Preprints of the 20th World Congress
The International Federation of Automatic Control
Toulouse, France, July 9-14, 2017

Preprint of: Kowalczuk Z., Czubenko M.: Emotions Embodied in the SVC of an Autonomous Driver System. IFAC-PapersOnLine. Vol. 50, iss. 1 (2017), pp. 3744-3749. DOI: 10.1016/j.ifacol.2017.08.573

Emotions Embodied in the SVC of an Autonomous Driver System

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Abstract: A concept of embodied intelligence (EI) is considered. None of such implementations can be fully identified with artificial intelligence. Projects that dare to approach AI and EI should be based on both the AI concepts (symbolic and sub-symbolic), in solving real problems of perception and decision-making. Therefore, the EI, in this paper, is understood as a methodology that uses all available resources and algorithms from the analytic and synthetic approaches, in order to implement an intelligent and autonomous agent.

Keywords: Learning, adaptation, autonomous vehicles, artificial intelligence, cognitive aspects.

1. INTRODUCTION

Engineers have long been attempting to make machines intelligent (like chess automates), autonomous (*tortoise*), or human-like (ASIMO). You can see it in the current development of autonomous vehicles and cars, which in future may get a great degree of autonomy. Moreover, the ideas of voice communication (Siri or Google Speech Engine) and computational models of emotions are attracting more and more attention in communication using natural languages, feature detection, and robots control.

Artificial Intelligence is a field that let us to build systems, similar to human in several aspects. It deals with issues such as reasoning, problem solving, knowledge representation, machine learning, natural language processing, machine perception, and others. We can distinguish two approaches (Kowalczuk and Czubenko, 2017a):

- symbolic (top-down, synthetic, or clean), using high-level logic (simplistic and black-box) mathematical modeling, knowledge-based processing, and machine learning (Newell and Simon, 1972),
- sub-symbolic (bottom-up, analytic, or embodied), involving small (white-box, physical, neuronal) models to first create a low-level, and next, by the *ad hoc* rules, higher-level solutions (Brooks, 1991).

Modeling the human mind can be done by applying the symbolic approach or the sub-symbolic method. It appears however that an intelligent combination of many methods should better reflect the effects of the human brain.

In principal, Embodied Intelligence represents the sub-symbolic approach, extending the cybernetic projects from the 50s, which tried to reproduce simple low-level *intelligence* (Flemmer, 2010; Anderson, 2003; Brooks, 1991), or newer cybernetic projects, like *homeostat*, staying stable despite disturbances, or *tortoise*, following light (Pickering, 2011). Often, it proves be sufficient to use *baby steps* by simulating a basic functionality and simple elements. Hence, a new branch of has emerged (Arkin, 1998). Various achievements from EI, behavior-based robotics, and top-down approaches, are indispensible in modeling the human mind. To get an intelligent interaction with an artificial agent, one has first to explicitly define what 'embodied intelligence' means (Starzyk, 2008).

Considered in this paper, *embodied intelligence* (EI) is different from the classical definition. Though many ideas to AI have been put into practice, none of them can be fully identified with AI. Projects that dare to approach AI and EI should be based on both the AI concepts (symbolic and sub-symbolic), in solving real problems of perception and decision-making. Therefore, Embodied (Artificial) Intelligence, in this paper, is understood as a methodology that uses all available resources and algorithms from the analytic and synthetic approaches, in order to implement an *intelligent* and *autonomous* agent.

There are a great number of intelligent and embodied systems, which are based on human motivation. Human is the highest of all species in many terms; thus the human system of motivation appears to be most adequate as a template of behavior. Ethical and rational foundations for such systems can be derived from the existing variety of the models of psychology and human intelligence. These achievements have notably contributed to AI. We can distinguish the following types of conceptual (behavioral and psychology-based) solutions:

- behavioral, based on pairs of stimuli & reactions,
- Beliefs-Desires-Intentions (BDI), where beliefs are certain states of an agent, desires represent its motivation, and intentions inform what the agent has chosen to do (Korecko et al., 2014),
- emotionally founded; also assigned to BDI; like Kismet, Mexia, iCube, Emys (Esau et al., 2003; Metta et al., 2011; Kowalczuk and Czubenko, 2016),
- driven by needs (Miwa et al., 2003; Novak, 2014),
- cognitive architectures, like LIDA, CLARION, SOAR, MANIC, DUAL, OpenCog, and others, with a key role of structure (Franklin et al., 2014; Sun and Helie, 2013; Laird, 2012; Kowalczuk and Czubenko, 2017a).

