Monitoring Daily Routine Anomalies in Assisted Living Environments

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Abstract. In this work, we introduce our approach for detecting and presenting anomalies of daily routines in assisted living environments. The proposed concept addresses the challenges of detecting, deducing and presenting the provenance, if such anomalies occurs. With our assistive knowledge- and model-based approach, users reach higher levels of awareness about their own lives and potential irregularities. Thereby, we consider the compelling issues of detecting causes of anomalies and also presenting them without overburdening the user. A prototypical implementation substantiates our approach and introduces our forthcoming user study.

Keywords: assisted living, anomaly detection, embodied assistance, context awareness, quality of life, social intelligence, context expectation

1 Introduction

Demographic change causes many yet unsolved problems for future decades, such as the rise of the expenditure of healthcare or the increased burden of caregivers [3]. As one solution, several kinds of Ambient Assisted Living (AAL) systems [14] have been proposed. This kind of system aims to assist users in their domestic environment assuring their independence as long as possible and improving overall life quality [3].

One type of such systems features domestic living environments with activity recognition [18, 19]. These systems monitor surrounding environments and user activities in order to ensure that the elderly are living safely and independently in their own homes. Additionally, they can detect a range of activities, e.g., walking, sleeping and eating. In its core, such systems with activity recognition algorithms match the current available data according to sensor values. For this purpose, supervised and unsupervised machine learning algorithms are used to build and classify training and real data.

However, beside the classification of uncorrelated activities, it becomes necessary to combine these activities to daily routines. Since a permanent interruption of routines could lead to diseases, ranging from sleeping troubles up to chronical depression [5]. Studies have shown that people, who live in regular daily rhythms,

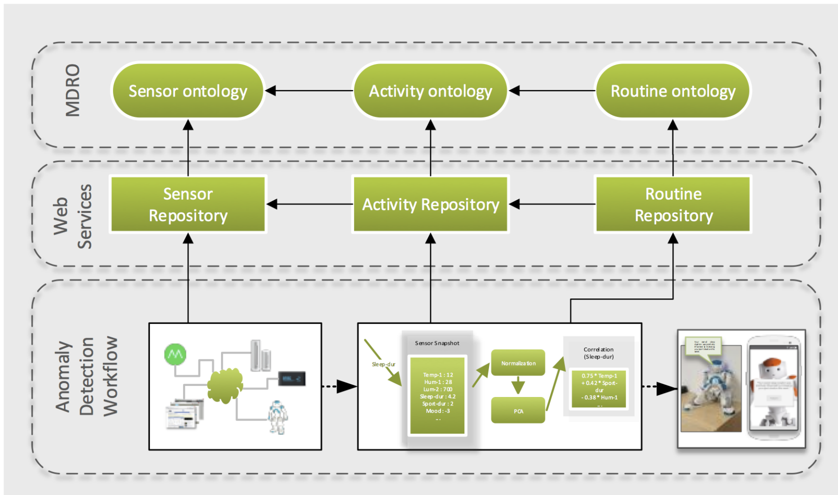

Fig. 1. Anomaly Detection Workflow

are less affected by these diseases. However, it is not always clear whether routines differ significantly from 'normal' ones. The influencing parameters are not necessarily obvious. Also, it is not properly understood how they influence the daily rhythms. This poses a challenge which we solve with our procedure. We developed a concept in our approach, which establishes awareness about such deviations and present potential provenances of it. With these findings, users, respectively caregivers, can analyse the parameters with a corresponding trend to get deeper insights about their own life.

In order to achieve the mentioned objectives, we have to answer three questions. First, how can we detect anomalies and the potential provenance proactively within our activity recognition process? Second, how can the user ask the system for trends, such as sleep or training duration, due to influencing factors? And the third aspect is how can we present the results to the user while keeping the information and system interaction intuitive? Thus, we present our solutions to tackle the mentioned problems by adapting concepts from the area of chronobiology, ambient intelligence as well as the domain of embodied assistance.

Our test environment (and system) is a domestic living environment, equipped with stationary indoor sensor devices, wearables and robotic companion for interaction purposes. In our case, NetAtmo[1] weather stations, wearables, a smart phone with particular applications and a NAO robot were used (see Fig. 1). All parts will be outlined in detail in the following sections. The remaining parts of

[1] http://netatmo.com

this article consider the following aspects: First, we discuss related work in the fields of chronobiology, assisted living environments and embodied assistance in Section 2. Then, Section 3 outlines our knowledge base and clarifies how it is applied. Afterwards, we present the corresponding awareness concept based on these model in Section 4. In Section 5, we finally draw conclusions including ideas for future work.

2 Related Work

We identified multiple approaches related to our work that can be classified into research of chronobiology, assisted living environments as well as approaches for embodied assistance. However, none of these approaches combine these fields, to raise awareness as necessary.

2.1 Chronobiology

In general cases, daily routine evolve on natural rhythms of one person. The field of *chronobiology* [12] examines impacts to our *biological clock*, such as typical sleeping cycle or times of high physical fitness.

Daily routines not only depend on personal matters, but also on exogenous and endogenous factors. These parameters influence the *biological clock*, as they act as orientation for the body. The most influencing example is the loss of daylight. For instance, experiments in a bunker showed that the loss of daylight extremely affects the sleep-awake rhythm. Beside the sleep irregularities, also diseases, such as manic-depressed behaviour, were discovered [17].

Another example is temperature and the exposure of light, which affect the overall activity of people. Changes in the atmospheric pressure can lead to headaches in some people and rainy conditions can reduce motivation to go outside. In contrast, spring time can lead to an extreme raise of activities until night time [12].

We use the findings of chronobiology for showing trends or factual knowledge about good life style, such as nearly eight hours of sleep or performing a ‘good’ amount of sport activities.

2.2 Detecting Anomalies in Assisted Living

The work of Yin et al. [19] illustrates an approach of activity analysis based on Hidden Markov Models (HMM). They combine multiple sensors (e.g., motion detector sensors) to HMM chains on a day-to-day basis. In contrast to other approaches, these models consist only of a correlation of sensor values to daily routines, without labelling activities. After assigning the different sensor states to HMM chains, the algorithm calculates a corridor of normal states. These reference values can be checked according to a current system state and if it is outside this corridor, the system can recognise an unusual and potentially critical situation. The advantage is that this system depends on no supervised learning.

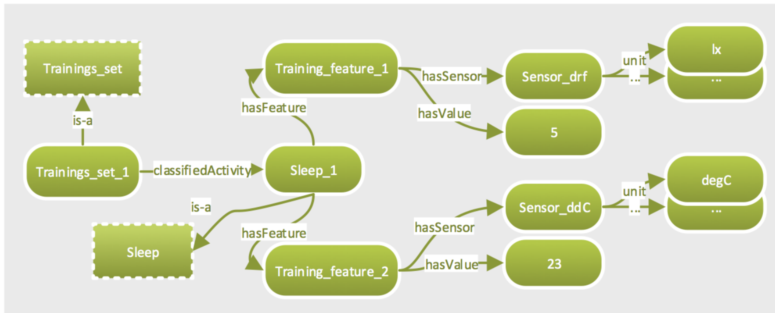

Fig. 2. Semantic Training Set (Activity Module and Sensor Module)

However, the drawback is the loss of the knowledge about the corresponding labeled activity.

The work of Botia et al. [4] uses a combination of state machines, binary sensors and rule sets for activity recognition. At the start of the system, the rule set consists of only a few rules, which are refined during runtime. Every rule corresponds to one activity and is assigned to the binary sensors, e.g. "If user is in room *A* and no *movement*, then switch in state *criticalSituation*". The user is permanently requested to solve these critical situations by correcting the system with a new normal activity. These corrections extend the rule set, by splitting old rules into new ones, "If user is in room *A* and is no *movement* and no *presenceOfArmchairSensor*, then switch in state *criticalSituation*". This system represents a good starting point to get information about deviations and the provenance. But it depends too much on specific (binary) sensors and it has been shown that rule-based systems could lead to a high overburden of the user [10].

