Retro-Projected Virtual Furhat: A Simple yet Advanced Social Robot

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Abstract. A robotic head is one of the most crucial components of a robot in HRI experiments as it provides the potential for interaction using facial expressions and dialogue. Retro-projected robots can be used in the field of affective computing due to their interaction abilities. Unfortunately, most robots are expensive and suffer from high complexity or risk of falling into the uncanny valley. Retro-projected robots offer an alternative where such problems are reduced greatly. In this paper, we present the design methodology of a retro-projected robot. We explain the optimal method for choosing the projector and a suitable fisheye lens, which are the main units in the robot. We retro-project Virtual Furhat using a laser projector on a 3D plastic transparent face mask fixed on a realistic foam mannequin head passing through a fisheye lens. We investigate many HRI factors by conducting interviews and asking subjects to fill out questionnaires. Our results show that our robot is trusted by the users, perceived to be safe, and perceived as social due to its responsive and interactive ability. However, it was not perceived to be empathetic, in line with this, it was rated negatively on the anthropomorphism factor as it appeared more artificial and machine-like to subjects despite being perceived to be kind and friendly.

Keywords: Retro-projected robot, Virtual Furhat, fisheye lens, laser projector

1 Introduction

The deep connection between emotions and physical health increased the research interest in affective computing. Affective computing utilizes hardware and software technologies to detect the affective state of a person leading to interest in affective state analysis, which is produced originally from human emotions. Theories of emotion that continue to influence our thinking started since the 19^{th} century [11]. When humans are involved in an interaction, feelings are always present, thus giving importance to research in emotion assessment [18]. Consequently, emotion recognition raises the question of how an emotion should

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be defined and what type of emotion can be recognized and distinguished successfully. Speech and facial expressions can aid in recognizing emotions. Furthermore, physiological signals such as EEG, EMG, and ECG can also be used and sometimes are preferred [19].

Imitations of the robot's verbal and bodily expressions can transmit emotions to the user based on emotional contagion and social identity theory. Examining emotional contagion and mood transitions in human-robot interaction (HRI) and comparing them to human-human interaction (HHI) became an interesting research field recently [21]. Mood contagion was proved to be recognized and have a contagion effect on users through pose and motion dynamics [22], yawning [14], posture with a facial expression [4], and inter-personal account of emotion [6]. One drawback that current research suffers from is the usage of robots that lack human-like facial expressions such as NAO [22], EMYS [14], Buddy [4], and Flobi [6]. Thus a need for robots that display human-like emotions appears. Furthermore, doubts regarding ambiguity in recognizing emotions will be eliminated due to the high affinity reached with a robot that has a human's face showing human-like facial expressions.

Due to the many benefits that retro-projected robots offer, there have been many attempts to build them through different methodologies. LightHead robotic face is from the very first works in this field rear projecting a 2D screen avatar on a 3D mask [8]. Other works that used projector heads are Mask-bot [13] and Mask-bot 2i [20]. Furhat robot is another back-projected robotic head [1]. To the best of our knowledge, the most recent attempt at designing a retro-projected robotic head is Taban [17].

Retro-projected robotic heads have many advantages. The complexity of their mechanical mechanism is very low due to not using mechatronic actuators or plastic skin. The power consumption is too low as it's only provided for the projector. Effective interaction is maintained due to the 3D face of the robot which allows an accurate mutual gaze. Furthermore, facial expressions can be easily recognized due to the 3D mask embodiment. Its motion is fast and has high reactiveness as no actuators are used. Many avatars can be projected, thus, flexibility and freedom of design are maintained to conduct many different HRI experiments. As we project Virtual Furhat onto the 3D mask, accurate lip movement is maintained. Similar to other robots, presence in actual space and observation direction dependability enhance the affinity of the robot. The mean time of failure is very high as it depends on the projector (30,000 hours for our projector). The animated face prevents the uncanny valley effect from occurring.

Retro-projected robots suffer from some problems. Adding more degrees of freedom (DOFs) will benefit the interaction at the expense of risking noisy operation leading to unnatural HRI. Eye and lip regions should be aligned with the face mask to appear realistic. Aligning eye and lip regions were discovered to be not trivial. Thus, a yawning robot will appear strange and unnatural to the user. Moreover, the projection must be far away from the projector, thus risking having a high volume for the robot.

