Generation of Expressive Trajectories for MOnarCH robot

Towards a stronger Bond between Humans and Robots

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"We humans have a love-hate relationship with our technology. We love each new advance and we hate how fast our world is changing... The robots really embody that love-hate relationship we have with technology",

from http://www.theglobeandmail.com/arts/books-and-media/daniel-h-wilson-on-the-art-of-making-scary-robots/article587888/

Daniel H. Wilson

Resumo

Os seres humanos mostram as suas emoções através do seu movimento corporal e das suas expressões faciais. Esta tese aborda a expressividade do movimento de robots móveis, de modo a melhorar a sua integração na sociedade. O trabalho foi realizado no contexto do projecto europeu MOnarCH (www.monarch-fp7.eu).

Os robots são geralmente vistos pela sociedade como máquinas que têm movimentos rígidos, e que, do ponto de vista dos humanos, movimentam-se de forma não natural. Assim, por forma a melhorar a Interacção Homem-Robots foram criadas trajectórias expressivas que mostrem emoções específicas e provoquem uma reacção por parte das pessoas em redor. A criação das trajectórias foi realizada no Instituto de Sistemas e Robótica do Intituto Superior Técnico de Lisboa (IST) e, de forma a validá-las, foram realizadas duas experiências em ambientes sociais, nomeadamente no IST e no IPOL (Instituto Português de Oncologia de Lisboa). A partir das trajectórias, foram extraídos padrões que permitem a caracterização das emoções matematicamente. Estes padrões têm como finalidade a geração de trajectórias mais complexas, do que as criadas inicialmente, de modo a que o robot possa expressar emoções também mais complexas (como remorso, vergonha ou orgulho).

Durante as experiências foi entregue um questionário, obtendo-se uma taxa de reconhecimento das emoções de 64,1 %, comprovando que é possível fazer robots expressarem emoções. Os resultados mostram que o movimento do robot MOnarCH chama a atenção das pessoas, fazendo-as sorrir e interagir com ele.

Palavras Chave

Expressividade Emocional, Robótica Social, Interação Homem-Robots, Aceitação de Robots por Seres Humanos

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.

Keywords

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

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Acronyms

AMCL - Adaptive Monte Carlo Localisation

ANOVA - Analysis of variance

FMM - Fast Marching Method

FFT - Fast Fourier transform

GUI - Graphical User Interface

HRI - Human-Robot Interaction

IPOL - Instituto Português de Oncologia de Lisboa

IST - Instituto Superior Técnico

LRM - Laboratorio de Robótica Móvel

MLD - Moving Light Displays

SVM - Support Vector Machine

WOZ - Wizard of Oz

1

Introduction

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1.1 Communicative Robots

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 facial expressions [1]. The research challenge of developing robust algorithms is the key, since it provides the tools for the acceptance of robots by society. The common sense regarding robot‘s movements is that they are machine alike, which, from a human perception, seems to be an unnatural behaviour. Thus, it is important to find techniques to allow humans to teach robots how to express emotions, by movements, that are inherit to humans.

Body movement is one of the nonverbal communication forms that people use to make assumptions about others feelings. Humans perceive emotion from what they have learn throughout their lives, and understand what others are feeling because they have seen it and felt it before [2]. People do not show their emotions all in the same way, due to individual and cultural differences [3–5]. However, relying on common sense, it can be said that there are common emotions which are recognized and, most of the times, expressed in the same way [6].

1.2 Movement for Communication

To make a robot to express some kind of emotion it is necessary to think how humans express them:

- How is human body movement? Which characteristics allows us to identify correctly other‘s feelings?
- Do people think about what they are expressing to others, or is it intrinsic?
- Do people need to change all body parts in order to show some emotion, or some parts of it are enough?

These kind of questions have already been partially answered [1, 7], however conclusions say it depends on the emotion being displayed at a particular environment. During humans life's, different situations arise that require them to behave accordingly, hence there are several variables that influence the way people react to those moments. This work aims to answer these questions when applied to a social robot working at a hospital, and improve how robots are seen by people.

To start the movement study it is important to separate the propositional movements from the non-propositional ones [8]. The first ones concern the physical cues, such as raising arms to demonstrate emotion happy; while the second ones are about the embodied features, such as the tempo or velocity, with which a movement is created.

The human being can express many emotions, however implementing them all would be an exhaustive work. This work relies on the six basic emotions of Ekman [7, 9] which are: *Happy, Sad, Disgust, Anger,* *Fear* and *Surprise*. The reason behind the choice of these emotions is their recurrent use in research, helping future comparisons of the work reported here with others. These emotions have been shown to be equally recognized by different cultures [6], which helps claiming that different cultures will associate easily each emotion with the same class of trajectories.

The main purpose of the thesis is to create emotional trajectories, being first made an attempt to only make use of the non-propositional movements (using velocity and orientation for body movement), and then add the propositional ones (movement from head and arms, and facial expressions). Meijer [10] contributed with some important inferences regarding what types of features could be used to distinguish between emotions. Some of the features used in his study were derived from the Laban Effort and Shape components, which are used to give a description of the dynamic qualities of movements.

To achieve the defined goal, common sense is used, initially, to find a relationship between human emotions and how can they be expressed through trajectories. Then, an intensive study is conducted on the principal social body cues displayed through movement, in different situations, namely dance [11] and social environments (as hospitals, universities or gardens).

Following sections will focus on the implementation of others body parts, namely head, arms, eyes and mouth. Using this approach it is possible to understand the importance of joining movements from different body parts.

1.3 Thesis Outline

The thesis is organized as follows: chapter 2 enlightens the reader about the research that have been made about the topic in question and how similar experiments were performed.

Chapter 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 third one presents the analysis performed to extract features from the trajectories.

Chapter 4 describes the conducted experiments, performed with the robot in two social environments, and the statistical analysis of the questionnaire results.

Chapter 5 ends by making conclusions about the performed work, and proposes some future work to do in this area.

1.4 Thesis Contributions

The main contribution of this thesis is a set of proven expressive trajectories, which causes natural reactions from people, and that can be applied in similar robots. It also validates that the more communicative robots are, the more acceptance they will receive from humans, and a better bond will be created.

In a world changing and converging more and more to a technological one, the insertion of robots in social environments is essential. It is of greater importance to give people a chance to connect and accept intelligent and “human like” machines, as robots; as it was when the first phone was introduced to humanity. Thus, helping to improve this relation is one of the goals to accomplish. It is expected that the created movements provide the necessary cues to make people believe that the robot is having a specific feeling, occasioned by a specific situation, perceived by both.

2

Related Work

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2.1 Assessment

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 [1,12–14]. This means that the way humans move gives them the required social body cues to understand their emotional state (as basic emotions, such as *Happy* or *Sad*), but not specifically (as complex emotions, such as remorse). For instance, a person can recognize other‘s feeling as being *Fear*, but *Fear* is a general feeling to what it might be a nervous or alert state. Complex emotions, such as alert and nervous, are not as easy to recognize as general ones are, such as *Fear*, *Happy* or *Sad*.
After testing the interaction between kids and Aldebaran's Nao robot [12] Aryel Beck confirms previous statements, indicating also that robot‘s head position has an important role in improving child‘s perception. The work done under the ALIZ-E project, [1, 15], studied how to implement expressive gestures in robots to achieve a better child-robot interaction.
Jeremy Fox [13] 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 comprehension between humans and robots is a meandering path and, besides the efforts that have been made in this area, there is still a lot to do. Ekman and Friesen [16] concluded that body movements provide cues about the intensity of emotions expressed.

Recent studies [10, 17] show that emotions can be recognized either by static or dynamic body movements. The study of body movement became a relevant topic very early, gaining emphasis in 1872, when Charles Darwin [18] showed the importance of extracting information from static body postures, and how humans and animals express emotions. Similar and derived studies came after: James [19], in 1932, asked people what emotions were identified when seeing images of a human pose, and what body parts gave them the signs of it. This method has as disadvantage the fact that static body poses represent only an instant of a social moment, hence some information is lost. Some of the extracted cues were applied on this work, namely head positions.
Concerning dynamic movements, Johansson [20] used moving light displays (MLD) attached to body parts to show that humans recognize motion patterns even with few information. The question of whether it was possible to recognize emotions using the movement of specific body parts was set. In computer vision, Kaliouby and Robinson [21] developed a computational model to identify emotions from head movements and facial expressions, whereas Camurri and Castelhano [11] proposed an emotion recognition system based on gesture dynamics captured from video, concluding that there are specific body cues which allow to distinguish between “high” and “low arousal” emotions and between “positive” and “negative” emotions.

Several studies were carried out on the topic of extracting cues from a particular body part: as the arms [10, 17], trunk [10] and eyes [22]. According to Ekman and Friesen [6], people generally recognize others emotion by their facial expressions, and not by body movement, which brings some difficulties to the development of emotional trajectories. To overcome this, studies of dance movements are seen as one way to solve it. Some authors claim that dance is one of the best ways to display emotions [8, 23]. Features like quantity of motion and contraction/expansion of the body were extracted and showed to be relevant for emotion recognition.

Most of the features identified on research were used to represent emotions from a mathematical stand point, allowing the creation of the trajectories and body movements performed by the robot.

Some research focus on implementing "typical human movements", and the creation of new different patterns began to appear [24]. Communication between human-robots improved a lot and helped to the development of a new range of application domains (security, domestic, health care, among others).

2.2 Methodologies for conducting experiments

Experimental studies can be conducted in distinct conditions, which end up by producing 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 [13]. This work does not uses induced stimulus 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 [25]. 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 [12], [13] and [22], respectively). The more people answer the questionnaires, the better, because in this way it is possible to get more opinions, providing a better support to the work under study.

Concerning the age of the people interviewed, it usually depends on the objective of the study. Both children and adults are used in [13], but there are others which only use children [12]. Since MOnarCH robot interacts mainly with children they are implicitly 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. According to [13] adults provide more reliable answers than younger people (under 15).

2.3 Experimental Assessment

2.3.1 Data Collection

Experimental studies are conducted in order to understand if the developed work meets the goals initially defined, being delivered a questionnaire to get people‘s reactions and opinions about the robot‘s expressiveness. The experimental studies were conducted in two environments: IST and IPOL.

An usual type of questionnaires are Likert Questionnaires, based on Likert Scales [26], which are rating scales. There are several rating scales, being the 5-point scale the most used because it has a central point for neutrality (for people whose opinion is neutral) and because of its unweighted characteristic. Using a 5-point scale (strongly disagree, disagree, neither agree nor disagree, agree, strongly agree) can have some disadvantages [27], since it produces higher mean scores when compared with questionnaires that only use 10 levels (being the difference statistically significant).

Another type of questionnaires use multiple-choice questions, wherein the target group is asked to answer the questions, with one of the available options. This kind of questionnaires is often used [10, 15, 28, 29] because it allows the analyzers to receive proper answers within the expected ones. There is however a disadvantage, which is the fact that the questionnaires have only a few options, ending up by increasing the recognition rates.

2.3.2 Data Analysis

After the experimental studies is necessary to analyze the obtained results. One option is to resort to statistical analysis which are divided into parametric or nonparametric. The difference between both concerns the amount of information and what represents the best the available data: mean (parametric) or median (nonparametric). Also, in parametric models the number of parameters being used is fixed, while in the other that number grows alongside training data. Examples of parametric models are ANOVA and Matched-pair t-test; and of nonparametric are Mann-Whitney test and Wilcoxon test.

To better analyze and get relevant conclusions from their results, most studies [8, 12, 17, 22, 29, 30] resort to ANOVA. This method is used to compare the variances between and within groups, computing the degree of similarity between them. First is necessary to set up the null and alternative hypothesis that will be tested and check if the data meets them. To do that, first the F_{ratio} 2.1 must be computed and its critical value is analyzed. If the F_{ratio} is large it means that the variability between groups is large relative to the variation within groups, and so the null hypothesis (of equal means) is rejected.

$$F_{ratio} = \frac{variance\ between\ groups}{variance\ within\ groups} \tag{2.1}$$

3

Movement for Communication

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3.1 Background

3.1.1 MOnarCH

MOnarCH robot, figure 3.1, was created to integrate a human social environment, namely the Paediatric Ward of the Portuguese Oncology Institute at Lisbon (IPOL). The robot's system consist of off-the-shelf sensing and motion technologies, which allows it to move autonomously around people. In IPOL, the introduction of the robot is a delicate matter since it should not disturb the natural environment of it.

Figure 3.1: MOnarCH

Its constitution comprises omnidirectional wheels, equipped with multiple sensors, and robust localization and navigation systems. This type of wheels helps it to move in any direction, allowing for 360 degrees of movement, which is a major advantage for the creation of expressive trajectories. The localization and navigation system is divided in three sub-systems: localization, motion planning, and guidance.

- Localization: a map is generated through the ROS package gmapping [31], which implements the FastSLAM algorithm which uses data from laser scan and odometry. Then AMCL algorithm [32] is used to efficiently estimate robot's position. AMCL uses an occupancy grid map of the environment to estimate the position and orientation of a robot as it moves around. Using a particle filter it represents the distribution of likely samples, wherein each sample is a hypothesis of where the robot is.

- Motion planning: based on a potential field approach using Fast Marching Method (FMM) algorithm [33]. This method solves the Eikonal equation [34] for a domain discretized as a grid (the map created in previous step). The algorithm computes the potential field mapping the goals as attractive poles and obstacles as repulsive poles.

