Playing Tangram with a Humanoid Robot

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Abstract

An open question in the area of social robot interaction is how to design test scenarios that on one hand provide the required complexity and on the other hand are still describable. The tabletop game Tangram has been selected as a test scenario for human-robot interaction. This paper describes how the required skills, to enable the humanoid robot ROMAN to play the game, have been ralized. Experimental results demonstrate the functioning of the system and show how emotion influences robot's motivation.

1 INTRODUCTION

For recent years, there has been a lot of research in the area of social interactive robots. Starting from the work of C. Breazeal [1] to the latest developments in the area of interactive robots as they are described in [2] or [3]. Currently most of the roboticists dealing with social interacting robots agree that an emotion component increases the performance of an interactive robot. Therefore, it is no question that an interaction situation for testing the interactive capabilities of a robot requires a minimum of complexity. The following requirements for the test scenario have been figured out:

- Enough space of action, to enable various actions and behaviors of the human being as well as of the robot.
- Limited complexity, so that all the required information can be perceived and the scenario can be described.
- A minimal length of the interaction process, so that changes of the emotional state and of the motivation of the interaction partners can/will happen.

Since scenarios like ticket window situations do not fulfill these requirements, the decision was made to realize the tabletop game Tangram as testing scenario. The game consists of shadow image presented to the player, which he has to be form using the puzzle pieces of simple geometric shapes.

The complexity and observability of the Tangram allows both the creation of complex or even unsolvable problems as well as the analysis of the game situation and the progress of the interaction partner.

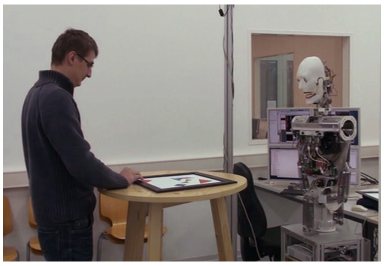


Figure 1: The humanoid robot ROMAN playing the Tangram game with a human interaction partner.

Interactive human computer scenarios with tabletop applications are available for a broad set of games. In [4] the realization of an interactive memory card game for a humanoid robot is described. Recently Verdie [5] used Tangram as interactive tabletop application and analyzed the position and orientation of the game pieces with an overhead camera. He extracted edges and corners of each piece and generated a tracking system to follow modifications of the game situation. Although this analysis is very accurate and provides a complete dataset for further analysis it is not transferable to a humanoid robot. Neither the precondition of a non-moving camera and table game nor the assumption of constant lighting conditions can be met in interactive human-robot scenarios.

This paper provides detailed information how the humanoid robot ROMAN, see Fig. 1, has been enabled to play the Tangram game. It is explained how the necessary skills have been implemented within the emotion-based architecture described in [6]. Furthermore, the results of an experiment to demonstrate the influence of emotion on the robot's motivation are discussed. The paper is arranged as follows: At first, a brief introduction to the emotion-based architecture that forms the basis of ROMAN's control system is given. Afterwards, the implementation of the components that are mainly involved in the Tangram game is described in detail. In Sect. 4 the experimental results are presented. Finally a conclusion and an outlook for future work are given.

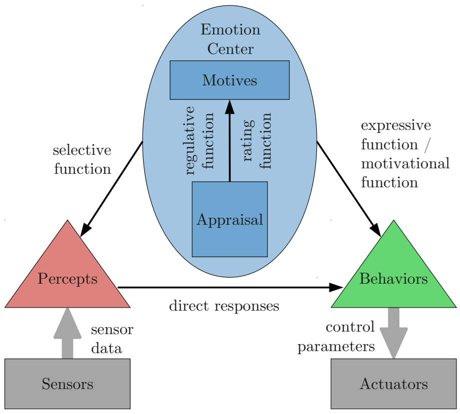


Figure 2: The structure of the emotion-based architecture that controls the interactive behavior of the robot ROMAN.

