# How to Make Robots Feel and Social as Humans

Building attributes of artificial emotional intelligence with robots of human-like behavior

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***Abstract*—Paper contributes to building attributes of artificial Emotional Intelligence (EI) aimed to be implemented in robots of human behavior as advanced intelligent robot interface. The main research objective of the paper regards to searching is it possible and how to make robots emotive and sociable as humans. For this purpose, the Meyers-Briggs theory on human personality, known from personality psychology, is employed for mapping human psychological traits and development of robot EI-controller. A customized multi-input and multi-output fuzzy inference model is designed to fit human affective and social attributes. The assumed fuzzy structure makes core of the robot EI-controller. Developed intelligent robot interface was implemented with small Aldebaran's Nao humanoid robot used to validate control performances and EI model developed. In the paper, was presented how the developed intelligent robot interface can be used for mapping different human personality traits and temperaments to the machine. Accuracy of the model used for building robot interface was verified by tests with human examinees by using corresponding on-line psychological tests – questionnaires.**

***Keywords-emotional intelligence; emotion-driven behavior; social robots; embodied mind; affective computing;***

## I. Introduction

To function in a complex and unpredictable physical and social environment humans are faced with applying their physical and intellectual resources to realize multiple goals in an intelligent and flexible manner. Two distinct and complementary information processing systems – *cognition* and *emotion* enable humans achieving of these goals by operating simultaneously [1]. The cognitive system is responsible for interpreting and making sense of the world, whereas the emotion system is responsible for evaluating and judging events to assess their overall value with respect to the human (e.g., positive or negative, desirable or undesirable, hospitable or harmful, etc.) [2]. When operating in the proper balance, the emotion system modulates the operating parameters of the cognitive system and the body to improve the overall mental and physical performance of the human. The scientific literature documents the beneficial effect of emotion on creative problem solving, attention, perception, memory retrieval, decision-making, learning, etc.

The fact that emotions are considered to be essential to human reasoning suggests that they might play an important role in autonomous robots as well [3][4].Today's autonomous robots can certainly improve their ability to function in complex environments and to behave appropriately in partnership with people. Using the properties of natural intelligence as a guide, a robot's cognitive system would enable it figure out what to do, whereas the emotion system would help it to do so more flexibly in complex and uncertain environments, as well as help the robot behave in a socially acceptable and effective manner with people [4].

In order to interact with social partners (whether it is a device, robot or another person), it is essential to have a good conceptual model of how the social partners operates [5]. With such a model, it is possible to explain and predict what the interlocutor is about to do, its reasons to doing it, and how to elicit a desired behavior from it. The work in this paper focuses on developing emotionally-driven and sociable robots for envisioned applications where the robot interacts with a person or another robot as a partner. The field of social robots and safe Human-Robot Interaction (HRI) opens new areas of applications like: healthcare, caretaking, assistance, edutainment and entertainment.

The paper is organized in seven sections. In Section 1, a brief introduction into the topics considered in the paper is given. Progress beyond the state-of-the-art is pointed out in Section 2. Necessary theoretic background as a platform for building of the EI model is given in Section 3. Section 4 addresses to modeling of human affective and social behavior dealing with concept and solutions. Model validation and implementation of EI interface with the small Nao humanoid robot are given in Sections 5 and 6. The paper is concluded in Section 7.

## II. PROGRESS BEYOND STATE-OF-THE-ART

Modeling of natural intelligence, artificial EI, embodied mind and embodied cognition are emerging research fields. They were thoroughly explored by many scientists in natural, human and technical sciences in the last decade.

Inspired by models of natural intelligence in biological systems, Breazeal [2] [6] designed an architecture that features both - cognitive system and Emotion System (ES). Both systems operated in parallel and are deeply intertwined to foster optimal functioning of the robot in its environment. The overall architecture was comprised of a distributed network of interacting agent-like processes that excite and inhibit one another by spreading activation. For modeling of

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the ES, a learning structure for dynamically deciding the appropriate number of kernels, were applied [6]. This work resulted in development the sociable machine Kismet [7], an expressive robotic creature with perceptual and motor modalities, tailored to natural human communication channels.

