An Emotional Framework for a Real-Life Worker Simulation

Emotional Valence Scoring Inside a Workflow Enhancement Simulator

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Abstract. Within the framework of the project 'The Smart Virtual Worker' we put forward a sound and functioning emotional model which adequately simulates a worker's emotional feelings throughout a typical task in an industrial setting. We restricted the model to represent the basic emotions by Ekman and focused on the implementation of 'joy' and 'anger'. Since emotions are uniquely generated, based on the interpretation of a stimulus by an individual, we linked the genesis of emotions to empirical findings of the sports sciences to infer an emotional reaction. This paper describes the concept of the model from a theoretical and practical point of view as well as the preliminary state of implementation and upcoming steps of the project.

Keywords: emotion framework, work simulation, workflow simulator, emotional valence, emotional model.

1 Introduction

Demographic changes in Germany, as in most of the industrialized countries, will result in an aged workforce [3], [5], [7]. To avoid a shortage of skilled labor, employers have to cope with the aging population by looking for adaptive strategies regarding their workflow in order to keep already qualified employees. E.g. established workplaces will have to be modified so the needs of older, qualified but limited employees, due to their age or medical conditions, are considered. The 'Smart Virtual Worker'(SVW)-project presents an opportunity to easily replicate established workflow parameters inside a virtual simulation to establish alternative routes, storage, or construction methods during the stage of production planning. This will help to keep acquired skills inside a company which would otherwise be lost to competitors or, in case of rare and specialized manufacturers, even be removed from the general workforce due to early retirement.

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A key component of the simulation is the consideration of emotional tendencies within an employee while performing a task. Since emotions are very uniquely linked to an individual, as are past experiences, lessons learned and many other aspects such as strength of mind, bodily endurance etc. [4], the challenge of any emotional model is to find a balance between unified emotional display and a generalized reasoning as to allow for a sufficient prognosis of emotions in the general population by the simulation.

1.1 Emotions in the Workplace

Scientific research regarding emotions has been widely focused on a meta-level of emotional classifications and origins [13]. To facilitate the model of this paper, a narrower look at emotional specificities is necessary. Emotions at work are as wide a field of possible research as emotions are in general, but since the goal of the SVW-project is to accurately simulate the emotional stability during a work task, it is necessary to focus on the individual and the situation of being at work. Psychological research in conjunction with a work environment is different from other forms of academic psychological research in general [14]. We subjugate our personal aspirations, as far as possible, during work hours to the needs of a company or a task. Hence there might be a wide array of psychological problems originating from work but a single task within ones measures of capability would result in a fairly steady emotional state. Especially since work-tasks are per se pretty much unemotional, apart from anecdotal reports. The typical work task is structured to be feasible and a worker will handle it while being balanced, although tending to either liking the task at hand or disliking it.

1.2 Robotic Applications

Since the SVW-project contains multiple individual modules, the emotional model is built as a standalone solution. This allows for a much wider array of possible implementation strategies like being an add-on component for already established system architectures. The input from a motion generation module and the integration of the output by any form of artificial intelligence or path planning module are basically the only adjustments necessary while the input from ergonomics can either be disabled or easily replaced by, for example, a movement limitation system of the robot. Furthermore, the ability for understanding an intention is closely linked to an emotional understanding [18]. With this in mind, an emotional action unit like the one presented here could serve as a basis for a system of social-cognitive reasoning, which in turn could ease the co-existence of robots as a household-help and human subjects, regarding the legibility and predictability of a robot's intended action [16]. It would facilitate Human-Computer interactions, e.g. by mimicking emotions like robot pets (Sony Aibo, Tamagotchi etc.) do, or signal a user about the internal working state of the machine by either displaying it by writing it on a display, flashing a light or by producing an emotional sound like low-pitched beeps, which already notifies users today about their rundown battery inside their cell-phones. Although the neurobiological system of a human is neither easily copied onto a machine nor would it be a very practicable approach, some beneficial approaches are available to have a machine 'compute' an emotion without being cognitive aware about it [17]. In addition, there are emotions one possibly would not want to install upon a machine. Robotic 'emotions' should be perceived as a useful new information channel which is beneficial for the suggested role the robot was built to perform. An angry Roomba or a sad car manufacturing robot is most probably not anyone's goal.