2 CONTROL ARCHITECTURE

As described in [7] emotion plays an important role for humans' social behavior. Therefore, the control system of ROMAN is realized as an emotion-based architecture, cf. [6]. The system consists of 4 main components (Fig. 2), *percepts*, *motives*, *appraisal system*, and *behaviors*, that enable ROMAN to act and behave in real world interaction situations. The perception system, *percepts*, collects information from the environment. These information e.g. face detector or color detector are combined using different fusions. That way a dynamic model of the interaction partner and the current situation can be created. [8] The *appraisal system* uses this information as well as the current internal state to evaluate the situation and derive an emotional state. The internal situation is represented by the previous emotional state and by the satisfaction of the different motives. Each motive represents a specific goal of ROMAN. The behavior of a motive can be explained using the control loop theory. Depending on the current state and on the target state a motive calculates its satisfaction and its activity. This activity is used to stimulate different actions. The current emotional state influences the calculation of the motives satisfaction and the robot's expressive behavior. The behavior system provides 4 main parts. The lowest layer is formed by so called "basic behaviors", which are directly derived from the robot's actuation system and represent motion primitives, like turn head left or turn head right. On the next layer actions and responses are realized by combining different basic habits. That way complex behavior like focusing the interaction partner (*actions*) are implemented. The highest layer is formed by the scenarios. A scenario provides information in which order the different complex habits need to be stimulated to reach a certain goal. The scenarios for their part are stimulated by the corresponding motives.

3 IMPLEMENTATION

This section provides detailed descriptions how the capabilities to play Tangram have been realized within the emotion-based architecture. It is pointed out which information need to be perceived and how the perceived information can be combined to get more complex information on the current situation. It is described which actions are required to play Tangram and how the Tangram scenario is implemented. Furthermore, details on the motivation system that causes ROMAN to play Tangram are explained. General information on the definition of the single components of the emotion-based architecture can be found in [6], whereas this section provides a detailed description of a specific example.

3.1 Perception System

The perception system of ROMAN consists of 2 stereo camera systems and 6 microphones. That way ROMAN is able to detect and focus its interaction partners by image processing and using the microphones ROMAN can estimate the position of a sound source and figure out whether the sound source is a human voice or not. Furthermore, ROMAN is able to detect the Tangram board and to evaluate the current state of the game with the help of its cameras. All sensors are included in the robot itself and no external sensors are necessary to handle the Tangram game situation. In the terminology of the UKL Emotion-based Architecture, every component that represents specific information is called *percept*.

The components mainly used for the Tangram scenario are: *Face Detector*, *Skin detector*, *Stereo Processing*, and *Tangram Detector*. The *Face Detector* is responsible for the detection of face candidates based on a previously trained face model. The combination of *Face Detector*, *Skin detector*, and *Stereo Processing* is used to determine the current position of a human in the robot's environment. In this particular situtation the position information is used to decide whether a human is categorized as "Tangram Player" or not.

To analyze the Tangram game from the robot's point of view requires visual analysis from a moving camera and unknown position and orientation towards the interaction area. Therefore, the robot must be able to detect the board and correct any distortions. The implemented approach simply uses color information to find and evaluate the Tangram board. Geometric primitives are used to correct perspective warping.

3.2 Tangram Motive

As already mentioned, within the UKL Emotion-based Architecture each motive represents a specific goal. The motives calculate their satisfaction depending on the achievement of these goals. Depending of the satisfaction value the motives state can be classified as "undersatisfied", "satisfied", "oversatisfied". Each motive's goal is always to reach a satisfied stated.

In case of the Tangram motive undersatisfaction means that the robot wants to play the game. The satisfaction value of the motive is increases if a human being plays the Tangram game with robot otherwise it is decreased. Therefore, it will stimulate behaviors that motivate persons to play the game or to go on playing. The longer the game lasts the more increases the satisfaction. After a while the motive becomes oversatisfied – boredom is experienced. In this state the motive will stimulate behaviors to make the human Tangram player quit the game.

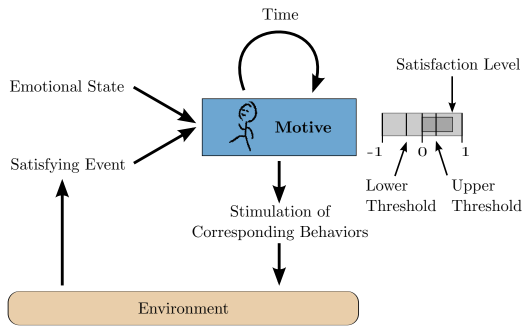


Figure 3: The functioning of a motive as a control loop: Depending on the presence of the satisfying event and on the emotional state the satisfaction of the motive is calculated. If this is below or above specific thresholds, the corresponding behaviors are stimulated in order to reach a satisfied state again.