3 Modular Daily Routine Ontology

The base of our activity recognition approach is a formalised, modular daily routine ontology called *MDRO* [9]. It provides a RDF-S/OWL vocabulary for annotating data sources, such as sensor values, factual knowledge from *chronobiology*, recognised activities and routines. In contrast to the related works in Sect. 2.2, we produce a continuous link between all these factors from sensor values towards saved routines.

The **sensor module** is a semantic description of sensors to get an unified view on heterogeneous sensor values and data types [11]. This means on one hand, physical sensors in the own surrounding, such as climatic sensors. And on the other hand, also uniformed, virtual sensors, such as location or sleep duration sensors. Additionally, we formalised *healthy* intervals that we acquired from *chronobiology* [12]. With these intervals it is, subsequently, possible to show

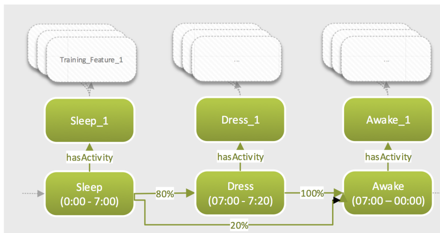

Fig. 3. Saved Routines with Links

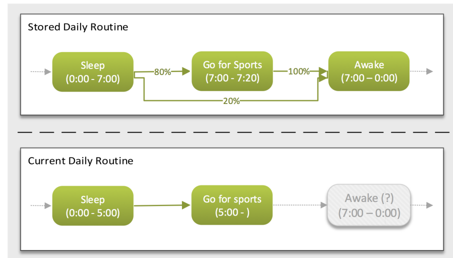

Fig. 4. Routine Deviation

the users *healthy* trends of their own life. A good sleep duration of 8 hours or a hint to perform sports in evening rather than in the morning can be presented and thus lead to a higher awareness of influencing parameters for well being.

The **activity module** holds information about possible recognised *activities of daily living* (ADL). As initial, but extendable set, we used the caring descriptions, mentioned as basic ADLs [8] and transferred them in an ordered semantic model of activities and sub-activities [9]. We also store the classified sensor values to corresponding activities in these module (Fig. 2). For instance, the classified activity *Sleep_1* refers to the training features, which in turn link to the sensors and the training value. The effective detection, respectively recognition, of these activities is described in detail in [10].

The **routine module** saves a directed chain of ADLs with corresponding transition probabilities. Every routine is a chained storage of activities with daytime transitions to the next activity (Fig. 3). The time represents the sliding window for the classification, respectively the continuous stay in one activity. For instance, if our activity recognition algorithm uses sensor values between 7:00 - 7:10 to determine the current activity, this combination will be stored as instance in the routine module and will be grouped until the activity switches. As shown in the illustration, the property *hasActivity* refers to one classified instance and this instance, in turn, to the semantic training set.

The **user module** is utilised for authentication mechanisms and assigns all mentioned parts to a particular person.

In summary, the *MDRO* models the concepts required for daily routine recognition. It is used to annotate sensor data, to formalise factual knowledge, to describe possible activities components and to save routines for users. Together, with these descriptions it is possible to give the user the awareness of anomalies.

4 Monitoring Anomalies

We split our approach in two awareness concepts. First, the proactive approach detects anomalies in the daily routines based on saved routines. In this procedure, the user gets information about the sensors, which have an impact on the deviation of the daily routine.

Second, the reactive approach is for higher user awareness. It shows which sensors directly affect each other, such as sports duration and outside temperature. And also how much they are affected and if it shows a positive or negative trend.

4.1 Proactive Detection

During runtime, the proactive detection recognises anomalies in the daily routines, based on different time slots (e.g. week, month, quarter). Fig. 4 illustrates the simplified stored daily routine and the current routine that is determined by our Activity Recognition Algorithm [10]. The user will be notified, if the routine differs and is informed on which basis this difference was determined. For instance, if a daily routine takes an alternative route from *Sleep* to, e.g., *Go For Sports* way to early. This transition is used for finding all causes (such as reduced sleep duration in case of a to warm or to bright sleeping room). Thus the user can decide whether to adjust the daily routine to these new values once or only should be informed about the anomaly.

To detect anomalies on the technical level, we have to group the stored graph and compare it to the current routine (Fig. 5). Since our routine always starts at 0:00 and ends on 23:59, we get always the *same* starting and end point. Beside finding starting and end points, another issue was to compare different kinds of the same activity, if it occurs on different times. We use the same approach as the work from Yin [19] and group the activities in frames of six hours, to not overburden the user. For instance, *Sleep* that started between 0:00 and 6:00 will be grouped to the *same* sleep. In contrast the occurrence of *Sleep* between 22:00 and 0:00 would be a non comparable instance of the same activity class.

Fig. 5. Routine Transformation

After we got a comparable structure, we use an adapted VF2 [7] graph matching algorithm, which detects isomorphic structures between the stored routine models and the current daily routine. We extended therefore the VF2 to not only detect structures, but uses the semantics in the nodes. With this approach, it is

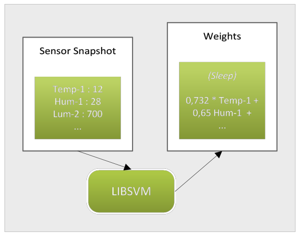

Fig. 6. Weight Comparison

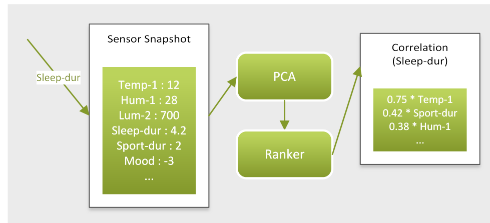

Fig. 7. Sensor Correlation Detection

possible to detect similar subroutines, even if different activities intermediates *normal* routines. The result is a map of all deviations between these two graphs.

After getting all points of interest, we fetch the training set, respectively the sensor values, of previous and currently classified activity from our model. The sensor values are fetched from two snapshots, see Fig. 6. The snapshot (*Sensor Snapshot*) holds the current sensor values, which led to the new assumed activity. With the help of LIBSVM [6, 10], we get ordered *weights* from the classifier and therefore the cause why the current activity not matches the stored one. These *weighted* sensors correlate directly with the provenance of the anomaly and are presented to the user.

4.2 Reactive Detection

The reactive detection is triggered by an explicit query which can be done by the user for his own dataset. The user chooses the desired feature (resp. sensor), e.g., *mood* or *sleep duration*, and will be notified about the main factors influencing the chosen feature. For instance, features, that affect the *sleep duration* could result in *room temperature*, *noise* and *sports duration*. Beside the influencing factors, we implemented rules that handle whether this change is a positive or negative one. The foundation of these assessments is derived from chronobiology and formalised in our sensor module, as previously stated. As standard, but changeable time slot, we choose a duration of one week.

The algorithm fetches the sensor values and firstly reduces the set of directly correlated sensors. This is done by the semantic (compound) description of our model. For instance, if *sleep duration* is the desired feature, it does not use sensors (compounds) which measure sleep directly. With this procedure, we avoid false positives such as, ‘sleep duration was mainly influenced by awake time’.

To find the correlation, we use particular Factor Analysis procedure, to find the interdependencies between sensors. In detail we search for correlations with Principal Component Analysis [1] and afterwards use a *Ranker* to order the correlation. The potential influencing factors will be automatically sorted by this procedure.

As this procedure gives no direct correlations in terms of percentages, we use the sensors with the highest probability for further processing. By the ranked sensors, we are able to calculate the trend of sensor values. This trend is calculated by a comparison of the last week and the *health* interval in our model.