1.3 Computational Models

Research in the field of computational models led to a vast number of published models. A good overview is presented in the meta-analysis section of [15] differentiating between emotional models having a rational-, anatomical-, dimensional- or appraisal-related approach. But since the main focus of these models is to adequately resemble the general emotional system of human beings, an adaptation to the SVW-project and its narrow focus on emotional reactions to work-tasks seemed not to be feasible. For instance most of the time the motivational part of many models is quite irrelevant for the worker's emotional state since the motivational goal of a worker is to complete a task in order to get paid, not to fulfill an intrinsic need [14].

2 Elements of the Model

To allow the model to work two types of numerical input are necessary (see Fig.1). First the planned action from the reinforcement learning algorithm for motion generation suggests a work task which has already been assessed regarding its possibility by the actuator module, which impacts the emotional model in three ways. The actuator assessment is characterized as being either feasible, being precarious or alarming.

Since emotions heavily depend on an individual's singular response to outer circumstances and the simulation aspires to be able to make individual recommendations for a better workflow, the emotional model contains an individualizing computation routine. Depending on three assessed factors about the physiology of the worker in question, the impact on the valence scales is adapted. These three factors are constitution, sensitivity, and experience, shortened in the model as C, S and E. We chose those three factors because they represent a feasible reduction of human physiological peculiarities. Constitution allows for an intuitive assessment of the agents strength and endurance, whereas the sensibility works as a damping variable which permits assessing the resilience when confronted with obstacles. The experience is again used as a damping variable to enable the model to, for example, heighten the resilience, since the agent simply 'knows' it has to keep the weight up just for a little longer to accomplish the work task successfully. In addition the model tracks the fatigue of the agent and henceforth the probability of a successful operation, which decreases over time and with growing exhaustion.

Regarding the emotional state, the model right now is focused on a pure valence-based emotional distinction, meaning for the simulated agent to either like the current emotional state or to dislike it. These two states are accordingly labeled as 'joy' and 'anger', but please do not think of these valences as being directly linked to these emotions. They are a continuum in which the emotional state tends to being joyful or leans into the other direction. So if asked, a person would report to be feeling okay or not, as emotions are not computed with a distinct level of something. In addition the model integrates another scale which mirrors a sympathetic arousal, which is used as a form of energy the emotional state of the current action invokes in the agent. In addition, following the theory of an emotional transaction by Zillmann [8], [9], [10], this sympathetic arousal enables the transfer of energy between the, currently two, emotional states implemented.

As a result, the emotional model outputs three variables. The artificial intelligence module receives information about the chances for exhaustion and the current emotional valence state, which is either positive or negative, and secondly, the assumed time requirement for a successful in-time work completion is handed over. The reinforcement learning algorithm will then score the emotional output and repeat the procedure by initiating another planned action into the module.

2.1 The Emotional Model - State of Implementation

The emotional model is implemented within the framework of the SVW-project. It is supplied with input from both the ergonomic and motion generation module, while the latter gets its input from the artificial intelligence module. The artificial intelligence module itself is responsible for planning a work process and requests an evaluation of a particular task-related element. The implemented planning is based on a hierarchical reinforcement learning algorithm, which chooses the next possible action based on the paramount emotional and ergonomic evaluation.

2.2 The Agent

Our agent, who simulates the human worker, includes attributes such as sex, weight, height and a resulting BMI score. Furthermore we differentiate between fitness-levels (the worker being either well-trained, considered to be of normal strength or weak), the work-experience, age and a score for sensitivity. These attributes define the required internal state and allow for an upcoming calculation of its unique emotional valence.

