Review of Animatronic Faces Focusing on Human-Robot Interaction

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***Abstract*—With the growing use of service robots in several fields, from customer service to healthcare, there is a rising interest in the development and evolution of anthropomorphic robots. These robots can provide more natural and empathetic interactions, enhancing user experience and expanding the possibilities of collaboration between humans and machines. This paper explores the evolution of robot faces for social robotics, capable of replicating facial expressions, focusing on their design, functionality, and role in Human-Robot Interaction. It investigates the mechanical structures and the level of anthropomorphism in the state of the art for social robots, especially regarding animatronic faces. The analysis extends to static, digital, hybrid and animatronic facial designs, highlighting their strengths and challenges. Emphasis is placed on the role of eyes in non-verbal communication, discussing their influence on human perception and interaction. Finally, the paper underscores the importance of balancing technical innovation with social acceptance in robotic design, providing a relevant study on how the appearance and behavior of robot faces affect user comfort and acceptance.**

***Index Terms*—Human-Robot Interaction; Animatronic Faces; Uncanny Valley**

I. Introduction

As service robots become increasingly present daily, studying Human-Robot Interaction (HRI) applied to diverse audiences becomes relevant [1]. In this context, people expect robots to operate in environments with individuals unfamiliar with technology. For this matter, these robots should display a high level of sympathy to avoid causing discomfort to users. Advancements in robotics have enabled the development of anthropomorphic robotic interfaces capable of replicating facial expressions movements, and even interacting with humans. This paper analyzes different models of robotic faces, exploring their features, limitations, and contributions to the field of HRI [2]. Studies indicate that social interaction takes place mainly through non-verbal communication. Hence, in the context of service robotics, it is aimed at making people feel at ease in the presence of such robots. By assigning the ability of facial expressions and eye gaze, the robot starts being seen as a trustworthy agent. These features enable the robot to indicate its intention [3].

Animatronic faces are mechanical and electronic systems designed to simulate human or fictional creature facial expressions. These devices combine actuators, sensors, and flexible materials to create facial movements, allowing the reproduction of expressions and speech synchronization. The construction of an animatronic face involves the integration of motors, motion controllers, and, in some cases, artificial intelligence to enhance naturalness and responsiveness to interactions.

Although anthropomorphic traces facilitate users to empathize with robots, these can negatively influence the level of realism. Mori coined the term Uncanny Valley [4] to describe the relationship between the degree of human likeness and the level of discomfort people perceive. It suggests that robots too similar to humans, tend to provoke negative responses due to their slightly unnatural features. The importance of visual and emotional cues in robot communication guides this analysis.

Through this review, the paper discusses how the design of anthropomorphic robot faces influences perception and acceptance in HRI. Therefore, this work focuses on the design, mechanical systems, and interactive potential of robotic faces in social environments. Thus, it examines various types of robot faces to understand the contributions, limitations, and potential improvements. In addition, it provides insights into future trends for animatronic faces while addressing challenges like the Uncanny Valley.

This review aims to build a strong foundation for the future development of social robots. Thus, this enables the application of animatronic faces to interact with people to conduct studies, such as assisting and informing people in public spaces (receptionists or health assistants), studying emotional recognition and response, and evaluating intrinsic communication with synthetic agents.

The paper is organized as follows: Section II overviews robot faces, their differences, and main features. Section III delves into the features of animatronic robot faces. Section IV summarizes those results, providing insights underscoring their key components. Finally, Section V concludes the paper and shows future trends.

II. Robot face

The human head comprehends the main features of both verbal and non-verbal communication. Due to this, the face is usually the focal point in social interaction. Furthermore, it provides an asymmetry that indicates the region of interest and the area of attention. Thus, it is common for robots that operate in human environments to present anthropomorphic facial traces [5]. Although this review has focused on animatronic faces, it is valid also to mention some other types of heads built into social robots, as classified in Figure 1. Most of those were referenced in other studies and can be found at the ABOT database. The ones detailed in this paper were selected based

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https://www.abotdatabase.info/collection#

on their mechanical animatronic face criterion, exhibiting eye movement. They were associated with published research detailing their design and functionality, as well as features related to the purpose of this paper. Most models were referenced in other studies, ensuring their significance in the field.