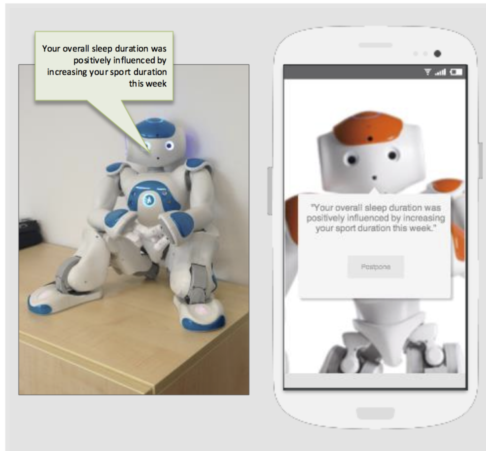

Fig. 8. Embodied Assistance

The combination of these factors is shown to the user and gives the awareness in form of: 'Your overall **sleep duration** was **positively** influenced by **increasing** your **sport duration** this **week**'. It is also possible to show the influencing factor's contribution rank. However, we propose that explicitly stating the contribution amount might overburden the user as the values have to be interpreted in the right way. Therefore, we show only the resulting sensors of the requested parameter, with the prior and current values.

5 Conclusion and further work

The increasing costs of our health care and social systems due to the changing population age structure in the western world pose a serious threat to our way of living [3]. One way to oppose these issues are domestic living environments with activity recognition [18, 19]. These systems monitor environments and user activities, which allows, for example, the elderly to stay at their homes for as long as possible. This can only be achieved by detecting and interpreting irregularities in daily routines and by providing this information to the relevant user groups, i.e., to family members as informal caregivers and to professional caregivers. Detecting these irregularities and, especially, their causes based on sensor values remains a challenging issue. Therefore, we have presented a knowledge-assisted approach to determine the derivation and showing the potential provenance to the user and caregiver.

A relative new way to enhance assisted living environments is the use of robots within smart homes. They can assist the residents but at the same time providing the feeling of companionship as well [13]. While the robotic home companions can provide actual embodied assistance, this assistance is based on the data gathered by the sensors and the interaction with the robot in the smart home, e.g. Companionable [2] and Mobiserv [16].

For interacting with the system in the way we plan to use an ECA [13], once as a mobile application and as a real robot, see Fig. 8. However, this approach can be used in all situations even the NAO is not accessible, e.g., while performing outdoor activities. Additionally to a large extend the user can reuse learned interactions methods from one platform to the other, e.g., the use of the voice control. Next to the Embodied Conversational Agent the same information is displayed together with buttons to be used for touch-based input. This way, at least two different modalities are available for presenting information and getting input from the user at every time. Besides the technological aspects robot companions seem to have psychological benefits as well [15]. Specially the social companionship aspect is important which is already achieved with very simplistic interfaces. However, not in all cases in which such a social engagement might be desirable can the robot companion be physically available. Depending on the users abilities and desire, he can choose between voice based communication, text based one or a mix of both. This approach is preferable in scenarios with a high probability of people having impairments or even disabilities such as in the elderly care setting.

Currently, we are planning to conduct an in-depth user study to measure the real user confidence of our approach and also determining the thresholds of overburden such as amount of resulting sensors in correlation detection or adjusting the frequency of notifying about daily routine deviations.

Acknowledgment

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Motivational Emotion Generation and Behavior Selection based on Emotional Experiences for Social Robots

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Abstract. As the number of social and psychological service robots increase, many robots which have emotions have been developed. In order to implement an emotion generation model, the authors of this paper suggest to employ the unified motivation theory which is proposed by Higgins. In addition, a behavior selection model based on emotional experience is suggested. A joint attention scenario is suggested in which a human and a robot play a 2048 game together with a follow-up interaction. A preliminary pilot test was conducted to examine the proposed method and it performed properly as intended. Finally, further experiment plans and expectations are discussed.

Keywords: Motivation, Emotion, Attention, Emotional Experiences, Social Robot

1 Introduction

People expect that robots will be partners coexisting with human beings and assist human not only physically but also psychologically. According to World Robot Declaration which was issued by the international robot fair 2004, one of the expectation for next-generation robots is that robots will be social members in our human society. After 10 years later, nowadays, robots can be found easily in our daily lives and they are being used in different and various social areas such as supporting the elderly's emotional communication, helping autism treatment, and so on. *Social Robotics*, is becoming one of the very important topics in the robotic field [1][2].

In order for robots to supply with psychological and sociable assistant, robots are expected to show emotional expressions. Researchers have been developed emotional robots, for examples, *KISMET*, *AIBO*, *KOBIAN*, *HRP-4C*, *KaMERo*, etc [3-7]. Recently, *Pepper* and *Jibo* were announced that they will be released in the near future, and got lots of people's expectation and interest. The market of social and emotional robots is getting bigger.

To design an emotional robot, the meaning of emotions for a robot needs to be firstly defined and a model for robot's emotion generation should be established.

There are several computational emotion models which already have been suggested [3][8-10], however, in this paper the authors in this paper will suggest a new perspective based on the generation of the emotional state through motivations as suggested by the unified motivation theory. This is a novel approach respect to the current computational models of emotions. In addition, we suggest a robot's behavior selection model based on emotional memory which has been experienced through interaction between a human and a robot.

Motivation and emotion imply social attention [11]. If a robot is motivated in a situation, it will concentrate and consume more resources on that situation, i.e. it shows more attention to the situation than other situations. Then, the robot experiences higher emotional intensity according to its motivational engagement level and situational results [12]. Reflecting this concept to the human and robot interaction scenario, a robot shows more attention to social situation or human companions which are more emotional, and the attention and emotion affect robot's social states such as intimacy, loyalty, and so on, so that the robot is able to properly behave based on the social states.

2 Proposed Method

2.1 Motivational Emotion Generation

The definition of emotion has not yet definitely defined. The most famous psychologist, Plutchik defined that every emotion is reaction to stimuli [13]. Although people sometimes seem to feel happy or angry in long time without any clear reason, psychologists have called it mood, global affect, or temperament, which are usually distinguished from emotion. In general, emotion is defined as temporal experience and reaction to certain events [14].

According to Plutchik's definition, the basic process of emotion generation is cognitive appraisal process, and the evaluated emotions raise physical changes and emotional reaction. As the cognitive appraisal theories describe motivation is a precursor of emotion, one crucial function of emotional experiences is to signal or provide feedback about motivational states [15].

Following the above concept, emotions of a robot can be defined as feedback signals from a robot's internal motivational states and they are caused by events. Therefore, motivational states and relations between motivation and emotion need to be organized as previous step for emotion generation.

Motivation is like a source of behaviors, and it makes goals and encourages acting. Since motivations, however, cannot be observed directly, several theories exist to explain them: considering motivation as all-purpose energy, motivation as approaching or avoiding something, or motivation as preferences directing choices, etc. In order to integrate motivational theories, Tory Higgins has proposed a unified motivation theory which describes motivation as a concept of three ways of being effective: *value*, *truth*, and *control effectiveness* [15]. *Value effectiveness* is about having desired result, *truth effectiveness* is about establishing what's real, and *control effectiveness* is about managing what happens. Following this theory, in a situation that at least one of the effectiveness occurs, robots are motivated and engaged, then, therefore they pay attention and feel higher level of emotions to the situation. This motivational attention and emotion cause dynamic changes in robot's behavior decision condition later on.

According to the theory, if an effectiveness is high (success), then we experience pleasant emotions, such as cheerful, quiescent, confidence, vigorous, etc. If the effectiveness is low (failure), in other words, if we fail to have the desired result, we experience painful emotions such as dejected, agitated, confused, Incompetent, etc. The relations between emotions and the motivational states which are value, truth, and control effectiveness are summarized up in Table 1. These relations are applied to the robot's emotion generation model.

Table 1. Relation between effectiveness and emtion in accordance with failure and success

	Failure (Pain)	**Success (Pleasure)**
Value Effectiveness	Dejected, Agitated	Cheerful, Quiescent
Truth Effectiveness	Confused, Surprised	Confidence, Sure
Control Effectiveness	Powerless, Incompetent	Vigorous, Officious

Moreover, among pleasant/painful emotions, the emotions can be distinguished by levels of arousal factor which is a basic element of emotion and *Regulatory focus theory* is applied to evaluate them [12]. According to the theory, the level of arousal is determined by regulatory focuses: *promotion focus* and *prevention focus*. There are three elements that determine the regulatory focus. Those are *Hedonic properties* (positive/negative outcome situations), *Standards* (ideals or oughts), and *Need satisfaction*. *Standards* are given in the context of situation and interaction, and *need satisfaction* is depending on robot's current conditions such as thirst, hunger, fatigue, etc. With these elements, *promotion focus* is determined by gain/non-gain situation, strong ideals, and nurturance needs, and *prevention focus* is determined by non-loss/loss situation, security needs, and strong oughts. After a regulatory focus is set, the level of arousal factor can be differentiated by the type of regulatory focus. The relations between the regulatory focus and the emotional elements in accordance with success/failure of effectiveness are summarized in Table 2.