Beginning with an outline of the theoretical and methodological commitments of standard cognitive science, Shapiro then examined philosophical and empirical arguments surrounding the traditional perspective [8].

Varela et al. have highlighted several themes clearly [9]: our dualistic tendencies to distinguish between subject and object, and the reification of representation in our framing of experience - both projected outward (idealism) onto objects in the world that can then contain and give shape to our inner representations, or assimilated symbols of an independent world 'out there' (realism).

Brooks theorized on the importance of emotional intelligence in predicting individual and group success [10]. Drawing off of a variety of disciplines including psychology, economics and cognitive research, Brooks made a case for the power of the unconscious mind in influencing our interactions, beliefs and decisions. We are products of our emotions, he said. “Emotions enable us to value things. We can’t make decisions if we can’t value things.” Brooks stressed out that “the mere act of affection rewires connections in our brains”.

Authors of this paper contribute beyond the recent research results in this field by searching for the answer how to make robots feel and sociable as humans. They go even further trying to give the answer how to make robot psyche to be of predefined (requested) human-like personality traits. The solution proposed in this paper concerns with design of an appropriate model of human affective and social behavior based on personality psychology that also takes into account real interior and exterior constraints.

## III. THEORETIC BACKGROUND

The platform for development mathematical model of human emotionally driven and social behavior is the Meyers-Briggs theory on personality [11] widely used in personality psychology. According to this theory, the personality type and temperament dominantly influence human psychological behavior.

### A. Personality Type

Personality psychology is a branch of psychology that studies personality and its individual differences [12]. According to the theory, "personality" is a dynamic and organized set of characteristics possessed by a person that uniquely influences individual cognitions, emotions, motivations, and behaviors in various situations. Personality also refers to the pattern of thoughts, feelings, social adjustments, and behaviors consistently exhibited over time that strongly influences one's expectations, self-perceptions, values, and attitudes. It also predicts human reactions to other people, problems, and stress [13] [14]. This scientific discipline uses the Myers-Briggs Type Indicator (MBTI) assessment as a psychometric questionnaire designed to measure psychological preferences in how people perceive the world and make decisions [15]. The MBTI sorts psychological differences into four opposite pairs, i.e., dichotomies (Extravert-Introvert, Sensing-iNtuitive, Feeling-Thinking and Perceiving-Judging). That results in 16 possible psychological, i.e., personality types. None of these types are better or worse. However, Briggs and Myers theorized that individuals naturally prefer one overall combination of type differences [12].

### B. Human Temperament

Under the notion “temperament” it is assumed in psychology, unlike to the term “personality”, the individual kinds of the psyche traits that determine dynamics of human psychological activity [16]. The temperament traits are expressed in an even manner in any activity nevertheless to its’ content, goals and motives, remaining invariant in the later years and which, in their interconnections, characterize the type of temperament [16]. The temperaments are (Fig. 1): *sanguine* (pleasure-seeking and sociable), *choleric* (ambitious and leader-like), *melancholic* (introverted and thoughtful), and *phlegmatic* (relaxed and quiet), Fig. 1.

A temperament type can be determined by filling corresponding questionnaires (tests) available at the Internet as well as corresponding personality tests [17] [18].

