Generation of Expressive Trajectories for MOnarCH robot

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Abstract—Humans show their emotions through body movement and facial expressions. This thesis addresses the expressiveness of movements of mobile robots, in order to improve their integration in social environments. The work was done under the framework of the European project MOnarCH (www.monarch-fp7.eu).

Robots are often seen by society as machines, which move in a rigid way, and from a human perception, seems to be an unnatural behaviour. Thus, to improve the Human-Robot Interaction (HRI) field, expressive trajectories were created to show specific emotions, and trigger feedback's from the people around. The generation of trajectories was done at LRM (Mobile Robotics Laboratory) of IST (Tecnico Lisbon), and experiments to validate them were performed in two social environments, namely in IST and IPOL (Portuguese Oncology Institute of Lisbon). Features were extracted from the trajectories to characterize emotions from a mathematical stand point. Those features are meant to allow the creation of more complex trajectories, than the ones initially created, in order to allow the robot to express complex emotions (such as remorse, shame or pride).

A questionnaire was delivered during experiments, achieving a recognition rate of 64.1%, which suggests that robots can express emotions through movement. The results showed that the movements of the MOnarCH robot capture people‘s attention, making them to smile and interact with it.

Index Terms—Emotions expressiveness, Social Robotics, Human-robot interaction, Robots acceptance by Humans

1 Introduction

HUMAN-ROBOT interaction (HRI) is currently one of the most challenging research topics. Communication in HRI can take many forms, it can be verbal and non-verbal, wherein the non-verbal can be expressed by body movements and/or face expressions [1]. The research challenge of developing robust algorithms is the key since it provides the unique tools for the acceptance of robots by humans, in social environments. Robots are seen as machines, thus it is important to find techniques to allow humans to teach robots how to express emotions, through movements.

Humans perceive emotion from what they have learn throughout their lives. People do not transmit their feelings all in the same way, due to individual and cultural differences [2], [3], however, relying on common sense, it can be said that there are emotions which are recognized and expressed similarly [4].

Some questions concerning expression of emotions through movement are: how is human body movement, do they think about what they are expressing to others while having some feeling, or is it intrinsic and, do they need their entire body to change in order to show an emotion, or just some part of it? These questions have already been partially answered [1], [5], and most conclusions say that it depends on the emotion being displayed in a particular environment. This work aims to answer them, when applied to a social robot, working at a hospital.

The objective is to create emotional trajectories that can be easily recognized by people, being only use body movements, at first, and then add facial expressions. To achieve this, common sense is used, initially, to find a relationship between human emotions and how are they expressed. Then, an intensive study is conducted on the principal social body cues displayed in different situations, namely dance [6] and social environments.

The work relies on the six basic emotions of Ekman [5], which are: *Happy, Sad, Disgust, Anger, Fear* and *Surprise*. The question of why implement these emotions on a robot that interacts mainly with children may arise. A possible answer is that, since these emotions are considered as basic emotions, and one of the goals of this work is to identify characteristics which represent emotions in mathematical terms, their study can lead to the creation of trajectories which will express more complex emotions. That is, using features from basic emotions, complex trajectories can be created and enhance the way MOnarCH moves, improving human-robot interaction. Also these emotions are commonly accepted as being equally recognized within different cultures [4].

The paper is organized as follows: section 2 enlightens the reader about research in this topic and how similar experiments were performed. Section 3 is divided in three sections: the first one introduces the robot, the second describes how trajectories were created and the mathematical theory behind it, and the last one presents the analysis performed to identify features from the trajectories. Section 4 describes the conducted experiments, performed with the robot in two social environments, and the statistical analysis of the questionnaire results. Section 5 ends by making conclusions about the performed work, and proposes some future work to do in this area.

2 Related Work

The Monarch robot is intended to work along hospitalized children, however they are not as accurate as adults when it comes to distinguish between similar emotions [1], [7], [8]. After testing the interaction between kids and Aldebarans Nao robot [7] Aryel Beck confirms previous statements, indicating also that robot's head position has an important role in improving child's perception. Jeremy Fox [8] paid special attention to how emotion recognition is employed by children, and at what age they reach adults perception levels, concluding that, children younger than 12 years, have bigger difficulties when perceiving other's feelings. Children's at IPOL have between 0 and 18 years old.

Achieving a better understanding between humans and robots is a meandering path. Ekman and Friesen [9] stated that body movements provide information about the intensity of emotions, but not on their quality.

Recent studies [10], [11] show that emotions can be recognized either by static, or dynamic, body movements. Charles Darwin [12] showed the importance of extracting information from static body postures, and how humans and animals express emotions. Similar studies came after: James [13], in 1932, asked to people what emotion was being expressed in images and what body parts gave them the signs of it. Concerning dynamic movements, Johansson [14] used moving light displays (MLD) attached to body parts to show that humans recognize motion patterns even with few information.

From this point, questions of whether it was possible to recognize emotions from movement of specific body parts was set. Several studies were carried out on this topic, namely: as the arms [10], [11], trunk [11] and eyes [15]. Ekman and Friesen [4], say generally people recognize others emotions by their facial expressions, and not by body movement, which brings some difficulties to the development of emotional trajectories. Some authors claim that dance is one of the best ways to display emotions [16], [17].