Cognitive architectures are most advanced technologically. On the basis of both the symbolic and sub-symbolic approaches, they implement the methods of processing and storing information, and different kinds of human motivations. Known cognitive architectures are founded on the BDI, and on behavioral or emotional aspects. The subject of this paper, an Intelligent System of Decision-making (ISD), considers behavioral, emotional and motivational contexts, supported by cognition. The prospect of implementation of the ISD on a car or robot creates the conditions for the embodiment of intelligence.

The basic concept and ultimate goal of our Intelligent System of Decision-making ISD (Kowalczuk and Czubenko, 2010a,c, 2011; Czubenko et al., 2015), and its subsystem xEmotion (Kowalczuk and Czubenko, 2013; Kowalczuk et al., 2016) is to prepare a framework for autonomous units, such as a car driver (Czubenko et al., 2015). Psychological theories are often conflicting and difficult to reconcile, thus the ISD system has been designed based on a coherent selection of them. The xEmotion subsystem considers emotions and implements them, taking into account their short term (expressions) and long term duration (concerning personality, for instance).

The Intelligent System of Decision-making is a unique system, which tries to map the human decision-making process, described by various models of psychology. Despite the existence of other similar systems, which usually model some selected psychological aspect (e.g. semantic memory, or decision making), none of them represents such an integral approach to modeling the human-like way of behavior. This approach, for instance, includes also the emotional aspect of human psychology (extending the appraisal theory of emotions), which acts not only for communication, but also to adapt the sets of the agent's reactions. This means that the ISD tries to implement most of the above-mentioned conceptual solutions.

2. INTELLIGENT SYSTEM OF DECISION-MAKING

Intelligent System of Decision-making, ISD, presented in (Kowalczuk and Czubenko, 2010b,c, 2011, 2013, 2014; Czubenko et al., 2015; Kowalczuk et al., 2016), is a universal system for agents that is founded on cognitive psychology and motivation theories. It mimics the way people make decisions, from the arrival of stimuli to the generation of a reaction. The ISD design is the result of a thorough modeling of human psychology. As a universal system (Fig. 1), ISD can control robots and unmanned vehicles, including cars (Czubenko et al., 2015).

As shown in Fig. 1, stimuli reach the ISD through different channels. Sensors are related to external stimuli (to feel the agent's environment) and internal stimuli (from robotic actuators). Perceived stimuli are stored in an ultra-short-time memory USTM (sensory buffers), and further processed in search of simple features, impressions (shape, color, texture, etc.). To recognize a simple impression, the agent applies various mechanisms, filters, masks, neural networks, fuzzy systems, decision rules, and others. Haar cascades, for example, are useful in recognizing head shapes. Such impressions and their locations in space are stored in a short-term memory STM. They can then be grouped together to form discoveries (objects).

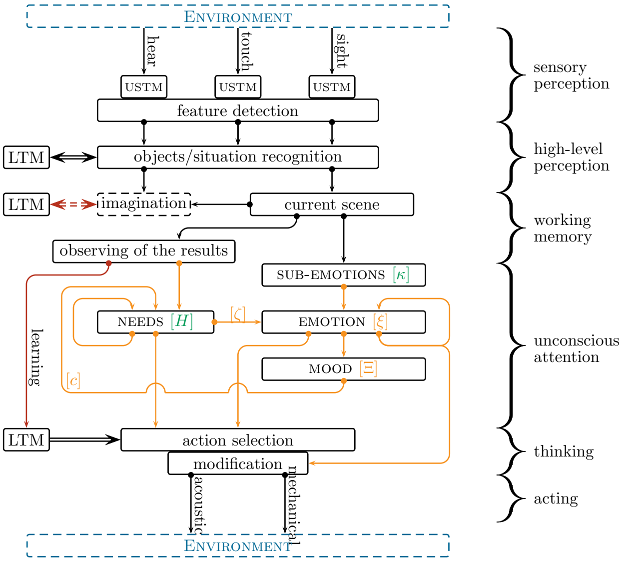

Fig. 1. View on ISD (Kowalczuk and Czubenko, 2017a).