## IV. MODELING EMOTIONS

While the artificial intelligence copes with tasks such as pattern recognition, context understanding, reasoning, decision making, etc., the emotional intelligence is responsible with humans for self-awareness, self-management, awareness of others and relationship management [19]-[21]. According to the theory of personality, human emotional reactions primarily depend on three factors [13]: (i) personality type, (ii) personality character, and (ii) temperament. These factors are mainly determined by genetic code and acquired by a birth. Also, behavior of individuals is strongly influenced by additional exterior and interior factors (Fig. 2). Under the term “exterior world” our physical and social environment (such as events, situations, acts or relationships with other persons) are assumed. The “interior stimuli” mainly concerns with our physical and psychological conditions (regarding to body and psyche) such us senses of fatigue, pain, disease, etc. Under the same term, the feelings like love, depression, anger, hatred, fear, satisfaction, etc., are assumed, too. The “social factors” regard to the conditions that influence some features of individual behavior.

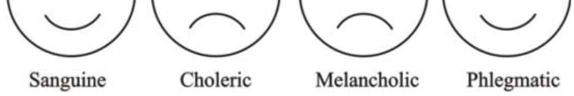


Figure 1. Emotion representation of four temperament types.

The “social factors” includes the following: family and school education, influence of companions, religion and affiliation to the social groups such as political parties, civil communities, clubs, etc.

To derive generic model of a human psychological behavior the following assumptions can be assumed. The considered biological system, such as human psyche, can be approximated by a deterministic, dynamic, non-linear, multi-input and multi-output (MIMO) system of arbitrary complexity. The input and output variables of the emotion-driven behavior (EDB) model are hardly measurable. They can be quantified (rated) by using corresponding psychological questionnaires [17], [18].

The variables of interest required for modeling EDB include qualitative information regarding personality profile, physical and social environment, emotional and health conditions, social factors, etc. They are quite heterogeneous, defined in the form that is more symbolic and descriptive than measurable and numerical. Generally, humans use to behave (in psychological sense) in a fuzzy manner by using corresponding linguistic variables. That means people use their different natural skills of sensing, symbolic and phonetic communication (e.g., body and facile gestures, phonetic meanings, etc.) to express their emotional state – feelings, mood, etc. Due to a fuzzy nature of human behavior, the modeling approach to be assumed in this paper as appropriate solution consequently belongs to the knowledge-based type. It assumes utilizing of a fuzzy logic system structure. Accordingly, the appropriate model structure of emotionally-driven and social behavior can be represented by a three-stage block structure presented in Fig. 2. It consists of three fuzzy logic blocks FIS-1 to FIS-3 where everyone contributes particularly to shaping of outcome event-driven emotional reaction(s).

Human affective behavior is generated and profiled by influence of three input variables (information carriers) that are: (i) “trigger-event” that arouses different psychological reactions, (ii) “behavior profiler” that shapes event-driven behavior in a way to fit particular personal profile of individual whose behavior need to be modeled, and (iii) “behavior booster/inhibitor” that intensifies or weakens the expressiveness of the affective manifestations of individual. The trigger-event (e.g., situation, interpersonal relationship, interaction or just an act) provokes (excites) corresponding affective reactions (mood) with individuals. It is well known that some persons react more intensively in emotional sense (depending on their personality type and temperament) to the same trigger-event than others.

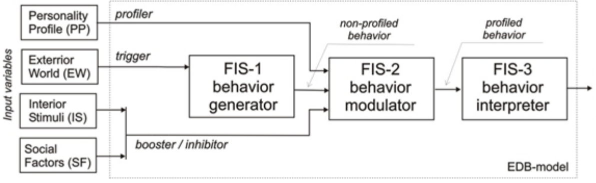


Figure 2. Block-structure of the emotionally-driven behavior model consists of behavior generator, modulator and interpreter.

These personality differences can be modeled by introducing corresponding “behavior profiler”. The “behavior profiler” modulates usual (generally expected) emotional reactions characteristic for this trigger-event. It is done in a way to imitate reactions characteristic for the particular personality profile and temperament of the individual whose behavior need to be modeled. The “behavior booster/inhibitor” in the model presented in Fig. 2 serves to intensify or weaken the intensity of emotional reactions depending on dominant personality traits and temperament type.

