selection point 9:

[0.7] [0.2] [0.7]: *So I gained a lot of weight as you can see in the pictures.*
[0.1] [0.0] [0.3]: *See how our love has blossomed over time.*
[1.0] [0.5] [0.5]: *I have been continually improved and upgraded at every stage.*

Selection point 10:

[1.0] [0.0] [0.5]: *Ladies and gentlemen. Thank you very much. You have been a wonderful audience.*
[0.5] [0.5] [0.6]: *It's been real. Take care of yourselves. God bless.*

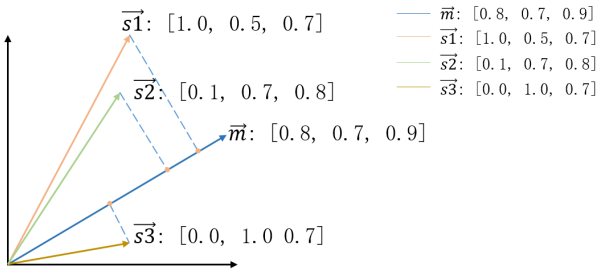


Figure 14 Dot product of Magician Personality Vector and Response Selection Vector

For example, in the selection point 7, the first sentence is expressed as the response selection vector of [1.0, 0.5, 0.7] since it is a formal, serious sentence using standard English grammar, it is neither nice nor aggressive, and it is somewhat political as it is related to the topic of cheating in a competition. The second sentence is expressed as the response selection vector of [0.1, 0.7, 0.8] because it is a silly sentence (for a robot), a little bit aggressive (as it is an imperative), and quite political as it also references cheating. The third sentence is expressed as the response selection vector of [0.0, 1.0, 0.7] because it is very funny, very aggressive (it makes fun of the judges), and a little bit political (as it questions the judgment of the judges). In other words, all responses are expressed by vectors such as [Humor, Aggressive, Political], and the final response is determined by the calculation of the developed Roulette Wheel Selection algorithm.

4.3 Roulette wheel selection

Our humanoid robot selects one response from various responses by applying the magician personality vector and response selection vector to the roulette wheel selection algorithm. First, in the speech acts algorithm, a dot product of the magician personality vector and response selection vector is computed. The result of the dot product is normalized to a value between 0 and 1, and then it is arranged using the roulette wheel selection algorithm. The selected response is more likely to be the higher of the dot product result of the magician personality vector and response selection vector. For example, a user sets *Robinion*'s personality vector to $\vec{\boldsymbol{m}}$ which is very serious and a little bit aggressive and very political and sets the response selection vectors above to $\vec{\boldsymbol{s1}}$, $\vec{\boldsymbol{s2}}$, $\vec{\boldsymbol{s3}}$ of selection point 7 (Figure 14).

The result of a dot product of m and $s1$, m and $s2$, and m and $s3$ is as follows.

$$\textit{Dot product}: \; s1_d = \vec{\boldsymbol{m}} \cdot \vec{\boldsymbol{s1}} = 1.88$$

$$\textit{Dot product}: \; s2_d = \vec{\boldsymbol{m}} \cdot \vec{\boldsymbol{s2}} = 1.3$$

$$\textit{Dot product}: \; s3_d = \vec{\boldsymbol{m}} \cdot \vec{\boldsymbol{s2}} = 1.33$$

Then, we normalize the result of the dot product to 0 and 1 as shown below (Figure 15).

$$\textit{Normalizes1}_n: \; s1_n = \frac{s1_d}{s1_d + s2_d + s3_d} = 0.41$$

$$\textit{Normalizes2}_n: \; s2_n = \frac{s2_d}{s1_d + s2_d + s3_d} = 0.29$$

$$\textit{Normalizes3}_n: \; s3_n = \frac{s3_d}{s1_d + s2_d + s3_d} = 0.30$$

The user cannot predict the roulette wheel result, but it is true that the first sentence with the higher dot product result is more likely to be selected. Our software system is more interesting because one cannot accurately predict the output presentation due to the use of the roulette wheel selection algorithm which is based on probability. In this research, we developed the magician personality vector, response selection vector, and roulette wheel selection algorithm based on a system of probability. So, our humanoid robot