Communication between human-robot improved a lot and helped to the development of a new range of application domains (security, domestic, health care, among others).

2.1 Methodologies for conducting experiments

The way experimental studies are conducted is a relevant issue to address, since different conditions will produce very different results.

A type of environment that can be created is to use different types of stimulus to induce a specific emotional state on the respondents. An example of stimulus used is: after seeing the original pictures (the stimuli), the child's ability to recognize a *Happy* face was tested [8]. In this work, the use of induced stimulus is not done since the goal is to get people's responsiveness immediately after having seen the robot's movements. Another way, is to carry out the experiments without people knowing the goal of it, and why is the robot there [18]. This kind of method is called WOZ (Wizard of Oz) method, wherein the operators of the robot (the wizards) induce people to think that they are interacting with an autonomous robot, when actually the robot is being conducted by the operators.

The type of people who will be interviewed is other topic to have in account, namely variables as the amount of people to reach and their age. Regarding the first variable, it is allowed to say that there is not a right number of people to reach. The number of answers obtained in this study is comparable with other studies (24, 49 and 98 participants, in [7], [8] and [15], respectively). Concerning the age of the people interviewed, it usually depends on the objective of the study. Since MOnarCH robot interacts mainly with children they are implicitly a target public. However, as proven in research, they do not recognize emotions as adults do thus, in order to see if the created trajectories express the intended emotions, adults are also part of the target group.

2.2 Methodologies of results analysis

2.3 Data Collection

Experimental studies are based in questionnaires to get people's reactions and opinions, regarding what is being study. An usual type of questionnaires are Likert Questionnaires, based on Likert Scales [19], which are rating scales. The most used rating scale is the 5-point scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree).

Another kind of questionnaires use multiple-choice questions, wherein the target group is asked to respond to some questions, with one of the available answers. This kind of test is usually used [11], [20], [21] because it allows the analyzers to receive proper answers within the expected ones.

The questionnaire used aims at testing people's feedback's towards the robot's movement, using multiple-choice questions. Likert questions are not used since the goal is not providing cues to people about the emotion being expressed with statements as: "Trajectory x expresses emotion $Happy$", but rather what is the emotion identified by them.

2.4 Data Analysis

After the experimental studies is necessary to analyze the obtained results. Several kinds of statistics can be used to analyze experimental results, namely parametric or nonparametric. The difference relies on the amount of information and what represents the best our data: mean (parametric) or median (nonparametric). In order to best analyze and get relevant conclusions about their work, most studies [7], [10], [15], [20] resort to ANOVA. ANOVA is used to compare the differences between group means, and computes the degree of similarity between them.

3 Movement

3.1 Background

The robot MOnarCH, figure 1, was created to be integrated in the Paediatric Ward of Portuguese Oncology Institute at Lisbon (IPOL).

Its system consist of off-the-shelf sensing and motion technologies, which allows it to move autonomously around people. In IPOL, the robot should not disturb the natural environment lived in there, and it is commonly called by "Gasparzinho". Its localization and navigation system is divided in three systems: localization (uses the AMCL algorithm [22] to efficiently estimate robot's position), motion planning (based on FMM algorithm [23]), and guidance (computes, in real time, velocities to find the optimal path to the goal).

Fig. 1: MOnarCH robot

3.2 Trajectories

3.2.1 *Common features*

An initial set of features is introduced, which will be used to create the trajectories. Further ahead this set will be enrich with new features, withdrawn by mathematical analysis in section 3.3. The new set of features aims to map, automatically, a specific trajectory into a specific emotion.

The features considered in this work were chosen accounting for robot structure. Further, their definition was inspired in several studies [15], [20], [21] and common sense. These features are divided as it follows:

Type of emotion: negative emotions, defined as emotions which humans do not like to feel; or positive emotions [24].

Direction of movement: forward, if the robot walks toward us; backward, if it moves away. Some emotions use both directions (mixed).

Velocity of movement: fast or slow movement. Some emotions use both types of velocities.

Orientation of the body: no changes, if the robot is always facing us; changes, if it does not.

Arms position: up, if the robot is mostly with his arms up; down, otherwise.

Head position: straight, if robot's head is mostly looking forward; turn, if it turns it.

Eye color: shades of yellow, blue, green, red, black. Figure 2 shows the correspondence between one emotion and each one of the others. A scale from 0 to 5 is used, wherein 0 means that there are no features shared by both emotions. For each emotion, in x axis, there is a bar, whose value, on the y axis, corresponds to the number of features shared between both.

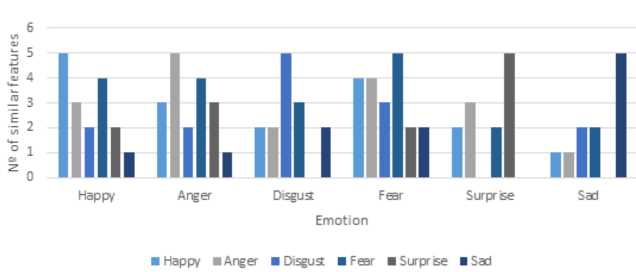


Fig. 2: Correspondence between emotions

It may be concluded that *Fear* shares more features with others, namely with *Anger* and *Happy*; while *Sad* only shares features with *Fear* and *Disgust*, not sharing nothing with *Surprise*. *Happy*, *Fear* and *Anger* have more in common than the sets between *Happy* and any other, which may come as a surprise, since the first is a positive emotion, while the latest are negative emotions.