- Guidance: given a FMM field, computes, in real time, the robot's velocity to find the optimal path to the goal.

3.2 Trajectories

3.2.1 Common features

This section builds an initial set of features, which will be used to create the trajectories expressing each one of the Ekman emotions, having the purpose of introducing to what features are foreseen to create a positive impact on how MOnarCH expresses itself, and moves in social environments. Further ahead this set set will be enrich with new features identified by mathematical analysis. The new set of features is intended to map, automatically, a trajectory into an emotion. A similar study shows the same approach [28], being demonstrated how correspondence between kinds of features, namely head positions, and emotions, can be achieved, regarding children and adults interpretations.

The features considered in this work were chosen accounting for the robot structure. For example, it would not make sense to choose as feature the hand position, since the robot does not have them. Further, their definition was inspired in several studies [22, 28, 29] and common sense.

The initial set of features is described next:

- type of emotion: negative emotions, defined as emotions which humans do not like to feel; or positive emotions [35];
- direction of movement: forward, if the robot walks toward us; backward, if it moves away. There are emotions that can use both directions (mixed) or be displayed by either one of them;
- velocity of movement: fast or slow movement. Once again, there are emotions with both types of velocities, however in the following table it was decided to choose the mostly used characteristic;
- 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.

Table 3.1 show the individual characteristics used to analytically represent each emotion, concerning the features described, and how can they be related with another.

Studying previous table, it is not easy to understand which emotions share similar features with others. For this reason the plot 3.2, was created in excel, showing the similarity degree between emotions. The similarity degree is a scale from 0 to 5, wherein 0 means that there is no features shared from both emotions, and 5 that both share the same characteristics. The features used are the first six represented in table 3.1, type of emotion, direction, velocity, orientation, arms position and head position. The graph should be interpreted as follows: for each emotion, in x axis, there is a bar, whose value, on the$y$ axis,

Table 3.1: Features characterizing emotions

	Type of emotion	Direction	Velocity	Orientation	Arms position	Head position	Eye color
Happy	Positive	Mixed	Fast	Changes	Up	Turn	Yellow
Anger	Negative	Mixed	Fast	Changes	Up	Turn	Red
Disgust	Negative	Mixed	Slow	Changes	Up/Down	Turn	Green
Fear	Negative	Mixed	Fast	Changes	Up	Turn	Black
Surprise	Positive	Forward	Fast	No changes	Up	Straight	Yellow
Sad	Negative	Forward	Slow	Changes	Down	Turn	Blue

corresponds to the number of features shared between both. A result of 5 means that the emotion in x axis is compared against itself, thus having the maximum of similarity. In this way it is possible to compute the distance between the maximum of similarity in a group (5) with each one of the similarities degrees of others emotions: for instance for the first group *Happy*, the maximum ($Happy - Happy$) is 5 and, as an example, the distance can be computed as:

$$distance = \sqrt{(5-4)^2 + (1-1)^2} = 1, (Happy - Fear) \quad (3.1)$$

$$distance = \sqrt{(5-1)^2 + (1-1)^2} = 4, (Happy - Sad) \quad (3.2)$$

The first pair has a smaller distance, thus it has a bigger similarity degree than the second one.

It may be concluded that *Fear* has more similar features with others, namely with *Anger* and *Happy*; while *Sad* is the opposite, showing to share few details with *Fear* and *Disgust* and having nothing in common with *Surprise*. *Happy*, *Fear* and *Anger* seem to have more in common than the joints between *Happy* and any other, which may come as a surprise, since the first is a positive emotion, while the later ones are negative emotions.

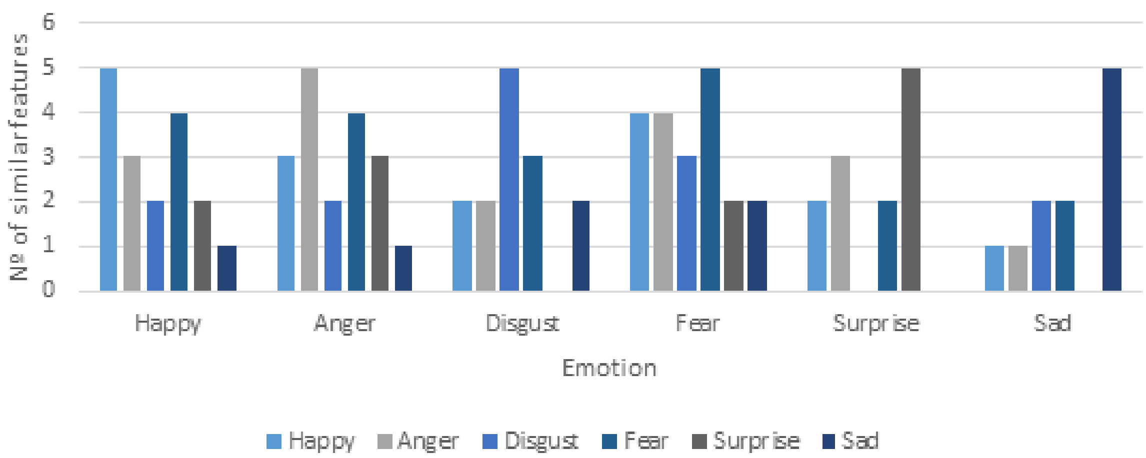


Figure 3.2: Correspondence between emotions

As previously said, the statements in this section are meant to be compared against mathematical results, obtained after the trajectories are established, in section 3.3.

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 [36], Pchip and Bezier curves [37].

Bezier curves have been widely used to generate trajectories for robots [37,38], being useful for paths that require quick changes. The method was, initially, used for *Sad*, as it tends to have a slower and smoother walk than others. When using at least four control points, it becomes very similar to cubic spline. After some tests, and having into account the similarity of produced positions and velocities with the ones produced by Spline, Bezier ended up not being used.

Another interpolation method used was Pchip. Pchip interpolates the given vectors, x and y, at specific intermediate points, in order to preserve the shape of the data and respect its monotonic nature. This method produces tighter curves that can be employed in paths where curvature is not required. It doesn't oscillates as much as spline curves, producing straightforward paths. It also showed that produces good results for trajectories expressing *Anger*, *Disgust* and *Surprise*.

Cubic spline also generates smoother curves, with less bumps and wiggles, than others as pchip. It is computed in a similar way as pchip. The difference is the choice of the slopes at each x (each point introduced is defined as an x,y pair), which is performed in order to produce a continuous second derivative leading to smoother outcomes. It is advantageous for trajectories that require sharper curves, because it computes the interpolation points in order to preserve the shape with low computational costs [36].

Cubic spline curves was the chosen method to produce the trajectories, except the one for *Disgust*, producing continuous paths that improve the self-expressiveness of the robot. *Disgust* trajectory is created with pchip.

3.2.3 Body Movement

This section explains how trajectories were created, describing for each one the intended emotion. To accomplish it, first an observation of each emotion in different situations, as people walking in the street, Youtube clips and films, was done, see figure 3.3. Additionally, several studies were considered, and many ideas were collected, regarding arms and head position, and eyes and mouth expressions.

Someone might infer why a specific trajectory is related with a specific emotion, or why one trajectory can only be related to one emotion. The answer is subjective since each trajectory is one, of many possible trajectories that humans perform, thus there is not a unique trajectory-emotion correspondence.

(a) Anger example: Eminem-Not afraid from *https://www.youtube.com/watch?v=j5-yKhDd64s*

(b) Happy example: *Mamma Mia* film

Figure 3.3: Examples extracted from Youtube and films

It also can be asked, how much truthfulness is there on the reasoning that led to the trajectories design. Dittman [39] answers that only probabilistic declarations can be claimed about how one would express a certain emotion, which means that the statements made can be seen as being admissible. Thus, the reasoning derived from common sense can be used, however, it also could have come from others sources, generating new results. Hence, the way features are combined can lead to the recognition of some feeling by one person, as well as being recognized as other by someone else. It is expected that some features are characteristic to some emotions, while others need a combination of features to be recognized.

Another relevant point is the position from where someone is in relation to the robot when perceiving emotions. The perception someone has might not be the same as other if, for instance, one is in front of the robot and the other one is behind it.

The creation of trajectories requires some attention when choosing initial points (of position and orientation) for interpolation procedures, because it can have a significant effect on the resulting trajectory. The transition from what it is intended to show, with the new trajectory, to what isn't supposed to happen is very small. After interpolation, the data regarding positions in x and y direction, orientation, and positions of head, are stored in a file, and given to the navigation code. The code also receives eyes colors for each position, and respective mouth design. Following sections describe the robot movement using only its lower body.

It may be asked why implement the selected emotions on a robot which interacts mainly with children. A partial answer was given in section 1.2. A more complete 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.

3.2.3.A Happy

Happy is one of the society‘s goals, and there is not a unique definition for what is it or how is it felt. People feel it when interacting with others or achieving goals in life, and show it through actions. *Happy* is the first emotion being discussed, having a big role on the interaction between robots and humans.

One of the scenarios from where someone can extract cues, concerning how *Happy* is expressed, is dance [8, 23]. Since this emotion is associated with fast movements and large amplitudes, the created trajectory has a variety of curves and changes concerning robot‘s orientation. It is intended to show that the robot is *Happy*, and wants to make others feel it.

Modern dance [8] tries to create a connection between human emotions and dance movements, hence providing relevant body cues to recognize emotions. The trajectory created, shown in figure 3.4, intends to show it by displaying a continuous and irregular movement. 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 values of velocity allows to move the robot quickly 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.

During the construction of the trajectories, it was concluded that both cubic spline and pchip have a similar behaviour concerning this emotion. The first trajectory, in figure 3.4, shows a dancing robot which has a more fluid movement than the one obtained with the second trajectory. The differences between the two methods are recognizable in the loop part, yielding to smoother curves with spline method. Also, spline allows the robot to use more space when performing the trajectory.

3.2.3.B Sad

Sad does not have a unique characterization 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

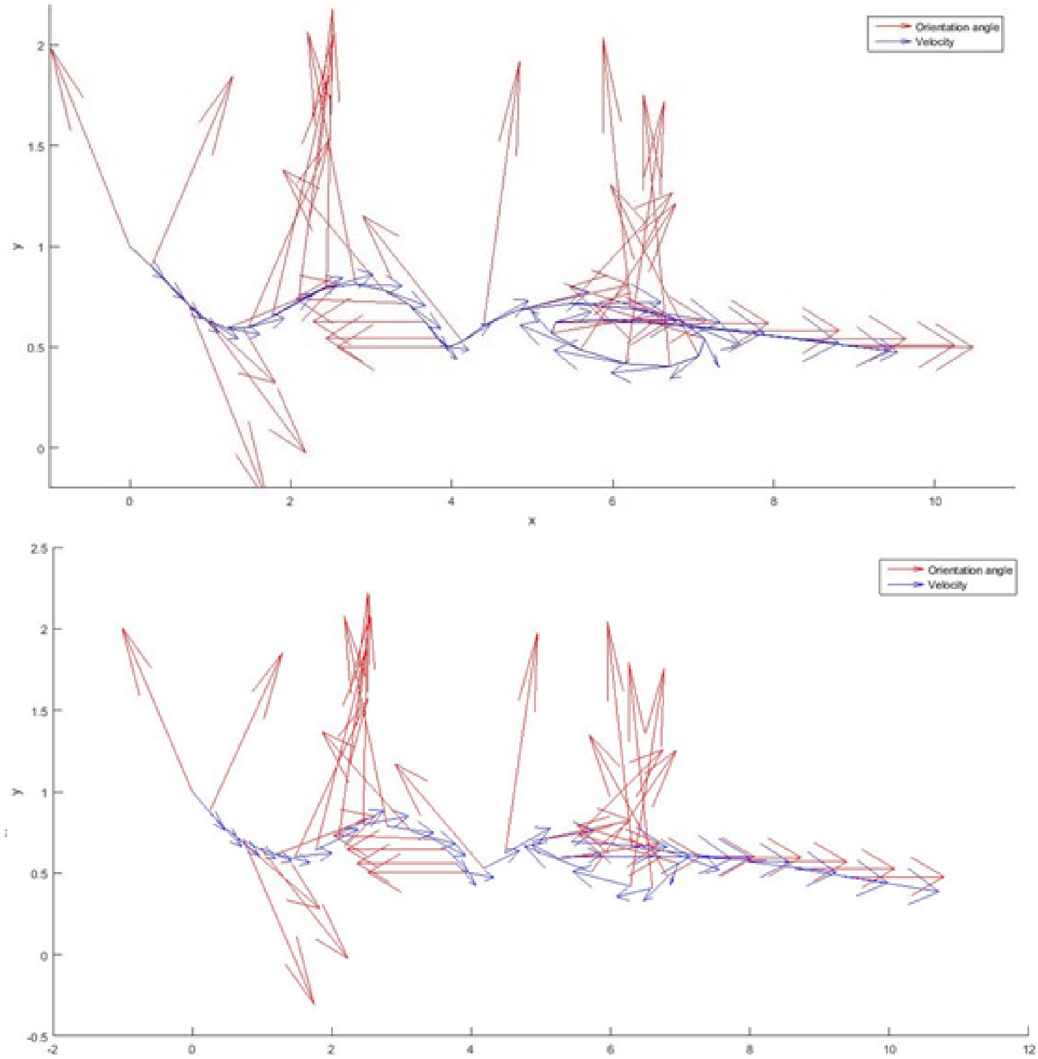


Figure 3.4: Happy trajectory: first uses spline, and second uses pchip interpolation

not straight and it can last for a long time.