Not recognized, grouped impressions are compared with objects stored in a long-term memory LTM (in its semantic part) with the use of some similarity/compatibility measures. When a similarity threshold is reached, unrecognized discovery is tagged as an actual instance of a matching object (from LTM) and transferred to a memory of the scene. Otherwise, the agent takes action to provide more information about this unrecognized object.

Recognized discoveries can affect an ISD motivational subsystem, in particular, the needs and emotions of the agent. The system stores the motivational contexts assigned to objects (in the semantic memory), based on previous experience (e.g. an apple can partly satisfy the need for food). On the basis of the objects in the scene memory, the agent's motivational and emotional context (fulfillment of the needs and inclusion of sub-emotions) are changed. These processes are part of the unconscious attention of the agent. If a need (for energy, for example) is directly linked with an internal gauge, its status may amend the degree of (un)fulfillment of this need.

The agent determines an appropriate emotion-dependent set of available reactions (i.e. reactions correspond to the emotion), wherefrom the agent selects the one that fulfills its current needs to the greatest degree. All possible reactions are stored in the long-term memory LTM.

2.1 *Decision-making*

The principal mechanism of decision-making in ISD is based on the concept of needs, which are main drives for acting. Needs are variables programmable by the designer. They can also be created autonomously by the agent, or adjusted for certain situations. Different sets of needs shape the 'personality' of the agent, according to its environmental conditioning. Observed objects/events, and actions performed by the agent (their inner and outer results), have impact on the state of the agent's needs.

Needs are grouped in a pyramid of 5 levels Maslow (1968). A need is an abstract, fuzzy quantity, which takes one or two of the three states: satisfaction, prealarm, and alarm

(Kowalczuk and Czubenko, 2011). It can be partially satisfied and partially pre-alarmed. A need is completely satisfied, whenever its crisp value equals zero.

An intelligent driver system govern by the ISD implements 7 needs in 4 Maslow classes (Czubenko et al., 2015):

- physiological/principal level: energy optimization
- physiological level: goal achievement
- safety level: security of car
- safety level: traffic regulations
- (self-)esteem level: speed
- (self-)esteem level: confidence
- self-actualization level: creativity.

The SVC is a method of switching between controllers due to different operating points of the system. Thus the agent's reaction is modified by the state of emotions which are meant to exert an optimal impact on the agent's needs. The emotional factor can thus accelerate the execution of reaction, change its power, fierceness, or, in the case of oral conversation, invoke emotional modulation. In the ISD system the emotions are used in a similar way: they change the set of available reactions, by which the agent can immediately, without a deep 'thinking', respond to specific, clear and extreme situations.

Implemented reaction is monitored by agent processes which belongs to the subsystem of unconscious attention. By monitoring its system of needs, the agent can detect changes caused by the recently applied reaction. The changes are stored in the LTM memory as a hypothetical effect of the adopted reaction.

Emotions are one of the most important factors of human behavior. Systems deprived of emotions, can be ineffective. Emotions in ISD play their role at a higher level of control (scheduling) than the basic ISD control founded on the system of needs. In robotic applications, emotions allow us to narrow down the set of possible reactions to those that are most adequate for the current state of ISD (Kowalczuk and Czubenko, 2013, 2017b).