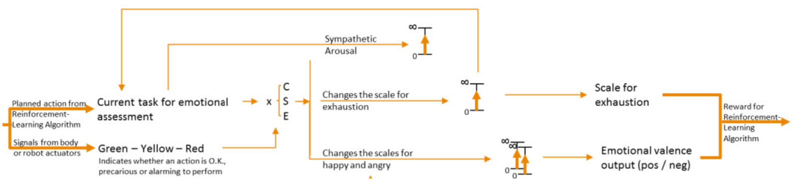

Fig. 1. Emotional model of the 'Smart Virtual Worker'

1. *The physiological attributes:* Based on the attributes for weight, height, BMI score and fitness, the athleticism of the agent is calcuated. This value enables us to compute how well trained the agent is and as a result, how heavy an object might be to allow even a weak worker to perform. The differences between a weak, a normal and an athletic worker are calculated as a resulting value of capability. So in the model an athletic worker has a capability value of 1.2, which means he is 20% stronger than an assumed normal worker. A very weak worker has a capability value of 0.9, meaning he is 10% weaker than our assumed normal worker (capability of 1.0).
2. Experiences: We assume that over time a worker gains knowledge about the tasks performed, leading to an experience value which defines his familiarity with the task at hand. For example, since he knows from past experiences that the current task includes heavy lifting, but only for a short time, he ‘clenches his teeth’ and endures this brief moment, compared to an inexperienced worker who might quit the task altogether. Within the model the experience value is set between 0.8 and 1.2, analogous to the fitness calculation. A very inexperienced worker is scored with a value of 0.8, a normal worker with 1.0 and a very experienced worker with a value of 1.2.
3. Sensitivity: The sensitivity value defines how much the worker is affected by any given situation. A worker with a high sensitivity reacts more intensely while a worker with a lower score of sensitivity does not. The model computes the sensitivity value being between 0.8 and 1.2. In this case a very thick-skinned worker has a sensitivity value of 0.8, a normal worker of 1.0 and a very sensitive worker is scored with a value of 1.2.

2.3 The Internal Emotional State

The internal emotional state is calculated on the basis of the described psychological and physiological values. This computation leads to a value which represents the personal appraisal of doing the work and a temporary estimation of the quality of work.

4. The input parameter: The computation of the emotional state is based on all of the described input values and objects within the simulation. The first input is the currently performed action including physical properties, for example: the involved objects and their weight (in kg), the time (in seconds) how long the action to be performed will take, and an ergonomic value. All described variables are either available from the database from the start or will be calculated just in-time from other modules of the project, as e.g. the ergonomic scoring. The ergonomic value ranks the physiological stress of the body. At the moment, this calculated value is based on the established RULA-system [11].
5. Level of activity: In order to compute the emotional valence, our module calculates a level of activity for the currently performed action. This computation is based on the evaluated guidelines of ‘BGI 582: Safety and health requirements for transport and storage tasks’ by the association ‘Vereinigung der Metall-Berufsgenossenschaften’ [12].

The output consists of four distinct levels of activity based on the values: carried weight, covered distance, action time, and a separate ergonomic value:

- 1: low level of activity, no handicap, and no overloading
- 2: increased level of activity, impairment by weaker persons is possible
- 3: more increased level of activity, impairment, and overloading of normal persons is possible
- 4: overloading of normal people

Based on these levels of activity, the internal basis for emotional valence now calculates the values for sympathetic arousal, joy, and anger.

6. Sympathetic arousal: The arousal (a) is influenced by the level of activity (l), the current exhaustion value (x_{act}), the experience (p), the rate of arousal adaption (t_a), the time for recovery (t_r) and a moderating value (r). This value lowers the score of sympathetic arousal over time, so if nothing stimulating is happening, the worker's arousal level might even go down to 0, resulting in a sympathetic stability. Also the moderating value cannot be too high, since an emotional state is able to influence another subsequent emotional state [9]. In this case the arousal is calculated as follows:

$$a_i = a_{i-1} + (d_x + d_a(l)) \cdot t_a \cdot p - t_r \cdot r \tag{1}$$

$$d_x = \left(100 - \frac{x_{act}}{100}\right) \cdot d_a(l) \cdot t_a \tag{2}$$

The value d_a is an array which defines the changes of the arousal depending on the level of activity (1). Within the model, the array d_a consists of four states ($d_a = \{0.25, 0.5, 0.75, 1.0\}$). This means, if the level of activity is i, the change of arousal is $d_a[i]$. For example, the change of arousal is 0.25 if the level of activity is 1. The change of arousal is increased by higher activity levels, while our parameters t_a and t_r are based on the length of an action ($t_a = \frac{t_{action}}{60}, t_r = \frac{t_{action}}{30}$). The value of recovery (r) is set to 0.04. Depending on the exhaustion, the term (d_x) increases the arousal, if the activity level is 2 or higher.