Fuzzy model blocks FIS-1, FIS-2 and FIS-3 (Fig. 2) are assumed to be of Mamdani type. The input and output variable vectors at the particular fuzzy blocks are of the arbitrary number depending on how comprehensive model wish to be developed. In the model presented in Fig. 2, the corresponding input/output membership functions of the FIS-1 to FIS-3 blocks are either the Gauss curves or Sigmoid functions. The number of fuzzy rules synthesized in the model varies depending on how comprehensive and accurate model is required. The proposed model architecture (Fig. 2), with three fuzzy blocks aligned in a cascade, enables easy monitoring of the model state variables.

Trigger-events to be considered in the model, presented in Fig. 2, can be rather numerous. The list of the trigger-event attributes used for modeling of human emotional behavior in this paper is given in [22]. At this stage of research, this number of event attributes is limited to approximately n1=50. This amount of attributes satisfies modeling requirements of majority usual scenarios to appear in everyday practice. The actual number of event attributes can be in principle very high - the larger number of trigger-event attributes in the model, the more comprehensive, accurate and complex model is. The number of emotions (moods) n2, modeled in the paper, is higher than the number of trigger-event attributes n1 (middle column, Fig.3). The right column, presented in Fig. 3, contains emotional reactions, i.e., attributes of reactions, caused by trigger-events. They are modulated by use of the fuzzy rules that take into account personality traits and temperament of the individual whose affective and social behavior is modeled. To clarify the methodology applied, the event “birthday anniversary”, taken as an example, represents combination of several particular event attributes such as: cheerful, funny, surprising, sociable, etc. To build a model, every particular event attribute as well as emotion state of the individual has to be quantified (rated) in an appropriate way. It can be done in a way presented in Fig. 4. Such an approach leads to correct definition of linguistic fuzzy variables as appropriate inputs to the corresponding fuzzy model blocks. For example, if take the attribute “cheerful” as a variable, its’ rating can be accomplished in the following way: (i) *not at all* (0%), (ii) *somewhat* (<25%), (ii) *very* (25-75%) and (iii) *entirely* (>75%). Concerning fuzzy rules of the model, they are determined based on the semantic-graph whose reduced (not complete) form is presented in Fig. 3. According to this graph, the following fuzzy rule, as an example, can be derived:

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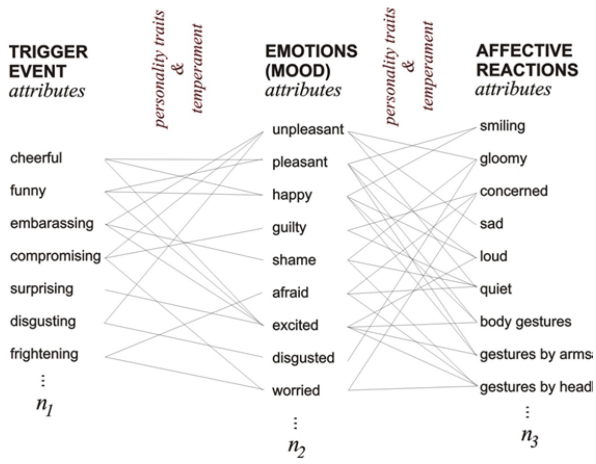


Figure 3. Example of functional interconnections between the trigger events, produced emotions and corresponding affective reactions.

if (*event*.is.*cheerful*) than (*mood*.is.*pleasant*) and (*mood*.is. *happy*) and (*mood*.is.*excited*).

By designing of the model rules, it is also necessary to take into account the influence of the personality profile of individual as well exterior and interior constraints.

The model designed in this paper includes 75 fuzzy rules, n1=20 trigger-event attributes, n2=35 emotion attributes and n3=20 different affective reactions. The number of rules can be much higher in the case of a more accurate and comprehensive model. Being we have implemented this model to a small humanoid robot with limited capabilities the number assumed was enough numerous to verify the performances of the designed robot EI-controller. More details regarding model building are given in [22].