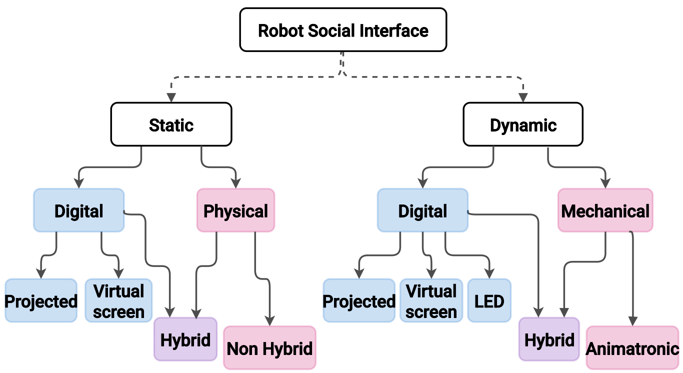


Fig. 1: Classification of robot social interfaces.

A. Static faces

Some robotic faces in the literature present a fixed expression [5]. The authors often use this feature solely to create an impression of agency in these robots. Thus, placing the cameras in these robots in the eye region and speakers in the mouth area is common. Examples of robotic faces with static expressions include: NAO; Pepper; Robovie-V4; and Romeo .

B. Digital faces

The most common methods for expressing emotions without mechanical parts involve face projection or the use of digital screens [5]. In the first approach, an internal projector is positioned within the head structure, with the front covered by a translucent material mask. Examples of robots utilizing this feature include SociBot™; Albert HUBO; and Furhat [6].

The other method of representing virtual faces is through virtual screens. These range from simple models focused on the eyes, such as EyePi, BEO, and PALbator [7]–[9], to more complex ones like Robio; HERA; and CHARMIE [10], [11]. This type offers advantages such as being lightweight and easily modifiable compared to other face models. However, visibility can be reduced depending on the ambient light intensity and the user's viewing angle. In the case of screens, the vast majority are flat, making it difficult to achieve an anthropomorphic face shape [3].

https://corporate-internal-prod.aldebaran.com/en/nao
https://us.softbankrobotics.com/pepper
https://robots.ros.org/robovie-r4
http://doc.aldebaran.com/2-5/home_romeo.html
https://www.hansonrobotics.com/albert-hubo
https://www.humanrobotics.ai

C. Hybrid faces

Certain robotic faces combine mechanical parts with LEDs (Light Emitting Diode) to display facial expressions. These hybrid models can exhibit a range of gestures similar to natural expressions. Examples include MARKO, iCub, and Twente humanoid head [12]–[14]. Other robots combine these features to enhance expressions, resembling cartoon characters, such as Flobi [15], Robothespian, and KOBIAN [16].

D. Mechanical faces

The category of mechanical robotic faces embraces a range of models found in the literature. Highly humanoid models commonly feature mechanisms that enhance realism in robots. Examples include Zeno, Sophia, and Little Sophia by Hanson Robotics©; Geminoid; Erica; and HRP-4C [17]–[19]. A subclassification of mechanical faces is animatronics, characterized by their anthropomorphic or zoomorphic aspects with a certain degree of unrealism. Therefore, this work considered some models of this type for comparison.

III. Animatronics Robot Faces

As animatronic faces are a large subcategory of mechanical robots, these faces can vary in style, mechanism, and Degrees of Freedom (DoF). Thus, it has presented some relevant models of animatronic faces (Table I) consisting of robotic faces that present gestures resembling humans and animals, with certain unrealism, which prevents them from falling into the Uncanny Valley [4].

A. Kismet

Kismet [20] is a widely referenced robotic face designed for natural human interaction. Inspired by infant social development, it learns through play and conversation. Rather than mimicking a human face, it resembles a youthful, fictional creature. Its 3 DoF neck aids camera positioning and simulates social responses. Elf-like ears, curved eyebrows, and flexible lips enhance expressiveness, while independent upper eyelids allow varied blinking. The eyes move independently in yaw and together in pitch. Its durable aluminum structure adds weight (7 kg), making it suitable for stationary robots but less ideal for mobile applications.

