The Positive Effect of Negative Feedback in HRI Using a Facial Expression Robot

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***Abstract.*- This research explores the use of facial expressions in robots and their effect in collaborative tasks between humans and robots. The positive effect is determined during a task in human - robot collaboration, derived from a negative facial expression issued as feedback by the robot (sad face) when a failure in the execution of the task occurs. This study analyzes whether or not human intervention exists on the initial presence of an unexpected failure, the response time of the intervention and the accuracy of the task. A comparison with a neutral facial expression is also performed.**

Keywords. *Collaborative Interaction, Minimalist Robot Head, Negative Facial Expression, Reaction Time.*

I. INTRODUCTION.

Nonverbal social cues help strengthen the interaction between humans and robots. Among the most explored ones are: pointing, observing, body language and facial expression. The role of emotions in human behavior has led to develop emotional computational analogues, capable of driving more intelligent and flexible systems in complex and uncertain environments [1]. Emotions can be identified as the means that serve individuals to establish values and improve their interaction and outcome. Based on emotional displays, individuals who perceive the emotions can create interpretations or assume the state of the person who shows them [2].

The human face serves many purposes, it shows an individual's motivation, which helps create a more predictable and understandable behavior for others; this is supported by sight and eye tracking. During human collaboration, gestures play a key role in communication, used daily to maintain, invite, synchronize, organize or finishing a particular activity [3]. Artificial emotions in robots and virtual agents favor feedback during interaction with humans [4]. Emotional models in robotic architectures are developed to make explicit the goals of robots and strengthen the link between person and robot [5].

This work explores the effect of a facial expression used as feedback and its positive effect on a cooperative task (human-robot interaction). Our study focuses on the influence of a negative facial expression (*sad*) on reaction and accuracy of human actions. In particular, we study the first sudden failure and the primal effect on the interaction.

II. BACKGROUND.

The uses of social signals integrated into robotic systems have been crucial to the HRI community. These signals are useful at the coordination of actions between humans and robots and help interpreting human reasoning and cognitive patterns. The motivation that gives meaning to the correct study of such factors is to improve the collaborative activities with common goals between humans and robots. It also measures and quantifies the impact of the interactions and influence on people [6]. Various aspects such as behavior, physical appearance, natural language, gazing, pointing, gestures, personality and body language might be related to the way humans empathize and perceive robots. It is considered that the use of nonverbal signals by robots improve social interaction with people. For instance, the robot's gaze can communicate care and caution, and express with facial expressions an emotional state [7].

The use of social signals have been extensively studied through robotic faces aiming to improve collaborative work focusing on the use of the gaze to coordinate and strengthen the interaction as well as predict and clarify intentions among colleagues, [7], [8], which influence accuracy and speed of human action [9]. With regard to robotic expression of emotions and facial gestures, multimodal communication in robots have been explored to create comfortable social interactions within complex environments such as interactive museums [10]and public displays [11].

In the field of manufacturing, it has been shown that the use of gestures in industrial robots contain a wide communicative content for the human parts. The readability of the robot gestures has a positive influence on an industrialized collaborative task, reflected in the continuity of an activity, reducing work-time and increasing productivity [12]. Nonverbal social cues may be beneficial in the interaction with robots used for specific tasks oriented towards service robots [13].

Human perception of gestures influences communication and discrimination of positive and negative effects. Identification of negative facial gestures (*sad*) affects the viewer's attention more effectively than a positive gesture (*happy*), regardless of whether the gesture identification search is intentional or unintentional [14].

Using feedback from negative social effects on robotic agents and the importance of positive effects on the job or part of the structure of it has been suggested for the design of robotic agents capable of altering their behavior [15].

III ROBOT FACE.

We developed GolemX-1, a minimalistic robotic face, capable of performing the basic emotions described by Ekman [16]. We consider the minimum of elements, fabrication accessibility and efficiency in readability of expressions for our robot's face since this will be used in the Golem II and III (Fig. 1) service robots [17]. The robotic face was inspired on some of the characteristics of the MiRAE robotic face and its minimal component development [18]. MiRAE has been tested with the Facial Expression Identification (FEI) rates for each of their expressions. MiRAE robotic face has the following features: a) Ability of facial expression based on the use of six horizontal lines, b) Reduction in the complexity of construction c) Readability of interpretation by human subjects of the basic emotions described by Ekman.