The emotional state influences the motivation in a way that if positive emotions are experienced while fulfilling a task this task is performed for a much longer time. On the ohter hand if negative emotions are experienced the task is stopped earlier. Furthermore, the desire to perform tasks related to positive emotions again is much higher than for tasks related to negative emotions. For the realization of this phenonemon two limits, an upper limit and a lower limit have been intorduced. The range below the lower limit represents undersatisfaction between the limits satisfaction and above the upper limit oversatisfaction. These limits are changed depending on the emotional state. A rather positive emotional state will increase both limits; a negative state will decrease the limits. That way it takes much longer to reach an oversatisfied state if positive emotions are experienced. If negative emotions are experienced the upper limit will be reached very early. Furthermore, if positive emotions have been experienced the lower limit is much higher. That means this motive will much faster reach an undersatified state and therefore become active again. On the other hand if negative emotions are experienced the lower limit will be quite low and it takes much longer time until the motive becomes active again.

The functioning of a motive can be described as a control loop. The control variable is the satisfaction and the controller tries to keep the satisfaction in a medium state. If the satisfaction is below a lower threshold or over an upper threshold specific behaviors are stimulated to reach a medium level of satisfaction. The principle functioning of a motive is depicted in Figure 3.

3.3 The Behavior System

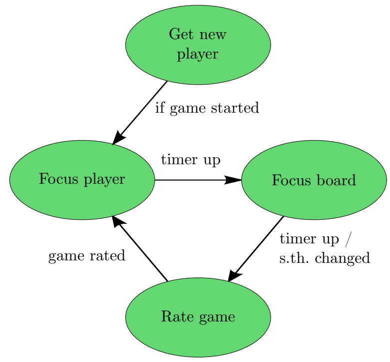


Figure 4: The Tangram scenario: The chain of actions that need to be executed in order to play Tangram is represented as a finite state machine.

The actions, complex habits, which are used for playing Tangram, are: *Look at Point*, that enables the robot to focus a 3D-point in its environment and *Search Object*, that allows ROMAN to look for a specific object in its environment. Furthermore, the so called *Speech Centre* is used, which can be regarded as a special ability to act – a complex habit. Besides the realization of verbal communication, the *Speech Centre* also activates speech adapted nonverbal expressions. As described in Sect. 2, the highest layer of the habit system, the so called *Scenarios*, provide information about the activation order of the different actions. This is realized by a finite state machine, where the single nodes provide information which action to stimulate, see Fig. 4. In order to play Tangram, ROMAN tries to find a human Tangram player. ROMAN is looking for a human being in its environment and asks the human being to play Tangram. If the human being starts playing Tangram, ROMAN will focus the player and after a while or if changes have been detected, it will look at the Tangram board, generate a rating of the current status of the game and on the performance of the human player. Depending on this rating ROMAN will give some comments to the human player. The runtime of the timer can vary. They depend on the current emotional state, more precisely on the arousal value, of ROMAN. The more aroused the shorter the timer runtime.

By implementing the scenarios in this way, new scenarios can be realized without lots of effort, since the structure is specified in the scenarios and the content in the actions. For the realization of a new scenario only the structure, a new finite state machine that specifies the stimulation order of the actions, must be implemented.

4 EXPERIMENTS

4.1 Playing Tangram

The setup for the experiments was as follows: The Tangram board was placed on the top of a table located in front of the ROMAN. A human being was told to enter the scene and play Tangram, see Fig. 1. During the experiments the robot was operating autonomously without any manual intervention. To evaluate the system a test run of about 5 min has been recorded. Throughout the test run, the activities of the percepts and the habits have been recorded. In the following an extract of about 2.5 min is discussed in detail. For the final paper the results of questionaire evaluation of the robot's behavior while playing the Tangram game will be presented.