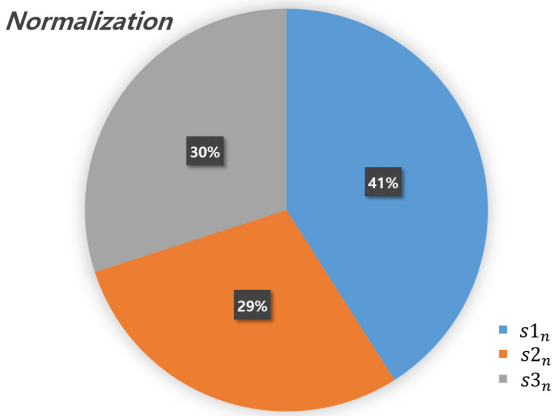


Figure 15 Normalize

can perform various magic shows through the magician personality vector, response selection vector, and roulette wheel selections (Yang *et al.,* 2019).

5 Human–robot interaction

HRI is continually being studied with AI and has received considerable attention in academia, laboratories, technology companies, and media. HRI, a state-of-the-art robotics technology, is a fusion science that is based on various academic fields such as Human–Computer Interaction (HCI), AI, Robotics, Sociology, and so forth. When a human approaches a robot, HRI, in which a robot estimates a person's intention and interacts with each other, is a approach that focuses on humans rather than technology. HRI is evolving into HCI, *Haptic*, AI, and a device intelligence and is one of the main technologies in the future where humans and robots will live together. Until now, most HRI research has focused on areas where robots can be used in real life (helping human work, service) and emotional interpretation of humans and robots. In addition, HRI has been focused on the interaction between a single person with a robot. However, performing arts is aimed at a large number of audiences. If robots are used in the performing arts such as a magic show, a musical, and a play, it is necessary to research the expansion of interaction objects and bi-directional & uni-directional interaction between humans (e.g. actors, audience, staffs) and robots. Humanoid robots are used more often in performance arts, but most robots act in uni-directional interaction with the audience. So, there is very little interaction between humans and robots in the performance arts. Like the Poppy project, there are a lot of interacting between Poppy and dancers while dancing (Lapeyre *et al.,* 2014). Humanoid robots, however, are less likely to respond to immediate reactions unlike the scenarios. In this paper, we researched HRI between our humanoid robot and participants, judges, and the audience in the robot magic show.

Interaction is defined somewhat differently depending on the field, but it is a kind of action that mostly occurs as two or more objects (human, machine, animal, etc.) have an effect upon one another. In this paper, interaction is defined not only as a bidirectional effect but also as a uni-directional influence from other objects that occur in the audiences appreciation in the performance arts. The reason for this broad definition of interaction is that the stimulation of the audience during appreciating the performance serves as feedback that affects the performance arts. In *Robinion*'s magic show, interaction occurs in five forms (HRI, HRpI, HRHI, HHpI, HRpI-HHI) as shown in Figure 16, and explained below. In this study, we define that interaction includes bi-direction and uni-direction. Passive interaction represents uni-directional interaction.

A: Human–Robot Interaction [HRI]
Bi-Directional interaction between *Robinion* and *assistant 1*
B: Human–Robot passive Interaction [HRpI]

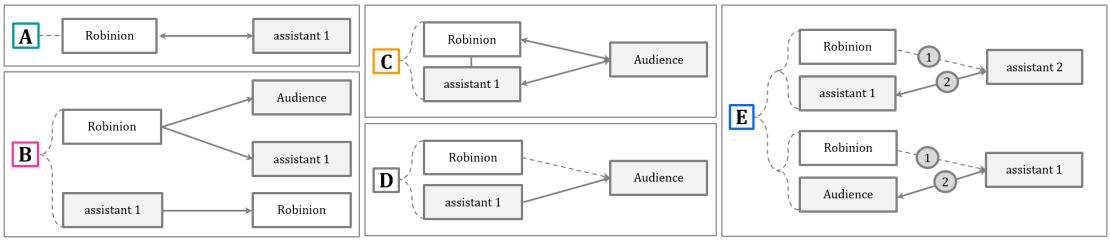


Figure 16 Type of interaction in the magic show

Uni-directional interaction from *Robinion* and *assistant 1* to the audience, and from *assistant 1* to *Robinion*