Our robotic face was limited to the readability of facial expressions with elements similar to those minimum requirements of the MiRAE robot. This resulted in a robotic face in which we avoid the excessive use of aesthetic elements and degrees of freedom (DOF) used in other robotic faces [19] [20]. Our robotic face is built with electromechanical equipment, manufacturing material and accessible construction processes at low-cost, easy maintenance and the electronic control equipment Arduino Uno[1]. GolemX-1 is capable of running both negative (sadness, anger, fear) and positive expressions (happiness, surprise), using 7 DOF. Our robot's face was subjected to a multiple choice online study to test the readability of the face and adjustment execution. For this study only 3 types of facial expression were used: Neutral, happiness and sadness (Fig. 2). Additionally, an upper body with arms was built to adequate the experiment for human-robot interaction, one of the hands is movable with 1DOF.

IV. EXPERIMENTS.

Our experimentation assumes the following:

- The use of gestures (facial expressions) is useful in the communication between humans and robots in a collaborative task.
- Facial expressions performed by a service robot provide feedback about achieved or failed progress in tasks
- The use of gestures in a service robot has influence over the human actions in a collaborative task.

Taking in to consideration the previous aspects we evaluate the readability of the GolemX-1 expression and the effect of the negative expression (*sad*) on human behavior when the robot fails to perform a task correctly. In the case of readability we followed an online survey methodology. In the case of the measuring the effect we design a teamwork scenario between human and robot. We focused on the first failure of the robot since it captures the naive response of the human subject in a collaborative interaction.

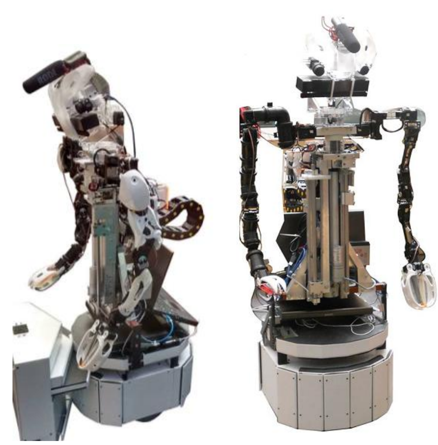
A. Facial Expression and Readability Test.

The objective of this experiment was to validate the readability of facial expressions issued by Golem X-1's robotic face. The following hypothesis was established:

H1: *The robotic face performs the negative facial expression of sadness in a legible manner.*

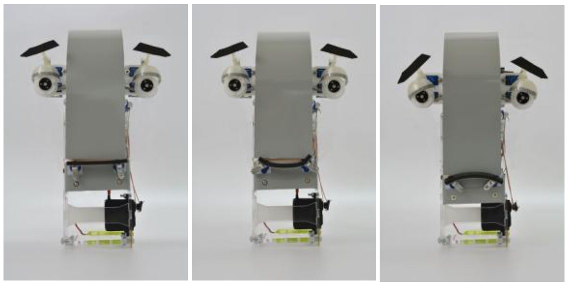
To test H1 we designed an online survey of facial expression identification. We showed to a subject a digital version of GolemX-1 expressing emotional gestures (*neutral, happy, sad, worry, surprise and fear*). We promoted the online survey among students and colleagues, 88 subjects answered the survey. We showed the robot faces with the six selected gestures randomly and one by one for the participant to choose an emotion from a list with random labels in each image. We invited several subjects from which 88 answered the survey. The majority of subjects were industrial design students; few of them were engineers in computer science. The average age was 24 years old.

Figure 1. Golem-III Service Robot.



[1] http://www.arduino.cc

Figure 2. GolemX-1. Expressive robotic face.



In order (Left to Right) Neutral, Happiness and Sadness expressions.

B. Collaborative Task Experiment and Scenarios.

The aim of the experiment was to determine the influence of negative facial expression of a robot on the human response, only when an unexpected failure occurs for the first time during a task. The experiment was designed to explore with non complex repetitive task the influence between the facial expression and the human actions and if this influence can be registered and significant in order to use in a collaborative human - robot task. The non complex execution of the task increases the control during an unexpected failure. Although in the experiment the robot face used facial expressions as main social cue, it also used its gaze as the robot’s attention indicator, which also allows smoother interactions. However, we avoided to alternate the direction of the gaze between human and object because the gaze is used to trigger human interactions in some collaborative task under different conditions [9]. The robot´s actions time response was empirically set so was suitable for human response after executing several test sessions.