For this emotion velocity plays a big role, as bigger velocities are not necessarily needed, however they also cannot be very low (the robot is *Sad*, not tired or exhausted). To achieve the “right speed”, several test had to be performed. Figure 3.5 shows the trajectory created for this emotion which should be easily recognized by the bystanders.

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

After Matlab interpolations it can be concluded that pchip and spline methods are very similar, with some differences relative to angles of curvature. Spline produces larger curves comparing with pchip, however these conclusions will only be acceptable when seeing the robot‘s movement. It is expected that

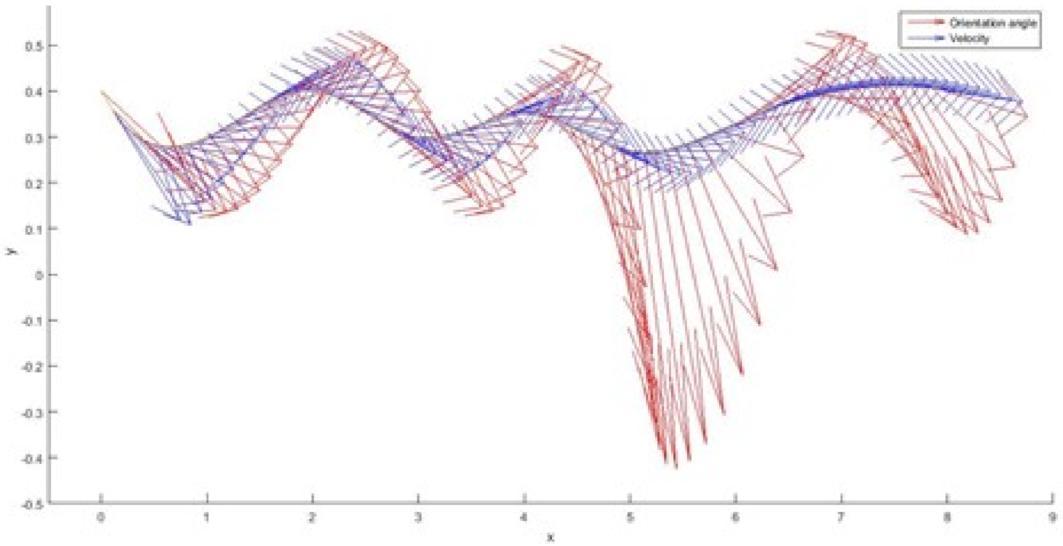


Figure 3.5: Sad trajectory

those differences won't be perceivable as they are in simulations. Bezier interpolation produces a different curve, despite having the same data than the ones before. The results work well for *Sad*, since they show the characteristics mentioned above (low speed and looks to one side and then the other). Spline also produced good results, being the chosen one.

3.2.3.C Disgust

Feeling *Disgust* is the same as feeling revulsion in response to an unpleasant situation. When someone is disgusted about something, usually they show it by making an "ugly face", showing that they disapprove or do not like something [40]. Thus, *Disgust* also does not have characteristic body movements, but rather distinctive face expressions. For this reason, the creation of movements for it is difficult if no others body parts are changed, namely the face. It is expected that suddenly velocities and orientation changes are able to give the impression of repugnance. Concerning other body parts, typical movements would be large head amplitudes, lifting arms in front of the body and closed body movements.

First trajectory of figure 3.6 shows the final trajectory used to express repulsion by something. The robot is walking and, at some point, sees something that it doesn't likes, stopping and moving back to the side. It gives the impression that the robot is looking to the disgusting object, and then turns suddenly to the original position, going on its way.

Unlike the others, pchip was the chosen interpolation method to compute the trajectory. This method allows people to better realize that the robot saw something bad and it wants to go away. Pchip produces a more linear backward movement, comparing with spline (second trajectory in figure 3.6), showing to the bystanders that there was an impulsive change in robot's mood. After seeing both trajectories, it can be concluded that spline does not produces the impulsive behaviour intended to express this emotion.

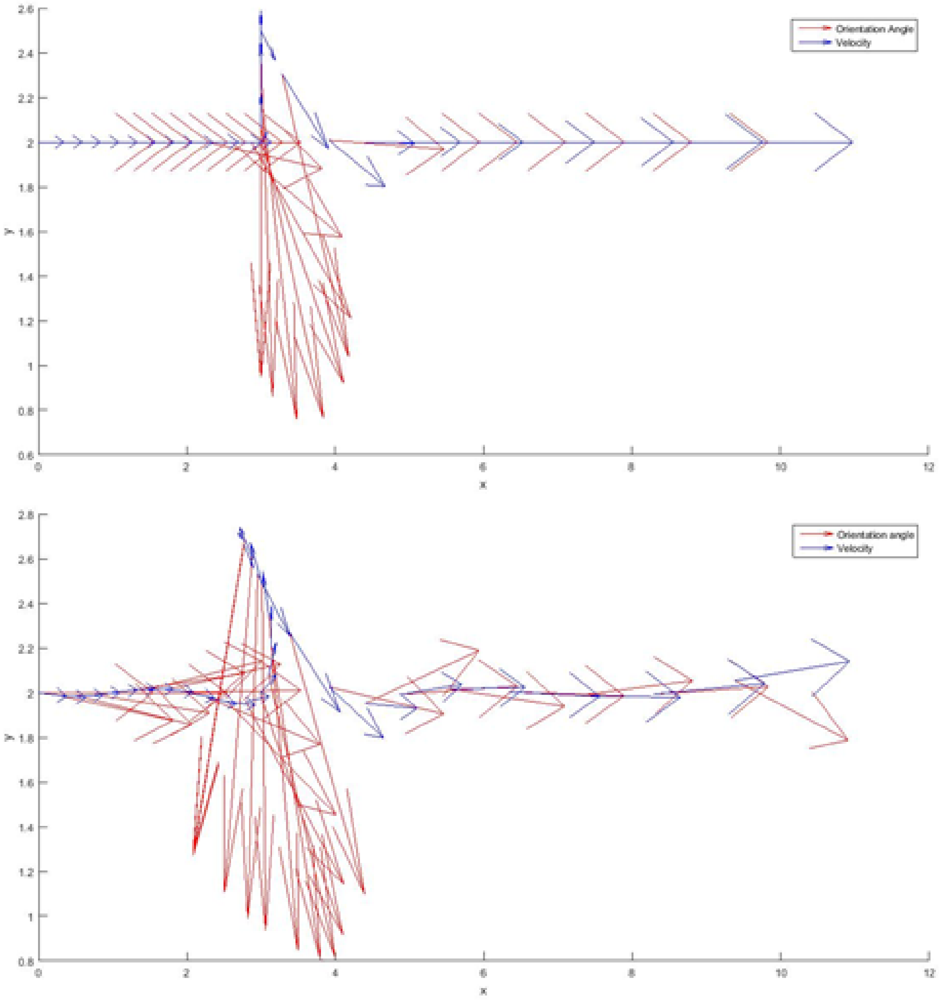


Figure 3.6: Disgust trajectory: first uses pchip, and second uses spline interpolation

Results using Bezier interpolation led to the conclusion that the method does not generates the intended trajectory, since it interpolates the given points independently of the order provided. Thus, it does not produces backward trajectories, not being relevant for this emotion.

3.2.3.D 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, thus a way of showing it with the robot is to make it to move forward and backwards, modifying velocity along the path, as if the robot was trying to intimidate someone. The trajectory created for the robot should have a short duration of time and display sudden changes both in velocity and orientation.

To represent it, the way rappers/hip-hop singers present their feelings in their songs was one of the

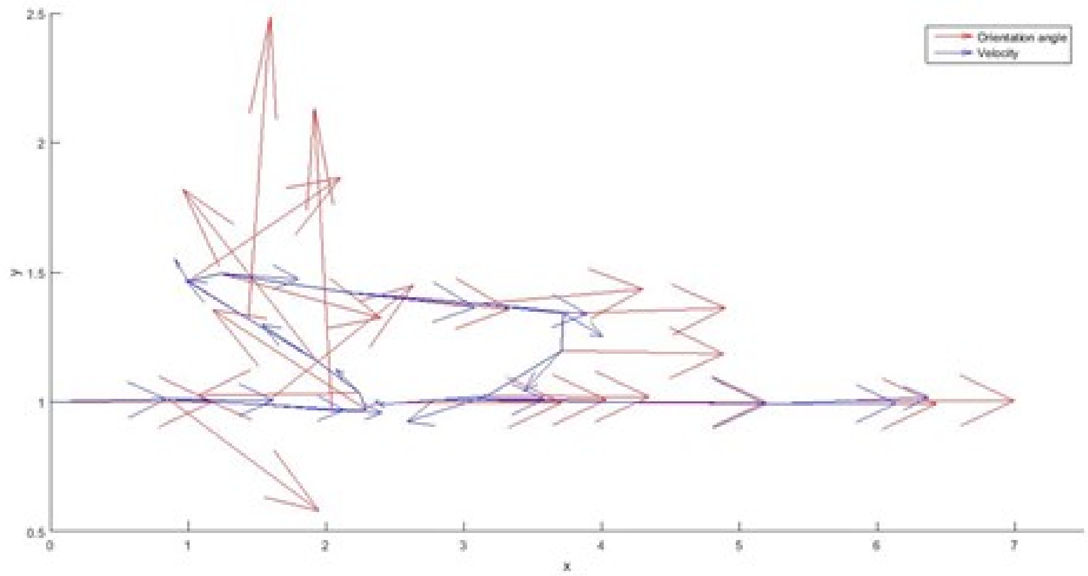


Figure 3.7: Anger trajectory

chosen scenarios 3.3a, because of their strong and impulsive movements. The implemented trajectory, in figure 3.7, 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. Orientation is an important variable since, for instance, if the robot changed it many times, the outcome perceived by the bystanders would be very different from the one intended. Its movements could be viewed as if it was disoriented or worried.

The interpolation method used was spline, however there are not almost any differences when using pchip. Spline allows the robot to show well defined and stiffly movements, giving the perception that it is undecided. Bezier method does not allows to produce trajectories wherein the robot inverts its direction, that is, the robot cannot comeback to a previous position, which, regarding this emotion, is not interesting.

3.2.3.E 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 in trajectory, accomplished by oscillating the given velocity and orientation. Figure 3.8 shows the trajectory designed to represent it.

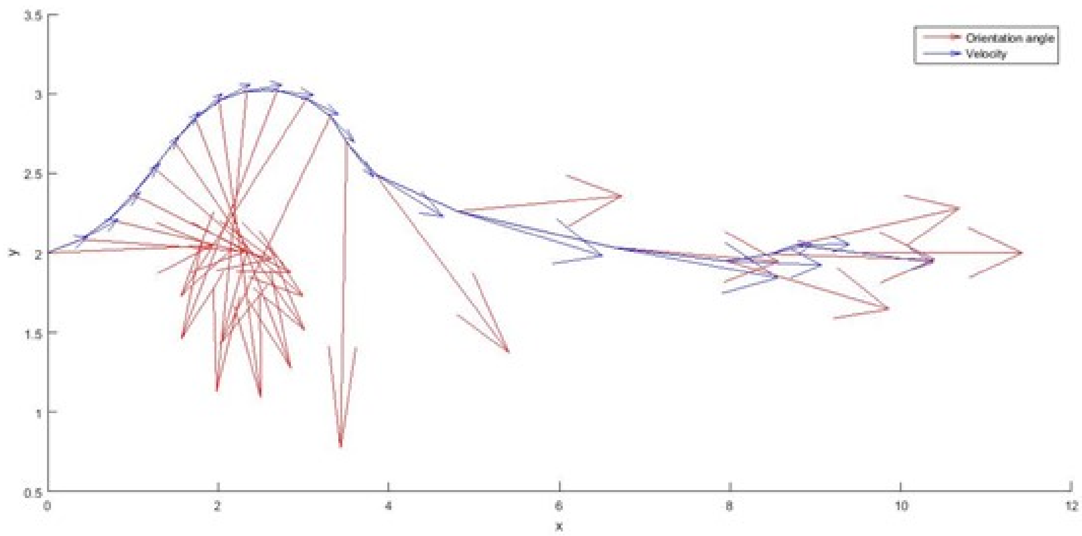


Figure 3.8: Fear trajectory

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, slightly turning 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.

Both spline and pchip work well to mathematical represent *Fear*. The robot orientation is important to enhance the moment when MOnarCH feels afraid.

3.2.3.F Surprise

Surprise is a state of mind activated by unexpected reasons which raises our eyebrows and opens our mouths, in an "o" form. According to surprisologist Tania Luna [41], surprise has always the following steps: "freeze and pay attention, get curious and find an explanation, shift perspective, and lastly share the experience with others".

Body reactions to good and bad surprises were studied in this work. In a good *Surprise*, people tend to increase their body movement, running towards the thing that made them feel good. Besides the speed up, someone can also turn on itself or run from one side to another. In a bad *Surprise*, people tend to stop abruptly and suddenly walk backwards. For example, when receiving bad and unexpected news, people will stop and think or act accordingly.