3.2.2 *Interpolation methods*

The six trajectories were created in Matlab software. First some points were selected and, using an interpolation method, it was possible to get the necessary amount of points to build the trajectories used by the robot. The interpolation methods commonly used are Cubic Spline [25], Pchip. Spline was the chosen method to produce the majority of trajectories, creating continuous and smoother paths which improve the self-expressiveness of the robot. Pchip interpolates the given data, producing tighter turns and straightforward paths, without oscillations. *Disgust* trajectory was created with pchip.

3.2.3 *Body Movement*

This section explains how trajectories were created, describing for each, the intended emotion. To accomplish it, first an observation of each emotion in different situations, as people walking in the street, Youtube clips, films, etc., was made; and several studies were considered.

Happy

Being *Happy* is one of the society's goals, and there isnt a unique definition for what is happiness or how is it felt. One of the scenarios from where someone can extract cues, concerning how *Happy* is expressed, is dance [16], [17]. Since this emotion is associated with fast movements and large amplitudes, the created trajectory, has a variety of curves and changes on the robot's orientation. The robot starts by moving its body from side to side, like a zig-zag-zig routine, changing its orientation and keeping a high velocity. Using higher velocities allows to move the robot quickly, producing bigger amplitudes and consequently using more space. This creates the impression that the robot is happily dancing. At some point of the trajectory it makes a loop, decreasing body velocity, and continues its path speeding up again. While the robot is performing, the bystanders start to feel excited due to the quick movements, thus creating a connection between both.

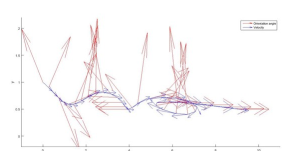


Fig. 3: Happy trajectory

Sad

Sad doesnt have a unique definition and is felt due to different reasons. The movement of a *Sad* person can be characterized as a slow walk, not facing other's eyes directly. The person will tend to walk randomly, without a destiny, which can be linked with an irregular gait, that is, its movement is not straight and it can last for a long time.

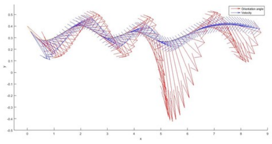


Fig. 4: Sad trajectory

The resulting trajectory, in 4, is envisioned to be immediately recognized by people. The robot walks in a low speed, without changing velocity or its path. Its orientation intends to show that it is seeking for attention from someone, thus moving its body from one side to the other. The change in orientation is supposed to be as smooth and slow as possible.

Disgust

Feeling *Disgust* is the same as feeling revulsion in response to an unpleasant situation. Humans show an ugly face demonstrating that they disapprove something [26], thus *Disgust* does not have unique body movements, but rather a distinctive face expression. It is expected that suddenly velocities and orientation changes are able to give the impression of repugnance. Figure 5 shows the robot walking and, at some point, it sees something that does not likes, stopping and moving back to the side. It gives a look to the disgusting object, and then turns suddenly to its original position.

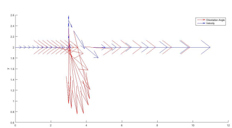


Fig. 5: Disgust trajectory

Anger

The trajectories do not need necessarily to show *Anger*, instead feelings as indecision or worry would better describe what the robot is expressing. Humans show it by leaning forward and invade other's body space which, in mathematical terms, translates into paths with different velocities. To represent it, the way rappers/hip-hop singers present their feelings in their songs, was one of the chosen scenarios because of the strong and impulsive movements. The trajectory implemented, in figure 6, allows the robot to walk forward, backwards and then forward again, giving the impression that it is irritated about something or someone. When turning backwards, the robot changes its orientation, showing an impulsive behaviour, thus enhancing the impact created when it turns forward again.

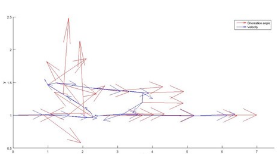


Fig. 6: Anger trajectory

Fear

The robot was not created to display negative emotions, however it is interesting to study how to create a trajectory to display *Fear*. This is a primitive human emotion, usually triggered by danger situations. Characteristic body movements are sudden changes and high tension of body parts. The body has its members closed, as if the person was trying to protect himself. The intended features for the trajectory are fast changes, accomplished by oscillating the velocity and orientation given. Figure 7 shows the trajectory designed to represent it. The robot is walking carefree and, when it sees something scary, it turns away as fast as it can. The velocity increases very fast to give the perception that the robot is in hurry to go away, turning slightly its body backwards, as if it was checking if something was behind it, or not. Then turns its body to the initial direction, running away and no looking back.

