Controlling a Social Robot - Performing Nonverbal Communication through Facial Expressions

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Abstract. This paper focuses on our primary goal to achieve the emotional behaviour of the new version of the social robot Probo. The ability to enhance nonverbal communication with children is possible through facial expressions, eye-tracking and face-to-face contact. The new social robot has 21 degrees of freedom (DOF), grouped in five subsystems, named generically: eyes, ears, trunk, mouth and neck. The robotic head is actuated using only servo motors and all the components are manufactured using cheap, flexible and easy technologies. In order to get the social robot head able to express emotions, a Graphical User Interface (GUI) was developed. In this way facial expressions are created through sliders or push buttons. Additionally, we investigated the possibility of controlling the robot with an Arduino board. In this case, using pre-programmed or learned algorithms, the robot is getting a semiautonomous level, based on the usage of various sensors, being able to express six basic emotions: happiness, sadness, fear, anger, surprise and disgust. So, based on the feedback provided by the sensors, the robot can react accordingly, enhancing human–robot interaction (HRI).

Introduction

Ge et al. [1] state that facial expression plays an important role in our daily activities. The human face is a rich and powerful source which is full of communicative information about human behaviour and emotion. The most expressive way that humans display emotions is through facial expressions. Facial expression includes a lot of information about human emotion. It can provide sensitive and meaningful cues about emotional response and plays a major role in human interaction and nonverbal communication.

As interaction between humans is highly influenced by non-verbal communication, such as facial expressions, gestures and pose, in a similar manner human robot interaction can be achieved. In the last decade, a significant number of emotion display robots, with numerous applications (HRI studies, robotic assisted therapy (RAT) with children or elderly people), were developed. The most remarkable social robots, with an imaginary pet-type appearance, are undoubtedly the MIT platforms Kismet [2] and Leonardo [3]. Other important robotic head examples able to express emotions can be EDDIE [4], iCat [5] and Doldori [6].

In this paper, the control of the new version of the social robot Probo [7] is presented. Based on a GUI, the emotional behaviour of the robot can be achieved. Six basic facial expressions (joy, sadness, anger, fear, disgust, surprise) and two additional states (neutral and sleepy) are created. These can be achieved by controlling each servo movement separately or by pressing a button which corresponds to a specific emotional state.

The paper starts with a description of the emotional parameterization models used in social robotics. Next section presents the new concept of the social robot Probo [7], in terms of CAD
development, mechanics, actuation and sensorial system. Then, the software control and the Graphical User Interface (GUI) concerning the emotional behaviour of the robot are described. Some conclusions and future perspectives are given at the end.

Emotional models

For both theoretical and practical reasons, some researchers define emotions according to one or more dimensions. A popular version of this is Russell's [8] dimensional, or circumplex model, which uses the models of arousal and valence. [9] developed the Facial Action Coding System (FACS) to taxonomize every human facial expression in a discrete way. Ekman devised a list of basic emotions containing anger, disgust, fear, joy, sadness, surprise (universal facial expressions). [10] offers a three dimensional model, that is a hybrid of both basic-complex categories and dimensional theories. It arranges emotions in concentric circles, where inner circles are more basic and outer circles more complex. Notably outer circles are also formed by blending the inner circles emotions.

For the robot to express a full range of emotions and to establish a meaningful communication with a human being, nonverbal communications such as body language and facial expressions is vital. The ability to mimic human body and facial expressions lays the foundation for establishing a meaningful nonverbal communication between humans and robots [11]. Moreover, according to [12], in any face to face communication, there are three basic elements: words, tone of voice and body language. He stated that body language and nonverbal communication represents 55% of the communication of feelings and attitudes. So, it can be concluded that through facial expressions, robots can display their own emotion just like human beings.

Robot concept

CAD Development. All mechanical parts are modelled in AUTODESK Inventor. In this way it could be verified that all parts fit and are manufactured exactly, and the final appearance and function, the quality of displayable emotions and the overall picture, can easily be evaluated. CAD modelled parts are manufactured by rapid-prototyping, only the neck parts are crafted in aluminium. The rapid-prototyping parts consist of the acrylic glass frame which supports all the head components, also manufactured by using 3D printing or laser-cutting technology. Also, due to the fact that the robot is equipped with a silicone mouth, flexible foam trunk and elastic elements used in the ears and neck system, a high degree of compliance and flexibility is provided.

![Robot Probo: a) new CAD design; b) new real prototype](image-url)
Mechanics. The new concept (Figure 1) has 21 DOF (Table 1), providing independent motions of all the actuated parts. It is a modular version, since it contains five subsystems, namely: eye, ear, trunk, mouth and neck system.

The eye system (noted with 4 in Figure 2) has 10 DOF and includes the eyeballs, the eyelids and the eyebrows. The eyes can pan (±45°) and tilt (±60°) independently, the eyelids can open and close (70°) and the motion of eyebrows (20°) intensify the facial expressions. The ears, 5 in Figure 2, are represented by two helical springs, placed at an angle of 45° from the top of the head, having a range of motion of ±60° and ensuring compliance during interaction. The helical springs will be covered with a flexible foam core, which will have the shape of an animal ear. In comparison with Kismet's ears which have 2 DOF each [2], so they can be lowered and elevated while they can point the ear's opening separately, in our case, to reduce complexity, the two rotations are combined in a single one.