In order to facilitate the recognition of this emotion, the robot should be set up to some kind of trajectory that anticipates the surprised moment. First the robot walks naturally, unpreoccupied, and then, when surprised, it starts to become excited and stops briefly. Then walks again, speeding up. Final trajectory is shown in figure 3.9.

The interpolation method used was Spline. The results with Pchip are almost the same, except for

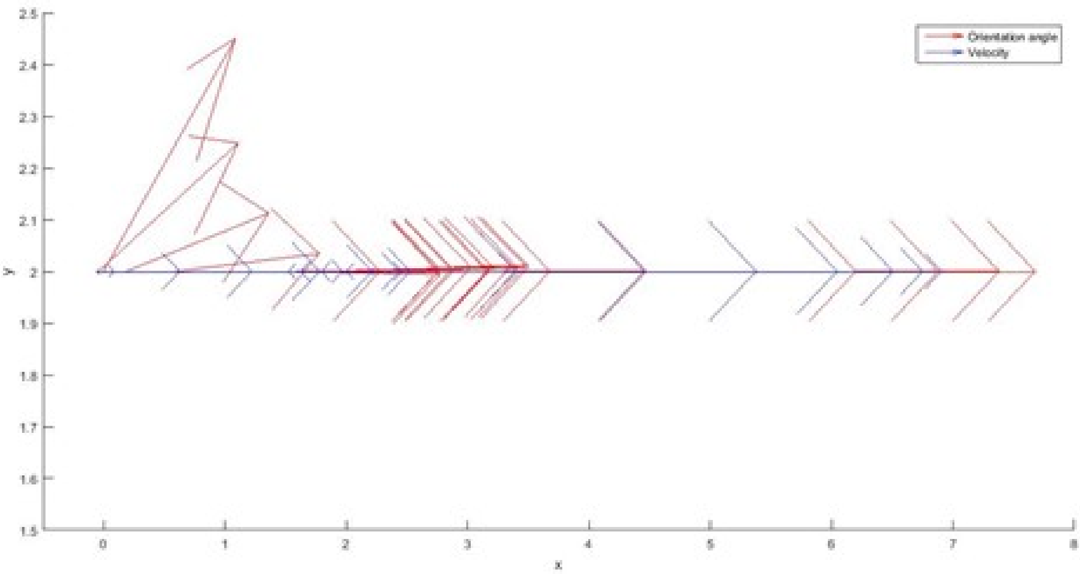


Figure 3.9: Surprise trajectory

minor changes in velocity. The simulated trajectory aims to satisfy the requirements imposed before.

Figures 3.4, 3.5, 3.6, 3.7, 3.8 and 3.9 were created in matlab. The red arrows represent the robot‘s velocity and blue arrows represent its orientation. Velocity was computed using the gradient of x and y positions, and orientation by calculating the sine and cosine of the robot‘s angle in each position. Both were plotted using *quiver* function from matlab.

3.2.4 Head Movement

After creating the trajectories for MOnarCH robot it is interesting to see if its expressiveness increases when adding movement from others body parts. 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 [12].

The addiction of head movement was studied in [12], wherein is created an affect space with a wide range of emotions, described by arousal (level of energy), valence (quality of a stimulus) and stance (how approachable the stimulus is) dimensions. Results concluded that moving the head down is linked with negative emotions, while moving it up is linked with positive ones [1]. MOnarCH‘s head only has one degree of freedom, which is move it to right or left; thus movements as lowering it down or lifting it up are not possible to execute.

Since the trajectories being studied are set up at this point, the design of the head movement was done as being dependent on them. Hence, the movement from this body part should follow and agree with the rest of the body movement designed. For positive emotions, as *Happy* or *Surprise*, head usually moves energetically in each direction, unlike negative ones, as *Sad*. A detailed explanation concerning the created movements is done next, and their mathematical representation is shown in figure 3.10.

- *Happy* (yellow): typical spontaneous and irregular behaviours, with fast changes in orientation, producing fluid movements. The goal is to lead the audience to an excitement and joyful moment, by looking around and reaching everyone with its look.

- *Anger* (red): the robot almost does not moves its head as the goal is having it always facing the target. It attempts to create an unpleasant moment by showing a rigid and ”robot-like” movement.

- *Surprise* (orange): (as for *Anger*) is also with the robot moving from A to B in straight line, but since this one is typically a state of excitement (positive emotion), its head moves to one side, instants before its time to show that something surprised it. The slightly side move behaves as a signal to catch people‘s attention.

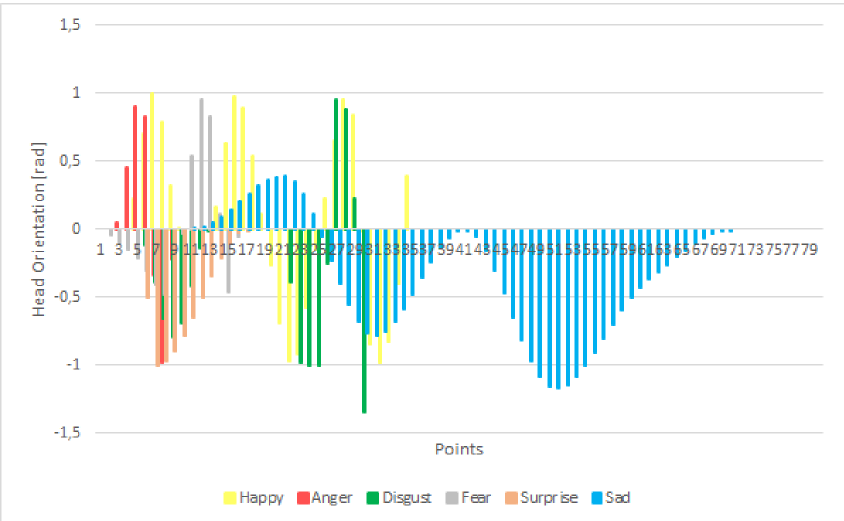


Figure 3.10: Head Movement

- *Disgust* (green): when the robot “faces” the “awful object”, looks at it, and then turns its face away, as if it was nauseous. Since the body movement, when it sees the “awful object”, is to move abruptly away from it, the head, instead of looking aside, turns to that object. This kind of trajectory is also intended to lead people‘s eyes for a focus point that made the robot to go away from.

- *Sad* (blue): this emotion has a very different behaviour from the previous ones. 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, for example *Happy*.

- *Fear* (gray): (as for *Disgust*) the robot expresses *Fear* by moving away from its initial direction, and looking to it. In order to enhance the key point, its head moves also there but then turns to the same direction of its body, showing that something made it "feel" afraid and it wants to run away.

  This is a relevant difference comparing with *Disgust*: in *Disgust*, when facing the focus point it looks at it, for some instants, and only then it moves away. *Fear* is the opposite, moving almost instantly its head to the other side of the focus point.

3.2.5 Arms Movement

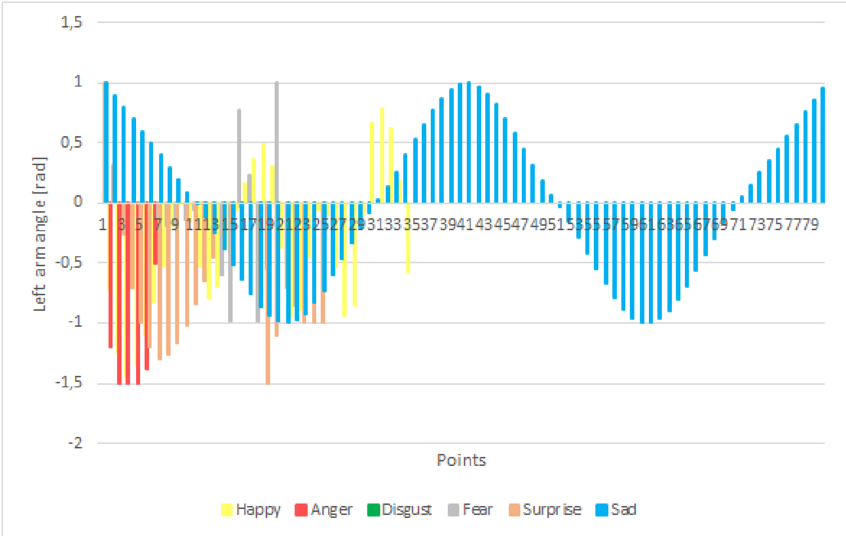
Arms movement is another important feature that alone does not have a big impact, but when added to the entire body improves the perception of the bystanders. MOnarCH‘s arms have only one joint (the shoulder), which reduces by far the amount of movements that it could be do if it had the same degree of freedom that humans do. This joint goes up and down, thus movements, as the ones studied in research [10] which show the importance of arm openness (associated with positive emotions that are translated in a receptiveness to others), will not be possible to execute. Other robot‘s restriction is the absence of hands. This is not crucial to the recognition of basic emotions, however, it could be interesting to shake robot‘s hands, for instance, when moving in a *Fear* trajectory.

When generating arms movement, first it is helpful to think for which emotions this body part would produce a significant impact, reaching to the conclusion that emotions as *Anger* and *Happy* are enriched by it. Figure 3.11 shows the arms orientation, in radians, where positive angles lowers the arms, while negative angles moves them up, followed by a detailed explanation next.

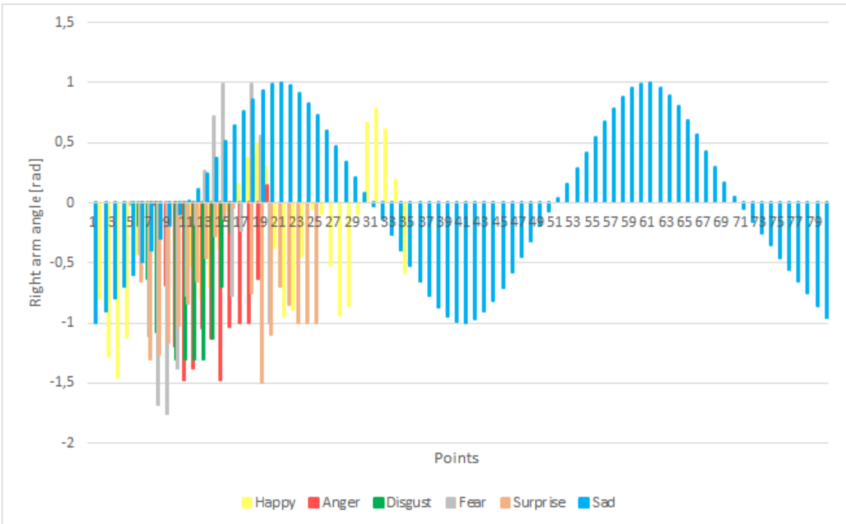
- *Happy* (yellow): (as for head movement) the goal is to show quick and inconstant actions. The robot expresses it through a continuous and parallel movement of both arms (exaggerates it further), especially in the end of the trajectory where they move up and down at same time (to express an excitement state).

- *Anger* (red): based on the youtube clip referred in figure 3.3a. To display this emotion usually there are big arm thrusts, pointing forward, sometimes with 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. Also for this emotion, the position of the arms in relation to the body center is higher than for others.

- *Surprise* (orange): (as for head movement) the trajectory designed in section 3.2.3 influenced greatly the design of arm‘s movement. The robot, in the middle of the trajectory, moves its arms up, displaying enthusiasm and interest for something. Its body stops, moves a little bit backwards and then doubles-quick towards others, with its arms up. This allows for a bigger interaction



(a) Left arm



(b) Right arm

Figure 3.11: Arm Movement

between the robot and people, since it seems that it is welcoming and it wants to connect with them. Almost, as if it was surprised for seeing us.

- *Disgust* (green): the robot almost doesn't moves its arms, using one of them, at the middle of the trajectory, to point out the object that it doesn't like. The trajectory initially produced also had a big influence regarding the movement of robot's arms.

- *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, like if it was tired and depressed.

- *Fear* (gray): arms enhance greatly the expression of this emotion. At the beginning, the robot lifts up one of the arms to amplify the movement. Then, as its body starts to escape, arms go down and move alternately for a while, to give the impression that it is running away.

3.2.6 Facial Expressions

Facial expressions provide the principal body cues concerning emotional feelings [42], being eyes and mouth two of the most relevant parts of the face. It is expected that adding facial expressions the recognition of emotions becomes trivial.

Due to MOnarCH structure the variables that can be changed regarding its eyes are color, velocity of change and intensity. The colors used to express each emotion were based on [22]. Therein, is investigated how LED patterns, in eyes of Aldebaran's Nao robot, could be used to imitate human emotions. Both velocity of change and intensity were studied by changing its eyes and inferring about what was expressive enough for a specific emotion. Figure 3.12 shows some of the MOnarCH expressions used to express a specific emotion.

Figure 3.12: MOnarCH's facial expressions: *Happy, Sad, Disgust, Fear, Surprise* and *Anger*

Although people do not change the color of their eyes, colors of MOnarCH's eyes change, not only to increase the connection towards others, but also to highlight the moment in which there is a change of moods. Next list describes all the assumptions used to create eyes expressions:

- *Happy*: associated with yellow, being linked with contentment and relaxed situations. Several shades of yellow (some almost orange) were used, which change as the robot moves. This helps people to have a better vision of the robot, as being a more interactive and "real" machine, instead of something monotonic.