Additionally, attributes of social behavior regard to interpersonal ability of communication and self-adaptation to group or team. The properties such as sociability (easiness of communication with others), cooperativeness, compatibility with others, interpersonal synergy, reliability and responsibility for the community interest, mutual tolerance, feel of belonging community, etc., are properties based on highly developed degree of EI. Brooks [10] pointed out that emotions are the motor-power of human individual and collective behavior. Attributes of social behavior of individuals strongly depend on personality profile and temperament but also on social constraints such as family education, companions, club memberships, religion, etc.

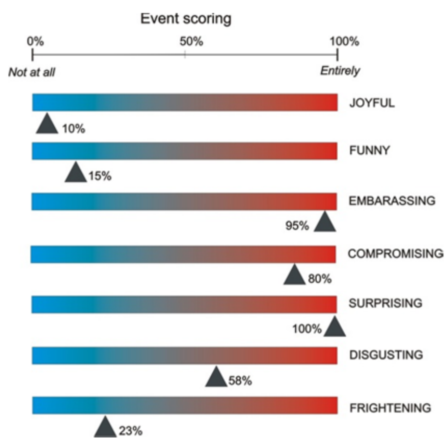


Figure 4. Example of rating (quantification) trigger-event attributes according to degree of experiance.

## V. MODEL VALIDATION

Model validation is accomplished experimentally by involving human examines in this procedure to provide reference values. Ten persons of different gender and age were requested to fill out the personality type and temperament test. Both questionnaires are available on Internet [17] [18]. The same examinees were asked also to fill out the questionnaires to assess their affective reactions (response) to the imagined (hypothetical) set of trigger-events taken from the life practice. The results were systematized and presented in [22]. In the paper, a characteristic trigger event, arousing emotional behavior, is chosen for model verification.

Trigger event example: *At the dinner table, someone told a funny joke. While laughing, you have suddenly burped loudly.*

The chosen event is experienced in a different way by interviewed persons. Model validation was done by comparison of the results obtained by testing human examinees (of known personality profiles) with corresponding results obtained by simulation of the generic model proposed in the paper. In such a way, the objectivity of model assessment is achieved.

Also, the model sensitivity test upon variation of exterior and interior factors (personality traits, social factors and interior stimuli) was done. The emotion trigger-event assumed in this simulation experiment has the attributes presented in Fig. 4. These attributes are independently rated by anonymous human examinees. The model of EI presented in Section IV is simulated taking into account the parameters that correspond to the following test-cases:

C-1: Personality type *INTJ* (Introvert=60%, iNtuitive=57%, Feeling=78%, Judging=69%); Temperament: *Sanguine*=80%; Interior stimuli: *none*; Social factor: *none*;

C-2: Personality type *ESTP* (Extrovert=60%, Sensing=57%, Thinking=78%, Perceiving=69%; Temperament: *Sanguine*=80%; Interior stimuli: *none*; Social factor: *none*;

C-3: Personality type *ESTP*; Temperament: *Choleric*=80%; Interior stimuli: *none*; Social factor: *none*;

C-4: Personality type *ESTP*; Temperament: *Phlegmatic*=80%; Interior stimuli: *none*; Social factor: *none*;

C-5: Personality type *ESTP*; Temperament: *Phlegmatic*=80%; Interior stimuli: *completely moody*; Social factor: *none*;

C-6: Personality type *ESTP*; Temperament: *Phlegmatic*=80%; Interior stimuli: *none*; Social factor: *strict family education*;

Simulation results presented in Table 1 represent the rated feelings (affective reactions) obtained by model simulation. Feeling attributes (Table 1) were aroused by the