B. KOBIAN

KOBIAN is a service robot designed for HRI research and daily tasks [16]. Its animatronic face expresses Ekman's six basic emotions and a neutral state. With exaggerated, manga-style gestures, it features highly dynamic eyebrows (4 DoF each) and a color-changing forehead. Flexible lips and a movable jaw enhance natural expression, while its eyelids enable blinking and emotional emphasis. The pulley-based mechanisms add complexity and risk of failure. Its eyes move together in pitch and independently in yaw, improving gaze

https://engineeredarts.com/robot/robothespian
http://www.ai.mit.edu/projects/sociable/baby-bits.html
http://www.takanishi.mech.waseda.ac.jp/top/research/kobian/KOBIAN/index.htm

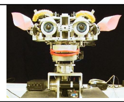
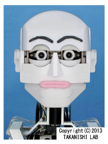
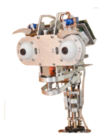
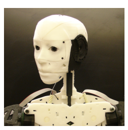
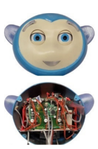
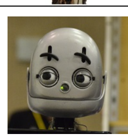
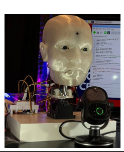
Faces	Robots' Name	Reference	Moving parts	DoF	Commercial	Open Source	Structure	Year
	Kismet	[20]	eyes eyebrows mouth ears	3 4 5 4	×	×	exposed	1998
	KOBIAN	[16]	eyes eyelids eyebrows mouth	3 5 8 8	×	×	covered	2007
	Muecas	[21]	eyes eyebrows mouth	3 4 1	×	×	exposed	2014
	InMoov	[22]	eyes mouth	2 1	✓	✓	covered	2014
	Eva 2.0	[23]	eyes eyelids facial muscles	6 2 10	✓	✓	partially covered	2020
	MARKO	[12]	eyes eyelids eyebrows mouth	3 2 0 0	×	×	covered	2022
	Open	[24]	eyes eyelids mouth	3 1 9	×	×	exposed	2022
	Jubileo	[25]	eyes eyelids eyebrows mouth	3 4 4 1	×	✓	covered	2022
	Adam	[26]	eyes mouth	4 1	×	×	covered	2023

TABLE I: Animatronic robotic faces comparison.

direction, but the gimbal-like structure limits internal space and expression range.

C. Muecas

Muecas [21] is a caricatured robotic face designed for natural expressions, integrating vision, audio, and inertia sensors. Its 4-DoF neck allows pitch, yaw, roll, and vertical movement, enhancing mobility but increasing control complexity. The mouth has a single DoF for opening and closing, while the eyebrows move in roll and indirectly in pitch, though their motor-driven structure may wear over time. The eyes move independently in yaw and synchronously in pitch via a linear screw system. Its metal-heavy structure complicates modifications, and the exposed mechanisms and the absence of eyelids may impact durability and user comfort.

D. InMoov

The InMoov robot head, developed by Langevin (2015) [22], is an open-source model designed to be accessible and replicable. While it features an anthropomorphic nose, it lacks eyelids and eyebrows, limiting its capacity for facial expression. The second version introduced these elements, increasing expressiveness. Its appearance avoids the Uncanny Valley due to its high level of unrealism, which helps reduce discomfort by lowering expectations of full realism. For example, the absence of materials that mimic human skin emphasizes its robotic nature, making it more acceptable in human interactions.

E. Eva 2.0

Eva 2.0 is an evolution of Eva 1.0 [27], focused on accessibility and open-source compatibility [23]. Its lightweight structure, produced via 3D printing, and a neck system with 6 degrees of freedom DoF enable fluid and realistic movements. Its silicone mask features 10 control points for facial expressions, but the limited range of lip movements and lack of an articulable jaw impact its naturalness. Additionally, despite their independent movement, the eyes also have a reduced angular range.

F. MARKO

Developed to assist in treating children with cerebral palsy, MARKO [12] combines LEDs and mechanical mechanisms for facial expressions. At the same time, 4-bar mechanisms guide its eyebrows, eyelids, and eyes. The questions about the project's efficiency are due to the complexity and space occupied by its structures. LEDs intensify emotional expressions but limit speech-related expressions due to the fixed mouth.