The following hypothesis was stated:

H2: A *negative robotic facial expression can influence the behavior of human actions.*

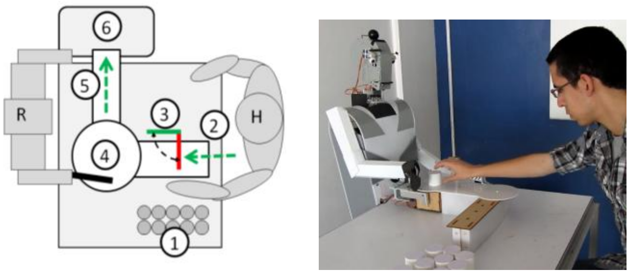
This experiment consists in a simple task with shared responsibility for the execution. The human and the robot cooperate to place ten cylindrical objects within a container. However we have programmed the robot to randomly fail to place the object in the container. An electromechanical system of interaction was used as workspace and as interface of the human-robot collaboration. The hand with 1DOF integrated to the upper body of the robot was also used to manipulate the objects. Fig. 3 shows the areas and system elements. At the start of the experiment interaction the workspace is placed at the center of a table. The human subject is located on one side of the table with the ten cylindrical objects. The robot, GolemX-1, is facing the human subject on the opposite side of the table. The robot's right hand is by the interaction system, beside the launching area, waiting to push the objects through the ramp that leads to the container. The subject must wait for the access barrier to open to place an object in front of the robot in the launching area. The subject is instructed to put only one object every time the barrier opens. Then, the access barrier closes and the robot pushes the object towards the ramp into the container. The subject cannot access or intervene in the action unless the barrier is open. Two video cameras were used to record the interaction.

The experiment procedure is performed as follows:

- Written instructions are given to the user. The researcher makes a test session to exemplify the general movements. This was done by placing the object in front of the robot. Once positioned, the barrier is closed; the robot observes the object and successfully throws it into the container. The robot starts the interaction. The barrier is opened and the robot faces forward.
- The human subject takes his place and the interaction starts.
- The subject places the first object in front of the robot. In the first try the robot pushes the object in to the container and a successful outcome occurs.
- The human place the next object and a successful outcome is repeated.
- The robot actions are randomized from the third execution onwards. A failure can occur at any point of the interaction. A failure is when the robot is not able to push the object. During a failed action, the robot looks at the object but the hand movement is limited to prevent the object from being pushed into the container. The robot does not look at the human again. Duration of the failed action: 9 seconds.
- After the failed action, the access barrier is opened for 11.5 seconds in order to give an opportunity to the human user to intervene in the work of the robot. During this time the robot continues gazing at the object.
- At the end of the allocated time the barrier is closed, the failed action is repeated once again and the barrier is reopened by 11.5 seconds. This is done in order to motivate a reaction from the human.
- The task finishes until the ten objects fall into the container.

Two types of scenarios were mounted using this same procedure. In the first one, the robot executes a neutral expression for the task. In the second one, the robot performs a positive facial gesture (happy) when the task is successful and a negative facial gesture (sad) when the task fails. The detailed actions are specified in Table "1".

Figure 3. Workspace Scenario.



(Left) Interaction system and collaborative Human-Robot workspace diagram: (1) Objects zone, (2) Human access, (3) Access barrier (red/closed, green/open), (4) Launch area and robotic hand, (5) Ramp, (6) Container. (Right) Human-Robot setup and workspace.

TABLE I. TASK DESCRIPTION.

Actions in general task	**Collaborative Human-Robot Task**		
	Human action	***Robot action Neutral face***	***Robot action Expressive Face***
Start (Succesful or Failed action)	The access barrier is open. The human subject puts the object in front of the robot.	Looks at the object.	Turns its head toward the object. Neutral face.
Successful action	The access barrier is closed. The human subject waits.	Moves its hand and pushes the object. Returns its hand to the start position.	Starts the positive facial expression. Moves its hand and pushes the object. Returns its hand to the start position.
Finish successful action Restart	The access barrier is open. The human subject can put other object.	Looks at the human waiting for the next object.	Finishes the positive facial expression. Turns its head toward the human and waits for the next object.
Failed action	The acces barrier is closed . The human subject waits.	Is not able to push the object. Waits for 9 seconds.	Is not able to push the object. Starts the negative facial expression for 9 seconds.
Finish failed action	The access barrier is open for 11.5 seconds.	Remains looking at the object.	Finishes the negative facial expression. Remains looking at the object.

As a random programmed activity the robot gets a success after 1 or 2 attempts more in order to avoid jamming the task

The experiment was conducted with 15 naïve human subjects (9 female, 6 male) for the scenario with a neutral expression; and with 15 subjects (7 female, 8 male) for the facial expressions scenario. All subjects were industrial design students and the average age was 22 years old. They were recruited by personal invitation.

V. RESULTS

A. Readability test.

The confusion matrix for the readability and accuracy of the neutral, sad and happy gestures are presented in Table "2". The rest of the gestures were omitted because they were not used during the experiment but they follow a similar trend. However, the gestures have to be improved in order to measure the impact of the positive effect. These observations are confirmed once we calculate the accuracy of the gestures.

From the table it can be noticed that neutral and sad gestures can transmit the intended emotion with accuracy. On the other hand, the happy gesture is less effective. We consider this is not relevant for our following experiment since we did not focus on this gesture at the moment.