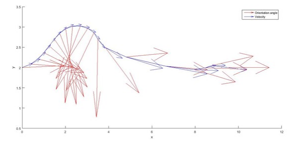


Fig. 7: Fear trajectory

Surprise

Surprise is a state of mind activated by unexpected reasons, which raises our eyebrows and opens our mouths, in an *O* form. Body reactions to good and bad surprises were studied in this work. The final trajectory shows the reaction to a good *Surprise*, wherein people tend to increase their body movement, running towards the thing that made them feel good. To represent *Surprise*, the simulated trajectory cause the robot to first, walk naturally, unpreoccupied, and then, when surprised, it starts to become excited and stops briefly. This moment is crucial to show a change of mood, starting to walk again, faster than before.

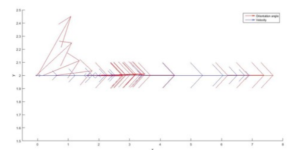


Fig. 8: Surprise trajectory

3.2.4 Head Movement

This section presents how the movement of robot's head was designed, being expected that moving it increases people awareness about what the robot is trying to display [7]. MOnarCH's head has only one degree of freedom, which is move it to right or left. Since the trajectories being studied are set up at this point, the design of the head movement was done as being dependent on them. For positive emotions, as *Happy* or *Surprise*, head usually moves energetically in each direction, unlike negative ones, as *Sad*. A detailed explanation concerning the head movements is done next, and their mathematical representation is shown in figure 9.

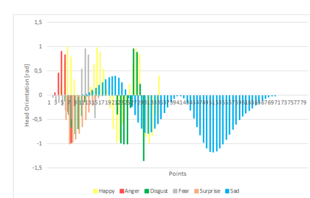


Fig. 9: Head Movement

Happy (yellow): typical spontaneous and irregular behaviours, with fast changes in orientation, producing in the end a fluid movement.

Anger (red): the robot almost does not moves its head as the goal is having it always facing the target.

Surprise (orange): robot's head moves to one side, instants before its time to show that something surprised it. The slightly side move behaves as a prior cue for what is about to happen.

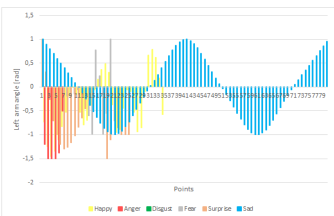
Disgust (green): when the robot faces the awful object, looks at it, and then turns its face away, as if it was nauseous about it.

Sad (blue): this emotion has a very different behaviour from the previous. The robot's head follows its body movement, moving slightly from one side to the other, as it was looking for attention. The velocity with which it performs the movement is considerable slower than for others emotions.

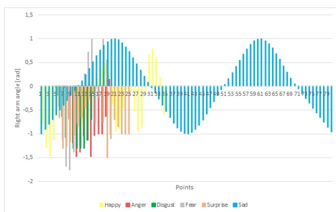
Fear (gray): the robot moves away from its initial direction, and looks, for an instant, to the "bad thing", moving then to the same direction of its body.

3.2.5 Arms Movement

Arms movement is another important feature that alone does not have a big impact, but when added to the entire body improves the perception of bystanders. Monarch arms only have one joint (the shoulder), which goes up and down. Figure 10 shows the arms orientation, in radians, where positive angles lowers the arms, while negative angles moves them up and a detailed explanation is provided next.



(a) Left arm



(b) Right arm

Fig. 10: Arm Movement

Happy (yellow): the goal is to show quick and inconstant actions. The robot expresses it through a continuous and parallel motion of both arms, especially in the end of the trajectory where they move up and down at same time.

Anger (red): big arm thrusts, pointing forward, making use of exaggerated movements of the entire body. The robot is mostly with one of its arms up, lowering it when moving backwards, and then raising the other one when moving forward.

Surprise (orange): MOnarCH moves its arms up, displaying enthusiasm for something.

Disgust (green): it almost doesnt moves its arms, using one of them, at the middle of the trajectory, to point out the object that it doesnt like.

Sad (blue): people generally have a slow walk, which is followed by a slow arm movement. The robot moves, alternately, its arms back and forth, as if it was tired and depressed.

Fear (gray): at the beginning the robot lifts up one of the arms, amplifying the movement. Then, as its body starts to escape, arms go down, and then move alternately for a while, in order to give the impression that it is running away.

3.2.6 Facial Expressions

Facial expressions provide the principal body cues concerning emotional feelings [27], being eyes and mouth two of the most relevant parts of the face. It is expected that, with these additions, the recognition of emotions become trivial. The colors used to express each emotion were based on [15], wherein is investigated how LED patterns, in eyes of Aldebarans Nao robot, could be used to imitate human emotions. Figure 11 shows some of the MOnarCH expressions used to express a specific emotion. In order to increase the connection towards others and highlight the moment in which there is a change of moods, robot's eyes change color throughout the trajectories.

Happy: shades of yellow were used, since this color is linked with contentment and relaxed situations.

Anger: linked with red [15]. This color is associated with hot opposing emotions, as passion or aggressiveness.

Surprise: both shades of yellow and blue are used, being the later one, the chosen to emphasize the surprised state itself.

Disgust: green is the selected color, since it is related with nauseated moods [28].

Sad: blue, which is linked with several states of mind (calm, reflection, pleased) [15], [28].

Fear: dark colors [15], as black or gray. However, it was considered best to use blue.