3. EMOTIONAL SYSTEM IN ISD

xEmotion sub-system in ISD covers the psychological theories of emotions, including the appraisal, evolutionary, and somatic theories on emotion. The system reflects a time division of emotions, taking into account short-term emotions (expressions), and long-term ones (e.g. personality). A principal mechanism for the compilation and interpretation of emotions in ISD is a circle of emotions, which will also be referred to as a 'rainbow' of emotions.

A description of the sub-system xEmotion is given in (Kowalczuk and Czubenko, 2017b), whereas an overview of the proposed various approaches to computational emotion can be found in (Kowalczuk and Czubenko, 2016). For simplicity, we present here only a part of the emotional sub-system, directly linked to the appraisal theory of emotion, and discuss the effect of emotions on the actions of the agent. Thus, we omit the phenomenon of pre-emotions (short-term emotions associated with impressions, representing the somatic theory), and the effect of equalia (emotions connected with a personal evolution of the agent, not necessarily related to the common human experience).

The main criterion for classification of emotions is their duration (Oatley et al., 2012). Similarly in the xEmotion system, we distinguish:

- emotional context of objects, or expressive sub-emotions (identified on the circle of emotions), related to perceived and recognized objects,
- emotional state of the agent, or classical emotion (using the common rainbow of emotions),
- mood, a nonlinear derivative of emotional evolution.

The emotional context of objects is part of the learning mechanism, which is shaped in the course of the inner development of strong emotions experienced by the agent in specific situations. In such cases the classical emotional context is written into a specific instance of each perceived object, or event, or its abstract definition (all imprinted in the LTM of the agent). Certainly, in a particular application, it is also possible to initially program some objects with an emotional context. Placed on the rainbow of emotion, sub-emotions weaken with time, what corresponds to the process of *scuffing* of objects in memory.

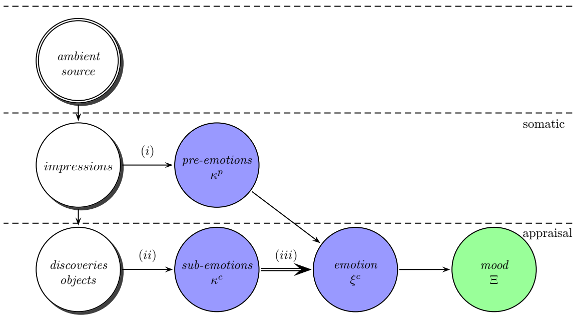

Fig. 2. Emotional components and basic relationships.

Expressive sub-emotions κ^c are relative to standard human emotional expressions, attributed to known objects, situations, or events, according to the appraisal theory of Lazarus (1991). Sub-emotions are modeled using the fuzzy set theory applied to variables defined in a two-dimensional (polar) domain (the circle of emotion). Within the rainbow of emotion, a single (sub)emotion is represented by two values: color (ω_{κ^c}) and intensity (r_{κ^c}). On the basis of the data, a corresponding linguistic variable (label), and a fixed value of its membership function, are also assigned to each sub-emotion.

The rainbow of emotions, used in xEmotion subsystem, refers to a spread paraboloid of emotions proposed by Plutchik (2001), which has been adopted for our purposes (Kowalczuk and Czubenko, 2013). The introduced modifications are related to three basic aspects:

- introduction of a common, explicit, neutral, and stable state (as the agent should principally stay in a neutral state of emotion),
- avoiding direct transitions among extreme emotions,
- reversal of the values of the emotion function (a result of the above two: as it is more natural to increase intensity with the distance from the neutral center).

The proposed adopted rainbow is displayed in Fig. 3. As a result of fuzzy modeling, it is possible to distinguish:

- fuzzy (colored) zone, based on the support of each membership function,
- emotion (color) zone, resulting from maximum of two membership functions (α-section for $\alpha = 0.5$),
- distinct emotion (strict color) zone, founded on the core of each membership function.

All emotional non-zero states are described using trapezoidal membership functions. This means that in the intersection of four membership functions, the agent can ‘experience’ four emotions.