- *Anger*: linked with red, by common sense and [22]. This color is associated with hot opposing emotions, as passion or aggressiveness, being the chosen one to show a negative emotion as this one.

- *Surprise*: it uses both shades of yellow and blue, being the later one, the chosen to emphasize the surprised state itself. Once again, color changes over time to show a ”living” machine.

- *Disgust*: green is the selected color, since it is related with melancholy and nauseated moods, which elicit this kind of feelings [43].

- *Sad*: blue can be linked with several states of mind (calm, reflection, pleased), being used to express *Sad* and *Fear*. *Sad* is not a pleased emotional state, however some argue that light blue can be related with it [22, 43].

- *Fear*: associated with dark colors [22], as black or gray. Using these colors would be the same as having the leds of the eyes turned off and, if using the leds from mouth the resulting face expression would look very strange. Thus, it was decided to use blue, provided that others body parts were sufficient enough to show it.

The mouth design was based on cartoons expressions, and some ideas were derived from [42]. New facial expressions, such as happily surprised, sadly fearful or angrily disgusted, are created through a Facial Action Coding System [42], derived from the six basic emotions. In total 21 emotions are shown, being among them the six emotions studied in this work. Study [15] 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. Their results show that children were as good as adults in recognizing its facial expressions, with the exception of *Surprise*.

When recognizing the emotion being shown through mouth, is expected that the overall outcome be easily identified by the bystanders. As for eyes, the shape of the mouth also changes during the trajectory, enriching the expressiveness of the robot and showing a bigger set of expressions.

- *Happy*: recognized by a smile, with mouth sides pulled backwards and slightly upwards [12], almost as if the mouth was getting closer to the nose. Robot‘s mouth changes between the one shown in figure 3.12 (the first expression), and another version which resembles an inverted triangle, upper lip almost straight and lower teeth appears (a big laugh).

- *Anger*: it is one of the expressions for which the mouth design is difficult, because of the way mouth is implemented on the robot (leds). People generally pull a face towards the aspect that they do not like. Their lips are either tightened together with a clenched jaw, or the mouth becomes square to expose the teeth clenched. An expression similar to this one was designed (last image of previous figure).

- *Surprise*: humans produce an “Oh” sound when expressing it. This sound makes them open their mouth in an “O” form, with a dropped jaw and parted lips. The robot, in the beginning, starts the trajectory with a smiley face, changing then to an expression similar to the one shown by humans, which allows to intensify the *Surprise* moment. Figure 3.12 is an example of it, picture at the middle of the second row.

- *Disgust*: expressed with 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. To show it, one side of the mouth is up and the other one down, as if the mouth was producing an "hmm" sound.

- *Sad*: human's mouth expression is with the mouth corners down and the chin raised. A trembling lip may appear, if tears start to fall. To not show always the same design of a *Sad* mouth, during the trajectory, a small version of the one shown in figure 3.12 was created. This other version is similar to 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, to create that effect, it was created a zig-zag expression. The shaking of the mouth is achieved by flashing the leds.

During tests, each emotion was recorded from one of the cameras available at the Mobile Robotics Laboratory (LRM - Laboratório de Robótica Móvel), see figure 4.1. The trajectories were filmed with the robot walking towards the camera. From the videos, images were extracted and overlapped in order to give a better view of the trajectories over time, using Adobe Photoshop. These images are shown in 3.14 and provide a static look of MOnarCH's movements.

Figure 3.13: Mobile Robotics Laboratory (LRM)

Referring to *Happy* trajectory it should be noted, at the middle of the figure, the part when the robot is with its back to the camera and then turns to it again. That moment sets the kind of emotion it is showing, which looks like as if the robot was skating or dancing. On the right side the robot is expressing *Sad*, using a smaller space, when compared with *Happy*, and looking slowly to each side.

Concerning *Disgust*, the recording was not as good as for others. It is difficult to recognize the moment when the robot moves away from its initial path (most distant part of the image). Image of *Anger* may be also difficult to interpret: in the part where there is image overlapping is the part when the robot changes direction for brief moments, walks towards to the camera and then backwards again (with one arm up).

Fear trajectory is easier to read. There is a moment at first, where the robot looks and moves to the side, increasing then its speed to run away. On the side, the robot is with its arms up showing *Surprise*, and moving in a straight path.

Figure 3.14: MOnarCH's expressive trajectories

3.3 Estimation of Features

This section presents the mathematical analysis done using the data from Matlab interpolations. The purpose is to identify key features in order to distinguish emotions. They also can be used to, automatically, map a trajectory into an emotion, using SVMs (support vector machines) as classifiers [44].

SVMs are an important topic in Machine Learning field, and consist of supervised learning models used to classification or regression problems. The algorithm for classification works as follows: it receives as input data a training set: $(x_1, y_1), ..., (x_n, y_n)$, which in this case $x \in \chi$ would be the extracted features, and maps them into classes, $y \in Y$ (representing emotions); hence solving the mapping $\chi \to Y$. The goal is to find the maximum-margin hyper-plane which divides (for example in two), the group of points $\overrightarrow{x}_i$, for which $y_i = 1$ (note that 1 refers to one of the classes/emotions), from the group of points for which $y_i = -1$ (-1 refers to other class/emotion). The hyper-plane is defined in order to maximize the distance between it and the nearest point $\overrightarrow{x}_i$, from either group.

3.3.1 Body Features

3.3.1.A Fourier Analysis

The Discrete Fourier Transform (DTF) is used to analyze signals with respect to their frequency response, decomposing the data (initially represented in time) into frequency components [45]. To compute it, Matlab function *fft* (Fast Fourier Transform, FFT) was used. FFT is computationally more efficient than DFT. This mathematical tool is important for signal processing because is easier to analyze small parts of a signal, instead of the entire signal. In (3.3) X_k corresponds to the frequency amount of current frequency (k), x_n is the value in time domain, N is the total amount of time samples of the signal and n is the current time sample.

$$X_k = \sum_{k=0}^{N-1} x_n e^{-i2\pi kn/N} \tag{3.3}$$

Figures 3.15 and 3.16 show the results of applying Fourier transform on x and y positions. The plots were computed in Matlab, using *fft*, with the following input parameters:

- t: Time vector of input signal
- L: Length of signal-number of points
- T: Sampling period
- Fs: Sampling frequency-inverse of T
- $f = Fs * (0 : (L/2))/L$: Frequency domain

Then, using function 3.4:

$$Y = fft(X) \tag{3.4}$$

the Fourier transform was applied to the variable being studied.

In 3.15, X corresponds to the points, in x direction, regarding final trajectories. The Fourier plots show the single-sided amplitude spectrum (positive frequencies) of the result, since one of the Fourier characteristics is the fact that it is conjugate symmetric.

Regarding Fourier transform in x direction, the identified features from figure 3.15 were:

- 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*.

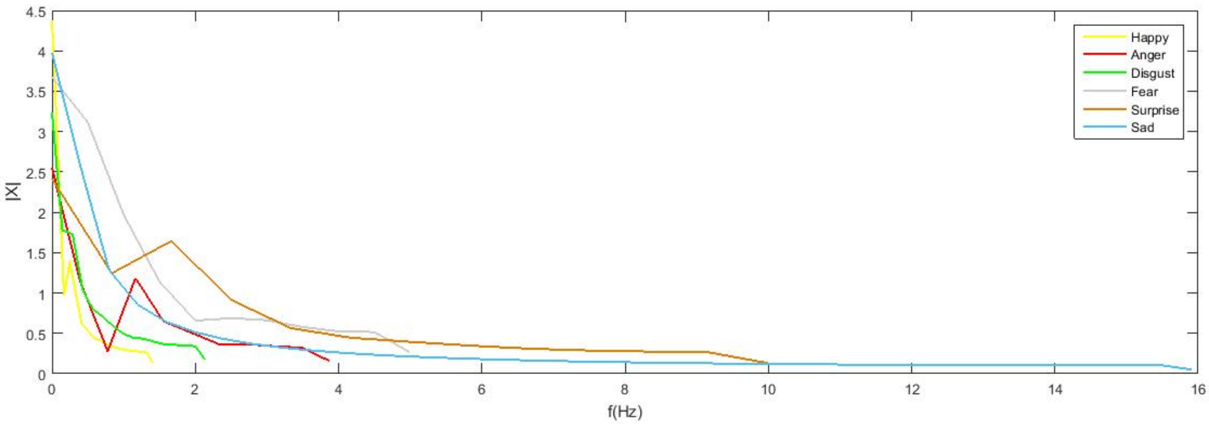


Figure 3.15: Fourier Transform applied to x direction

Figure 3.16 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*

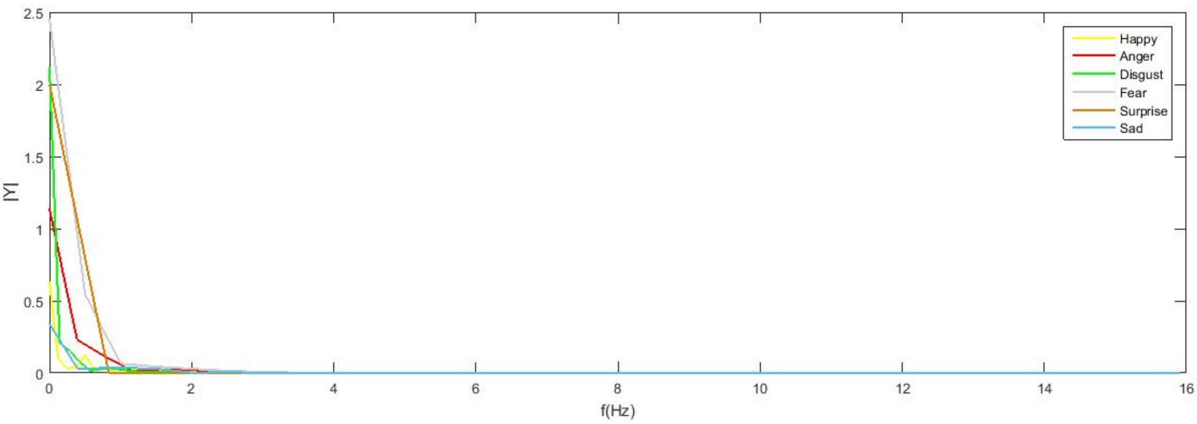


Figure 3.16: Fourier Transform applied to y direction

Figures 3.15 and 3.16 show that there is a bigger use of space in x direction, than in $y$direction, due to the fact that most movements are done in a straightforward direction.

3.3.1.B Velocity Profile

Throughout this work, the importance of velocity has been largely emphasized due to the change of perception produced. A velocity profile is presented and features are extracted. The Fourier transform of it was also computed in order to perceive better which emotions have higher frequencies, or which ones change it more frequently.

From figure 3.17, the identified features 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.

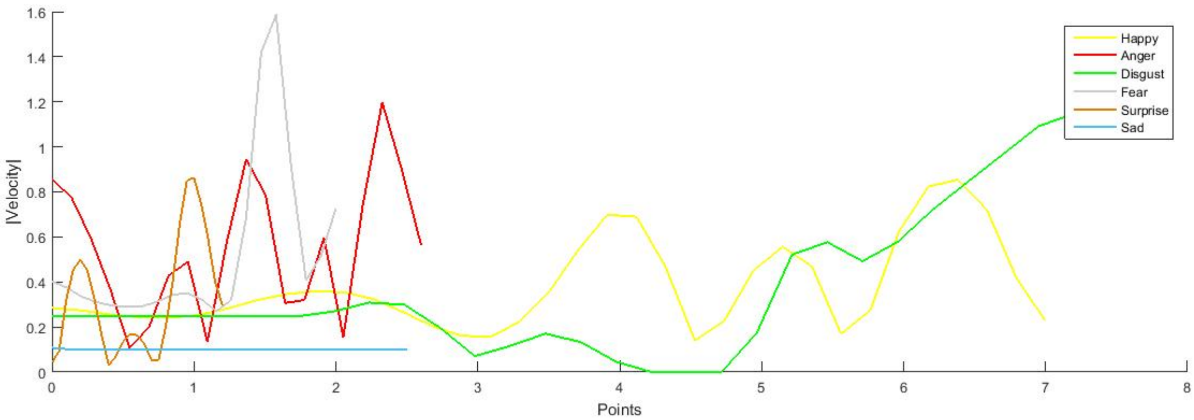


Figure 3.17: Velocity Profile of Basic Emotions

- Smaller and stable velocities (in the beginning): *Sad* and *Disgust*. However, *Disgust* starts to increase its velocity in the middle of the trajectory, reaching both null and higher velocities. Thus, a way of differentiating between them would be to check which increases velocity at the end.

- 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*, as it was concluded in section 3.3.1.A for y direction, also has a singular pattern: it starts slow, small variations of velocity, and then alternately, increases and decreases its speed.

Fourier transform of 3.17 is in figure 3.18, 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.

