# Functional and Non-Functional Expressive Dimensions: Classification of the Expressiveness of Humanoid Robots

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**Abstract.** In Human-Robot Interaction (HRI), an important quantity of work has been done to investigate the reaction of people toward expressive robots. However, the large variability of available expression modalities (e.g., gaze, gestures, speech modulation) can make comparison between results difficult. We believe that developing a common taxonomy to describe these modalities would contribute to the standardization of HRI experiments. This paper proposes the first version of a classification system based on an analysis of humanoid robots commonly seen and used in HRI studies. Features from the face of robots are discussed in terms of functional and non-functional dimensions, and a short-hand notation is developed to describe these features.

## 1 Introduction

Population aging around the world motivated the growth of number of projects on assistive robots and other intelligent devices, from assistant-like software for smartphones to mobile robots in elder care facilities. One of the objectives pursued by the Human-Robot Interaction (HRI) community is the development of natural, human-like behaviors for intelligent autonomous systems. These systems are often embodied by robots or virtual agents on a screen, both sometimes designed to have a human-like appearance. Many studies have been conducted on the impact of expression modalities in various interaction settings. For instance, the perception of robot smiles has been studied, and results can influence HRI design [1]. Studies have also been made on how to approach humans with mobile robots to initiate interaction [2] and maximize politeness [3]. Furthermore, having a directed or averted gaze also has an influence on the minimal comfortable interaction distance, increasing or decreasing depending on the gender of the person [4]. Similarly, a robot with a motion-oriented gaze behavior can be perceived as more engaging and human-like [5], and it has been shown that a robot matching the personality of its users by adopting its gaze behavior can have a positive impact in a puzzle-solving task [6]. The appearance of the robot has also an impact on its perceived effectiveness, as it has been observed that people systematically preferred robots for jobs when the human-likeness of the robot matched sociability requirements [7]. Studies have also been made on the perceived safety of the motion of industrial robots in both real and virtual settings [8]. This illustrates how different robots, even with the same objectives, can have a different impact depending not only on their overall behavior, but also on their physical appearance and motion capabilities.

To achieve standardization in HRI experiments, using identical robots would avoid introducing unwanted factors. Obviously, this is not possible in a practical sense. Except for a few popular robots like NAO from Softbank Robotics (former Aldebaran Robotics) [9] or PR2 from Willow Garage [10], there are not many other interactive robots that achieved the kind of commercial success necessary to make this feasible. Furthermore, research groups that are more interested in the design aspect of interactive robots understandably prefer to conduct experiments with their own unique systems. However, we posit that there is an alternative to having researchers use identical robots. In order to facilitate comparison between different robots used in similar HRI experiments, we propose the development of a classification system for the expressiveness of humanoid robots. This paper illustrates the development of such a classification system for describing robot expressiveness, based on a selection of robots that can often be seen in HRI research. von Zitzewitz et al. [11] propose that human-likeness of humanoid robots can be quantified by a network of parameter fields as perceived by humans. Two of these fields are visual appearance and behavior, which describes parameters such as motion and nonverbal communication.

The goal of this paper is not to propose a psychological analysis of how humans perceive expressions reproduced by robots, but rather to provide a common language to describe technical features used by robots in HRI studies. Hence, the notation proposed in this paper aims at describing expressive capabilities, not emotional ones, as we believe that the perception of emotions is out of the scope of this work. In this paper, expressive capabilities refer to robot motion (or simulation with a display) that act as a non-verbal communication channel.

This paper is structured as follows: Section 2 describes a selection of robots that can be seen in HRI research, focusing on their capabilities for facial expressions. Section 3 proposes a classification system and a shorthand notation for describing these capabilities based on features that are either functional (that have uses beyond expression) or non-functional (that are exclusively used for expression). Finally, Section 4 concludes the paper with suggestions on how this classification could be extended to other features of interactive robots.

## 2 Expressive robot features found in HRI studies

To develop a classification system of expressive features, a selection of robots found in HRI and social robotics studies was made. The robot selection used in this paper is not meant to be exhaustive. Instead, robots were selected to show sufficiently different ways of reproducing human features and behaviors, and thus help in the development of a classification system. To extend the selection

(a) (b) (c) (d) (e) (f) (g) (h) (i)

Fig. 1: (a) ASIMO, (b) Baxter, (c) FLASH, (d) IRL-1, (e) M-1, (f) NAO, (g) Nexi MDS, (h) Rollin' Justin, (i) Wakamaru.

of humanoid robots beyond legged ones, "humanoid robot" in this paper refers to robots that have a human-shaped head with eyes. Furthermore, we decided to not include androids in this selection. The notation developed in this paper is meant for robots that are closer to the machine-like end of the uncanny valley [12], and cover capabilities that are not necessarily human-like, for instance the use of LCD displays for some features. The following subsection describes briefly each robot, and is partially based on the following studies involving expressive robots and human interpretation: FLASH [13,14], IRL-1 [15], NAO [16–18], Nexi MDS [19,20], and Wakamaru [21,22]. A general survey on automatic recognition and generation of body movements for affective expression can be found in [23]. The pictures used in this section were obtained either from the robot manufacturers' website, cited work, or taken by the authors of this paper.