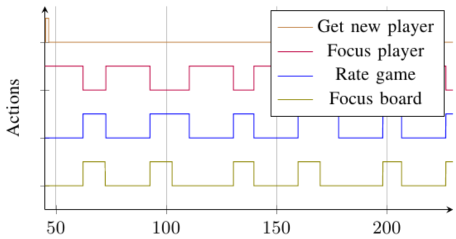
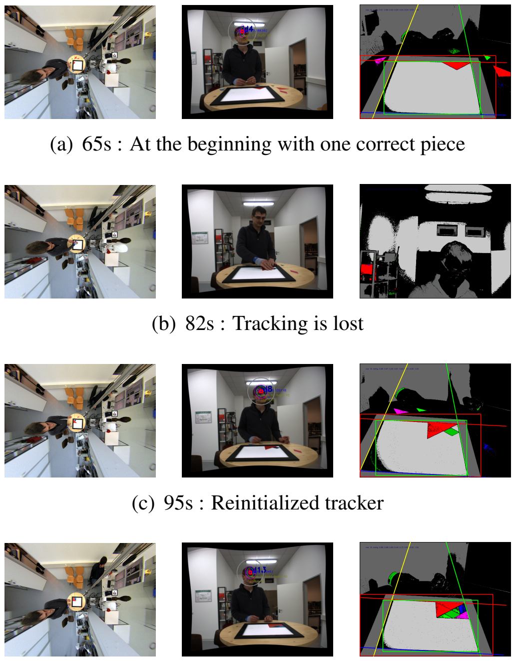


Figure 5: This plot shows the activity of the actions involved in the Tangram game, while ROMAN is playing the game.

The behavior of the robot is stimulated by the "Tangram Motive" as described in Section 3.2. When the motive is unsatisfied it stimulates the Tangram scenario and robot tries to find a human being willing to play the game. The activities of the actions of the Tangram scenario during a Tangram game, are depicted in 5.
Here two gaps at 80 and 110 seconds are visible. During these periods the tracking of the human interaction partner is lost due to the fact that the face is turned towards the Tangram board. After approx. 45 s ROMAN detects a human being.
Therefore, *Get new player* gets active and ROMAN asks the human being to play Tangram. At the same time *Focus player* gets active and ROMAN focuses the possible Tangram player. The human being starts to play the game and after approx. 62 s *Rate game* gets active, stimulates *Focus board* and ROMAN starts to evaluate the current solution. Afterwards, ROMAN tells the human player which tiles are placed correctly, and so on. During the whole process of playing Tangram it can be seen, that *Focus player* is inhibited when *Focus board* gets active. Furthermore, in some situations (after 102 s and 160 s) *Rate game* is longer active than *Focus board*. This is because the whole process of rating the game consists of looking at the board, evaluating the current state, and telling the human being about the current state.
Figure 6 depicts a top view, body view and eye view image captured during playing the Tangram game. The experiment shows that the perception system is able to extract the two basic percepts $P_{tangram}$ and P'_{person}. Furthermore, it shows that if the human tracking is lost reinitialization occurs. It also shows that the realized habits enable the robot to handle the interaction situation.



(a) 65s : At the beginning with one correct piece

(b) 82s : Tracking is lost

(c) 95s : Reinitialized tracker

(d) 162s : Puzzle solved

Figure 6: Image sequences captured during the test run. The tracking of the interaction partner is shown as well as the rating of the Tangram situation. The top view image is given as reference.

4.2 Influencing the Robot's Motivation

A typical behavior that can be observed by humans is that positive emotions increase the motivation to continue the currently performed task, while negative emotions decrease the motivation and the humans give up the tasks much faster. As described in before the emotional state influences the calculation of the motives satisfaction by shifting the tresholds. If the robot is in a positive emotional state it will take much longer until the motive becomes over stimulated – bored – and if negative emotions are experienced the thresholds will be decreased and the over stimulation will be reached much faster.
To test this function the Tangram game is played twice. In the first run positive emotions are provoked in the second run negative ones.
To have the robot experiencing positive emotions the interaction partner places the tiles correclty and the time between placing two tiles has been chosen rather small. If the Tangram motive of the robot is active, the robot wants to play the game; it should now experience positive emotions. On the other hand, to bring the robot in a negative emo-

tional state the Tangram player places the tiles wrongly and also takes a lot of time until placing the next tile. Therefore, the robot's emotions should become more negative. This should lead to a faster over stimulation and the robot will try to end the game. The time until the robot wants to quit the game is meassured.