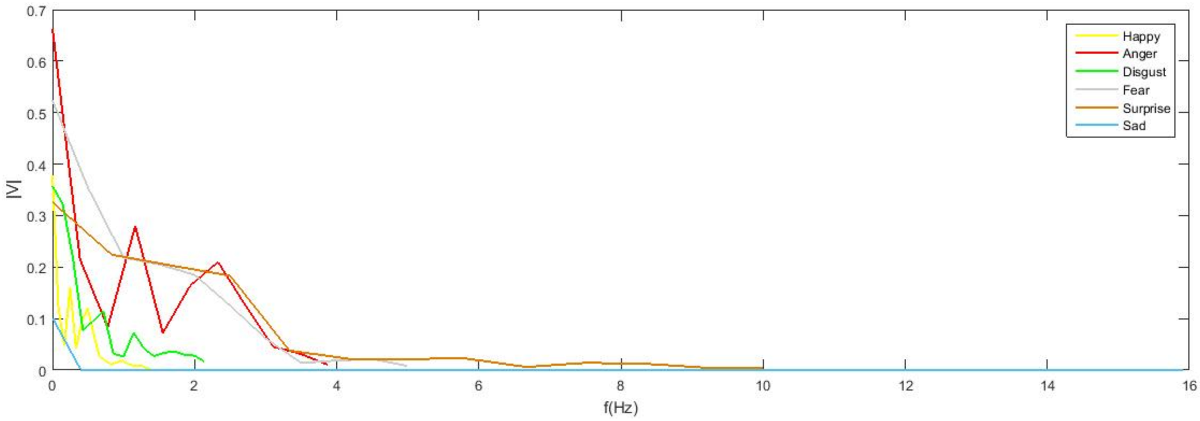


Figure 3.18: Fourier transform applied to velocity

It can also be concluded that there are some emotions that require more time to be expressed, like *Sad*, *Surprise*, *Anger* or *Fear*. This will happen for all frequency responses, because these trajectories were generated with more points, thus occupying a bigger frequency spectrum. As a consequence, tend to have their frequency peaks located in higher frequencies, except for *Sad*.

3.3.1.C Orientation

The orientations used to display each emotion are another variable that can be used to get more features. Orientation is very important because it improves robot‘s expressiveness and creates a stronger impact on people‘s perception. Positive orientations make the robot turn to the left (maximum angle - π rad - puts the robot backwards), and negative angles makes it turn forward. The features identified from figure 3.19 are:

- Null or little orientation: *Surprise*. When expressing it people tend to look forward, to the key point that got them surprised. The trajectory changes a little its orientation to create a stronger connection between the robot and the bystanders, however, the key variable is the change of velocity (already discussed).

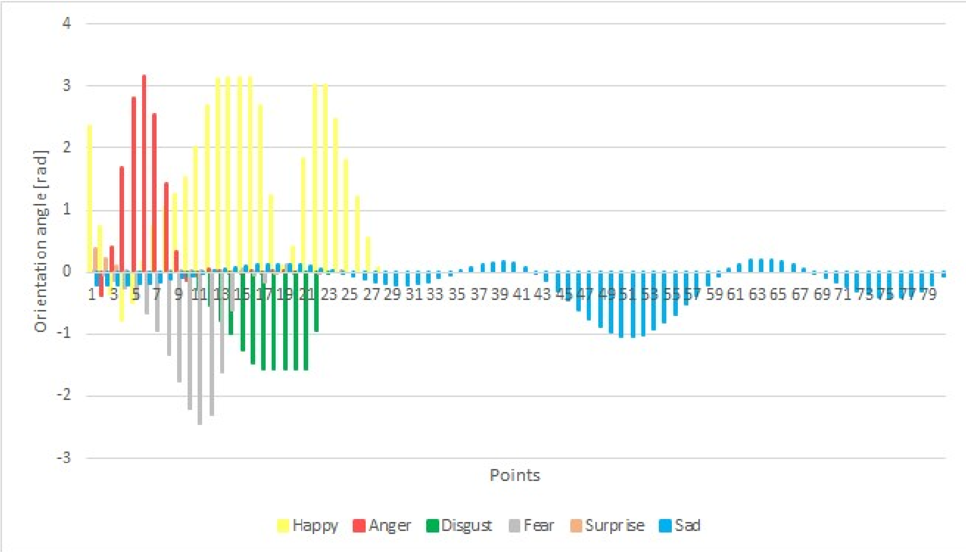


Figure 3.19: Orientation of MOnarCH's position

- 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.

At this point, it should be reminded that all identified features are in relation to the generated trajectories. For example, the feature called "Null or little orientation" used to recognize *Surprise* can be easily put aside, if a different trajectory is created. Thus, to recognize an emotion, all features should be used.

3.3.1.D Correlation

An interesting topic regarding this thesis is if it is possible to relate emotions with others, regarding their body language. A statistical measure used to compute the correspondence degree between two variables is correlation. Two kinds of results are provided below, both showing the correspondence between one emotion against itself, and against each one of the others. The first one was generated using Matlab, and displays a graphical interpretation of the data, and the second one was computed in excel (tool from office) and shows the numerical results.

The results from the matlab computations (using *xcorr* function) show the measures of the similarity between velocity (V) of one emotion and shifted copies of velocity (of the same or other emotion) as a function of the lag, figure 3.20. When a variable is computed against itself (plots shown in diagonal), its correlation is maximum for a lag of zero value. The more a signal is shifted, the smaller will be the correlation value, because the difference between the signal and the shifted signal is bigger.

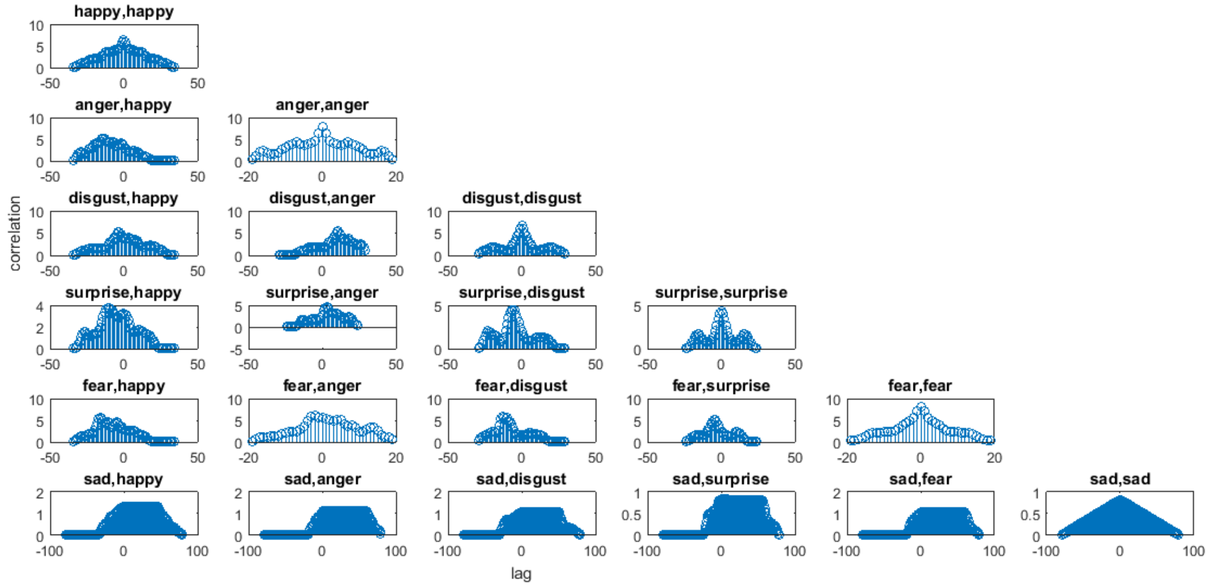


Figure 3.20: Correlation plot of velocity

For example, in plot *Happy,Happy*, the correlation value for a lag of 0 is 5, and when the second signal (*Happy*) is shifted, to right or left, the result decreases. When computing the cross-correlation between different emotions, if vectors x and V have different sizes, Matlab function *xcorr* will append zeros at the end of the shorter variable. This situation happens for all emotions, except when using *Anger* against *Disgust*, since these have the same length. The features identified are explained next:

- Number of shifted computations: *Fear* and *Anger* have a number of computations of 19, since they both have the smallest amount of points. When they are correlated against any other emotions, the number increases. 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*). They do not agree with table 3.20 because the correlation in matlab (besides the velocities values) has also into account the number of points that each trajectory uses.

  For example: the pair (*Happy, Sad*) has an approximated correlation value of 1.3 (in matlab) and 0.11 (in excel). While (*Sad, Anger*) has an approximated value of 1.12 (in matlab) and 0.47 (in excel). First pair does not make sense, since they are opposed, and the value may be due to the fact that both have the largest amount of points. Second pair makes more sense, as both are negative emotions, thus sharing more characteristics.

- 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 do not have relevant differences when correlated, with left or right versions, of others emotions.

Table 3.2 shows the mathematical values of correlation computed in excel. As in Matlab, the correlation function used, adds zero to the smaller vectors. A correlation value of 1 means perfect match, which, generally, happens only in auto-correlations.

- Maximum correlation (pairs): *Happy* → *Surprise*; *Anger* → *Fear*; *Disgust* → *Happy*; *Fear* → *Anger*; *Surprise* → *Happy*; *Sad* → *Anger*.

- Minimum correlation (pairs): *Happy*→ *Sad*; *Anger* → *Disgust*; *Disgust* → *Fear*; *Fear* → *Disgust*; *Surprise* → *Sad*; *Sad* → *Surprise*.

- Lower average of correlation values: *Sad*.

- Higher average of correlation values: *Anger*.

Table 3.2: Correlation matrix of the module of the velocity

	Happy	**Anger**	**Disgust**	**Fear**	**Surprise**	**Sad**
Happy	1					
Anger	0,352663	1				
Disgust	0,433763	0,058261	1			
Fear	0,235979	0,622405	0,032282	1		
Surprise	0,496112	0,3943	0,209741	0,284953	1	
Sad	0,117532	0,4755	0,19088	0,262394	0,059329	1

Similar values, in relation to the ones obtained for correlation, can be achieved, if the trajectories are somehow changed, in respect to velocity. However, the expressiveness of the robot would change if the resulting velocities were very different from the ones obtained, hence the recognition of emotions would be harder. For example, it would not make sense to drive a "*Sad* robot" in a high velocity, or drive a "*Happy* robot" in low velocity. Those scenarios can be created however, if the goal is to "help" people to recognize robot‘s emotions, the given velocity must be set up right.

3.3.2 Head Features

3.3.2.A Fourier analysis

A Fourier analysis of the orientation angle of robot‘s head was also computed, with the purpose to complete the analysis being done and provide more information to allow the differentiation between trajectories. From next figure following features were deducted:

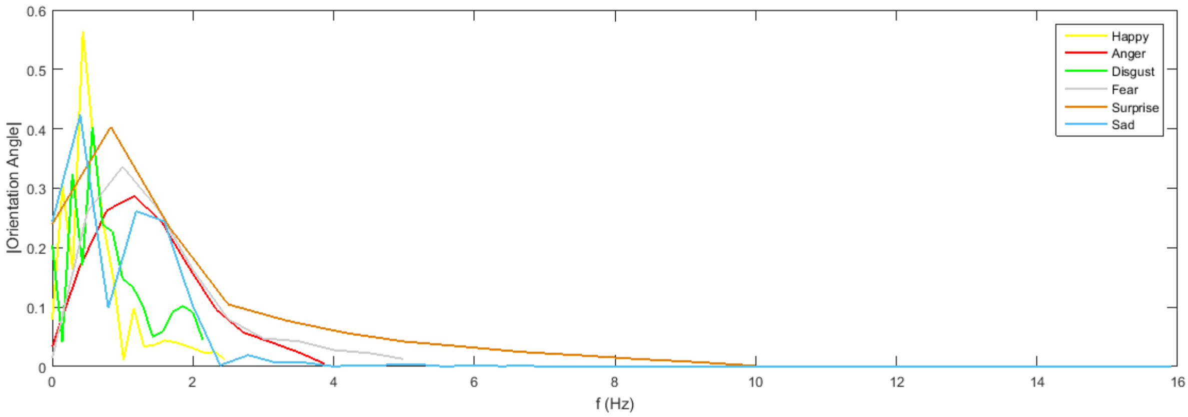


Figure 3.21: Fourier transform of head‘s orientation

- 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*.

3.3.3 Arms Features

3.3.3.A Fourier analysis

Concerning arms, a similar analysis as the one provided for head is presented. Figure 3.22 shows the Fourier analysis for left and right arms. New features were identified, namely:

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

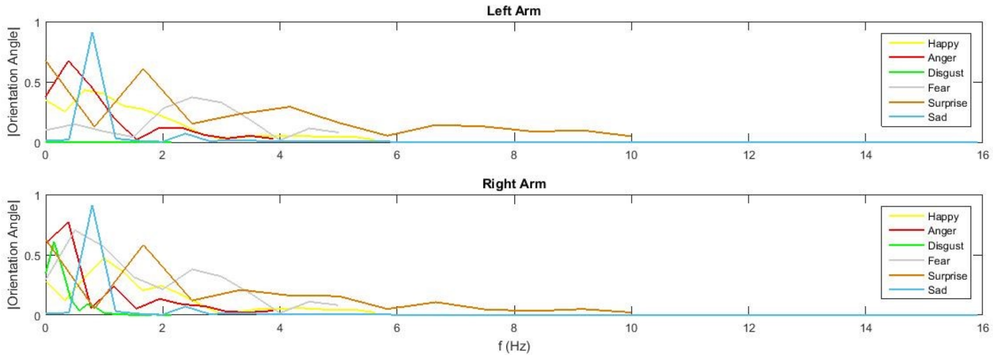


Figure 3.22: Fourier transform of arm's orientation

- 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*) appear to have their maximum value of orientation module in lower frequencies, unlike positive ones, which present their maximum in higher frequencies.