Available retro-projected robots provide a great alternative for researchers who want to do HRI experiments. However, several key aspects were lacking which can hinder the process of building a robot. There was no clear explanation for the optical system installed. No clear scientific way was provided for choosing the fisheye lens specs. Thus, it was installed based on trial and error which can be inconvenient. Moreover, as the retro-projected robot research started around 2011, machine learning and large language models (LLM) were not as common as now, thus leading to building robots that are not powerful in terms of holding a dialogue with the user. None were able to exploit the power of facial expressions to its full extent. Retro-projected robots are required to use 3D printers or mold the face mask using specific measurements. Heavyweight and noise from actuators affected the simplicity of building the robot and risked interrupting the interaction. Moreover, research requirements in ensuring high affinity and correct emotion recognition dictate building a robot with a human-like look and facial expressions thus facilitating affective computing research coupled with HRI.

We show complete steps of building a simple portable lightweight inexpensive robotic head. We build a simple robot that does not require molding or 3D printing a face mask. We show a complete manual for choosing the suitable projector and fisheye lens. We integrate Virtual Furhat with ChatGPT to make the robot interactive and responsive to users. We show an alternative way of using Furhat's powerful capabilities without buying the actual robot (costs at least fifteen thousand USD in 2023) which can be a barrier stopping researchers from launching their HRI experiments. We conducted interviews and asked subjects to fill out questionnaires to verify the usability and acceptance of the robot. A robot suitable for affective computing HRI experiments is provided with a clear guide to follow.

2 Related Works

The concept of back-projecting a face robot on a nonflat surface has been investigated and studied extensively as it improves HRI and makes it more natural. In [9], the authors project a face robot on a dome screen through a (Digital Light Processing) DLP projector. It suffered from being bulky and heavy.

Due to the undeniable evidence of the persuasiveness of a robotic face in HRI, Retro-projected Animated Faces (RAF) technology emerged where a robot face is retro-projected onto a semitransparent facial mask [8]. It served as an alternative to mechatronic and android heads. A picoprojector and semi-transparent display were used. It's a low-cost flexible solution. It suffered from the limited light power of the picoprojector (7 to 40 lumens) which hindered its operation in bright light conditions. The iCub face was adopted for the robot face. The authors named the robot that utilized RAF technology "LightHead" and showed the effectiveness of the robot in displaying human social-emotional behaviors [7].

"Mask-bot" is a life-size robot head that uses head animation and utilizes AV speech synthesis and perception [12,13]. It can be built easily using a mask screen, LED projector, fisheye lens, and pan-tilt unit. This robot head suffered from projectors with low brightness as it was proposed in 2011. A portable small-size projector was needed thus portability was hard to be met along with high brightness. The authors added DOF through motors to the robot which added more weight to it affecting its portability.

"Mask-Bot 2i" was developed over Mask-bot by adding a video camera while matching the natural head movements of an average human [20]. Mask-Bot 2i focused on the complete modalities that a robotic head needs. A mirror was combined with the fisheye lens to provide a lower volume. It's lighter and more quiet than Mask-bot.

"Taban" is a retro-projected social robotic head for HRI [17]. Taban is a cost-effective portable robot that can produce different facial expressions and different 3D face animation avatars. It uses a rear projector to project animations onto a translucent 3D printout mask. It's a well-developed robot despite it being more expensive than our proposed alternative as it costs around three thousand USD. Moreover, 3D printing is needed, unlike our flexible alternative.

Furhat [1] is a robot head that deploys a back-projected animated face that is realistic and human-like without risking falling into the uncanny valley effect due to the usage of facial animation. Furhat can be used when using a virtual avatar on a flat 2D screen will not suffice. It facilitates studying and validating patterns in HHI and HRI. In Furhat, the robot's animated face is back-projected on a translucent mask, thus the principle is similar to other robots. However, Furhat enjoys a rich library of facial expressions and performs speech recognition, and multi-person face tracking leading to advanced reliable multimodal input processing and operation.