Table 2. Relations between the regulatory focus and the emotional elements(valence, arousal) in accordance with success and failure of effectiveness

	Failure	**Success (Pleasure)**
Promotion Focus	Pain, Low Arousal	Pleasure, High Arousal
Prevention Focus	Pain, High Arousal	Pleasure, Low Arousal

Through these procedures, we can evaluate a robot's two emotional elements, valence (pleasure/pain) and arousal, from motivational states. With these two elements, we can use two-dimensional emotion space that has two axes: valence axis and arousal axis. Let a robot's emotion state be a vector $\mathbf{a}[n]$ in the emotion space at step n and let elements of the vector at step n be $valence[n]$ and $arousal[n]$. Thus, the emotion state of a robot at step n is defined as

$$\mathbf{a}[n] = (valence[n],\ arousal[n]) \quad (1)$$

where $valence[n] \in [-1, 1]$ and 1 denotes maximum of pleasure, -1 denotes maximum of pain, and $arousal[n] \in [-1, 1]$ and 1 denotes maximum level of arousal, -1 denotes minimum level of arousal.

To evaluate specific emotion type i and its intensity $e_i[n]$, we can employ Russell's *Circumplex model* [16]. The model indicates where the 28 target emotions are distributed in the two-dimensional emotion space. Let the position vector of the target emotion be $\mathbf{t}_i = (valence_i,\ arousal_i)$ where i is an emotion type among 28 target emotions described in *Circumplex model*. The number of emotion types may narrow down to the emotions that are mentioned in Table 1. Then, the distance between $\mathbf{a}[n]$ and $\mathbf{t}_i$ determines the intensity of specific emotion $e_i[n]$ by using Gaussian shape function as

$$e_i[n] = \exp\left(-\left(\frac{\|\mathbf{t}_i - \mathbf{a}[n]\|}{2\sigma^2}\right)\right) \quad (2)$$

where σ is a parameter for the narrowness of the Gaussian shape and it is determined by developers. Furthermore, we may consider the specific emotion $e_i[n]$ as an element of the emotion vector $\mathbf{e}[n]$ that contains all emotion values if it is needed. The authors in this paper will soon publish a paper that explains how to formulate the previously exposed theories as a computational model to calculate a robot's emotional states.

With these evaluated emotions, a robot is able to show not only its emotional expressions but also reveal its internal motivation states in given situations, so that human companion can recognize robot's attention level and realize how much the situations are important to the robot.

2.2 Behavior Selection based on Emotional Experiences

While motivational emotions are being generated, the emotional experiences are also memorized with the situational information. Especially, events that cause highly aroused emotion are well remembered [17][18]. Then, the selectively remembered emotional experiences affect attention and selection preference when behavior decision is being made [19][20].

Likewise, a robot may store and use its emotional experiences. Since the robot's emotion elements, valence and arousal, are obtained from the motivational emotion generation model, the robot can selectively memorize events which are attentive based on the arousal level. Later when the robot faces situations, it can divide its attention proportional to emotional levels that are related to the situations. The higher level of emotion causes more attention to the event, and the robot has preferences to the decision choices that match attributes of emotional experiences. The integration of Emotional memory and behavior decision in an autonomous robot has been recently tried by researchers [21-25].

Suppose one sample S_k consisting of situational states $\mathbf{s}[n_k]$, the robot's emotion $\mathbf{a}[n_k]$, and step n_k is stored when an emotion is evoked at step n_k. Then, the set of all samples $\mathbf{S}$ can be described as

$$\mathbf{S} = \{S_k | S_k = (\mathbf{s}[n_k], \mathbf{a}[n_k], n_k),\ k = 1 \cdots N\} \quad (3)$$

where N is the number of samples. If a situation is given as $\mathbf{s}_{\text{given}}$ in the recalling stage, corresponding subset of samples is described as

$$\mathbf{S}' = \{S_k | S_k = (\mathbf{s}_{\text{given}}, \mathbf{a}[n_k], n_k),\ S_k \in \mathbf{S}\} \quad (4)$$

As explained above, the level of arousal is used as modulating factor for memory. The modulating factor α_k can be redefined as (5) within a range [0, 1] and the modulated and re-evaluated valence $v_k[n]$ of one sample at step n can be defined as (6)

$$\alpha_k = (arousal[n_k] + 1)/2 \quad (5)$$

$$v_k[n] = \alpha_k \cdot\ valence[n_k] \cdot \gamma(n - n_k) \quad (6)$$

where $\gamma(\cdot)$ is a time regression function with which more recent emotional experiences remain significant. Then, given the situation, the total accumulated valence $v_{\text{total}}[n]$ among $\mathbf{S}'$ at step n can be evaluated by calculating

$$v_{\text{total}}[n] = (\textstyle\sum_{\mathbf{S}'} v_k[n])/M \quad (7)$$

where M is the normalization value which can be calculated as $\sum_{\mathbf{S}'} \gamma(n - n_k)$.

Now, suppose the set of robot's action candidates for the situation is **A** and each action candidate has valence attribute v_{action}, for example, giving the glad hand is an action with positive valence and avoiding is an action with negative valence. Then, the robot makes a decision: selecting an action that matches emotional experiences.

$$\text{action} = \arg\min_{\mathbf{A}} |v_{\text{action}} - v_{\text{total}}| \quad (8)$$

3 Experimental Application Scenario

For the experiment, authors of this paper have implemented a joint attention scenario in which a human and a robot play a *2048* game together shown as in Fig 1. Basic situation is that the robot recommends a direction at every step of the game and the human participant press a key to move to next step in which the participant doesn't need to follow the robot's recommendation. According to the participant's reaction, the robot generates its motivational emotion, and shows its emotional expressions. During that time the experienced emotion is simultaneously memorized with the user information. The game ends when the score reaches to 2048 or when there is no possible direction.

In this joint attention scenario, the robot has distinguished motivational states. For the value effectiveness, the robot is motivated to get 2048 score or higher score of the game than previous game scores. For the truth effectiveness, the robot is motivated to establish consistency of the acceptance rate of the human participant. For the control effectiveness, the robot is motivated to make the human follow its recommendation so that it can manage the game. These motivational states may differ between robots' personalities or developer's design purposes.

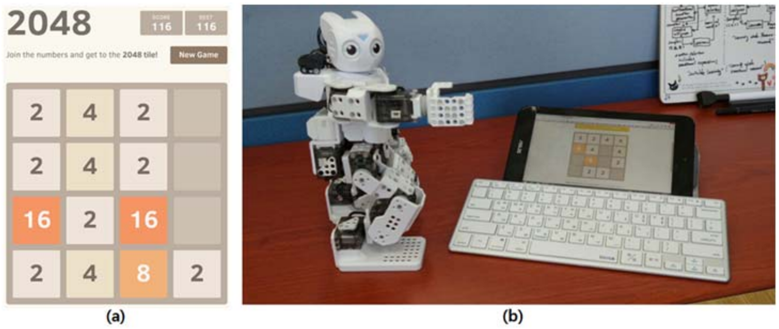

Fig. 1. (a) *2048* game implemented in MATLAB; (b) *2048* game is displayed on a window pad and DARWIN-MINI is recommending a direction for next step of the game.

Fig. 2. An interaction scenario after *2048* game in which the robot decides whether to follow human's lead or not

After the game ended, another interaction scenario is situated in which the human leads the robot to go somewhere by pulling the robot's hand as shown in Fig. 6, then the robot decides whether to follow human's lead or not in accordance with the robot's emotional experiences which were previously generated and memorized through previous game.