C: Human–Robot–Human Interaction [HRHI]
Bi-Directional interaction between *Robinion* & *assistant 1* and the audience

D: Human–Human passive Interaction [HHpI]
Uni-directional interaction from *assistant 1* to the audience

E: Human–Robot passive Interaction & Human–Human Interaction [HRpI-HHI]
Uni-directional interaction from *Robinion* to *assistant 2*, then Bi-Directional interaction between *assistant 1* and *assistant 2*

Uni-directional interaction from *Robinion* to *assistant 2*, then Bi-Directional interaction between *assistant 1* and the audience

6 Result

In this section, we discuss the result of *Robinion*'s magic show in IROS2018-HAC. First, we analyze the response selection which is chosen by the roulette wheel selection in the magic show. Then, we show how the HRI occurred in the magic show.

6.1 Roulette wheel selection

We set Robinion's personality to [0], [1], [0.8] before the start of the magic show. In this magic show, *Robinion* is a very aggressive and political magician with no humor at all. *Robinion* selected one response from each of the 10 selection points in the show. We show the normalized values after the dot product operation at each selection point in Table 3.

When comparing the normalized values of the selected sentences, the highest normalized value is selected four times (Selection point 1, 5, 6, 9) and the second highest value (Selection point 2, 4, 7, 8) was also selected four times. The lowest value was selected twice (Selection point 3, 10).

Depending on how the user configures *Robinion*'s personality, the normalized value of each sentence changes and the result of the roulette wheel selection algorithm changes as well. If we show this magic show repeatedly, the narrative of 'failure and success' is the same, but different sentences can be selected for each of the selection points, so the audience can enjoy different shows every time.

6.2 HRI-Robinion magic show

Figure 17 shows 24 important scenes where an interaction took place in the magic show that *Robinion* performed in *IROS2018 Humanoid Robot Application Challenge - Robot Magic*. In Figure 17, the HRI, HRpI, HRHI, HHpI, and HRpI-HHI, which are classified in Figure 16, are labeled as colors: green, pink, orange, gray, and blue.

In the analysis of 24 images, the HRI was the most frequent, occurring 9 times, the HRpI was the next highest with 8 occurrences, the HRHI occurred 3 times, the HRpI-HHI occurred twice, and the HHpI & ''none'' both occurred just once (Figure 18). We counted the occurrence frequency about 24 important