3 Retro-projected Virtual Furhat Robotic Head Equipment

To build the robotic head, the following items must be purchased and they are as follows:

1. Realistic foam mannequin head (costs 660 Yen ($\approx$ 4.5 USD) from Daiso (a large franchise of 100 yen shops in Japan)). Its dimensions are 22cm x 20cm x 34 cm.
2. Plastic transparent mask (costs 1,500 Yen ($\approx$ 10.4 USD)) from Amazon Japan. Its dimensions are 21.6 x 16.2 x 8.9 cm. It weighs 50 grams.
3. 0.35X High Definition Fisheye lens (costs 2,850 Yen ($\approx$ 19.7 USD)) from Amazon Japan. Its dimensions are 7.5 x 6 x 5.5 cm. It weighs 270 grams.
4. Anker Nebula Capsule 3 Laser Projector (costs 799.99 USD) from Nebula's official website. The model number is D2426. Its dimensions are 170 mm in height and 83 mm in diameter. It weighs 0.95 kilograms. Its display technology is DLP 0.23 DMD. Its brightness is 300 ANSI Lumens.
5. Two cans of spray paint with colors "Pearl Clear" and "Matt White".
6. HDMI cable to be used in connecting the PC to the projector.

Furthermore, Virtual Furhat must be installed on the PC to project Furhat's face onto the face mask. Through this method, the robot will inherit the intended 3D depth information through the depth cues provided by the face mask.

4 Retro-Projected Virtual Furhat Robotic Head Construction Steps

In this section, we write the detailed steps we followed in building our retro-projected robotic head.

4.1 First Step:

We cut the face part off the "Realistic foam mannequin head" using a "Hot Wire Foam Cutter". We cut the back part of the foam mannequin head to allow the projector rays to pass through it. The foam mannequin head should be cut to be as shown in Fig. 1a and Fig. 1b.

4.2 Second Step:

We spray the "Plastic Transparent Mask" with "Pearl Clear" air spray. The spraying will be required to be done more than once depending on the mask itself. In our case, we sprayed the mask six times. It's advisable to spray the mask till it's clear that it's not as transparent as before.

Next, spray the mask with "Matt White" air spray. The mask should not be sprayed with the "Matt White" spray more than the "Pearl Clear" air spray. In the end, the mask should be as shown in Fig. 1c and Fig. 1d.

4.3 Third Step:

After choosing a suitable fisheye lens, we designed a lens holder made of (Medium-Density Fibre) MDF material that can hold the lens inside the foam mannequin head. We use a laser cutting machine to cut the MDF board and obtain our lens holder as shown in Fig. 1e. After that, we fix the lens holder inside the foam mannequin head as shown in Fig. 1f.

4.4 Fourth Step:

In the end, we stick the mask to the foam mannequin head using adhesive tape as shown in Fig. 1g. Furthermore, we design a holder for the projector we use, thus the final design will be as shown in Fig. 1h.

We projected two different faces from Virtual Furhat onto our robotic head and it can be seen in Fig. 1i and Fig. 1j. Note that, a wig was added to enhance the robot's realistic look through facial occlusion.

We are trying to limit the costs and follow an approach of "Do It Yourself" (DIY) to facilitate and democratize the needed tools to build a usable reliable robot that can be used to launch HRI experiments.

(a) Front view of the foam mannequin head after being cut

(b) Side view of the foam mannequin head after being cut

(c) Front view of the mask after being sprayed

(d) Rear view of the mask after being sprayed

(e) MDF fisheye lens holder

(f) Fisheye lens holder fixed in the foam mannequin head

(g) The face mask attached to the foam mannequin head

(h) The final design with the projector holder

(i) Projecting face 1

(j) Projecting face 2

Fig. 1: Retro-projected robotic head construction steps

5 Projector Full Description

In this part, we explain the projector's specs and highlight the most important parameters and their relationships and correlations to assist researchers in either justifying using our same projector or providing assistance on how to choose the right projector for their robot. We explain different aspects of the projector used in terms of display settings and other aspects that should be considered.