4 Preliminary Result and Discussion

A preliminary pilot test was conducted and examined if the proposed method would perform properly as intended. Figures from Fig. 3 to Fig. 7 present the preliminary result.

Fig. 3 shows an example of changes of the game score and acceptance rate from step 1 to step 300. The game score is the biggest block number of the board, and acceptance rate is obtained from the average rate of acceptancy in recent 30 steps. As it is shown, the acceptance rate is not consistent in time and it depends on how much the human user has intention to follow the robot's recommendation.

Fig. 4 shows the corresponding changes of three types of effectiveness: value, truth, and control. 1 denotes success of effectiveness and -1 denotes failure of effectiveness. Value effectiveness is sensitive to the game score as shown Fig. 4 (a). If the game score increases, i.e., the biggest block changes to higher number, the robot gets closer to the goal and the value effectiveness is successful in the progress. Otherwise, if the game score doesn't increase, the likelihood to the ending condition of the game at which there is no direction to move blocks is getting higher, so that the value effectiveness is failed. Truth effectiveness depends on the consistency of acceptance rate as shown Fig. 4 (b). If consistency of acceptance rate of human is high, the robot can establish the reality of how frequently human will follow the robot's recommendation or not, so the truth effectiveness is successful. Otherwise, the truth effectiveness is failed. Control effectiveness is sensitive to the acceptance rate by smoothing the acceptance rate as shown in Fig. 4 (c). If the acceptance rate is higher than 0.5, then the robot has more authority to manage the game and the control effectiveness is successful. If the acceptance rate is lower than 0.5, the robot has lower authority so that the control effectiveness is failed.

Fig. 5 shows valence and arousal factor of robot's emotion corresponding to successes or failures of effectiveness. Valence can be directly evaluated by averaging three types of effectiveness. In Fig. 5 (b), changes of the level of arousal are depicted with each portion of each type of effectiveness. Though in this paper, the portion of each type of effectiveness is averaged, it could be weighted by predefined personality or could follow the winner-takes-all rule, or could affect emotion independently.

Fig. 6 shows specific emotions $e_i[n]$ which is independently calculated by equation (2). For simplicity, in this paper only 8 emotions are depicted in Fig. 6, which emotions are the representative of each quadrat or axis of two-dimensional emotion space and picked from Circumplex model. First four emotions: pleased, exited, aroused, and distressed depicted in Fig. 6 (a), are more dominant emotions, Later four emotions: miserable, depressed, sleepy, and content depicted in Fig. 6 (b), are less dominant emotions in this result. During the first 50 steps, aroused and distressed emotions were dominantly generated because there was no significant reward from game and lots of uncertainty of the game. Exited and aroused emotions were dominantly generated near 100-th step because there was a reward that is from score increase and consistent acceptance rate. During the last 80 steps, exited and aroused emotion were dominantly generated because there were a big score change and consistent acceptance rate.

As mentioned in chapter 3, after 2048 game ended, an additional interaction scenario happened. The human leads the robot to go somewhere by pulling the robot's hand, then the robot decides whether to follow human's lead or not. In the interaction scenario, there were four action candidates for the robot: shaking off, ignoring, hesitating, carefully following, and openly following with valence attribute -1, -0.5, 0, 0.5, and 1, respectively.

Assuming that the 2048 game ended at 300th step, the total accumulated valence v_{total} at 300th step was about 0.1 as shown in Fig. 7. As looking at the changes of the total accumulated valence v_{total}, it was negative during the first quarter of steps, and

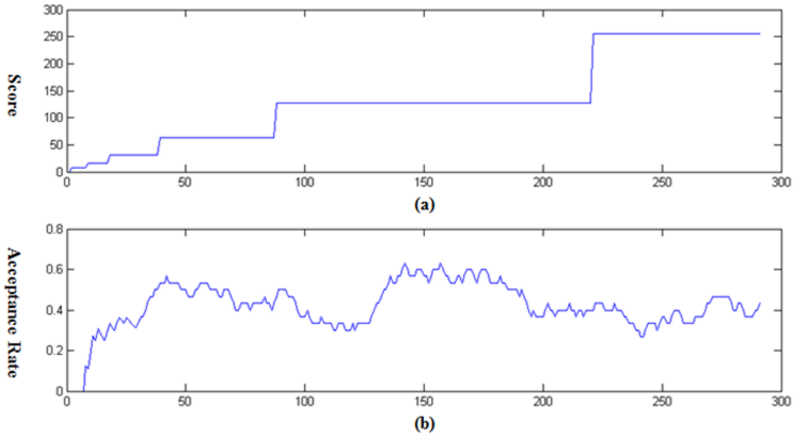

Fig. 3. (a) Changes of the game score which is the biggest number of the game board; (b) Average acceptance rate within recent 30 steps

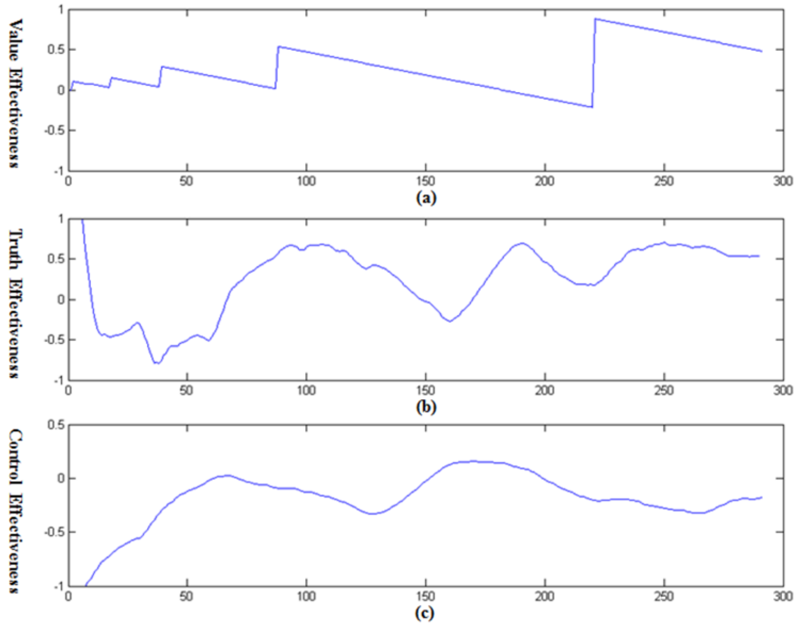

Fig. 4. (a) Changes of value effectiveness; (b) Changes of truth effectiveness; (c) Changes of control effectiveness

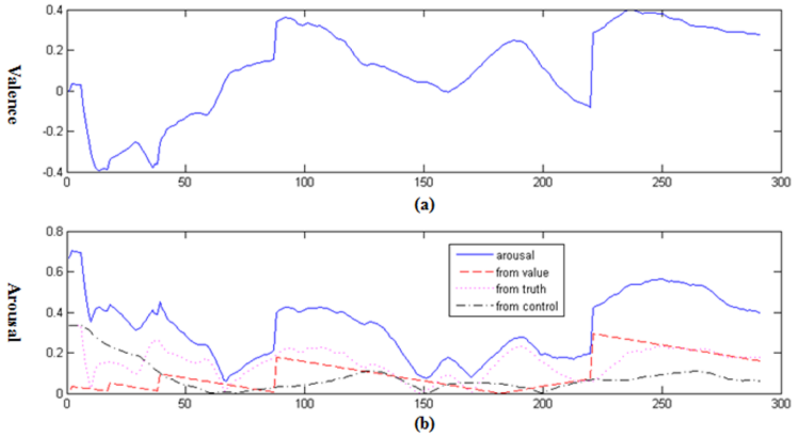

Fig. 5. (a) Changes of valence;
(b) Changes of arousal depicted with each portion of effectiveness