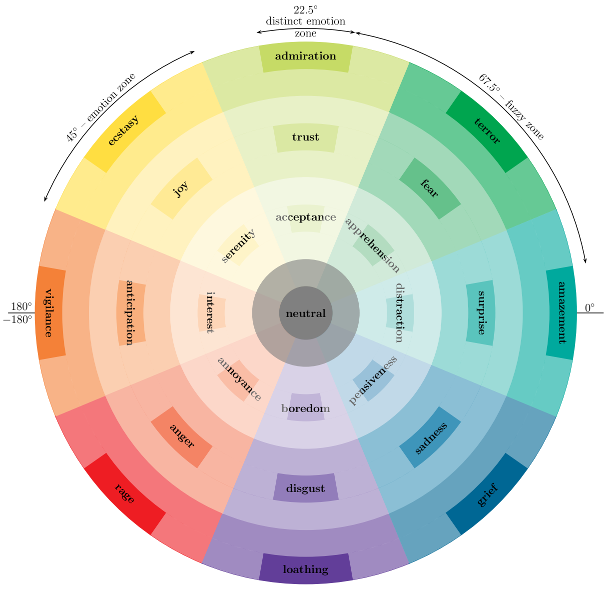

Fig. 3. Rainbow of emotion; width of full color (max membership) takes $\Delta°$, and full width takes $3\Delta°$.

Identification of an object, associated with a sub-emotion, generates a corresponding contribution (in polar coordinates) to the agent’s emotional state. Such sub-emotions are weighted (according to the value of membership function), and then a ‘gravity’ center of them is computed.

Classical emotion ξ^c defines the actual, proper (principal and common) emotional state of the agent. It is monitored and controlled directly on the circle of emotion, based on the following four system components:

- previous emotional state (with a forgetting effect),
- the level of fulfillment of the agent’s needs, which, when satisfied, may improve the emotion by anticlockwise rotation (toward joy), or, if unsatisfied, may deteriorate it by clockwise rotation (toward rage), where the maximal shift is $2 \cdot \Delta°$,
- calming-down effect (appealing to the neutral state), which diminishes only the radius of classical emotion,
- sub-emotion center, which softly (by weighting) attracts the point of classical emotion.

These operations are graphically shown in Fig. 4. Similarly to the process of sub-emotions, a linguistic value of the classical emotion is inferred, which then controls the corresponding set of reactions, based on the SVC method.

The classical emotion influences the choice of specific reactions of the agent, by defining a set of admissible reactions (e.g. fear unlocks the reaction of escape), others are inactive without a proper arousal.

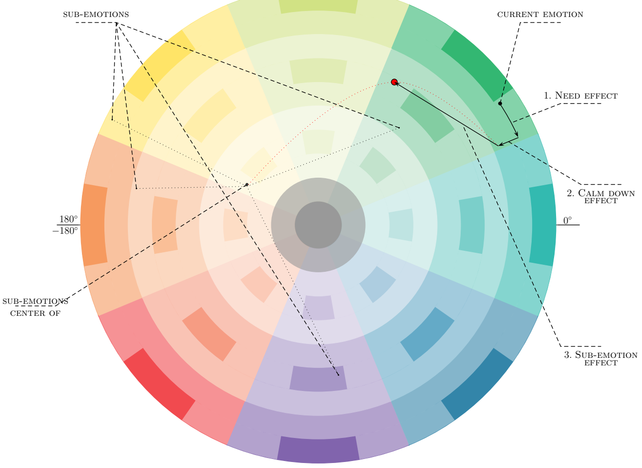

Fig. 4. Evolution of emotions.

The last emotional aspect of ISD is mood, which changes the kernel of the membership functions of needs and results in new interpretation of the fulfillment of needs (meaning their faster or slower satisfaction). The mood is derived via a TAWS function (Kowalczuk and Czubenko, 2011), which always increases and decreases according to the increase or decrease of the angle of the emotional state of the agent, but for saturation (positive or negative). The xEmotion sub-system controls the speed of achieving the fulfillment states of needs, according to the sign of mood.