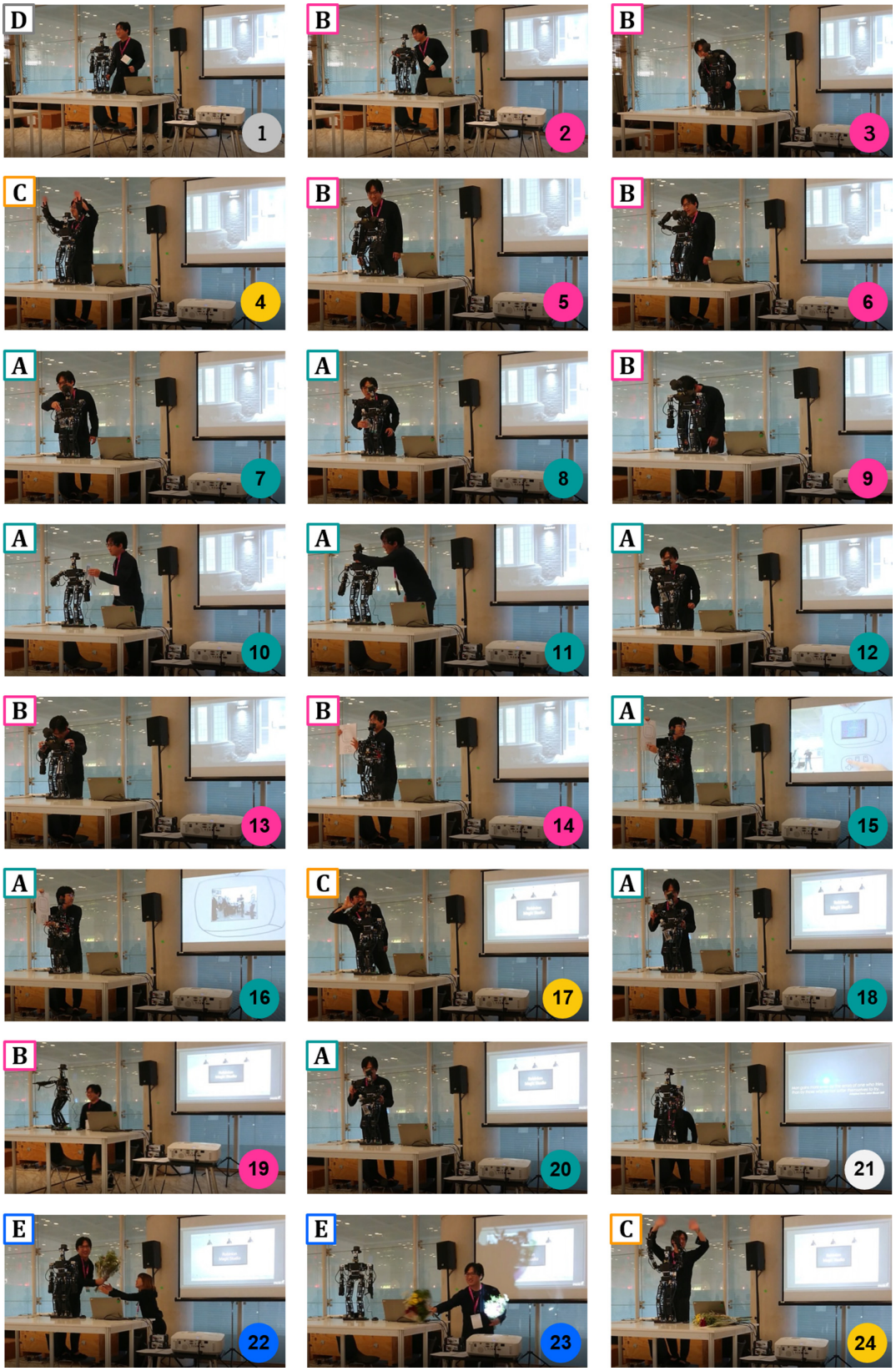


Figure 17 Human–robot interaction in the magic show

Table 3 The result of the normalization in *Robinion*'s magic show

Robinion's personality (IROS 2018 Robot Magic)		Humor	Aggression	Political		
		0	1	0.8		
	sentence	Humor	Aggression	Political	Dot product	Normalization
1-A	Give me a second. I need some preparation time. 1 or 2 minutes	0.8	0.4	0	0.4	0.27
1-B	Wait! I am not ready. Slow down idiot.	0.2	0.9	0	0.9	**0.60**
1-C	I am nervous...	0.1	0.2	0	0.2	0.13
2-A	Look what happens if you use the same motor for 6 yrs.	0.3	0.5	0.6	0.98	0.31
2-B	Jaesik, It's about time you changed my shitty old motor.	0.2	0.9	0.5	1.3	**0.41**
2-C	It seems my motor is in need of upgrading.	1	0.5	0.5	0.9	0.28
3-A	I'm sorry Jaesik.	0.8	0.1	0.5	0.5	0.16
3-B	It's all your fault!	0.5	0.9	0.9	1.62	**0.52**
3-C	You can't teach an old robot new tricks.	0.3	0.5	0.6	0.98	0.32
4-A	Don't panic, bro!	0	0.7	0.2	0.86	0.28
4-B	You always keep pushing me.	0.8	0.8	0.7	1.36	**0.45**
4-C	Let me see what I can do.	1	0.4	0.5	0.8	0.26
5-A	It sounds too quiet.	0.5	0.7	0.5	1.1	0.35
5-B	Come on. Let's make some noise!	0.3	0.8	0.5	1.2	**0.38**
5-C	Let's do it Gangnam style.	0.1	0.3	0.7	0.86	0.27
6-A	Third time lucky. I can do it.	0.8	0.5	0.5	0.9	0.33
6-B	Do you think I can really do it?	1	0.3	0.5	0.7	0.26
6-C	The last two times I was just practicing. No more fooling around.	0.2	0.7	0.5	1.1	**0.41**
7-A	Show the judges so that they believe me.	1	0.5	0.7	1.06	0.27
7-B	The judges will never believe me! Show them.	0.1	0.7	0.8	1.34	0.34
7-C	Those stupid judges will never know the secret of my trick!	0	1	0.7	1.56	**0.39**
8-A	That is not a whisky bottle you know.	0.3	0.9	0.9	1.62	0.37
8-B	If you break it, I will kill you.	0.3	1	0.8	1.64	**0.38**
8-C	Handle it carefully.	1	0.7	0.5	1.1	0.25
9-A	So I gained a lot of weight as you can see in the pictures.	0.7	0.2	0.7	0.76	0.40
9-B	See how our love has blossomed over time.	0.1	0	0.3	0.24	0.13
9-C	I have been continually improved and upgraded at every stage.	1	0.5	0.5	0.9	**0.47**
10-A	Ladies and gentlemen. Thank you very much. You have been a wonderful audience.	1	0	0.5	0.4	0.29
10-B	It's been real. Take care of yourselves. God bless.	0.5	0.5	0.6	0.98	**0.71**