Fig. 11: MOnarCH's facial expressions: *Happy, Sad, Disgust, Fear, Surprise* and *Anger*

The mouth design was based on cartoons expressions and in [27], wherein new facial expressions, such as happily surprised and angrily disgusted, are created through a Facial Action Coding System, based on the six basic emotions. Study [29] was particularly interesting for the development of expressions for MOnarCH, since the robot (Probo) used by them to show emotions, is also to be used around hospitalized children.

Happy: recognized by a smile, with mouth sides pulled backwards and slightly upwards [7], almost as if the mouth was getting closer to the nose.

Anger: generally people's lips are either tightened together with a clenched jaw, or the mouth becomes square to expose the teeth clenched.

Surprise: humans generally produce an Oh sound when expressing it. This produces an open mouth in an O form, figure 11 (middle of the second row), with a dropped jaw and parted lips.

Disgust: shown by having the upper lips pulled upwards from the sides, and then, when repulsion starts to become impossible to bear, the lower lip is pulled downwards from sides. One side of the robot's mouth is up and the other one down (as if the mouth was producing an hmm sound).

Sad: mouth corners down and chin raised. To not have always the same design of a sad mouth, during the trajectory, a small version of the one shown in figure 11 was created. This other version looks like a flat mouth.

Fear: one way of showing it is having the mouth opened and pulled outwards. In a panic moment people's mouth may start to tremble and, in order to create that effect for the robot, it was created a zig-zag expression. The shaking of the mouth is achieved by flashing the leds.

3.3 Estimation of Features

The features identified in this section can be used to automatically map a trajectory into an emotion, using SVMs [30] (support vector machines) as classifiers. SVMs are supervised learning models used to classify data in specifics categories. Thus, it is expected that the features can be used to categorize each emotion however, it should be noted that they are derived from specific trajectories. This means that they represent how someone could express the emotions under study, but it does not mean that everybody expresses them likewise.

3.3.1 Fourier Transform applied to body position

Figure 12 shows the results for each emotion with respect to the position coordinates x and y. The plots were computed in Matlab, using *fft*, and the identified features, for x, are:

Oscillating behaviour: *Happy*, *Surprise* and *Anger*, because they change position more often; while *Sad* and *Disgust* show a smoother and oscillations-free signal.

Hyperbole branch behaviour: for *Disgust* and *Sad*.

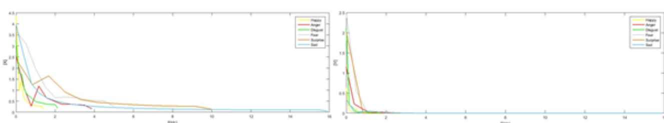


Fig. 12: Fourier Transform of body position, left: x, right: y

The right image on figure 12 shows the Fourier transform applied to y direction, wherein the relevant features are

Decrease, stabilizes, decrease: *Fear*, *Anger* and *Disgust*, their module of y decreases fast at first, then stabilizes for some time, decreasing again. *Sad* and *Surprise* both decrease, at first, but then stabilize.

Wavelike: *Happy*

3.3.2 Velocity Profile

A velocity profile is presented and the respective Fourier transform is presented, computed in order to understand which emotions have higher frequencies, or which ones change it more frequently. The identified features, from figure 13, are:

Higher velocities: *Fear* and *Anger* reach the higher velocities, which agrees with the necessity of the robot to speed up in order to run away from something (*Fear*) or make a point by invading others place (*Anger*).

Oscillating movement in x axis (in the beginning): this model is shared by *Anger*, *Fear* and *Surprise*, as their oscillating behaviour is almost the same. The differences are:

- in the value of the velocity module; which, in the beginning, is more stable for *Fear* than for the others;
- in the last part: *Surprise* and *Anger* finish their path by decreasing velocity, unlike *Fear*.
- length: *Surprise* uses less points, then comes *Fear*, and at last *Anger* with the bigger amount of points.

Smaller and stable velocities (in the beginning): *Sad* and *Disgust*. *Disgust* starts to increase its velocity in the middle of the trajectory, reaching both null and higher velocities.

Increase of speed (at the end): *Disgust* and *Fear*, as they tend to have faster movements when facing the object that led to them.

Happy, shows a singular pattern: it starts slow, small variations of velocity, and then alternately, increases and decreases its speed.

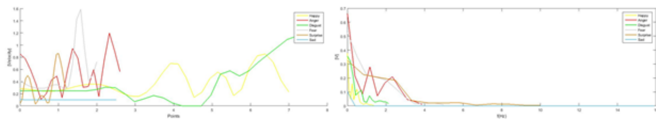


Fig. 13: Left: Velocity Profile of Basic Emotions, Right: Fourier transform of velocity

Figure 13 shows, on the right side, the Fourier transform of velocity, which confirms interpretations made before, regarding time response analysis:

Oscillating behaviour: pattern shared by *Anger*, *Disgust* and *Happy*.

Down, stable, down, stable: shared by *Surprise* and *Fear*. This pattern is similar to the one before, however is not as perceivable because the trajectories do not change position (in y) so often.

Monotonic decrease of velocity module: *Sad*, due to the smaller and unchanging velocities throughout its path.

3.3.3 Orientation of body position

The features identified by studying figure 14, are summarized next. Positive orientations make the robot turn to the left (maximum angle - π rad puts the robot with its back to us), and negative angles makes it turn right.