4. SIMULATION OF THE DRIVER AGENT

The simulation scenario was similar to a previous test (Czubenko et al., 2015), where the signs of ‘lane change’ were omitted, and only few signs of recommended speed were considered. Instead, this test included an encounter of a pedestrian on the road. The decisions and emotions of the xDriver are given in Tab. 1 and Figs. 6, 7, and 8. As can be seen there, in the first stage, the system xDriver works like cruise control (CC), while in the second phase, when seeing a pedestrian on the road, the subsystem xEmotion developes its emotion, which, under the SVC, changes the *modus operandi* of the system xDriver, resulting in a qualitatively different reaction.

The initial part of the (discrete) simulation shows how the agent xDriver selects the appropriate reaction, based on its system of needs (for details see (Czubenko et al., 2015)). Every action of the agent is extended until the car reaches the goal – for instance, implements the decision of 90 km/h or neutral action indicated as ‘keep the current speed’ (lack of success or changing the emotion trigger another cycle of thinking). Overshoot shown in Fig. 6 is the result of non-optimal tuning of the applied PI controller, which was put into operation for each change in the agent’s decision about its speed. It should be noted that the red dashed line shows the current speed limit in advance of 350 m. On the same basis, the pedestrian was observed by the agent xDriver from a distance of 350 m (see Fig. 5).

The main part of the emotional simulation begins at 445 m, where the agent perceives a pedestrian. A man on the road induces in the agent the sub-emotion of terror, which remains as long as the xDriver is approaching the

Table 1. Reactions of the xDriver agent.

Distance [km]	xDriver reaction	Driver emotion
0.00	increment speed to 90	indifference
0.66	brake to 50 [km/h]	indifference
0.79	keep current speed 0	indifference
0.85	increment speed to 50	indifference
1.06	brake to 50 [km/h]	indifference
1.09	keep current speed 0	indifference
1.26	increment speed to 90	indifference
2.09	keep current speed 0	indifference
2.45	brake to 30 [km/h]	indifference
2.62	keep current speed 0	indifference
3.25	keep current speed 0	indifference
4.45	increment speed to 90	indifference
4.61	increment speed to 90	distraction
4.63	emergency brake 0	surprise
4.63	emergency brake 0	fear
4.65	emergency brake 0	terror
4.85	keep current speed 0	terror
4.85	keep current speed 0	fear
4.85	keep current speed 0	surprise
4.85	keep current speed 0	distraction
4.85	increment speed to 90	indifference
5.65	keep current speed 0	indifference

pedestrian. In effect, the xDriver system brakes, stops, and waits until the passer-by leaves the road. Though, human sub-emotions last only a few seconds; for our purposes, sub-emotions are held until their mother objects are in the agent's attention (xDriver sees the obstacle). Evolution of the classical emotion *felt* by the xDriver is the following: first, it turns to distraction, surprise, next fear, and finally to terror, as shown in Figs. 7 and 8, and as explained in (Kowalczuk and Czubenko, 2016, 2017b), using the polar translation. The effect of this mechanism can be observed in Fig. 7, where under the influence of the applied single sub-emotion, the classical emotion goes up, and then falls down to the neutral point (in the absence of any sub-emotions) along the same trajectory.

A change in the (labeled) classical emotion interrupts the currently executed action of the agent, and switches it to a new set of available reactions (the effect of SVC), and thus shapes the way of functioning the xDriver. The action 'emergency brake' is associated to the emotions of terror and fear, while other reactions work only if the agent's emotional state is 'indifference'. The exception is the action 'keep the current speed', which as neutral, may be chosen in any case. Emotional states of the agent are fuzzy; they infiltrate (Fig. 3). Thus the agent may have (at the same time) maximally four fuzzy emotions. For example, at a distance of 4.61 km the agent has two different emotions ('indifference' and 'distraction'), and may choose reactions associated with 'indifference' (most of reactions), and 'distraction' (in this simulation – none).