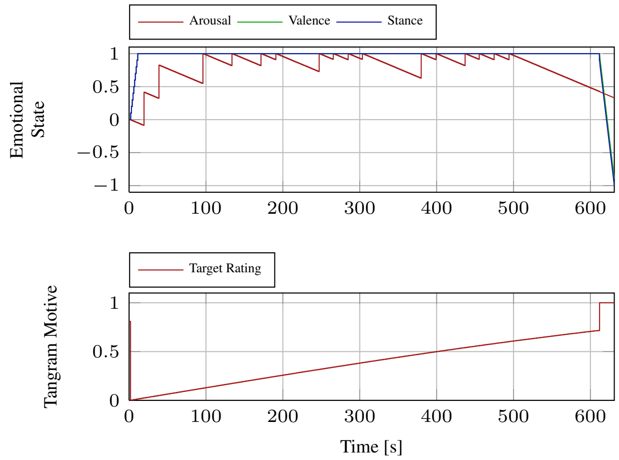


Figure 7: The activity of the *Tangram Motive* while the robot experiences positive emotions. The target rating indicates the motivation of the robot to play the game (0 = high motivation, 1 = low motivation).

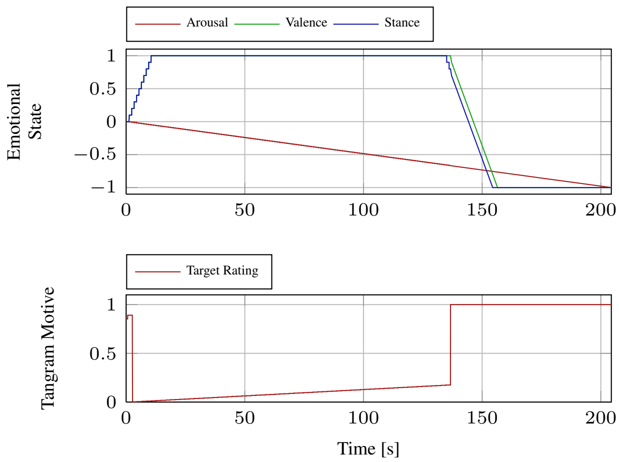


Figure 8: The activity of the *Tangram Motive* while the robot experiences negative emotions. The target rating indicates the motivation of the robot to play the game (0 = high motivation, 1 = low motivation).

The robot's emotional state is represented using the 3 categories *arousal*, *valence*, and *stance*, where arousal describes how thrilling a stimulus is, valence describes the satisfaction of the robot in the current situation, and stance describes how desired a perceived stimulus is in the current situation. Furthermore, the *target rating* of the Tangram motive is plotted. Internally it is calculated as the absolute value of the satisfaction. It can be regarded as a meassurement for boredom. If the target rating reaches 1 the robot wants to stop the currently performed task. The results of the experiment are depicted in Figure 7 and Figure 8. In both situations the robot started in a neutral emotional state, arousal, valence, and stance were all equal to 0. Since the Tangram player is already present in the scene her presence does not affect the aroual value. That means the only way she can increase the arousal is by placing the puzzle pieces.

It can be seen that the emotional state starts from 0. After a few seconds the target rating falls from 1 to 0 since the motives desire is satisfied. Directly after the decrease of the target rating, which has been caused by the human playing the game, both valence and stance start increasing and raising to 1. The incease of valence is caused by the satisfaction of the motive, the increase of stance by the perception of the desired stimulus – somone is playing the game with the robot. The big difference when comparing the two diagrams of the emotional state lies in the shape of the curve representing the arousal value. While in Figure 7 the arousal value is increased in single steps and it sloly decreases between these step, in Figure 8 the arousal value constantly decreases. This different behavior of the arousal value is caused by the Tangram player. In the first case the Tangram player is very active and places the Tangram tiles correctly. Everytime the robot recognizes an action of the player in order to improve the current state of the game the arousal is increases. In the second case the player does not try to solve the game.