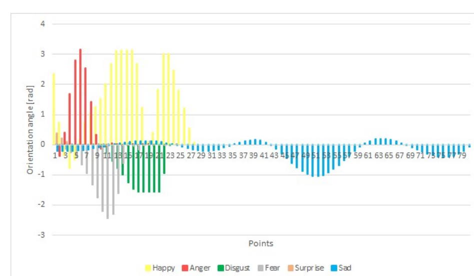


Fig. 14: Orientation of MOnarCH's position

Null or little orientation: *Surprise*. To express it, people tend to look forward to the key point that got them surprised.

Higher angles of orientation: *Anger*, *Happy* and *Fear*. Both tend to use more space and consequently change orientation often.

Periodic behaviour: *Sad* and *Happy*. Regarding *Sad* is due to the lack of strength and liveliness that people feel during these moments.

3.3.4 Correlation of velocities

The statistical measure correlation was used to compute the correspondence degree between emotions, using *xcorr* function of matlab. This function show the measures of the similarity between velocity of one emotion and shifted copies of velocity (of the same or other emotion) as a function of the lag. The identified features, from figure 15, were:

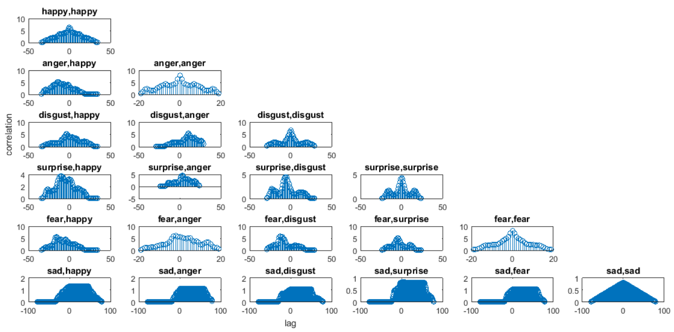


Fig. 15: Correlation plot of velocity

Number of shifted computations: *Fear* and *Anger* have a number of computations of 19, since they both have the smallest amount of points. The others use more shifted versions of the signals with which are being correlated, namely *Disgust* 29, *Surprise* 24, *Happy* 34, and *Sad* 79 versions.

Maximum value of auto-correlation: *Happy*, *Anger*, *Disgust* and *Fear* show values higher than 6, while *Surprise* and *Sad* have values under 4.5.

Maximum value of correlation: the values are, approximated: 5.6 (*Happy*, *Fear*), 6.05 (*Anger*,*Fear*), 5.9 (*Disgust*, *Fear*), 4.6 (*Surprise*, *Happy*) and 1.3 (*Sad*, *Happy*).

Higher correlation values for left shifted values: *Happy*. The opposite is *Sad*.

More stable correlation values for left/right shifted versions: verified for *Fear* and *Surprise*, whose values dont have relevant differences when correlated, with left or right versions, of others emotions.

3.3.5 Fourier Transform applied to head orientation

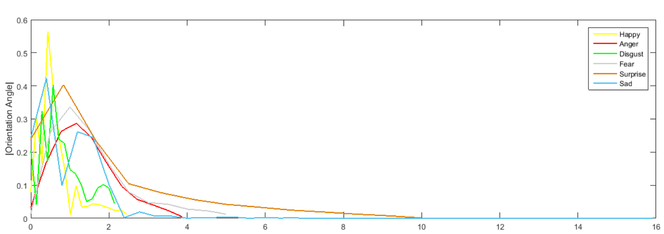


Fig. 16: Fourier transform of head's orientation

From previous figure the following features can be deducted:

Triangle pattern: *Surprise, Anger* and *Fear*. The module of orientation increases and then decreases, showing that the robot only turns its head once.

Oscillating behavior: *Happy* and *Disgust*. It means that the robot changes often its head position.

Head turns to one side: *Surprise* and negative emotions as *Fear, Anger* and *Sad*.

Frequency with module peak: $<$ 1 Hz: *Happy, Sad, Disgust* and *Surprise*; $>=$ 1 Hz: *Anger* and *Fear*.

3.3.6 Fourier Transform applied to arms orientation

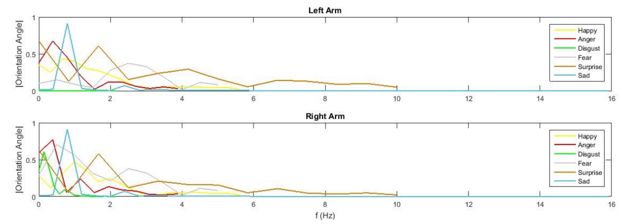


Fig. 17: Fourier transform of arm's orientation

Same frequency response for both arms: *Sad* and*Surprise*. The movement is synchronous, moving up or down almost at the same time (*Surprise*), or when arms move in the same way (*Sad*). *Sad* arms move back and forth in alternate form.

Higher module, lower module of orientation angle: *Fear*. As one arm moves in small frequencies, the other one doesn't moves; and then the opposite happens: the quite arm starts to move, in higher frequencies, and the other one slows down.