3.3.4 Features summary

In order to compare the analytical results (section 3.2.1) with the mathematical results (section 3.3), a plot of the module of the analyzed variables was created and it is shown in figure 3.23. The plot is composed by:

- In gray background are the range of frequencies for each emotion, with vertical axis between 0 and 16 Hz (right side).

- Dots correspond to maximum values of the module of:
  - Hmax, Almax, ARmax: orientation of head and, left and right arms.
  - Velmax, Xmax, Ymax: velocity and positions in x and y directions.

- Lines correspond to mean values of the module of:
  - Hmean, Almean, ARmean: orientation of head and, left and right arms.
  - Velmean, Xmean, Ymean: velocity and positions in x and y directions.

This section shows that the trajectories can be correlated to specific emotions. A set of features is provided to allow mapping trajectories into emotions. Figure 3.23 led to the following conclusions:

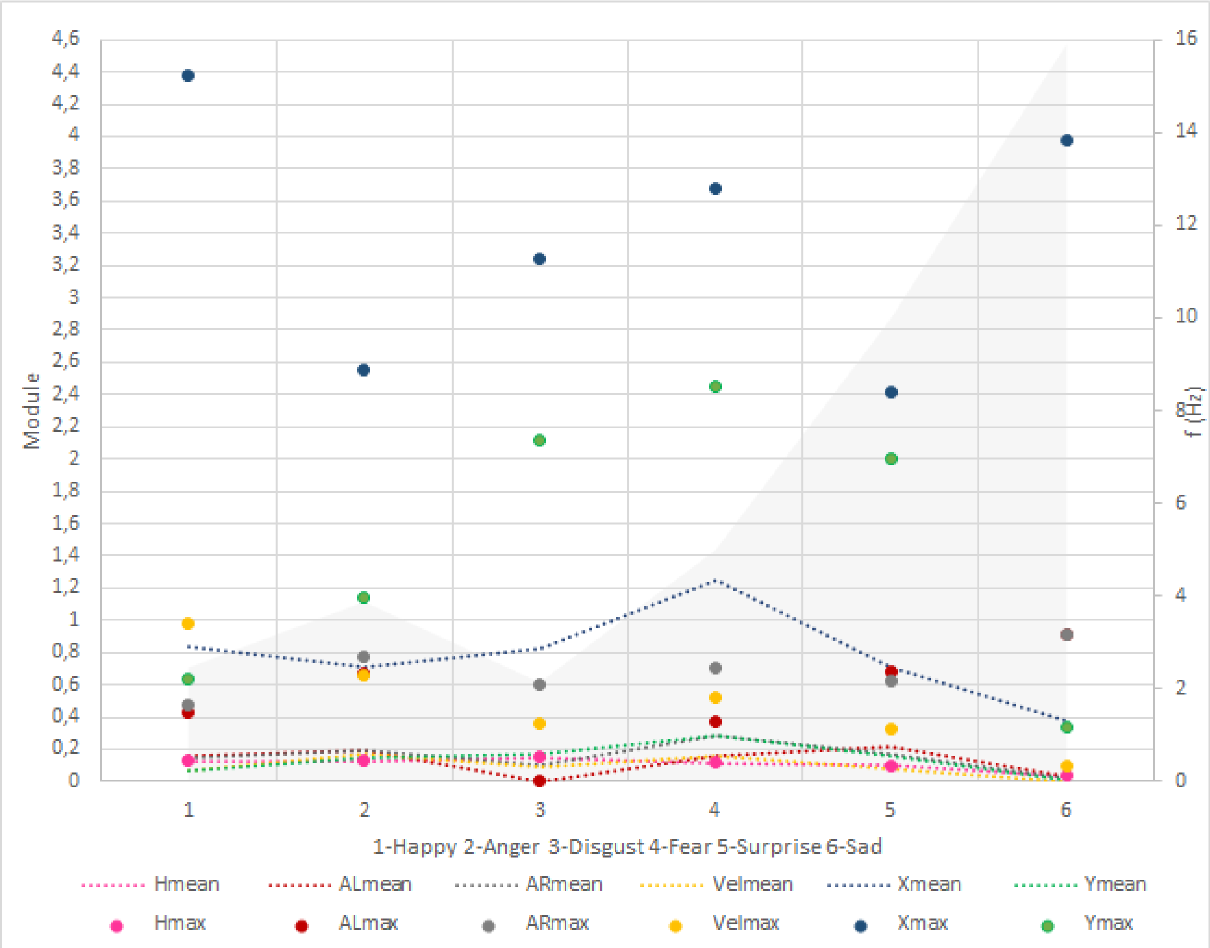


Figure 3.23: Summary plot

- *Happy* shares similar results with *Disgust* (from analytical results both were associated with *Fear*) and it can be inferred that these three are somehow connected.
- *Fear* was more related with *Happy* and *Anger*, in analytical results; now is mainly with *Anger*, which makes more sense due to the fact that they are both negative emotions. Previously *Surprise* and *Fear* were connected, mathematically *Surprise* shows to share a few characteristics with *Fear*.
- *Sad*, unexpectedly shares more similarities with *Surprise* in mathematical results, before it was linked with *Disgust* and *Fear*.
- Frequency band:
  - higher (>= 8 Hz): *Sad* and *Surprise*
  - medium (>= 3 Hz and < 8 Hz): *Anger* and *Fear*
  - smaller (< 3 Hz): *Happy* and *Disgust*

- Maximum Values (average):
  - higher (>= 1.2): *Happy* and *Fear*
  - smaller (< 1.2): *Anger, Disgust, Sad* and *Surprise*
- Mean Values (average):
  - higher (>= 0.3): *Fear*
  - medium (>= 0.1 and <0.3): *Anger, Disgust, Happy* and *Surprise*
  - smaller (< 0.1): *Sad*

4

Experimental Study

Contents

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4.3 Analysis of the Experiments 48

Previous chapters introduced the conceptualization of expressive trajectories, to be applied on a robot in social environments, and a set of features was provided to allow the creation of new trajectories expressing specific emotions.

This chapter intends to validate the trajectories previously generated, by showing that they are sufficient to express the emotions for which they were created. To accomplish it two experimental studies were conducted, wherein the robot performed the created trajectories and a questionnaire was delivered. The experiments were held in a stimulus-free environment in order to understand if the robot‘s movement was 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 (Portuguese Oncology Institute of Lisbon), in figure 4.1.

Figure 4.1: Left side: corridor in IST, Right side: corridor in IPOL

The questionnaire used is shown in annex A. It is a multiple-choice questionnaire, wherein the questions evaluated, in it and during experiments, 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?*

Likert questionnaires are not used, since these type of surveys intend to get people‘s feelings/opinions in terms of the extent to which they agree with the statements raised. The goal of the questionnaire was not to know if people agreed, or not, with statements such as: "Trajectory 1 represents Happy", but rather "which emotion was recognized regarding the trajectory seen", by them. Moreover, people did not have to think if the trajectory seen was, or not, similar to a specific emotion. They just had to answer what was the emotion recognized.

Also, if the questionnaire consisted on Likert questions, the way people should answered them would have to be explained, thus impairing results. When explaining the questionnaire people, especially children, could end up by answering the latest answers, not providing an honest answer.

4.1 Experiments at IST

IST was the first place where experiments were conducted due to the fact of being easily accessible by the robot, which usually is on the 8^{th} floor. This environment is usually with many people, which increases the possibility of getting more completed questionnaires. Since experiments were done in an university environment, the probability of the robot capture people‘s attention is higher, because they have more interest for technological subjects. Nevertheless, efforts were made to reach people outside this context, as coffee and cleaning workers, and random guests.

The entrance of the North Tower of IST is a place where students speak to each other and cross to go to the elevators or classrooms. When entering the building, people can see a stairway, with two small halls on each side that lead to the elevators and to the corridor where the robot was set to walk. Figure 4.1 shows the corridor, wherein on the left side is the entrance of the building, and on the right side are the elevators and classrooms.

Before starting, the robot was taken to the corridor by elevator, where it was going to perform the trajectories. The communication with the robot is achieved by using a wi-fi access point, which on the 8^{th} floor is a private wi-fi network whose radius does not reaches the entrance of the building. Thus, a new access point had to be created by an external router to allow the communication with the robot.

The environment dynamics, at the time of the experiments, was noisy, with a lot of 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. Sometimes, it went closer to the elevators, as an attempt of getting people‘s spontaneous reactions when leaving the elevator. 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, even if they do not stay around for too long.

   A GUI (graphic user interface) 4.2 was created to command Monarch from one place to another, while displaying emotions. The default button allows the robot to move with all body parts active. If buttons eyes, mouth, head or arms are pressed, those body parts will be included during the trajectory correspondent to the selected emotion. When pressing *Happy, Sad, Anger, Disgust, Surprise* or *Fear* buttons, the respective emotion will be displayed through robot‘s movement.

2. After the trajectory has been executed, the questionnaire, in annex A, is delivered to the people in

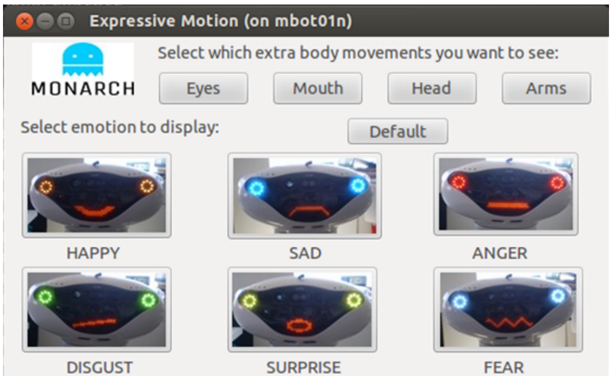

Figure 4.2: MOnarCH's graphical interface, GUI

the area. This way guarantees that the public does not know why the robot is there and does not have any prior knowledge of what they are about to see. These type of environment conditions [25], allows to get more reliable and honest answers from the bystanders.

During experiments recordings of the environment were made. The snapshots, in figure 4.3, show that MOnarCH creates a positive impact on people by catching their attention and making them to interact with it. The experiments showed that, seeing a "living and interactive" robot along with the trajectories created, makes people smile.

Figure 4.3: Images of experiments done in IST

4.2 Experiments at IPOL

IPOL is the place for which MOnarCH was created, and where a similar robot (to the one in IST) is in operation. The target group in this environment were the children, who usually are in their rooms, but sometimes go across the corridor on the way to the playroom. During experiments, cleaning staff, nurses, doctors and visitants were also able to see and interact with the robot.

The dynamics in the Paediatric Ward at IPOL, during the tests, was very quiet, with only a few people wandering in the main corridor. Legal constraints impose that no recordings are done in this environment.

The steps covered were similar to the ones at IST:

1. The robot was set in motion, performing a trajectory in one of the direction of the corridor, figure 4.1. The reason why the robot just walked in only one direction was because, at the time, most people were in the halfway down of the corridor and, in order to deliver the questionnaires and reach a bigger amount of people as well as positioning the robot, it was easier to make it performing the trajectories towards people.

2. After having attention from the bystanders, the questionnaire was delivered. Most children did not know how to read, thus an explanation of the questions had to be given. The explanation was simply a translation of the quiz, not providing cues or the right answer.

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, and most important, especially in IPOL, it brings happiness.

4.3 Analysis of the Experiments

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. It should be referred that, in IPOL, negative emotions (as *Fear* and *Disgust*), were performed more often than others (as *Happy*), due to the fact that the first ones did not performed the same time in IST. Also, results from both places have more answers regarding *Happy* because, except for *Sad* and *Anger*, all other trajectories start with a happy face.

In total, 61 questionnaires were obtained, 45 in IST and 16 in IPOL. Some people provided more than one answer, allowing to get a bigger set of answers than the number of people asked. For example, if two images were selected (in first question) and two emotions were also selected (in third question), than two pairs image-emotion were obtained. When doing such selection of image-emotion pairs, labeling errors may occur, however due to the fact that most answers were from people with an age rate of 22.61, it can be rebutted that the results are sufficiently reliable. A total of 78 answers were obtained, 61 from IST, and 17 from IPOL.

In IST, the average age of the inquiries 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 when image 4.3 was shown. The image displays some moments of the experiments in IST, however it can be concluded that people do react to the robot, by looking to it. One of the moments with more interaction towards MOnarCH was when classes ended and some people took photos and "spoke" with the robot. Thus, it can be concluded that its presence and movement captures people's attention.

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, using the two factor (two questions) ANOVA without repetition tool. To compute it, first the null-hypothesis had to be defined as:

$$H_0 : \alpha_i = 0, \forall i, factor1(question1) \tag{4.1}$$

$$H_0 : \beta_j = 0, \forall j, factor2 : (question3) \tag{4.2}$$

The null hypothesis, for both questions, can be translated into: "there is no significant difference between the means (α_i and β_j) of the recognition of emotions in question 1 and in question 3".
If the $F-value > F-critical$ (or $p-value < 0.05 = \alpha$), than the null hypotheses is rejected, thus at the 95% level of confidence it is concluded there is significant difference on the recognition of the emotions. Table 4.1 shows the results after applying ANOVA on the results obtained on the questionnaire.