5.1 Display Settings

Anker Nebula Capsule 3 Laser Projector display specs are as follows:

- Resolution: 1920×1080
  Certainly, a higher resolution is always desired. Picking a resolution that is native to the PC's resolution is also a desired approach. It's important to consider that the projection surface (i.e., the mask) is small, however, the projected robot will be spread through the fisheye lens.
- Aspect ratio: 16:9
  It is the shape of a screen's display/image area. It is the ratio between its width and height. Currently, 16:9 or HDTV is the most common aspect ratio in use. From our investigation, different aspect ratios do not have a big effect on the face projected on the mask. In our projector, the aspect ratio is fixed.
- Throw ratio: 1.20:1 (D:W)
  The throw ratio is a property of the projector that you can use to calculate how large an image your projector will produce. Our projector belongs to standard throw projectors where the throw ratio is higher than 1. There are short-throw projectors where the throw ratio goes from 0.4 to 1. Calculating the throw ratio can be done by using this equation

  $$Throw\ ratio \times desired\ face\ mask\ size = throw\ distance, \tag{1}$$

  where the desired face mask size is measured diagonally in centimeters, meters, or inches. Throw distance is the distance that you have to place your projector back from the projection surface for the projector to work properly and display a decent image/video.
- Throw distance: 1.06 m - 3.18 m
  A high throw distance is not an advantage in our work as it means that the robot will not be compact. However, a small throw distance is not optimal as it implies that the projected screen size is small. Thus, we need to reduce the 1.06 m to a lower degree where the robot face is projected decently. There are some methods to reduce the throw distance to reach an optimal projection for the robot's face and they are as follows:
  1. Moving the projector closer to the mask: Although moving the projector up closer to the mask will reduce the throw distance, it will cause distortions in color and brightness, along with hot spots on the screen as a result of the image being too small.

2. Setting Up Mirrors: By directing the projector toward a mirror, and then directing the mirror toward a screen, the throw distance can be reduced although the light coming out of the projector traveled the needed full distance. That solution is unsuitable as it will not be compact and still requires a big space to be implemented. Note that, a first surface mirror will be used in such an implementation. A first surface mirror is a mirror that has a reflective surface on the outside, attached to a strong non-reflective backing. Standard mirrors are not recommended as they can create a *ghosting effect*. Ghosting happens when the transparent layer of the mirror creates a second reflection on the surface.
3. Using short throw (Wide-Angle) Lens: This solution is very common among works that built retro-projected robots before. It can project large pictures from short distances. The lens focal length is between 24 – 35mm which is shorter than that of a normal lens, thus producing a wider field of view. It creates the distance between the picture and the projector that it physically lacks. A short focal length results in a wider angle, higher magnification, and a large image. We are only concerned about the robot's face part of the image. Certainly, a zoom projector can lengthen or shorten the projection distance as needed.

5.2 Other Aspects to Consider

– Audible noise: Audible noise refers to the noise that the projector produces while in use. Audible noise should be as low as possible in order not to affect the interaction during HRI experiments. The operating noise is about 28db which comes mostly from the fan. 28dB is equivalent to the noise level of a library.
– Battery life: 2.5 hours thanks to the 52 Wh built-in battery and the utilized CAIC technology that uses every pixel to conserve energy.
– Light Source Life: 30,000H which ensures using the projector for an extended period, thus reliability is guaranteed.
– Other aspects to consider: Anker Nebula Capsule 3 Laser Projector offers many advantages. The most prominent is a compact projector that is also portable, thus an HRI researcher can conduct HRI experiments anywhere outside the lab which ensures convenience. However, some disadvantages are raised with that projector. First, although the projector can be carried in a bag easily, the cover glass of the projector lens lacks any kind of coverage to offer protection, which leads to the cover glass being very prone to any scratch which will affect the image/face quality negatively. Second, when more brightness is required/selected, the projector starts to heat up and the battery life shortens. At full brightness, the battery life reduces from the expected 2.5 hours to only 1.5 hours, thus putting a constraint on the length of HRI experiments. Third, brightness seems to excel in dark conditions far more than in ambient light conditions. Although this problem can be more related to projecting on a translucent mask rather than the projector itself, we mention it for the sake of comprehensiveness as we noticed this issue

while trying to project the robot on the wall before projecting it on the face mask. This issue leads to subjects preferring to interact with the robot in a dark environment despite the high brightness of the projector. Fourth, due to the small chassis of the projector, there is no capability provided to change or add any lenses. However, we made small MDF designs and laser cut them to obtain a small apparatus that could hold the rest of the robot out of the projector side to conduct our experiments easily and conveniently. Fifth, as with any single-chip projector with sequential color (meaning each primary color is projected one at a time), the Capsule 3 Laser can show rainbow artifacts (red/green/blue flashes), however, we did not notice any flashes. It's worth mentioning as some people are prone to seeing them. Sixth, full charging takes 3 hours on fast charging, which can interrupt HRI experiments. Thus prior preparation is needed. However, the projector can be used while being charged. Lastly, it is recommended to turn off the auto keystone adjustments and avoid using manual keystone. Digital keystone adjustment can introduce artifacts and lower image brightness.