Oscillating behaviour with lower module of orientation angle: positive emotions as *Happy* and *Surprise*. Despite having a lower value in vertical axis, they oscillates more, thus being more energetic.

Frequency with module peak: negative emotions (*Anger, Fear, Sad* and *Disgust*) have their maximum value of orientation in lower frequencies, unlike positive ones, which have it in higher frequencies.

4 Experimental Study

The validation of the created trajectories is accomplished by doing an experimental study, in two social environments, wherein the robot performed the trajectories and a questionnaire was delivered. The experiments were held in a stimulus-free environment in order to understand if the robot's movement is enough to stimulate the bystanders curiosity. Experiments were performed at the North Tower entrance of IST (Tecnico Lisbon), and at the corridor of the Paediatric Ward of IPOL. The key questions evaluated during tests, and in the questionnaire were:

1) *Is robot's movement significantly interesting to capture public's attention?*

2) *Is body movement expressive enough to show an emotion, and be easily recognized by the public?*

3) *Is robot's movement seen as a "human kind of movement"?*

4) *Is there a meaningful difference between children and adult's perception in relation to the expressions shown by MOnarCH?*

4.1 Experiments at IST

The IST environment consists of a corridor at the main entrance of north tower, and it is usually with many people, which increases the possibility of getting more questionnaires. The environment dynamics, at the time of the experiments, was noisy, with people moving around. The robot was set to walk from one side of the corridor to the other, performing a specific emotion in each direction. The steps followed during the experiment were:

1) Each trajectory was shown for at least 2 minutes, which allows to ask people to classify the trajectories seen by them.

2) After the trajectory has been executed, the questionnaire is delivered. This way guarantees that the public does not have any prior knowledge of what they are about to see.

During experiments recordings of the environment were made. The snapshots, in figure 18, show that MOnarCH creates a positive impact on people by catching their attention and making them to interact with it.

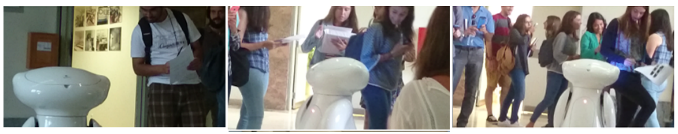


Fig. 18: People's reactions towards MOnarCH

The analysis of the questionnaires is made in section 4.3. The experiments showed that, seeing a "living and interactive" robot along with the trajectories created, makes people smile.

4.2 Experiments at IPOL

IPOL is the place for which MOnarCH was created and where children were asked to answer the questionnaires. The dynamics of the environment, during the tests, was very quiet, with only a few people wandering in the main corridor. The steps covered were similar to the ones at IST:

1) The robot was set in motion, performing a trajectory in only one of the directions of the corridor.

2) When people were paying attention, the questionnaire was delivered. Most children did not know how to read, thus an explanation of the questions had to be done. The explanation was simply a translation of the quiz, not reviling the right answer or giving cues.

Preliminary conclusions suggest that, comparing both places, the robot is suitable to interact with people from all ages. Further, MOnarCH really captures people's attention.

4.3 Results Analysis

This section presents a statistical analysis of the results obtained from the questionnaires. First, results from both environments are analyzed separately, and then are treated together. The results have more answers regarding *Happy* because, except for *Sad* and *Anger*, all other trajectories start with a happy face.

In total 78 answers were obtained, 61 from IST, and 17 from IPOL. In IST 35,5% were male, 35,5% female and 28.9% did not answer. In IPOL 50% were male, 37,5% female and 12.5% did not answer. The average age of the inquiries, in IST, were 25.18 years, and in IPOL 15.56 years.

Answer to question 1: *Is robot's movement significantly interesting to capture public's attention?*

The answer to this question has been introduced throughout last sections, namely in figure 18. The image displays only some moments of the experiments in IST, however it can be concluded that people do react to the robot, by looking to it.

A statistical analysis, called ANOVA, was also computed in order to see if there was a significant difference between the recognition of emotions in question 1 (facial expressions) and in question 3 (identified emotions). The analysis was done in excel by using the two factor (two questions) ANOVA without repetition tool.

To compute it, first the null-hypothesis has to be defined, for both factors, being: "there is no significant difference between the means of the recognition of emotions in question 1 and in question 3". Table, in figure 19, shows the results after applying ANOVA on the results obtained on the questionnaire.

IST	***F-value***	***p-value***	***F-critical***
Question 1	0,734125	0.60478	2.602987
Question 3	0.560729	0.728974	2.602987
IPOL	***F-value***	***p-value***	***F-critical***
Question 1	0,500562	0,772855	2.602987
Question 3	0,365579	0,867218	2.602987

Fig. 19: Two-factor ANOVA without repetition

Since the $F-value < F-critical$ (or $p-value > 0.05 = \alpha$), the null-hypothesis are accepted, suggesting that emotions are equally recognized when comparing the answers from both questions. Moreover, there is no relevant difference in how people identified the emotions shown, either by seeing the facial expressions (question 1) or by seeing the MOnarCH body movement (question 3).