Therefore, the intensity of the Tangram game is not increased and since no other person enters the scene and no loud sounds have been perceived the arousal value decreases constantly. As already mentioned the absence of any arousing stimuli leads to boredom. This phenomenon is considered in the calculation of the motives satisfaction. Low arousal decreases the thresholds for undersatisfaction and overstatisfaction. The lower the threshold for oversatisfaction the earlier the corresponding oversatisfied state, which means that the robot is tired of its currently perfomed task. On the other hand if the current situation entertains the robot and provides interesting stimuli – represented by high intensity – the threshold for overstimulation will increase and therefore it will take much longer time until the robot becomes bored. This behavior can be seen when comparing the two diagrams for the *Tangram Motive*. The decrease of valence is caused by the unsatisfied state of the motive, the decrease of stance is caused by the fact that there is still someone playing the game although the robot wants to quit. In the first case (Figure 7) the emotional state changes the threshold for oversatisfaction in a way that the motivation to play the games lasts for 612.7 s, while in the second case (Figure 8) the robot looses its motivation already after 135.04 s.

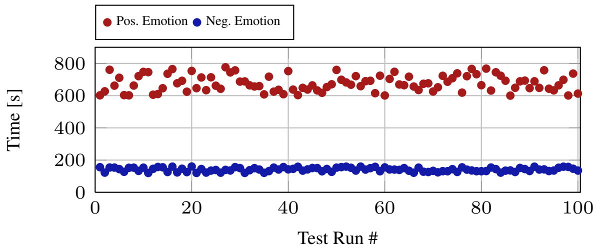


Figure 9: For every test run the time until the robot looses its motivation to play the Tangram game is plotted, once for the case where the Tangram player tries to provoke positive emotions (red dots) for the robot and once for the case where negative emotions are induced (blue dots).

To ensure the consistancy of the described robot behavior, this experiment has been repeated 100 times in simulation. The results of these test runs are depicted in Figure 9. For every test run two dots are plotted. The red one indicates the time until the robot looses its motivation to play the game in the cases that the player tries to motivate the robot, the blue dot represents the case where the player tries to demotivate the robot. It can be seen that there has been a significant different between the motivated case and the demotivated case. It is obvious that when the robot experiences positive emotion the variation is much higher than in the case where negative emotions are experienced. This is because motivation of the robot depends on the progress in the game. Therefore, it depends on the puzzle pieces placed by the Tangram player and on the recognition of these pieces by the robot. Since these parameters are not constant throughout the interaction the achieved results varie. In the case where the robot should be demotivated the player does not change the puzzle pieces. Therefore, this parameter does not affect the robot's emotional state and therefore there is less variation in these results.
The achieved results show that the realized architecture implements a major aspect of the motivational characteristic of emotion. Positive emotions increased the robot's motivation to continue the currently performed task significantly compared to negative emotions that lead to the opposite behavior. The mean time of all test runs while experiencing positive emotions until the robot looses its motivation comes up to 683.6111 s, while the mean time for the negative emotional case is 140,0602 s.

5 CONCLUSIONS AND FUTURE WORKS

This paper provided detailed information how to implement the necessary skills for enabling the humanoide robot ROMAN to play Tangram. The whole implementation is realized within the UKL Emotion-based Architecture described in [6]. This architecture is especially designed for controlling interactive robots. To evaluate the functioning of the implemented components experiment results have been introduced that prove that ROMAN is able to handle the Tangram scenario. Using this scenario an experiment has been conducted that shows the influence of emotion to the robot's motivation. For the future further experiments using the Tangram scenario will be conducted to investigate the influence of emotion to human-robot interaction. For example whether the human interaction partner is able to deduce the robot's motivation depending on the robot's interactive and expressive behavior or contrary to the experiment presented in this paper it can be investigated whether the robot can influence the motivation of its interaction partner by changing its own emotional reactions. Appart from this, further interaction scenarios should be realized to test whether the results achieved for the Tangram scenario can be transfered.

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