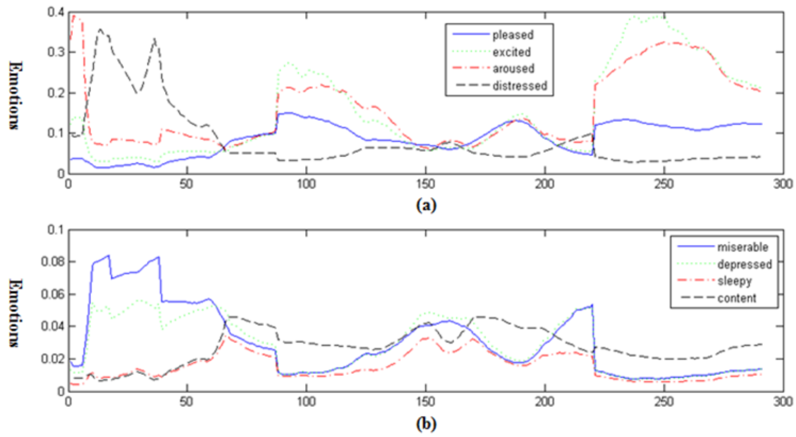

Fig. 6. Intensity changes of each emotion (depicted separately for readability)

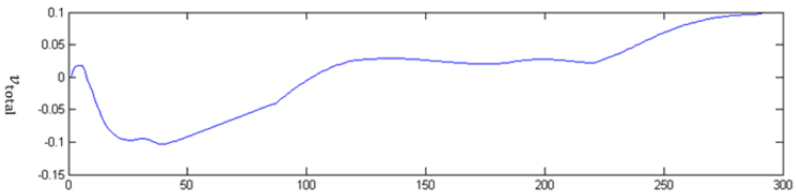

Fig. 7. Changes of the total accumulated valence v_{total}

during the middle period, the valence value was recovered, and then finally v_{total} reached almost to the number 0.1 although this number is not significantly big.

At the behavior selection process, the robot decided an action which has the closest valence attribute, i.e. to hesitate to follow the human's lead, which means that the robot still doesn't think the human is friendly enough. The robot may sometimes carefully follow the human's lead with this v_{total} by adding probabilistic parameter to the decision process. This probabilistic concept will be discussed in next paper.

The reason why the value is not big enough is that the subject didn't follow the robot's recommendation very much. Maybe the subject was motivated to play the game just for enjoying himself/herself. For next experiments, it seems to be needed to give reward to subjects so that they are motivated to get higher score and more to follow the robot's recommendation, then, compare results caused by them to results caused by those who are not motivated to follow the robot's recommendation.

For further study, two kinds of robots will be compared: one robot acting by the proposed method, and the other acting randomly. Then, we will monitor participants' psychological changes such as how the participants feel when the robot shows emotional expressions while playing the game, how the participants feel when the robot follows or disobey participants' lead after the game, how much the participants' acceptance rate of robot's recommendation changes when playing more games.

The authors of this paper are expecting the participants to anthropomorphize the robot that has motivational emotions and emotional experiences and to think that the robot has a personality; the acceptance rate or robot's recommendation will increase; and finally participants will accept the robot as a social partner.

5 Conclusion

In this paper, a motivational emotion generation model is proposed. The model employs the unified motivation theory which is proposed by Higgins, and explains relations between motivation and emotion. In addition, a behavior selection model based on emotional experience is suggested; with which decision preferences are more affected by highly aroused and attentive emotional memory.

To test the proposed method, a joint attention scenario is suggested in which a human and a robot play a 2048 game together and a follow-up interaction is conducted to observe the robot's behavior selection that is influenced through the game. A preliminary pilot test was conducted and examined if the proposed method would perform properly as intended. As a result, the robot showed corresponding motivational emotions and behaved properly based on the emotional experiences in the proposed framework. However, more advanced experiments are needed, and further plans and expectations are discussed for a comparison of a robot that has motivational emotion and emotional experiences and another robot which is not.

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Beyond Patting: The Role of Attention in Expanding the Human-Pet Robot Relationship

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Abstract. Companion animals can provide a sense of social support to isolated people, including the aged, providing physiological and psychological benefits. Although pet-like robots have been developed they have focused on patting response behaviours which represent only a small part of the human-pet relationship. In this paper we explore aspects of human-pet robot interactions that might benefit from the application of attention models; including feelings of shared experience, dependence, constant availability, and non-judgemental support.

1 Introduction

Pet ownership has consistently been shown to have positive physiological and psychological benefits to human health. The health savings due to pet ownership were estimated at $988 million for Australia for the 1994-95 financial year [7]. Unfortunately some of the most socially isolated people who would most benefit from a companion animal are also the most ill equipped to care for them. This could potentially be unhygienic for the person and life threatening for the animal. Australia is facing an aged care crisis with increasing numbers of vulnerable elderly and decreasing numbers of aged care workers. The Australian department of Health and Ageing estimated that the aged care workforce will need to double or triple by 2050 [2]. At the CSIRO, Australia's government research organisation, we are currently developing pet therapy robots that both monitor the health of aged care patients and provide social support.

Interacting with animal-like robots has been shown to have social and psychological benefits [19] and foster social interaction [11] in aged care patients. The robot interactions have been limited to simple expressions and sounds triggered by touch. In recent models they have included the ability to respond to the robot's given name. Studies have not been conducted to show if these interactions are enough to foster long term engagement and therefore benefit. There is also ethical concern that these robots have a possible infantilisation effect on aged care patients [17] and that any suggestion that it is a true relationship is a deception.

Studies with companion robots for the elderly have only scratched the surface in simulating pet relationships. In this paper we explore the human-pet relationship in more detail and the role of attention in reproducing the necessary behaviours.

2 The Human-Pet Relationship

Married or co-habiting couples demonstrate stronger health and longer life expectancy than those who are divorced or single [12]. Animals have an important role in the lives of people in transition; for example the newly married, divorced or widowed [14]. A lack of social support is a significant risk factor for subsequent physical and psychological problems [18]. Companion animals are a social support in and of themselves, but also act as facilitators of social interactions between other human beings [3]. Beck and Katcher [3] suggest that sharing our lives with companion animals promotes a sense of safety and consistency.

> "by encouraging touch and giving humans a loving creature to care for, the interaction with animals stimulates physical reactions that are very necessary and important in humans. [4]"

To expand the relationship with pet robots beyond their responding to touch we need to investigate what it means to be a 'loving creature for someone to care for'. Attachment theory suggests that humans have a need to protect and be protected [1]. Pets depend on humans as children rely on parents for their continual care, protection from danger, and explanation on their behalf because of their lack of language. Further to this many older pet owners regard their pet as a symbol of independence [6]. This symbol allows them to manage the process of becoming increasingly dependent on other humans for their needs; including financial. The pet is dependent on them, and therefore they are not at the lowest step on the social hierarchy. This 'need to be needed' can manifest itself even more strongly giving a socially isolated person a reason to get up in the morning and a reason to take care of themselves effectively [20].

As social supports pets may reduce loneliness and contribute to a general sense of well-being in their owners [16]. Study results report that as social supports their benefits include their [5]:

- constant availability
- non-judgemental support
- unconditional love

This sense of non-judgemental support may be explained by pets appearing to be indifferent to our physical appearance, social status, material possessions, relative intelligence, and conversation skills. People that feel rejected, a burden, or invisible to society may find the relationship and support they need in an animal.

Simulating unconditional love may be a controversial prospect at best, but many of the other perceived advantages might benefit from the application of attention models; including feelings of shared experience, dependence, constant availability, and non-judgemental support.

3 Attention

3.1 Shared Experience

Shared experience is an important aspect of the feeling of sharing your life with another. Kaplan and Hafner [10] describe joint attention as a shared intentional relation to the world. This extends beyond ‘simultaneous looking’ and is an active bilateral process. Joint attention is intentionally directed perception that involves one or more parties trying to achieve a goal. Kaplan and Hafner [10] specify four stages of joint attention that will be used to describe pet robot requirements:

– **Attention detection** - eg. tracking the other agent’s behaviour and gaze.
– **Attention manipulation** - eg. pointing gestures and words.
– **Social coordination** - eg. turn-taking and role-switching.
– **Intentional stance** - eg. interpreting other’s intentions, including those different from one’s own.