Table 4.1: Two-factor ANOVA without repetition

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

Since the $F - value < F - critical$ (or $p - value > 0.05 = \alpha$), the null-hypothesis, (4.1) and (4.2), 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). The results also suggest that there is no significant difference regarding the recognition of emotions in both places, IST and IPOL.

A plot of ANOVA is shown in figure 4.4, created in excel with a 95% level of confidence, wherein it can be seen that the recognition average is similar for all emotions. *Happy*, in both environments, has a slightly bigger average degree of recognition, however that might be due to the fact that most trajectories start with a happy face.

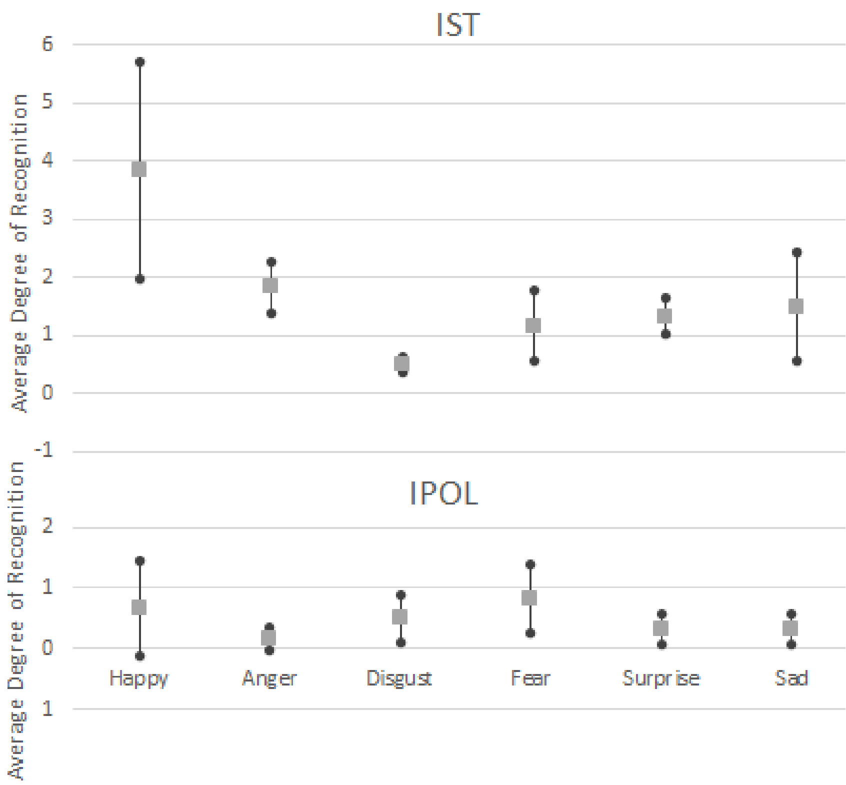

Figure 4.4: Plot of the mean with 95% confidence interval

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

To answer this question, is necessary to give a look at images 4.5 and 4.6. In both is represented the percentage of recognition rate of emotions. First images show the results obtained in IST wherein:

- *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.

Figure 4.7 shows the percentage of recognition of each emotion from both experiments. A correct recognition rate of 64.1% was achieved, which shows that it is possible to make a robot to express

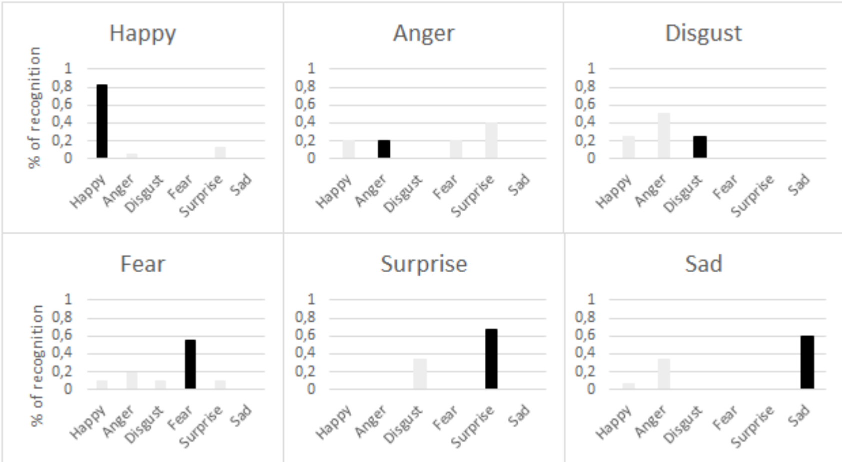

Figure 4.5: Results of the questionnaire (IST)

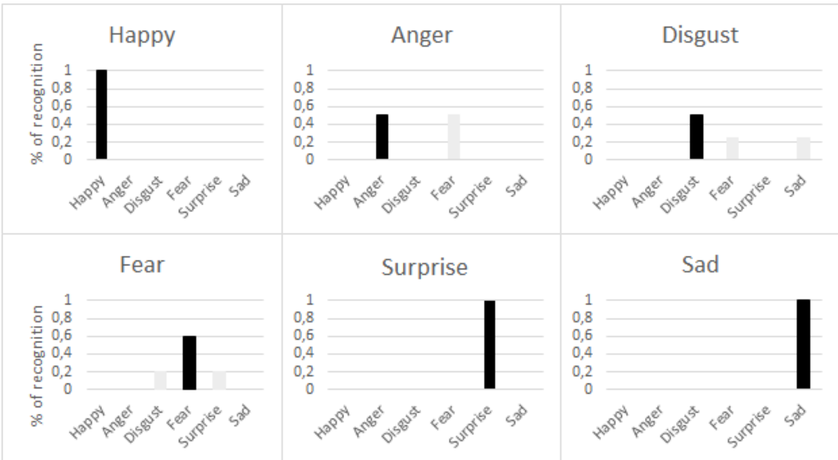

Figure 4.6: Results of the questionnaire (IPOL)

emotions.

Happy has the best recognition rate of 85%, being some times mistaken with *Surprise*. *Anger* shows to have the more homogeneous results, that it, is not always correctly recognized, being mistaken (almost equally) with *Fear* (28.5%), *Surprise* (28.5%) and *Happy* (14.3%). *Disgust* is correctly identified most of the times, and is mistaken with all other emotions, except *Surprise*. *Fear* has also a good recognition rate (56.3%), however sometimes is also incorrectly identified as one of the others emotions (except *Sad*). *Surprise* is recognized 75% of the times, being only confused with *Disgust* (25%). At last, *Sad* shows to be correctly identified 62.5% of the times, being identified as *Happy* (6.25%) and *Anger* (31.25%).

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

The answer to question 3 is obtained from the second question of the questionnaire. Possible answers 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,

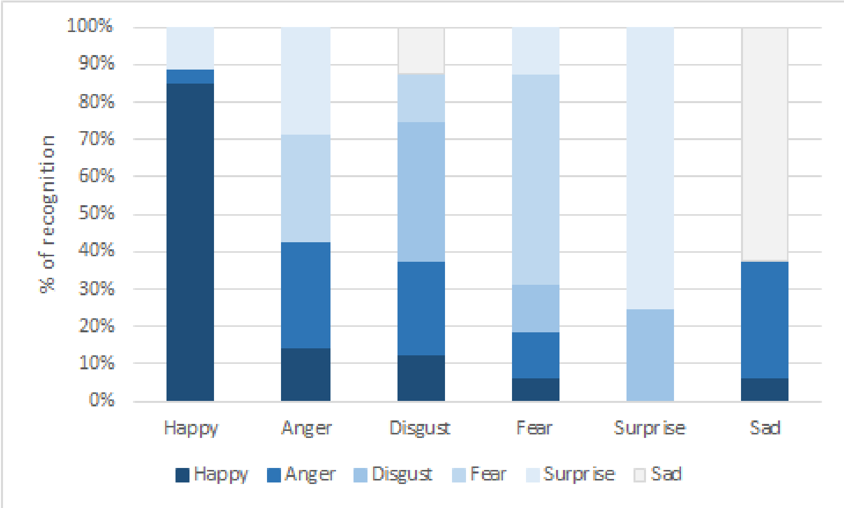

Figure 4.7: Total percentage of recognition of emotions

13.3% that is similar to an animal walk and 9.33% did not respond.

The Uncanny Valley [46] 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.
During experiments, most of the people did not understand the question, thus higher results for machine may be connected with the fact of the robot being a machine.

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 answered the questionnaire was small, some conclusions might be drawn from previous results. Comparing figures 4.5 and 4.6, is possible to say that children gave more right answers than adults. However, from results in IPOL, there are answers provided by adults, which influences the recognition rate. In IPOL, 50% were children with ages below 12 and 50% were adults with an average age of 21,5 years.

5

Conclusions

Contents

5.1 Future Work 55

This thesis aimed at improving Human-Robot Interaction, by making a robot to express emotions, namely *Happy, Anger, Disgust, Fear, Surprise* and *Sad*. The main objective was to enhance the interaction between humans and MOnarCH, in a social environment, showing that the robot captures people 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. In a sense this set of features corresponds to a basis of mathematical space. A small introduction of each emotion was presented in chapter 3, with a discussion on how people perceives the movement of the robot. 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 in chapter 4. Those features yield a mathematical representation of the emotions. The results suggest that basic emotions, such as the ones studied on this thesis, can be represented by a small set of features. This analysis also served as a way to validate the initially defined set of features.

To show that the trajectories express a specific emotion, two classes of experiments were performed in social environments, IST and IPOL. During these experiments a questionnaire was delivered (in annex A) to get people‘s feedback on their acceptance towards the robot and if specific emotions were recognized. 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 percentage of 55.55%, while adults reached 65.21%. Despite the overall recognition percentage not being very high, there are studies with lower scores: Johnson [22] got a percentage of 40% regarding the recognition of emotions from the facial expressions of Nao robot. There are also others with higher recognition percentages, such as Saldien in [15], wherein people had to recognize emotions from Probo robot movements. He reached a recognition rate around 78%.

The similarity between the movement of MOnarCH and that of people was also addressed in the questionnaire. The main conclusion was that most people think that it resembles a machine. Also, despite the number of children answering the questionnaire being significantly lower than adults, the results suggest that there is no relevant difference in the way they perceive robot‘s emotions.

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 in the thesis. The result is the acceptance of the robot by generic people.

5.1 Future Work

Future research on Expressive Movements should focus on the creation of SVMs, making use of the feature set built in this thesis. 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* [42].

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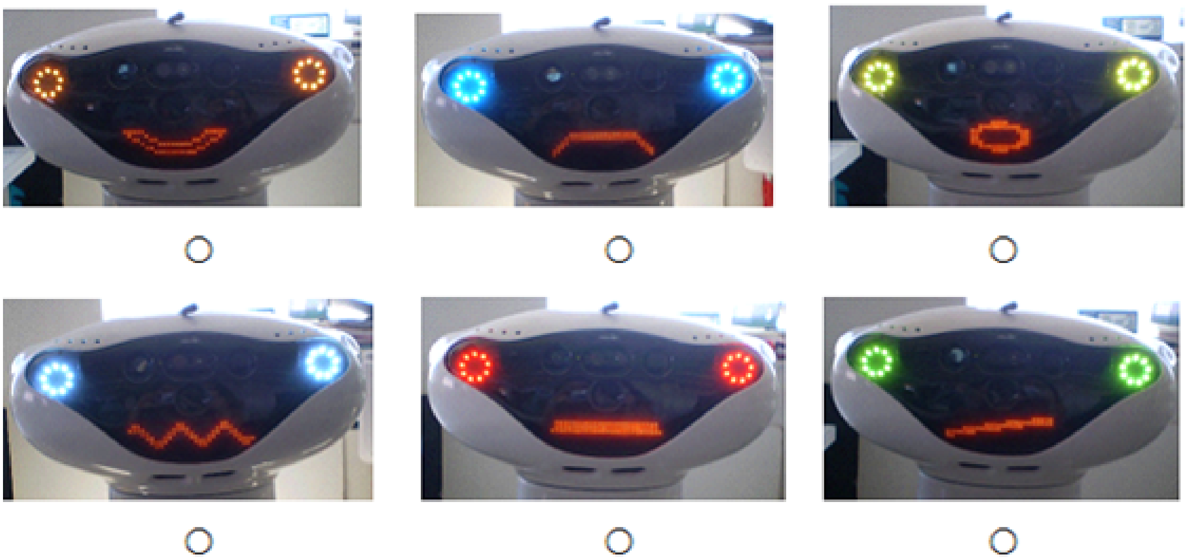
A

Questionnaire

The questionnaire used during the experiments is shown next.

Idade:_____ Sexo: ○ Feminino ○ Masculino

Qual a expressão facial que observou?



○ Nenhuma das anteriores

Como classifica o movimento do robot?

○ Máquina ○ Animal ○ Humano ○ Nenhuma das anteriores

O robot parece estar:

○ Contente ○ Triste ○ Surpreso ○ Zangado ○ Com medo ○ Enjoado

○ Nenhuma das anteriores

Figure A.1: Questionnaire