Also, when the agent chooses the action of 'emergency brake', it is interrupted, but continued to be chosen (two times), due to the change of emotion. After the 'emergency brake', and obtaining the zero speed (stopping), when the pedestrian goes away, no new sub-emotion affects the xDriver agent. Thus, the agent sticks to 'keeping the current speed' (0), until its emotion relaxes to the neutral state (even if it may choose other reactions, resulting from the border between 'distraction' and 'indifference'). After calming down, the agent chooses to move on and take a standard reaction of 'increment speed'.

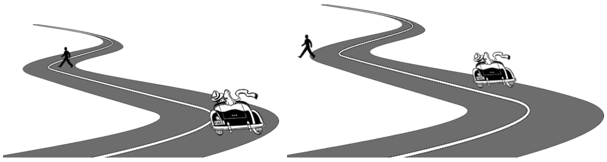

Fig. 5. Encounter of a pedestrian on the road.

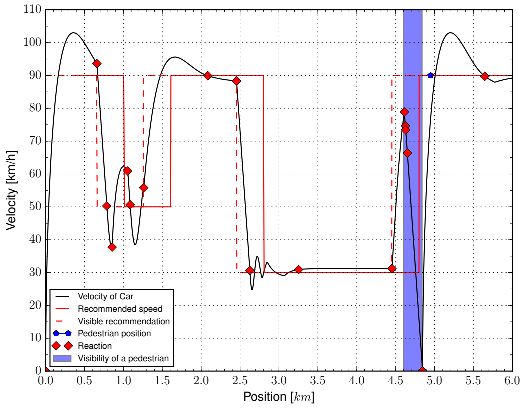

Fig. 6. Velocity (black) of the xDriver car, visible recommended speed (red dashed), decision points (red diamonds), and perception area (blue area, at 4.70 km), and real position of the passer-by (blue pentagons).

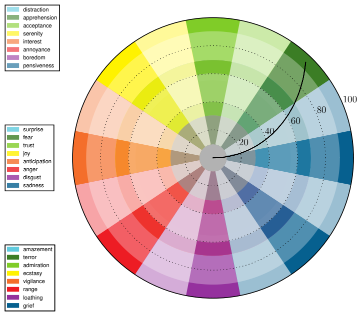

Fig. 7. Evolution of emotion in the xDriver simulation; along with the labeled lower (for intensity 30-40), middle (for 60-70), and upper (for 90-100) emotions.

5. SUMMARY

The xEmotion sub-system of ISD is designed to support the possibility of selecting a most appropriate response of an autonomous agent, or robot, to changes in the surrounding. Such agent under the control of the ISD system can perform efficiently due to a system of emotions, which – from the control theory viewpoint – can be interpreted as scheduling variables.

In general, emotion in the ISD is used for scheduling the control of the agent (for decision making and reaction shaping), and also for several tuning purposes. In other social and psychological applications, the xEmotion system may also model different variants of human personality.

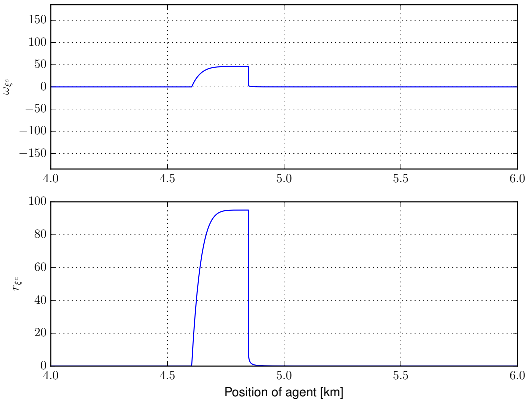

Fig. 8. Time evolution of emotions in xDriver.

The developed sub-system xEmotion integrated in a coherent way with psychological theories, allows the agent to create individual emotions, in response to observations, as it is in the case of an interactive avatar, dictobot (Kowalczuk and Czubenko, 2010a), or an automatic autonomous xDriver(Czubenko et al., 2015), for instance. The processed emotions can be used both to promptly select a suitable reaction using the proposed two-level procedure, as well as to present emotions to another, external agent, which is in accordance with the contemporary trends in robotics. Effective operation of such autonomous systems depends also on a properly developed system memory (Kowalczuk et al., 2016).

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