TABLE I. SIMULATION RESULTS: TABLE OF FEELING RATES

| | C-1 | C-2 | C-3 | C-4 | C-5 | C-6 |
|---|---|---|---|---|---|---|
| ***Feeling rate*** | % | % | % | % | % | % |
| Unpleasant | 50.49 | 51.72 | 51.84 | 45.89 | 45.94 | 46.55 |
| Guilty | 84.82 | 87.98 | 85.78 | 67.88 | 70.36 | 72.69 |
| Shame | 97.41 | 97.41 | 95.45 | 79.82 | 79.82 | 82.70 |
| Frightened | 49.86 | 51.48 | 51.63 | 45.62 | 45.71 | 46.29 |
| Excited | 45.80 | 48.80 | 49.37 | 42.60 | 43.13 | 43.35 |
| Disgusted | 43.49 | 46.32 | 46.98 | 40.33 | 40.98 | 41.07 |
| Warried | 48.37 | 50.88 | 51.13 | 44.83 | 45.00 | 45.52 |

imposed trigger-event example and modulated by corresponding interior and exterior factors such as: personality traits, temperaments, emotional states and social factors. The presented results validate model sensitivity upon variation of the previously mentioned factors. By comparing the feeling indicators presented in the columns C-1 and C-2 of Table 1, it is evident that an ESTP person demonstrates emotions in a more intensive way than one IFTJ person. Also, an ESTP choleric person (C-3) is more sensitive than corresponding sanguine (C-2) and phlegmatic (C-4) persons. A moody person (C-5) and a person that is subjected to the strict social constraints (e.g., family education) are slightly more sensitive than others with the same temperament and personality. Affective reactions that are generated by the model proposed in Section IV commonly can be displayed by the feeling charts, as presented in Fig. 5.

The obtained simulation results and verification of model properties make us believe that the EI model designed in this paper can be effectively implemented with robots to enable them to feel and be social as humans. In the next section it will be demonstrated.

## VI. IMPLEMENTATION OF ROBOT EI-INTERFACE

Robot interface (software algorithms), based on the model of human affective and social behavior developed in this paper, is implemented in the controller of the Aldebaran's Nao humanoid robot [23]. Block-diagram of the high-level control structure is presented in Fig. 6.

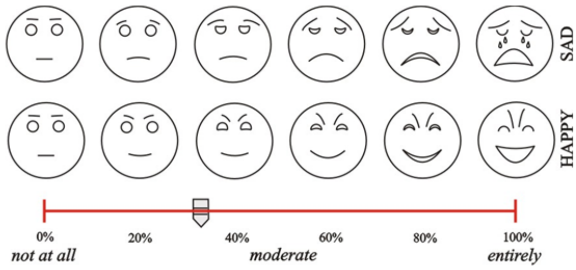


Figure 5. Example of feeling charts. Mood rating scale with respect to the sadness and happiness

### A. Software Implementation

As a widely used open robotic platform, the Nao robot provides a relatively fine possibility of simple implementing advanced control algorithms through the Naoqi robotic application [23]. The Naoqi application is an open and fully accessible software module which provides easily access through all major ports of the Nao robot. The Naoqi application is embedded Nao software that includes fast, secure and reliable development platform. It allows easy implementation of new features that can improve functions of the Nao robot. The Naoqi allows an implementation of algorithms that share its Application Programming Interface (API) to the other systems and supports the development of modules that run on the Nao platform or on a remote PC system. Software development can be accomplished in Windows, Mac OS, or Linux environment. A software package that collects signals from the visual system of the robot is written in Open CV. Through the Naoqi, the application gathers information from one of the video cameras implemented in the head of the Nao robot. It is not possible at once to combine signals from both cameras due to the configuration of the controller built into the Nao robot. So, images from selected high-definition camera are transmitted to remote PC, via Naoqi implemented software applications by wireless communication.