B. Collaborative Task Experiment and Scenarios.

The reached accuracy for the sad expression of 85% allows using GolemX-1's robot face in order to study the negative feedback convey by the sad gesture in a collaborative task. In particular, this experiment focus on the first robot failure to push the object into the container. For this we focus on the behavior of the human when this happened. This situation defined a specific failure pattern which was analyzed in the following aspects:

- We identify the type of behavior during the human subject intervention to the failure (or lack of it).
- The reaction time form the opening of the barrier to the time the subject intervenes during a failure.
- The performance of the subjects following the instructions of the task.

We considered that an intervention from the subject happened if she or he tried to help during the course of the task. By analyzing the video recordings of the interactions, four types of intervention were identified in case of failure: 1. The subject changed the position of the object. 2. The subject changed the current object for another from the stash. 3. The subject placed an extra object into the launching area. 4. The subject waited. Table "3" presents the frequency these behaviors shown in the scenarios.

TABLE II. FACIAL EXPRESSION TEST AND ACCURACY

	Facial Expression			
Response	***Neutral***	***Happy***	***Sad***	***Accuracy***
Neutral.	**67**	11	3	76.1%
Happy.	0	**56**	1	63.3%
Sad.	6	0	**75**	85.2%
Others.	15	21	9	——

"Others" correspond to angry, fear, surprised and worried facial expressions

TABLE III. TYPE OF ACTION AND INTERVENTION ON TASK

Action -Intervention	***Neutral Face Experiment.***	***Negative Face Experiment.***
The human subject changed the object's position.	**7**	**14**
The human subject changed the object.	**1**	**1**
The human subject put more objects in the launch area.	**4**	**0**
The human subject waited until the robot gets a success.	**3**	**0**

In Table "4" we observe that the frequency in behaviors is different among scenarios. Using a neutral facial expression feedback produces the subject to place more objects or to wait more frequently than when using a negative facial expression feedback. Both putting more objects and waiting go against the flow of the task, for instance, making sessions longer. In table 5 we can see the frequency on terms of the behaviors being positive or negative to the continuity of the task. Both behaviors have different statistically significance when compared ($p< 0.05$)[2].

By analyzing the reaction times from both scenarios we notice that when only using the neutral feedback, the average reaction time is longer than when using the negative feedback (11s, neutral; 7s, sad). However, when doing a more strict analysis we don't find evidence of statistic significance ($p>0.05$)[3] (Fig. 4).

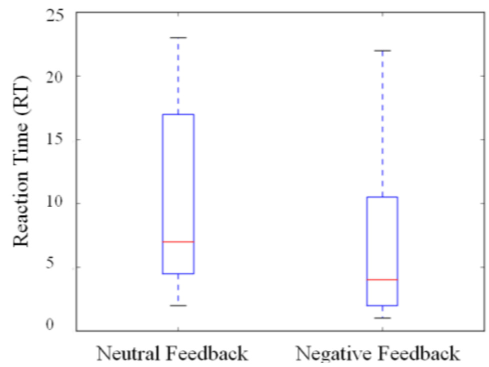
VII. CONCLUSIONS

This research explores the effect of negative facial expression feedback during a collaborative human-robot interaction task.

TABLE IV. POSITIVE AND NEGATIVE EFFECT

	Effect in the task	
Type of robotic face in experiment	***Neutral feedback***	***Negative feedback***
Positive effect	8	15
Negative effect	7	0

Figure 4. Time Distribution on Reaction Time.



First, we measured the readability of the sad facial expression of GolemX-1 robotic face using an online survey. We founded that this expression was one of the best expressed gestures. Since it has been shown that this gestures influences the attention of the human subject [21] we proposed to used as a negative feedback.

This negative feedback was embedded into a collaborative task for which we measured its effect. We founded that providing feedback regulates the behavior of a human collaborative partner. First, the subject avoided breaking the instructions and second it gave a communicative signal that fomented an intervention. This means that subjects that first face a failure reacted with more positive behaviors towards the continuity of the task than the ones given neutral feedback.

As future work, we are currently analyzing the behavior of the subject in the whole task rather than first failure and we are working into improve the readability of the positive gestures in our robotic face: happy and surprise. We also plan to test different negative gestures feedback such as: angry, worry and fear. Even though there is evidence that negative gestures have a negative impact on the subject's mental state, for instance when the Negative Attitudes Towards the Robot (NARS) test is applied [22]. We hypothesize that negative gestures have a place in human-robot interaction that will have a positive effect on the task and the mental state of the subject.

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[2] Statistical significance calculated by Exact Fisher method for an experiment with a power of 0.9 for a sample of 15 per case.

[3] Statistical significance calculated by Pair t-test method for an experiment with a power of 0.9 for a sample of 15 per case.

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