G. Open

The Open robot [24] was designed to replicate facial expressions based on the Facial Action Coding System. Using 4- and 5-bar mechanisms, its construction enables the reproduction of 94% of human movements. However, the exposure of its mechanisms and the lack of distinction between materials and colors can cause discomfort in human interactions.

https://inmoov.fr/

H. Jubileo

Jubileo [25] is the robotic head of the DoRIS robot, focused on HRI research. Its independent eyebrows and eyelids use components like paper clips, resulting in instability and wear. The eyes also face mechanical challenges, being highly prone to detachment and deformation due to using unconventional materials.

I. Adam

The authors designed Adam's robotic [26] head for HRI applications. Its neck and eye systems use ball joints, allowing wide and precise movements. However, the absence of eyelids and the central hole in the forehead for a camera may generate feelings of strangeness. Additionally, the complexity of the ocular mechanism makes the design susceptible to failure.

IV. Analysis of Animatronic Faces

Table I summarizes the main features of the analyzed animatronic face models, highlighting advancements and limitations over 15 years of evolution. The fourth column of the Table presents the moving parts of each model, and the fifth relates the DoFs to those elements. As can be seen, the element present in all the faces is the eyes, most of which move independently in yaw and together in pitch. Those with complete individual mobility between each eye can make more natural gestures. The other features have more varied DoF, e.g., the mouth is sometimes accompanied by flexible lips that allow not only the representation of speech (Muecas, InMoov, Jubileo, and Adam) but also intensify the expressions displayed (Kismet, KOBIAN, and Open). The "Commercial" and "Open Source" columns indicate if the models are available for sale and if the project is freely accessible. As the analyzed ones focus on research, most are unavailable in the market. However, it is notable that both commercial robots listed, InMoov and Eva 2.0, are also open source. Most robots found in the literature are closed projects, which limits the applications of these models. The second to last column states whether the mechanisms can be seen by the public or if they are covered. Although it is almost an even relation, exposed structures are more susceptible to damage and tend to be less friendly. On the other hand, covered faces are usually present as kinder, except if the material used has a high resemblance to human skin. Thus, there is a perception of amicability on robots such as KOBIAN, MARKO, and Jubileo rather than, e.g., Muecas and Open, which are exposed, or even Eva 2.0 due to their silicone skin. The last column describes the year when each model was built, giving an idea of the technology available during the development of these robots. Thus, the robot faces described in this review were chosen due to their relevance in the field of HRI device development.

To decide on an animatronic face's design, it is logical to consider mechanical features and degrees of freedom and ponder design philosophies such as the trade-offs between mechanical complexity and user-friendliness and how these trade-offs affect the perceived realism and reliability. The impact of aesthetic elements—such as material choice and the visibility of internal mechanisms—play an important role in mitigating or exacerbating the Uncanny Valley effect. Additionally, integrating cognitive and control systems that support dynamic responses is key to linking the physical expressiveness of the robot face with its capacity for adaptive behavior in human-robot interactions. Consequently, it is possible to compare these multidimensional aspects to perceive the strengths and limitations of each model.

V. Conclusion

The analyzed animatronic robotic faces demonstrate advancements in facial expressions, gestures, and their impact on HRI. Among the elements found in robotic faces, it stands out that moving eyes represent a major feature in non-verbal communication. As it is the main element for displaying facial expressions, it is worth analyzing its mechanisms and range of motion. One can also observe that, indeed, those with big eyes and large pupils have a friendlier appearance, e.g., Kismet, KOBIAN, and Jubileo, than the ones with less visible eyes and small pupils, e.g., Muecas, InMoov, and Open.

Most animatronic faces presented here display anthropomorphic traces at an unrealistic level. This way, they can reproduce facial expressions similar to humans and avoid the uncanny valley. Thus, the presence of animatronic faces in social robots positively impacts HRI. The development of machines such as these can contribute to social robotic advancements. Furthermore, regardless of the mechanical advancements, advancements in cognitive systems are also needed to develop a robot capable of interpreting human emotions and responding in a contextualized manner. This phenomenon can be seen in the recent development of humanoid robots, where having a simple yet expressive face is still a challenge.

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