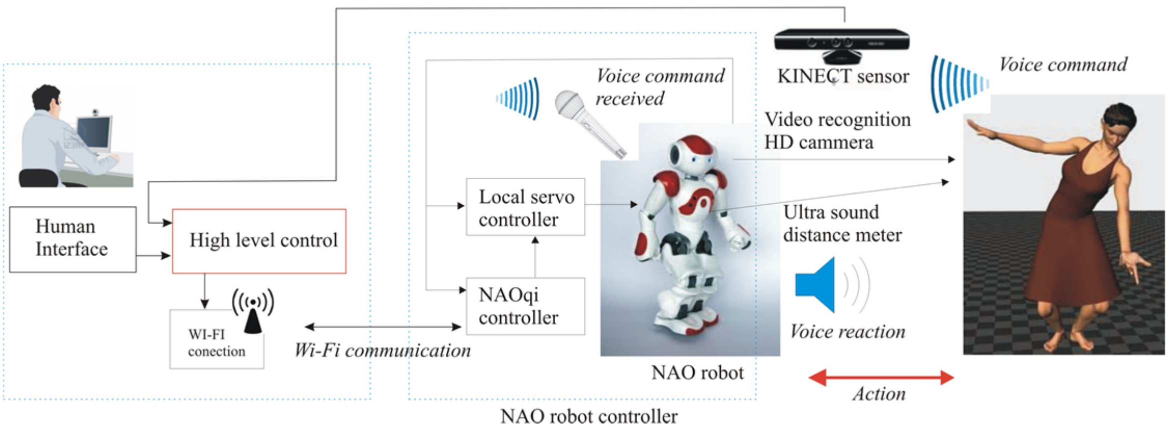


Figure 6. High-level system description. The control block-diagram of the NAO humanoid with EI-controller.

Remote PC provides signal processing and recognition of individuals based on face recognition applications. When the Nao robot observes and locates the person for possible cognitive interaction, an ultrasound sensor is activated to determine the distances to the interlocutors. Based on the vision algorithms and signals from ultrasonic rangefinder, the distance between Nao and interlocutor is obtained and estimated and modules of cognitive analysis are activated. Cognitive analysis module of persons, together with face recognition module, analyze the condition of the interlocutor, based on the movement of arms and legs of the interlocutors, coordinate all the parameters of cognitive analysis and decide about the emotional state of the interlocutor. In accordance with all analyzed cognitive parameters of the interlocutor, a conclusion is made and desired movement of the Nao robot are generated achieving its' hands, and at the same time it is generated desired audio message that Nao robot directs to the interlocutor. So, the audio system is included into the algorithm. Namely, entire action is initiated by the voice. The block diagram of the overall cognitive task is shown in Fig. 6.

## B. Embodiment of Social Behavior Attributes in Robot

Attributes of social behavior were implemented in Nao robot controller as an advanced EI-interface. The task of EI-controller is to enable robot some basic functions of social behavior attributes characteristic for behavior in groups. Bearing in mind the real technical constraints of the hardware, some of the particular attributes of social behavior, shown in the semantic graph in Fig. 7, were implemented with the Nao robot. Principle of implementation of fuzzy model in realization of some features of social behavior is similar to the principle of implementation the functions of affective behavior presented in Fig. 3. In this case, instead of a trigger-event, physical and social environment arouse corresponding emotional reactions and interpersonal relationship (communication, collaboration, etc.) between robot and others. In the paper, Nao robot is requested to express some elements of social behavior based on relativelly modest perceptive capabilities. They are based on embedded robotic vision, external Kinetic sensor (for gesture recognition) and speach recognition system. Fuzzy model, that is core of the control interface implemented in Nao robot, includes variables that carry on neccessary information regarding stimuli received from social environemnt such as audio and physical incentives: invitation voice, salutation, body and arms gestures, dialog sequences, etc.