![Fig. 2. Exploded view of the robot](image)

In contrast to other robotic heads, an intriguing anatomical part was added to the robot, namely the trunk (noted with 3 in Figure 2), to enhance certain facial expressions and to increase interactivity. This part has three combined degrees of freedom. The main components of this system are represented by the trunk itself, made from an expandable foam core, three flexible cables, separated 120° apart, and the drive mechanism. The cables are wounded around three discs attached directly to the servo output shaft providing a spatial movement of the trunk. Depending on the number of actuated cables, on their position in relation to a system of axes attached to this subsystem, and on the stroke of each wire, we obtain a spatial deformation of the trunk.

The silicone mouth has three actuated parts (lower lip and mouth corners) and a fixed part (upper lip), constrained by the acrylic glass structure (2 in Figure 2). The range of motion of the lower lip is limited by the mechanical construction to a value of 25°, and the mouth corners can realize a rotation of ±45°.

The mechanical solution (noted with 1 in Figure 2) of the neck is a serial mechanism, equivalent to a spherical wrist, with three degrees of mobility, providing three motions: head pan, head tilt and head swing. The ranges of motion include rotation around vertical axis (±60°), inclination forward/backward around horizontal axis (±30°) and inclination left/right in frontal plane (±30°). To compensate the gravity, and consequently to reduce the required motor torque for tilting or swinging the head, the neck was equipped with helical tension springs, similar to the robotic head ROMAN [13]. Based on this principle it was concluded that if the set of spring pairs are well dimensioned,
the required torque around the motor shaft is reduced to approximately the torque introduced by the inertia of the head.

Table 1. Degrees of freedom

<table>
<thead>
<tr>
<th>Parts</th>
<th>eyeballs</th>
<th>eyelids</th>
<th>eyebrows</th>
<th>ears</th>
<th>trunk</th>
<th>mouth</th>
<th>neck</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOF</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>21</td>
</tr>
</tbody>
</table>

**Motors.** For robot actuation digital servo motors (Hitec) were chosen. Therefore, to actuate the eyes and ears 12 micro servo motors HS 5055MG (1.6 kg-cm) were used, for the mouth and trunk 6 standard servo motors HS 5485HB (6.4 kg-cm), and the neck motions were assured with 3 high-torque servo motors HS 7980TH (34 kg-cm) and 2xHS 7954SH (24 kg-cm). These servo motors are compact, low cost and easy to obtain. With their internal logic and the PWM-signal, they can easily be controlled.

**Sensors.** The robot is equipped with tactile sensors, placed on the trunk, ears and eyebrows. Additionally, by using the camera placed between the eyebrows, a microphone and a speaker, the perception system (visual, auditory and tactile system) is acquired. In this regard, our next steps in the development are focused on the implementation of different sounds to intensify the emotional behaviour and also we would like to teach the robot simple spoken commands.

**Facial expressions**

**Control software.** The control software was created first with Arduino programming language and secondly, Arduino & Matlab, providing a GUI presented in Figure 3. Matlab Support Package for Arduino enables the communication between Matlab and Arduino over a USB cable. This package is based on a server program running on the board, which listens to commands arriving via serial port, executes the commands, and, if needed, returns a result. This approach helps to start programming right away without any additional toolboxes, in an easy manner [14]. The Arduino microcontroller generates PWM signals from the motor commands transmitted via USB driving the servo motors.

![Fig. 3. Graphical User Interface](image)

The emotion display can be controlled in two ways: by a set of push buttons for the discrete basic emotions (*Facial Expressions* panel), or by a control panel which sets each servo motor separately (*Servomotors* panel).

1. Control of separate servo movements - the *Servomotors* panel has 21 sliders, setting each servo in its own operational range. The minimum and maximum values of the servo position are defined and limited for each motor in order to prevent servo damage during operation. When the GUI
becomes active, all the servo motors are placed in a defined neutral position and the robot is set in the neutral state.

2. Control of the discrete basic emotions - six push buttons trigger default position settings for the six basic emotions, defined by [9], namely: joy, sadness, anger, disgust, surprise and fear. Additionally, there are two push buttons which enables the neutral and sleepy state. When a button is pressed, the robot shows that particular state, and the GUI displays an image with the corresponding expression created by the robot’s virtual model, developed by [15] (in e.g., in Figure 3 is displayed the facial expression which corresponds to the joy state). There is no soft transition between these states and the robot changes emotions suddenly. The facial expressions shown by the robot are highlighted in Figure 4.

In a next phase, it will be investigated the possibility to express emotions through a circumplex model of affect [8], with two dimensions - valence and arousal, which has been implemented in the robot Eddie [4] and in the former version of the robot Probo. Within this circular model, a pointer can be dragged continuously generating corresponding expressions and continuous transitions between them.

The Reactive Behaviour panel is referring to the robot reactions based on the feedback received from the sensorial system. At this point, the robot will reach semiautonomous level since it will respond to different external stimuli. In this way, the robot will reach the joy state when the tactile sensor from the eyebrow will be touched or the robot will be angry when its trunk will be tightened. Also, with the video camera it can be triggered eye-gaze based interaction and face to face contact between the robot and the child. Still, at this time this panel is in a preliminary phase and it will be discussed in a future paper.

**Summary**

In this paper, the emotional behaviour of a new version of the social robot Probo is presented. Based on a GUI, facial expressions could be obtained in two ways: control of separate servo movements or control of the discrete basic emotion. Current research is focused on implementing a two dimension model of affect, so the transition between different facial expressions will be
continuous. In the next steps a recognition user study of facial expressions will be conducted. Also, the reactive behaviour based on the feedback provided by the sensorial system will be investigated.

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