### 2.1 Robots

**ASIMO** is a well-known legged robot manufactured by Honda [24]. It is of average height (1.30 m), with an oriented but expressionless face, although its two cameras can appear as eyes under the right lighting.

**Baxter** is a relatively tall (1.78 m to 1.91 m with adjustable pedestal) commercial robot from Rethink Robotics [25]. Its two arms with 7 degrees of freedom (DoF) are compliant and can be interacted directly with for example for teaching tasks. Its display shows virtual eyes and can be oriented on its pan angle. While it does not by default, its display could also be used for a mouth.

**FLASH** is a 1.30 m of height robot built by the Wroclaw University of Technology for the EU FP7 LIREC Project. It includes the EMYS head [13], which can be seen in standalone form in facial expression-related works such as [14]. While FLASH does not explicitly have eyebrows or a mouth, the upper and lower discs can act as them. Furthermore, its eyelids can go up and down as well as rotate around the optical axis.

**IRL-1** is a 1.40 m of height custom robot from Université de Sherbrooke [26]. Its articulated expressive head comes from a previous robot named Reddy, which is also known as Melvin [27] and CRAMER [28].

**Meka M-1** is a 1.80 m of height humanoid robot built by Meka Robotics (now part of Google X). Multiple versions of this robot exist around the world with different head shapes. The version selected includes eyes with cameras and functioning eyelids.

Another robot, REEM [29] from Pal Robotics, is a robot of similar height (1.70 m), but is available with either a differential mobile base or legged locomotion. Regarding facial expression, the EU RobotCub project robot iCub [30], while smaller (1.04 m) and legged, has very similar facial expression features, and uses LED matrices for the mouth and eyebrows.

**NAO** from Softbank Robotics (former Aldebaran Robotics) [9] is a small (58 cm) humanoid, legged robot. Its face, while mechanically fixed, can be oriented, and its multi-segmented eyes can change colors and shape as a mean of expression.

**Nexi MDS** from the MIT Media Lab was built in collaboration with UMASS Amherst's Laboratory for Perceptual Robotics, Xitome Design, and Meka. It is meant to be approximately the height of an adolescent child. It is also known as Octavia at the Navy Center for Applied Research in Artificial Intelligence, and has been used in social engagement studies [31].

**Rollin' Justin** is a robot from the Deutsches Zentrum für Luft- und Raumfahrt (DLR, German Aerospace Center). It has a shoulder height of 1.60 m. Its arms are based on the third generation of the DLR Light Weight Arm (LWR III), and is notably used in research on compliant whole-body manipulation [32].

From an expressiveness point of view, PR2 from Willow Garage [10] can be compared to Rollin' Justin, as it also has fixed cameras that can be perceived as eyes, an oriented head and an omnidirectional mobile base.

**Wakamaru** is a robot that was developed by Mitsubishi Heavy Industries and was meant for natural communication with humans [33]. It is 100 cm tall, includes two articulated arms, and an oriented head with fixed eyes.

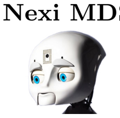
### 2.2 Common features

Table 1 lists expressive features such as having eyebrows or a mouth that are common to at least two robots from the selection, and the following describes the differences between these robots for those features.

*Eye gaze* For eye gaze, we observe a wide variety of solutions, from completely virtual in the case of Baxter, to unique features such as an extra DoF for eye popping with FLASH. Some of them have fixed orientation (e.g., ASIMO, NAO, Rollin' Justin, Wakamuru), and rely entirely on the head to direct the gaze. An advantage of having eyes that can be rotated separately from the head is a faster reaction time to new gaze targets. Except for three robots (i.e., ASIMO, Rollin' Justin, and Wakamaru), all have a pupil distinguished from the rest of the eye. Also, three robots use cameras for eyes (i.e., Meka M-1, Nexi MDS, and Rollin' Justin), which indicates that the robot can actually see with them. This is not the case for all robots. For instance, hiding the eyes of the NAO does not block its cameras located on the top of its head and its mouth.