Yonezawa et. al [21] concluded from experiments with a stuffed toy robot that joint attention affected human interactors positively only when combined with methods for maintaining eye contact. This is likely also applicable to pet-like interactions.

Shared experience can involve shared response to abnormal events. These events might include loud noises, new visitors, or extreme weather conditions. These in turn could trigger curiosity behaviours, or simulating appropriate responses, such as heat seeking in cold weather. This could be implemented in a ‘simultaneous looking’ sense in which both parties simply react to similar events. Reliable attention detection might allow the robot to respond to events that it cannot detect itself. However, including social coordination and intentional stance behaviours to involve an interpretation of the owner’s reaction to the event might elevate this to a shared experience. For example, behaviours that might be interpreted as ‘Did you hear that?’ and ’Should I be concerned?’.

Habituation and sensitisation models allow an agent to autonomously adapt to its environment.

> “Individuals do not receive a positive or negative feedback for their responses from the environment. Instead, they measure the effectiveness of their responses based on their internal judgement of the significance of the repeated stimulus.” [13]

However, to create shared experience it may be necessary that the dominant party (the pet owner) guides habituation and sensitisation in the robot. Humans and pets are not social equals, and pets are expected to learn our rules and ways of living. The pet must look to the human to determine the appropriate response to events; both normal and abnormal.

3.2 Dependence

The goal for much of robotics is to increase their autonomy to the stage where human intervention is not required. In the case of the human-pet robot relationship dependence may be a necessary requirement.

Attention manipulation is a candidate for providing the sense of the dependence of the pet robot deemed necessary for attachment. The robot should be able to direct the human to any needs or fears it might have until they are appropriately met.

A simple system to implement would be to require the owner to charge the robot's batteries. The robot then ceases to function when the owner neglects it. This does not have the same responsibility as not feeding a living creature, as the robot would be essentially unharmed if allowed to run flat. Potentially the robot could lose any personalisation it has acquired to provide incentive.

Another approach would be to foster empathy in the owner that increases their desire to keep the robot safe. Imitation has been shown to be linked with empathy [8]. Social coordination is required to play imitation games that could assist in this process.

3.3 Constant Availability

It is a simple matter to program a robot to be always present at the owners home. However to appear 'constantly available' there are technical challenges in reliability to consider. The robot would need to be technically robust and easy to keep charged. In addition the robot would need to reliably find and provide attention for the owner. It is unlikely that pet owners are referring to the availability as an inanimate object might have, in that they can lay their hands on it at any time, but more that the attention is there any time they need it. The robot should then have a system that accurately sense when their attention is required and provide it at a priority to other tasks. In practice this may involve sensing when the owners social needs are not being met and make itself available for patting or company.

It is suggested that animals feel empathy as they appear to be affected by the emotional distress of others. Animals may become agitated or distressed by anothers distress, and act to eliminate the stressor or soothe them [15]. The robot actively making itself available when the owner is distressed may extend this to a more animal-like interaction. At its simplest this is an attention detection problem, but emotional events may be harder to recognise than physical ones.

3.4 Non-Judgemental Support

Because of the requirement to program perceptive and discriminatory behaviours into our robots, in a sense we gain ''non-judgemental support' for free. The robot will only pay attention to the characteristics of their owners that they are explicitly told to. What we program the robot not to pay attention to may be as beneficial as what we do. For robots that are also acting as physiological and psychological health monitors it may be important to track and report on these without appearing to be disapproving. It may be that animals are able to express concern, interest, and attention in a manner that is non-invasive and non-patronising. One of the design decisions to be made in a health monitoring robot is whether it should be verbal or non-verbal.

Reproducing the non-verbal attention of pets may be necessary to generate feelings of non-judgemental support. Puppies that have had little to do with humans are able to follow gaze and pointing gestures, whereas wolves cannot. This suggests the process of domestication has resulted in skills in interpreting human social cues. Dogs themselves use gaze, body orientation, and pointing cues to establish joint attention [9].

4 Conclusion

Pets provide us with a relationship that extends far beyond the affection we give and they receive. Joint attention methods such as attention direction, social coordination, and intentional stance may assist in elevating these interactions to the sense of a shared life and social support.

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Building Emotional Authenticity between Humans and Robots

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1 Introduction

On June 5^{th} 2014, a robot named Pepper, hailed as emotionally responsive and meant solely to emotionally interact with human beings, was unveiled in Japan. *"Our aim is to develop affectionate robots that can make people smile"* [12] stated Softbank CEO Masayoshi Son. But what did Masayoshi mean the robot would "make people smile?" Did he mean the robots behavior might elicit a smile from a human? If so, some people smile when they are angry in order to make themselves less aggressive in a tense situation. Certainly, he did not mean he developed a robot to make people angry! So we may assume Masayoshi meant human interaction with Pepper would make people "happy". However, by what methodology do we determine the robot created happiness in us? The viewpoint of this essay is that the humanities and specifically the performing arts are in an excellent position to develop a model of behavior between humans and robots in order to present a clear, authentic emotional relationship between them. Meaning, the social intelligence of a robot interacting with a human is akin to the dramatic relationship between human beings while performing for an audience.

The stage is the social arena and the performance styles are the tools with which to sculpt a meaningful performance. We must begin to understand how we perform for each other all the time as we are essentially building robots to perform for us. This is not an entirely new concept. Erving Goffman, notable sociologist used the metaphor of the stage to dramatize his views of how human social interaction is a series of performances that we tweak and mold instantaneously both inter- and intra-personally.

> "Within the walls of a social establishment we find a team of performers who cooperate to present to an audience a given definition of the situation. This will include the conception of own team and of audience and assumptions concerning the ethos that is to be maintained by rules of politeness and decorum" [5].

Goffman discusses the presentation of self through a social situation in which we often try to cooperate with our fellow social actors. *"Typically, but not always, agreement is stressed and opposition is underplayed"*[5], yet the expression of emotion in human beings does not always follow such agreeable rules. Goffman wrote specifically how the individual compartmentalizes his responses into a *"front"* of the house –the actor and performer– and the *"back"* of the house –the performers true identity [5].

This essay seeks to present a system to express deeper emotional authenticity through the utilization of performance behavior, gesture, shape, and relationship. This is accomplished through the implementation of traditional performance techniques re-contextualized from a human/human stage model to a human/robot social intelligence model.

2 Social Intelligence, Attention and Authenticity

When analyzing social intelligence between robots and humans, we must be cognizant of the complexity and specificity of emotional connections human beings share with each other in the multitude of everyday moments of interaction. Why is the artist involved in this decision? Performers study an art form nearly 3,000 years old that demands a level of authenticity and skill from a collaborative team including actor, director, and playwright. There are few art forms or disciplines as adept as that of the theatre artist to convey how to create, hold, build, and challenge attention from a group of people –the audience– from whom no previous relationship was originally held. And yet, social intelligence, by definition, strives to do just that. Drama and the performing arts, specifically well-known performance techniques, can be used to understand, deepen, and clarify emotions, as well as, focus attention in a social relationship not only through human connection, but by expanding performance techniques to relate to human beings interacting with robots and vice versa.

Many visionaries have used the medium of drama and performance to express their artistic ideas. Constantin Stanislavski (1863-1938) emphasized natural, (re)created, emotional expression in response to the arguably more superficial theatre of the time. "The approach we have chosen –the art of living a part– rebels with all the strength it can muster against those other current 'principles' of acting. We assert the contrary principle that the main factor in any form of creativeness is the life of a human spirit, that of the actor and his part, their joint feelings and subconscious creation"[9]. Theatre director/actor Stanislavski is widely considered the 'father' of modern theatre and his Stanislavski system was the framework for "the method" which was refined and popularized by Lee Strasberg in the U.S.

When creating successful drama in the theatre arts we speak about specifics of a character through their *behavior*, their *gesture*, their *shape* and the interaction of those attributes functioning through the very specific *relationship* implied between the characters. In order to make sense of behavior, gesture, shape, and relationship, the artist must determine the *given circumstances* of the play.