6 Rear Projection Performance

Flux is one of the most important parameters that should be considered when rear-projecting a robot face, thus we dissect it in this section.

TV is a broad-angle light source, thus flux information is not used. Laser produces a confined beam, which makes flux to be an important parameter in choosing a laser projector for the robot's head. Flux is measured in *Lumens*.

The lumen may be thought of as a measure of the total quantity of visible light emitted from a source in a particular beam or angle. Simply put, lumen is the unit of measurement that shows how strong or intense a light source is. Lumens are particularly important in projectors because they help offset the ambient light in the projection area and translate to a bright visual effect. The average lumens in a projector is 1500, which is optimal in a controlled lighting area, and 2,500 if projecting in daylight. However, (American National Standards Institute) ANSI standardizes the lumen to *ANSI Lumen* to measure the brightness of a light source.

ANSI devised the ANSI lumen primarily to measure a projector's video lumen output. The ANSI lumen is vital to consider when choosing a projector because the ANSI tests it and can guarantee that your projector will reach the level of brightness specified. The unit of the ANSI lumen measures the overall light output from a projector, whereas the unit of a regular lumen only measures the light output in a particular beam or angle. This means that ANSI lumens are brighter because they take into account the total amount of visible light emitted from a projector. *Anker Nebula Capsule 3 Laser Projector* provides a flux of 300 ANSI Lumens, which is the maximum amount of light the projector is capable of producing.

For constructing the robot head, flux is affected by the ambient light level. This factor is considered to be crucial as it states the parameter of how bright the required projector needs to be. Consequently, it defines the ability to use the robot in indoor or outdoor experiments. It can indicate how clear the robot head is to the participants in the HRI experiments. Certainly, the price and projector's brightness are directly proportional. The projector's brightness needs to overcome the ambient light. The different ambient light conditions can be differentiated as follows:

– Low ambient light: Indoors (e.g., home or lab) where lights are off. Outdoors away from artificial lighting can be suitable too. Projectors with 300 to 600 ANSI lumen ratings will suffice.
– Moderate ambient light: Indoors where artificial lights are on. Outdoors at night where artificial lighting or street lights exist. Projectors with 600 to 2000 ANSI lumen ratings will suffice.
– Strong ambient light: Outdoors during the day or indoors where natural light can enter. A 2000 ANSI lumens projector could be necessary.

7 Fisheye Lens Description and Discussion

For the robot's face, the goal is to reduce the throw distance while magnifying a portion of the screen to make the robot's face fill the face mask while being compact. Thus, a question arises, *what kind of lens can be used to reduce the throw distance and project the robot face?*

A fisheye lens is the solution that many prior works relied on. We also use a fisheye lens. However, differently from other works, we explain why the fisheye lens is chosen and we show how to choose the correct focal length for the fisheye lens that will be used.

When verifying the operation of the fisheye lens with the projector to make sure of the right projection of the face on the face mask, a white paper board can be held in front of the projection system to make sure of the right projection of the face on it before fixing the face mask.

The fisheye lens is most suitable for back projecting the robot's face due to the *barrel distortion*. Barrel distortion causes curved lines at the edges of the photo thus projecting the face in a way where the face mask is filled with the face and looks more realistic. Fisheye lenses offer an enormous field of view (FOV). Thus, it aids in collimating the face of the robot into the face mask. The difference will be seen away from the center and in the edges/corners of the photo. Due to this, the center of the frame appears to bulge outwards and the image obtained is known as a curvilinear image.

There are two types of fisheye lenses and they are full-frame and circular. A full-frame fisheye lens is suitable for the robot face as the circular fisheye forms a circular image which is unsuitable for the robot face. Note that, a full-frame fisheye lens is sometimes called a diagonal fisheye lens.