7. The values of emotion: The calculated emotional valence (e) is labeled as either joy or anger and is influenced by the level of activity, the level of exhaustion (x_l), the length of activity (t_{action}) and the sensitivity (s) of the agent. In this case the emotional value is calculated as follows:

$$e_{act_i} = e_{act_{i-1}} + (d_{ex}(x_l) + 1) \cdot d_e(l) \cdot s \cdot t_{action} \tag{3}$$

$$e_{act} = \begin{cases} e_{joy}: if\ l = 1 \\ e_{anger}: if\ l = 3,4 \end{cases} \tag{4}$$

$$d_{ex} = \begin{cases} 0: if\ \ x_l = 1 \\ \frac{x_{act}}{2}: if\ x_l = 2 \\ x_{act}: if\ \ x_l = 3,4 \end{cases} \tag{5}$$

Both emotions are scored independently from the other, so if the level of activity is 1.0, the value of joy is increased. If the level of activity is 3.0 or higher, the value of anger is increased

(4). Actions which have an activity value of 2.0 are considered emotionally steady. The change of emotion is defined by the array $d_e = \{0.5, 0.25, 0.75, 1.0\}$. Exhaustion leads to an increase in anger if an action has the activity level 3 or 4

(5). The level of exhaustion (x_l) is dependent on the strength of the worker. We divide strength into four categories: the area of recuperation $(x_l = 1)$, normal workload $(x_l = 2)$, short-time maximum strength $(x_l = 3)$ and evolutionary emergency reserve $(x_l = 4)$ (see Fig. 2). A worker can only perform inside the range from recuperation to short-time maximum strength. The boundaries of these areas depend on the constitution of the agent. A stronger agent has higher thresholds than a normal agent and a normal agent has again higher thresholds than a weaker agent. These limits are currently fixed for the chosen agent model.

8. The value of exhaustion: This value (x) is influenced by the time of activity (t_{action}), the level of exhaustion (x_l), the calculated level of activity (l) and the corresponding score of the recovery parameter. The current exhaustion of an agent is calculated as follows:

$$x_i = x_{i-1} + d_x(l) \cdot x_l \cdot t_x - t_r \cdot r_x \tag{6}$$

Like the sympathetic arousal the exhaustion has a moderating mechanism as well (6). The time of recovery (t_r) and the moderating value (r_x) define how much time an agent needs to rest. If there is no strain on the worker, the moderating mechanism decreases the value of exhaustion down to 0. The array d_x consists of the four states

0.35, 0.45, 0.65 and 0.75. The time rates depend on the length of an activity ($t_x = \frac{t_{action}}{60}, t_r = \frac{t_{action}}{30}$) and the moderating value (r_x) is set to 0.03.

9. The output parameter: Currently the output of our model is the emotional valence of an action which is dependent on the dominating emotion and the level of arousal. The dominating emotion is e_{joy}, if $e_{joy} > e_{anger}$. If $e_{anger} > e_{joy}$ then the resulting dominating emotion is e_{anger}. Otherwise no emotion is considered to be dominant. The emotional valence is positive if the dominating emotion is joy, and negative if the dominating emotion is anger. If no dominant emotion exists, the valence is zero. The value of the emotional valence's change is defined by the calculated arousal of an action.

Demonstration of the Emotional Model.
We defined three typical workers to demonstrate our model:

- A weak worker (male, 60 kg, 1.85m, BMI=17.5, 30 years, capability value =0.9, e=1.0, s=1.0)
- A normal worker (male, 80 kg, 1.85 m, BMI=23, 30 years, capability value =1, e=1.0, s=1.0)
- An athletic worker (male, 90 kg, 1.85 m, BMI=26, 30 years, capability value =1.2, e=1.0, s=1.0)

Also, we defined different tasks to demonstrate the model. The global task is carrying 20 boxes from one point to another. One episode of carrying one box consists of four elementary behaviors: 'walk to the box', 'grab the box with both hands', 'walk with the box to a target' and 'release the box'. Every action has its own parameter such as length of time, object involved and a corresponding ergonomic value. The involved object has the attributes *weight* and *dimension* which are provided by the database of the SVW-project. To demonstrate different stresses and strains, three different boxes with 15 kg, 20 kg, and 30 kg are simulated.