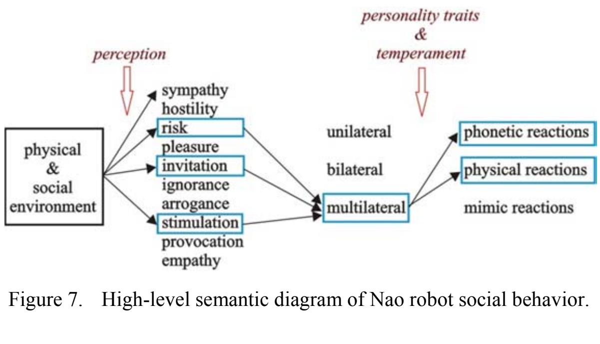


Figure 7. High-level semantic diagram of Nao robot social behavior.

Robot also checks for possible risks of interacting with others by recognizing exsitance of some irregular physical gestures originating from the interacting persons. Also, type of communication, assuming unilateral, bilateral or multilateral modus, determines character of robot interaction.

Nao robot interacts with social environment by using its' audio interface (microphones and speakerphones) and physical gestures through movements of body and arms. The rating scale of phonetic and physical reactions implemented in the Nao robot is presented in Fig. 8.

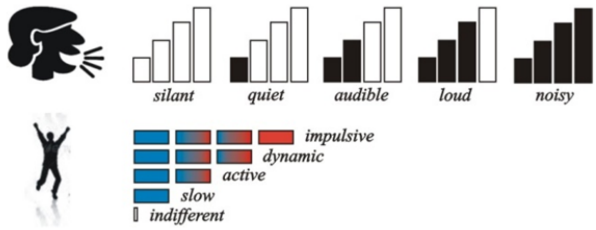


Figure 8. Rating scale of phonetic and physical reactions implemented with Nao robot.

## C. Experiments with Nao Robot

The task „teamwork" is a typical scenario that includes attributes of social behavior. In this case, temperamental and strongly motivated individuals accomplish this task easier and in a more efficient way than ones with weak temperament and low motivation. In this example, group of junior researchers from laboratory invites (stimulates by voice) Nao robot to join them and salute (Fig. 9). Nao robot, having an advanced EI interface, recognizes calls, locates persons in the surrounding, recognizes their gestures and responses them by stretching arm forward and speaking the kind words. In such a way, robot expresses its' social behavior as presented in Fig. 9. In this experiment, personality traits of a joyful, sociable and temperamental individual are imposed to the NAO robot. The experiment was repeated by changing robot parameters (features) making robot to be a "person" of properties that regards to a reserved (introverted) and melancholic person.

Figure 9. NAO robot demonstrates EI capabilities by communicating with young reserchers from the IMP Robotics Laboratory.

By comparison of robot affective reactions obtained in the previously mentioned experimental sessions, the expected validation of the proposed modeling concept is achieved.

## VII. CONCLUSION AND FUTURE WORK

The paper concerns with development of robot EI interface designed to ensure advance robot capabilities – emotional and social behavior as humans. Developed interface is based on generic model of natural emotional intelligence that includes human emotion-driven and social behavior. EI model is synthesized by implementing multi-input and multi-output fuzzy inference system. The purpose of artificial EI in robots is to increase the autonomy through building advance cognitive features such as: emotion understanding, self-management, managing relationship with others, etc. The novelties given in the paper regards to modeling approach of human affective and social behavior attributes based on theory taken from personality psychology. Model takes into account personality traits, type of temperament as well as interior and exterior constraints – emotional conditions, social factors, etc. Model validation was done by comparison of experimentally acquired indicators from human examinees and indicators obtained by model simulation. Convergence of experimentally obtained and simulation results indicates that developed EI-model can be used with robots for embodiment of mind and cognitive capabilities. The EI-interface was implemented with NAO humanoid robot. It was demonstrated how Nao robot demonstrate some attributes of social behavior based on its' EI-controller. Additional model extension and validation are planned in the future by using extensive experimental results with human examinees. The model structure will be upgraded by including new attributes of emotion and social behavior. In such a way, the EI-model will become more comprehensive and accurate.

## ACKNOWLEDGMENT

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