Answer to question 2: *Is body movement expressive enough to show an emotion, and be easily recognized by the public?*

Tables in figures 20 and 21 show the degree of recognition of emotions, wherein a result of 1 means full recognition. Concerning the results from IST:

- *Happy* is the most recognized emotion, opposing to *Surprise* and *Disgust*. As said before, this can be due to the fact that most trajectories show a happy face.
- *Anger* and *Disgust* both have low recognition rates, being that the first one is confused with *Surprise*, *Happy* and *Fear*; and the second with *Happy* and *Anger*.

Regarding the results from IPOL: *Happy*, *Surprise* and *Sad* were correctly recognized, opposing to *Fear* and *Disgust*. This results do not have a big significance since the number of respondents is smaller than the number of answers obtained in IST.

	Happy	*Anger*	*Disgust*	*Fear*	*Surprise*	*Sad*
Happy	0,826	0,043	0	0	0,13	0
Anger	0,2	0,2	0	0,2	0,4	0
Disgust	0,25	0,5	0,25	0	0	0
Fear	0,091	0,182	0,091	0,545	0,091	0
Surprise	0	0	0,333	0	0,667	0
Sad	0,067	0,333	0	0	0	0,6

Fig. 20: Results of the questionnaire in IST

	Happy	Anger	Disgust	Fear	Surprise	Sad
Happy	1	0	0	0	0	0
Anger	0	0,5	0	0,5	0	0
Disgust	0	0	0,5	0,25	0	0,25
Fear	0	0	0,2	0,6	0,2	0
Surprise	0	0	0	0	1	0
Sad	0	0	0	0	0	1

Fig. 21: Results of the questionnaire in IPOL

Figure 22 shows the overall percentage of recognition from all questionnaires. A correct recognition rate of 64.1% was achieved, which shows that it is possible to make a robot to express emotions.

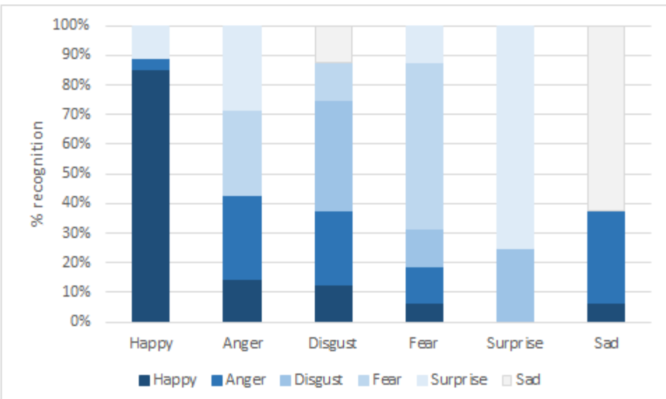


Fig. 22: Total percentage of recognition of emotions

Answer to question 3: *Is robot's movement seen as a "human kind of movement"?*

Possible answers to this question were: machine, animal, human or none of the previous. Results show that 14.6% of the inquired think that robot's movement looks like a human walk, 62.6% responded that is similar to a machine walk, 13.3% that is similar to an animal walk and 9.33% did not respond.

The Uncanny Valley [31] theory says that if the robot movement starts to become very similar to the one of a human, it will cause a low emotional response from the humans towards the robot. Hence the goal is to make MOnarCH express itself in a way that is similar, but not exactly equal, to humans. The goal of this question was to understand if the movement shown by the robot was rigid and mechanical, like a machine, and not if it was recognized as a human walk.

Answer to question 4: *Is there a meaningful difference between children and adult's perception in relation to the expressions shown by MOnarCH?*

Besides the fact that the number of children who responded the questionnaire was small, some conclusions might be drawn from previous results. Comparing figures 20 and 21, is possible to say that children gave more right answers than adults. However, in results from IPOL, there are answers provided by adults, which influences the recognition rate. In IPOL, only 50% were children with ages below 12, being the other 50% adults with an average age of 21,5 years.

5 Conclusions

This paper aimed at improving Human-Robot Interaction, by making a robot to express emotions. The main objective was to enhance the interaction between people and MOnarCH, in a social environment, proving that it captures people's attention by making them stop and interact with it.

An initial set of features was used to create expressive trajectories, using body, head and arm's movement, and facial expressions. The trajectories were defined using Cubic Spline and Pchip matlab based interpolation. A Fourier and correlation analysis was used to allow the identification of relevant features, yielding a mathematical representation for emotions.

Two experiments were performed, in IST and IPOL, and a questionnaire was delivered. The results show that the robot does influence people to react with it. Moreover emotions were recognized correctly 64.1% of the times. Children under 12 years reached a recognition rate of 55.55%, while adults reached 65.21%.

In summary, MOnarCH has certain built-in characteristics that act as facilitators in the generation of expressive movements, which can be characterize by the set of features discussed. The result is the acceptance of the robot by generic people.

6 Future Work

Future research on Expressive Movements should focus on the creation of SVMs, making use of the features set built in this work. The creation of SVMs will enable:

- the generation of complex trajectories, spanning large spatial areas, hence increasing the interaction time with the robot;
- the recognition of emotions from arbitrary trajectories;
- the generation of trajectories, which express complex emotions. For example, by combining certain features from *Happy* with others from *Surprise*, it is possible to create a new trajectory, which will express the emotion *Happily Surprised* [27].

Appendix A
Questionnaire

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