On the basis of the input parameters which are provided by other modules or by the database, the internal state of a simulated worker while performing is calculated. The following images demonstrate the model's output with different agent types carrying the different boxes.

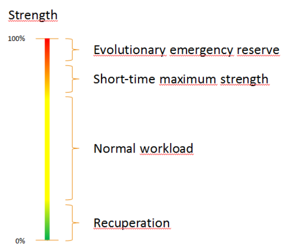

Fig. 2. The strength of an agent is divided into four categories. The limits of these parts depend on the constitution of the agent.

Fig. 3 shows the calculated emotional valence value for an athletic (blue line), normal (red line), and weak worker (green line) executing the task process with a 20 kg box. The different worker types show very different emotional reactions during their work. At first, the athletic worker carries the boxes with ease, which is why its emotional valence value does not change to a negative value before the 16th box (grey lines). At this point the curve progression shows a positive valence value of 11.06 at 'walk to the box' while 'grab' and 'carry the box' result in a negative valence value of -11.38 or -11.81, respectively. This is the result of the exhaustion, which increases the anger factor by a higher increment that the factor joy as increased by the previously easy work. In the next step, if the worker is walking without any load, the value of joy is increased so much that the emotional valence value will be positive again. But during the upcoming episode, the exhaustion level rises beyond the agent threshold and the worker carries the following boxes with a negative emotional reaction.

In comparison, the normal worker carries the first box with different emotional valence values. The elementary behaviors 'walk to the box' and 'release the box' are easy and increase its value of joy. Our normal worker 'grabs the box with both hands' and 'carries the box' with a negative valence because for him the weight of the box is laborious. Additionally, after two boxes the worker is so affected by the weights that the recovery period 'walk to the box' is insufficient to retrieve a positive valence.

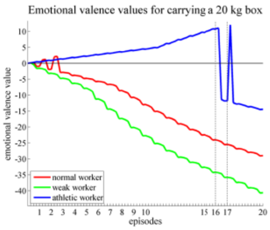

Fig. 3. The emotional valence value for carrying normal and weak worker

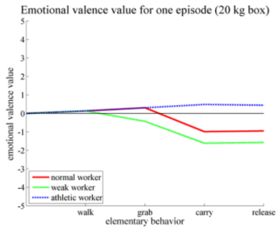

Fig. 4. The first calculated steps for carrying a 20 kg box. One episode consists of the elementary behaviors: walk, grab, carry and release.

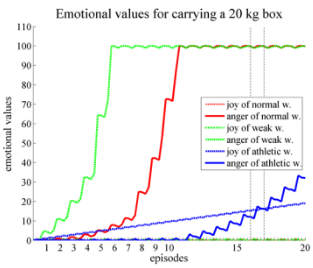

Fig. 5. Emotional values of joy and anger during the task processed by the chosen agents

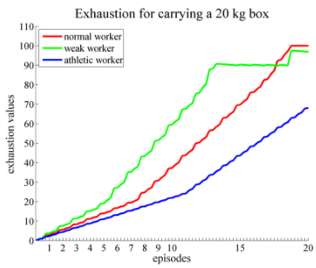

Fig. 6. The exhaustion for the different agent types based on carrying a 20 kg box