Table 1: Description of the features found on the selected robots. The letters P, T, and R refer to Pan, Tilt, and Roll, respectively. (1) These robots feature an additional tilt angle on the neck.

| **Robot** | **ASIMO** | **Baxter** | **FLASH** | **IRL-1** | **Meka M-1** |
|---|---|---|---|---|---|
| |  |  |  |  |  |
| Eye gaze | Fixed | Virtual | Fixed | P, T | P, T |
| Head orientation | P, T | P, T | P, T (1) | P, T | P, T (1), R |
| Eyebrows | None | Virtual | None | R | None |
| Eyelids | None | Virtual | None | None | Yes |
| Mouth and jaw | None | None | None | Mouth | Mouth (LEDs) |

| **Robot** | **NAO** | **Nexi MDS** | **Rollin' Justin** | **Wakamaru** |
|---|---|---|---|---|
| |  |  |  |  |
| Eye gaze | Fixed | P, T | Fixed | Fixed |
| Head orientation | P, T | P, T (1), R | P, T | P, T, R |
| Eyebrows | None | R, lift | None | None |
| Eyelids | None | Yes | None | None |
| Mouth and jaw | None | Both | Mouth | None |

*Head orientation* All robots in this selection can rotate their head, although Baxter does not have closed-loop control of its tilt angle because of the lack of a position sensor. Three robots (i.e., Meka M-1, Nexi MDS, Wakamaru) have an extra DoF for roll angle, and two robots (i.e., Meka M-1 and Nexi MDS) control the tilt with two actuators (neck and head).

*Eyebrows* Two robots in this selection have physical eyebrows (i.e., IRL-1 and Nexi MDS). However, FLASH can use the tilt angle of its upper disc to represent the brow on a wide range of motion. Furthermore, the eyebrows on Nexi MDS have an extra DoF, vertical lift, which means they can rise or lower from both corners. Finally, Baxter has eyebrows on its display.

*Eyelids* Three robots have mechanical eyelids (i.e., FLASH, Meka M-1, and Nexi MDS), while one can display them on a screen (Baxter). While FLASH only has top eyelids, they can be rotated in addition to being closed. The rotation of the eyelids can play the role of frowning eyebrows.

*Mouth and jaw* Only one robot has a mechanically actuated mouth (IRL-1), represented by two flexible tubes moved by the rotation of four mouth corners. However, FLASH has a lower disc that can act as a jaw, and Nexi MDS has a fixed lower lip mounted on an articulated jaw. As with other features, Baxter could be programmed to display a mouth.

## 3 Classification of expressiveness

From the set of technical features described in Section 2, a generalization and the construct of a classification system can be attempted. In this paper, two dimensions of this classification will be looked at: functional and non-functional. Functional expressive features are robot features that have an utility beyond producing expressions and This is obviously the case for robot capabilities such as locomotion or speech, but the gaze can also be used in a neutral fashion to change the orientation of sensors, and indicate where the robot is looking. However, eyebrows usually do not have any other function than expression. Furthermore, while it can be argued that expression always have a function as a communication channel, functional features in this paper refer to features that also go beyond communication. We believe that separating features in such a way is important from the point of view of robot designers as functional features carry additional constraints. For instance, the size of the eyes with embedded cameras also has to provide proper sensor apertures. Table 2 summarizes the classification system for functional features.

### 3.1 Gaze

Gaze, achieved by rotating the head and/or the eyes, serves both functional and expressive requirements. On robots such as Rollin' Justin, it is necessary to direct its cameras. For gaze, we propose to classify it on a spectrum: G0 for robots without gaze, G1 for a gaze from a fixed head, and G2 for a gaze from an oriented head. Furthermore, to distinguish robots that have mobile eyes, meaning they can orient their gaze independently from their head, the "+" suffix is added. This implies the possibility of performing expressive motions such as nods with the head without changing the target of the gaze. Finally, for robots that use a display for the gaze, the "V" suffix is added. Categories G0 and G1 are not represented by the robots in Section 2. However, robots such as Kompaï [34] from Robosoft, which features painted eyes on a fixed head, can be considered as G1. Similarly, Care-O-bot 4 [35] from Fraunhofer IPA in its fixed head configuration would be G1V, and G1+V if its display is programmed with oriented eyes.