The ONLY difference between different fisheye lenses is the size of that circular image. The longer the focal length of the fisheye lens, the larger the image. A circular fisheye lens will have a shorter focal length than a diagonal one. For practicality, a diagonal fisheye lens with a longer focal length will be more suitable for the robot as there will be a distance whatsoever between the projector and the lens, which will be compatible with a diagonal fisheye lens.

The fisheye lens that we use has a diameter of 58mm, a magnification power of 0.35X, a Max focal length of 150mm, a Minimum focal length of 58mm, and a Lens-fixed focal length of 58 mm.

8 Fisheye Lens Usage and Calculations

A lens that covers a hemispherical field (180°) is called a fisheye lens. Such a property made it typically applied for whole sky views at night with a long time exposure to record meteorite trails, also for time-lapse photography in traffic flow surveys. The fisheye lens is considered an ultra-wide-angle lens. It inherits a large distortion that should not be treated as an aberration but as a result of the projection of a hemisphere on a plane [16]. Experimental methods in choosing a suitable fisheye lens for the robot are highly susceptible to errors and painstaking which necessitates our contribution in clarifying its calculations for roboticists.

For simplicity of our calculations, we consider the fisheye lens as a thin lens. A thin lens is one where the thickness of the elements plays no significant role and as such is negligible [10]. Moreover, a lens is considered to be a thin lens when the diameter is about 10 times larger than its thickness.

Focal length and forming an image with one lens can be calculated by the following equation:

$$\frac{n'}{z'} = \frac{n}{z} + \frac{1}{f}, \tag{2}$$

where n is the refractive index of the medium between the projector (object) and the lens, and n' is the refractive index of the medium between the lens and the face mask (image plane). The term f denotes the focal length of the lens, and the terms z and z' denote the distance between the projector and the lens, and the lens and the face mask, respectively. Since the medium is air, equation 2 will be

$$\frac{1}{z'} = \frac{1}{z} + \frac{1}{f} \tag{3}$$

as n and n' are equal to 1. Through the sign convention that going to the left from the lens will produce a negative value leads to z having a negative sign.

A complete face (well-formed image) can be projected only when the lens is far by at least one focal length away from the projector. This gives a hint that a fisheye lens with a small focal length is preferred for the correct suitable projection of the robot's face on the face mask. Since the focal length of our fisheye lens is 58 mm, then z should be at least 58 mm. Realistically, z will be more than 58 mm due to the setup restrictions.

Magnification is thought to be a property of the lens itself, which is true to some extent, however, magnification is also a result of how the system is laid out.

If magnification is desired, then z must be smaller than z' (but not smaller than f, otherwise, the face image will not be formed) and vice versa. The parameters z, z', and f must be determined while considering that they depend on each other.

In reality, magnification doesn't contribute much to the system as a magnifier application can be used on the PC while projecting the face, thus canceling the need for lenses with high magnification.

In a nutshell, there will be some tweaking to make the face projection right through the magnifier application. Thus, the magnification power of a lens is not a factor to be concerned about. Furthermore, a fisheye lens with a medium focal length is recommended. We tried a fisheye lens with a focal length of 37 mm and it was too small to contain the whole projection from the projector. Thus, a focal length higher than 50 mm is recommended. Eventually, due to the setup itself, the distance between the projector and the lens will be more than 50 mm, thus securing a full image formation.

9 Experiment Protocol and Results

Four Japanese subjects participated in our experiment by having a conversation with the robot. We integrated Furhat with ChatGPT. We configured Furhat to hold conversations in Japanese as it was originally in English. Subjects had a conversation for 5 minutes each, separately. We held interviews with the subjects to know about their interaction with the robot and asked them the following questions:

- How was your experience and interaction with this robot?
  Answer: I had fun getting answers to my questions.
- What did you like the most about this robot?
  Answer: Getting fast accurate answers to my questions.
- What did you hate the most about this robot?
  Answer: Turn-taking during the conversation as the robot sometimes cuts the conversation while I'm still talking.
- What are the advantages of this robot?
  Answer: Practicing interpersonal communications and getting accurate answers.
- What are your concerns about this robot?
  Answer: If I become silent, it will say, "Sorry, I couldn't hear you", so I feel that I'm being forced to speak, and the conversation will feel oppressive. Moreover, it didn't feel like a conversation because the questions were being asked one-sidedly also not knowing where the story ends.
- Did you feel in any way that this robot is dangerous?
  Answer: Not at all.
- Did you feel safe around this robot?
  Answer: Yes.
- Would you like such a robot installed in different places providing help to people?