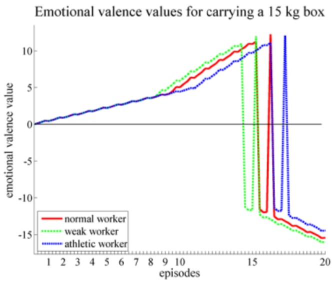

Fig. 7. Emotional valence of different workers for carrying a 15 kg box

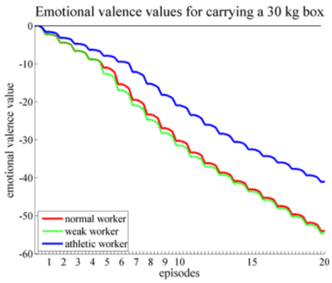

Fig. 8. Emotional valence of different workers for carrying a 30 kg box

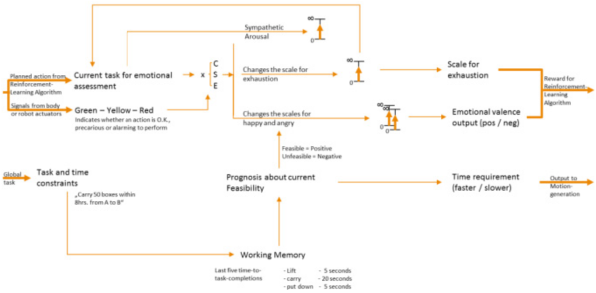

Fig. 9. Enhanced emotional model of the "Smart Virtual Worker"

Furthermore, the worker will carry the next boxes with a negative emotional reaction. All while our weak worker carries all 20 kg boxes with a continuously negative valence, since with his values the boxes are too heavy.

Fig.4 clarifies the different reactions for carrying a box. All workers start with an emotional valence value of zero. After ‘walk to the box’, all of them have a small positive valence value, since this is not a strenuous activity. Following the task ‘grab the box’, our weak worker has a negative valence value because the box is too heavy for him. At this point the normal and athletic workers react with a positive emotional valence but only the athletic worker with his physical strength has the attributes to carry the box easily. He is the only one still performing with a positive valence during the next elementary behavior ‘walk with the box to a target’.

In Fig. 5, it is demonstrated why the emotional valence is switched. As described above, the dominating emotion is the one with the highest value. The weak worker shows a strong rise in the emotional values of anger (dark blue) and only a small rise of joy (light blue). This results in anger being the dominating emotion for the following episodes. The normal worker has a small slope of anger (dark red) and joy (light red). These small slopes enable the model to switch between the two dominating emotions. Since both values are very similar, an emotional switch due to external influences is quite easy to facilitate. For the emotional values of the athletic worker the slope of joy (light green) is high at first but with rising exhaustion levels (see Fig. 6) the anger (dark green) increases. Consequently, the dominating emotion in episode 16 is switched (grey lines). The Fig. 7 shows our three workers carrying a 15 kg box. At first, all simulated workers carry the weight of this box quite easily. But similar to carrying a 20 kg box, the workers are exhausted by the process of carrying. The weak worker is exhausted faster than the normal worker and the normal worker is exhausted faster than the athletic worker. For this reason the dominating emotion is switched for the weak worker at the 15^{th}, for the normal worker at the 16^{th} and for the athletic worker at the 17^{th} box. If the carried weight of the box is 30 kg, all workers have a negative emotional valence while performing the task (see Fig. 8). There is only a very narrow difference between the worker types.

3 Conclusion

The model calculates the emotional valence of different workers performing a predefined task. We demonstrated that the emotional valence and therewith the interpretation of the actual situation depends on the attributes of the machine and the number of repetitions. We have shown that the model can simulate different attributes. In addition, we showed that an elementary behavior like 'joy' and 'anger' is interpreted differently, depending on the number of boxes carried before.

Our next steps will be to further implement the depicted model in Fig. 1 while attempting to evaluate our preliminary predictions about the individual emotional responses within a real-world scientific experiment by implementing the model into a robot. Furthermore we want to expand the model to include a form of memory-system which would allow for a planning routine (see Fig. 9). With this addition the model opens up a new computing path which is dependent on the global task of the robot. If the task would be to carry 5 boxes from point A to point B, the module is able to track the necessary time for one iteration and hence compute the remaining time for the other four boxes. If however the task is to be completed in less time than anticipated, the robot could either try to compute a different / faster route, accelerate its movements or, if the time-limit is not feasible, report this discrepancy back to the user. This would happen by putting the robot into a less favorable emotional state, which is easily understood by the human operator.

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