scenes in the magic show. As shown in the analyzed results of the images, it can be seen that HRI occur a lot in the magic show.

7 Conclusion and future work

In this study, we analyzed the results of *Robinion*'s magic show participating in *IROS2018-Robot Magic*. Based on the communication model between the audience and the performers, we researched the composition of the magic show where different HRIs occur each time according to the personality of our magician and response selection. First, the HRI which occurred in the magic show is defined into five categories. Although HRI only takes place between humans and robots, in *Robinion*'s magic show, interaction occurs in five forms (HRI, HRpI, HRHI, HHpI, HRpI-HHI). Our five categories of HRI are obviously important factors to consider in the performance art of using robots. Second, *Robinion* can select different responses (motions and presentations) based on personality. We classified the magician personality traits and the response selections into three aspects: humor, aggression, and political. This study is just one result out of a possible 39 350 dialogues and 32 motions performed by one personality

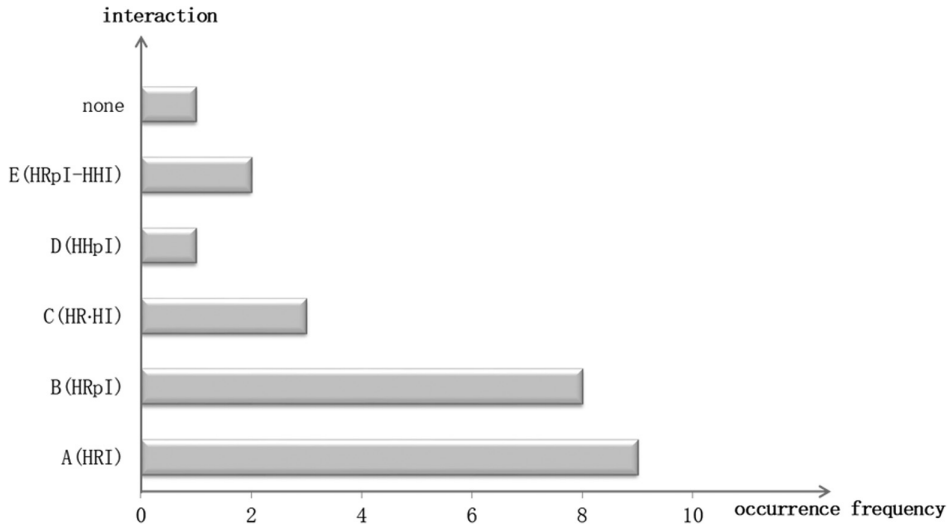


Figure 18 Interaction occurrence frequency in the magic show

of the magician. However, the audience can appreciate a different magic show every time according to the magician's personality. In other words, the audience does not feel bored even if they watch the same magician's show several times. Our unpredictable personality-based magic show can be a very exciting magic show because a lot of HRIs can occur that the audience cannot predict even if the audience watch the same magician's show several times. In addition, in *Robinion*'s magic show, the audience expressed a variety of reactions such as applause, sadness, happiness, sighing, and so forth. The interaction that occurs through various forms of communication between the audience and performers is obviously an important factor in robot performance arts. *Robinion*'s magic show introduced a new way of doing performance arts by allowing various magician's personalities, and it could have a new impact on the appreciation by breaking the stereotype of existing robot performance arts.

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