Answer: It would be great for people who live alone. It would be nice if it's being sold to the public. However, the accuracy of the answers and the dialogue itself has to be guaranteed.

– Did you interact with a robot before? If yes, what is the main difference between this robot and other robots you interacted with before?

  Answer: I did not interact with a robot before. However, as the robot has a human face, I felt at ease.
– If this robot is sold in the market, would you buy it? would you recommend it to others? Answer: We received several different answers to this question and they are as follows:

  1- I would want to buy it. It would be great for people who live alone. 2- There is a high possibility that people will not buy it because their iPhone Siri and Alexa are sufficient. 3- I wouldn't buy it as I didn't trust it yet. 4- I would recommend it to my grandparents and others.
– Do you have any recommendations or suggestions to further improve this robot? Answer: We received several different answers to this question and they are as follows:

  1- It would be nice to reduce the chance of mishearing. 2- I want the robot to ask me questions to feel that it's a conversation. 3- I hope it can be more accurate in answering questions. 4- I hope it can use different photos of people (avatars) so it would feel as if I'm having a conversation with that person.

Note that, subjects preferred to interact with our robot in a dark environment as the face of the robot will be more clear to them. Moreover, for simplicity and to avoid distracting the subjects while interacting with our robot, we used a headset connected to the PC where Virtual Furhat is operating.

To obtain more meaningful results from our experiment, we asked the subjects to fill out the Godspeed questionnaire [2], the multi-dimensional measure of trust (MDMT) [15], robot's perceived empathy (RoPE) [5], and the robotic social attributes scale (RoSAS) [3].

The Godspeed questionnaire measures five key concepts in HRI: anthropomorphism, animacy, likeability, perceived intelligence, and perceived safety [2]. MDMT measures how much the user trusts the robot [15]. RoPE is a questionnaire about the user's perception of the robot's empathy [5]. RoSAS investigates the user's perception of the robot's social attributes.

As we can't obtain statistically sound results due to the low number of subjects, we highlight our deduction from their answers generally through qualitative analysis.

From the answers received from the Godspeed questionnaire, we realize that our proposed robot performed poorly on the aspect of anthropomorphism as it appeared more artificial and machine-like to the subjects. Our robot performed moderately on the animacy aspect and excelled in being perceived as responsive and interactive. Our robot was perceived very positively as it excelled in the likability aspect. It was perceived as kind, friendly, and nice. The robot was perceived as intelligent as it scored high by the subjects in the questions about "perceived intelligence". The robot was perceived as safe as subjects scored it high in being relaxed and feeling calm.

The subjects rated the robot highly on the MDMT questionnaire, which means that the subjects trust the robot to a high degree. The robot was rated highly on aspects such as being reliable, consistent, competent, respectful, genuine, and ethical.

From the answers received from the RoPE questionnaire, despite the perceived intelligence of the robot in understanding the users, it wasn't perceived as empathetic. Users agreed that the robot understands them, but it's not connecting with them emotionally thus empathy is perceived to be very low. It was perceived that the robot reacts to what it hears but doesn't see the way the subjects feel.

From the RoSAS questionnaire, the robot is perceived as safe. It rated high socially due to being interactive and responsive. However, it rated low emotionally as it wasn't perceived as being compassionate or emotional, which is in line with its low RoPE score. It was perceived as highly reliable, competent, knowledgable, and capable, which verifies the high score in the MDMT questionnaire.

10 Conclusion

We showed the design and methodology for building a retro-projected robot using a laser projector and a fisheye lens. We discussed thoroughly the methodology behind choosing the right specs for the projector and the fisheye lens. After building the robot, we conducted interviews and asked subjects to fill out questionnaires to validate our robot. More work should be done to improve the projection of our robot as it is crucial for smooth HRI interaction. We plan to use OpenGL in our future work to align the eyes, nose, and lips and make it more aesthetic. Lastly, a cheap portable robot was built that can be used for HRI and affective computing experiments.

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