### 3.2 Mouth

The mouth can also be seen as a functional element. If the motion of the mouth is synchronized with speech generation, it can be used as a visual cue (e.g., to identify which robot is speaking in a close group). For the mouth, we propose a classification similar to the one used for the gaze: M0 for robots without a mouth (e.g., ASIMO, Baxter, Rollin' Justin, Wakamaru), M1 for a fixed mouth (e.g., NAO, alternative Rollin' Justin), and M2 for mouths with one or more DoF (e.g., FLASH, IRL-1, Nexi MDS). For robots using a display or a LED matrix for their mouth, the V suffix (Meka M-1) is also added.

Table 2: Classification of the features.

| **Robot** | **G0** | **G1** | **G1+** | **G2** | **G2+** | **M0** | **M1** | **M2** |
|---|---|---|---|---|---|---|---|---|
| ASIMO | | | | * | | * | | |
| Baxter | | | | | V | * | | |
| FLASH | | | | * | | | | * |
| IRL-1 | | | | | * | | | * |
| Meka M-1 | | | | | * | | | V |
| NAO | | | | * | | | * | |
| Nexi MDS | | | | | * | | | * |
| Rollin' Justin | | | | * | | * | * | |
| Wakamaru | | | | * | | * | | |

### 3.3 Non-functional expressive features

Purely expressive features can be harder to classify from a number of DoFs standpoint. For instance, eyebrow-frowning on FLASH is performed by its eyelids, which prevents a one-to-one relationship between DoFs and capabilities. Since facial expressions are largely inspired from human ones, we propose to use Action Units (AUs) of the Facial Action Coding System (FACS) [36], which are used notably for emotion recognition. FLASH has already been classified in this manner [13], and Shayganfar et al. used AUs to express emotions with Melvin, which shares its head with IRL-1 [15]. Thus, the face expressiveness of a robot could be described with respect to the set of AUs that it can reproduce. However, AU-related capabilities are not always orthogonal. For instance, while AU1 (Inner Brow Raiser) and AU2 (Outer Brow Raiser) can be performed by IRL-1, they cannot be combined, which is a feature available on Nexi MDS and achieved by the eyelids and the upper disc of FLASH. Furthermore, for G2 gaze robots, their oriented head allows at least AU51 to AU54 (head pan and tilt), and some robots (Meka M-1, Nexi MDS, Wakamaru) can achieve AU55 and AU56 (head roll). For robots with at least a M2 mouth, facial AUs are listed in Table 3.

## 4 Conclusion

This paper presents the first steps in a proposal for classifying the expressiveness of robots found in the HRI community. From functional expressive features, a short-hand notation has been developed, which can be augmented with the help of facial AUs for non-functional ones. We believe that having a common set of terms for describing the expressive features of robots will help the description of standardized HRI experiments. The underlying goal of this work is to arrive at a full classification of whole-body expressiveness. For instance, robots such as Rollin' Justin, different versions of Meka M-1, and most legged humanoid robots can control the tilt angle of their torso. Beyond balance and manipulation reasons, the angle and pose of the shoulders in a static posture have also a role

Table 3: AUs achievable by robots with an articulated face. A "*" indicates an AU that can be achieved independently, and a "*X" an AU that is mutually exclusive with AU "X". Data for FLASH and IRL-1 comes from [13] and [15].

| Action Unit | FLASH | IRL-1 | Meka M-1 | Nexi MDS |
|---|---|---|---|---|
| AU1: Inner Brow Raiser | * | *2 | | * |
| AU2: Outer Brow Raiser | * | *1 | | * |
| AU4: Brow Lowerer | * | | | * |
| AU5: Upper Lid Raiser | * | | * | * |
| AU10: Upper Lip Raiser | | * | * | |
| AU12: Lip Corner Puller | | * | * | |
| AU17: Chin Raiser | * | | | |
| AU20: Lip Stretcher | | *25 | * | |
| AU25: Lips Part | | *20 | * | |
| AU26: Jaw Drop | * | * | | * |

in emotion recognition [37]. Arm gestures, another functional expressive feature that is DoF-related, and the spoken expression of emotions, whether by content (e.g., stating "I am happy") or by the modulation of speech, are two other important components of expressiveness. Furthermore, non-human features such as the color-changing LEDs in the eyes of NAO, offer a large range of expression that cannot be easily associated to human ones, and it is thus important to include them in a future extension of this notation.

By generalizing functional and non-functional expressive features of each subsystem of an autonomous robot and evaluating them on a scale of their human-likeness, producing a complete taxonomy for the expressiveness of interactive robots for comparative studies will be possible. Furthermore,

## Acknowledgements

This work has been partially funded by EU Horizon2020 ENRICHME project grant agreement no. 643691C.

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