These technical terms are defined as follows:

Given circumstances: the givens of the moment in a play. Essentially, where a character finds themselves (physically and emotionally) at that moment in their world and how they respond to people and events and unfolding around them because of those givens.

Behavior: How a character behaves physically and emotionally in order to approach the given circumstances of the specific moment. For example, a character may get down on bended knee to request a proposal of marriage while another drags their partner to the nearest justice of the peace.

Gesture: The movements a character uses within their characters behavior and for what specific effect. For example, take a simple gesture of holding or shaking hands. What variety can be expressed in this simple gestures and what is the meaning in the choice to serve the relationship?

Relationship: What are the parameters of the person with who we share the stage or social arena? For example, are they a peer or subordinate? We speak and act differently to the police officer that has stopped us for speeding than we do to the teenager that has come home past their curfew.

Shape: What is the overall tone of the character and genre the play is trying to express? Can we describe it as comedy, drama, dramedy?

In regards to all the defined terms above, it is assumed that a deepening in the understanding of what the given circumstances are at any one moment culminates in a heighted state of social intelligence. The ability to be cognizant of our social attention skills can be trained; however, is not necessarily training for an artist only. It can be training for an engineer or a roboticist. It is training to explore the nuances of how attention is manifested in social intelligence through the application of performance. One type of attention necessary to understand the given circumstances of social interaction would be the exploration of sensory data. An awareness of what we see, hear, smell, feel kinesthetically both inside our bodies and the tactile experiences on the surface of our bodies, as well as taste. An artist develops an ability to create a relaxation in their body and thereby concentrate the stream of sensory impulses occurring in order to focus, to prioritize, or to give attention to the given circumstances the sensory data refers to. At the moment the sensory data is received, the will of the artist engages. The will is what determines the course of action given the stream of sensory data. It is not enough to simply feel, the will guides the artist in their dramatic objectives and choices. In a social intelligence arena with human robot interaction, the will is the determination that guides attention. In a performance, attention is greatly affected by sensory data culled from the individuals memory, which then affects the artist emotionally.

Yet, the training of sensory impulses and will are not meant to create actors out of an audience of lay people, they are meant to specify and analyze human behavior –which we are all familiar with– from the performative point of view of the artist and now applied to human-robot interaction. The social intelligence of a character in the given circumstances of the current scene, the inter-relating with other characters or the audience, and ultimately how or why the character behaves, is the research now transcribed to the relationship between humans and robots. The very best conclusion for human-robot interaction would contain not only an authentic sense of how humans behave between themselves in relationship-based dramatic circumstances –theatre arts– but also how a human may interpret and thereby behave with a robot with whom *they may begin to have very human-like emotional relationships with.*

3 The Building Blocks of Authenticity

3.1 Toward Performative Arts

If we are to look toward the artist for answers in how humans respond to humans and ultimately how humans may respond with robots, there is a need to research the many technicians, directors, and artistic visionaries, who created performance styles for the performing artist. These performance styles present an exploration of behavior, gesture, shape and relationship as it relates to how human beings interact and how robots must behave if human beings are to authentically interact with them. Research points toward the efficacy of long-standing performance techniques or styles, styles that has survived through not only decades but centuries of performance. The preference to present two different, yet mutually compatible, framing mechanisms to illustrate how human beings may interact with our robot companions, is a helpful aspect.

The first technique presented is Vsevolod Meyerhold's biomechanics [1]. Meyerhold's biomechanics is a performance technique that stresses external physicalization, gestures, behavior, and avant-garde themes and movement to create emotion and authentic characterization in the performer. It is representational, abstract, and features a theatrical expression known as the grotesque[1]. Biomechanics is an external performance technique created, developed, and best exemplified by Meyerhold with his work in Russia from the 1890s to the present. *Life of Man* by Leonid Andreev with its exemplary lighting design is one example of Meyerhold's innovative work from this time [1].

Although contemporaries, Meyerhold's techniques were quite different from the second presented performance technique: Lee Strasberg's method [10]. Originally developed from Constantin Stanislavski's techniques, Strasberg's method technique stresses thoughts, psychological motivations and desires, personal memories, and naturalistic behavior and movement to create emotive characterizations in the performer. Internal performance technique was created, developed, and best exemplified by Lee Strasberg and his work to create the method system in the United States from the 1920s to the present. Most notable of Lee Strasberg's work was the co-creation of the legendary yet short-lived, The Group Theatre, and specifically the production directed by Strasberg of *Golden Boy* by Clifford Odets produced to notable acclaim both on Broadway and in London [3].

This research utilizes aspects of both contrasting performance techniques to fully develop intense and effective emotive bond between humans, and now as technology is creating emotional robots, between humans and robots.

[1] The grotesque theatre as defined by Bert Cardullo and Robert Knopf is simply "the resolving of tragic situations into comedy or the reverse" [2]

The function of a performance technique is to deepen the authenticity of the performer so the relationship between the player and the audience is more immersive and ultimately more satisfying. We go to the theatre to feel something –a human connection, an understanding of why this human being, in these circumstances, made these choices. That understanding is similarly translatable to a relationship between a robot and a human, in fact it is wanted and desired. Attention for social intelligence will be most effective if it stresses immersive emotional and relational bonds. As robots move into the social arena of companions to humans, it is imperative to understand and create relationships on a sincere and accessible performance level.

The proposed performative methods might be an innovative and interesting way to elucidate a unique insight to the authentic emotional responses required when working with actors, digital characters (videogame characters), animators, and now, engineers and roboticists.

3.2 When Emotions are more than Right or Wrong

When speaking of emotion, a significant caveat is that although there may be many different ways to express emotion, there are very few emotions to express. Some psychological studies theorized a model of emotions based on only a limited number of primary emotions. Paul Ekman theorizes six basic emotions [4] while a recent study conducted at Glasgow University now proposes only four [7]. Yet, through this limited landscape the artist seems fluent in a nearly infinite variety of expression across a landscape of social, cultural, and geographic framing structures. One method for accessing emotional authenticity in performance is to eliminate a judgment of right or wrong in defining the emotion.

There is a common tendency to assign emotion as *right* or *wrong*. Anger may be considered a *bad* emotion while courage is *good*. However, research consistently highlights that authentic, expressive human emotion relies very little on the *right* or the *normal* relationship. This tendency has been observed in sociological studies made by MIT professor, Sherry Turkle. Turkle introduced a study she conducted with children and a robot named Cog [11]. In her analysis, Turkle notices the children enjoying their interaction with Cog. The children played with the robot and seemed to nurture it and care for it. *"They treated it as a creature with needs, interests, and a sense of humor"* [11]. The children seemed quite bonded to the robot and accepted Cog as a playmate as they would a human child or peer with all the usual emotional responses that human beings reserve for their human counterparts. The children's behavior implied that Cog was not less of a playmate because Cog was not human. This summation was not completely unexpected by Turkle who has cited Joseph Weizenbaum's work regarding the Eliza Effect and its strong emotional influence on its participants [11]. However, Turkle also planned a meeting with Cog where each child was systematically shown Cog's inner mechanisms and working parts. Cog was exposed as plastic, metal, and digital instructions. The childrens relationship with Cog was not *normal* in any socially conforming version of a typical relationship, yet none of this mattered. The children again quickly related to Cog in the same nurturing, relational manner as before the nuts and bolts explanation. Nurturance is the relationship in this given circumstances that drove the children's emotions to care for Cog. The children cared for Cog the same way they seem to care for and feel for each other. Even though, as Turkle laments, *"To have a relationship, the issue is not only what the human feels but what the robot feels"* [11]. Turkle summarized the study stating nurturance should be known as the "killer app" [11], creating a bond between humans and non-organic objects that is incredibly strong. Therefore, although cultural norms of *right*, *wrong*, or *normal* may be recognized, they are secondary to the authenticity and creation of emotion, and the relationship that may form because of that creation of emotion.

3.3 Human-Robot Mutual Need: an Analogy with Drama

One way to deepen the relationship between humans and robots is to note that human relationships are often based on mutual need. Drama is a series of ever unfolding conflicts continually testing the bounds of which character's need is currently being fulfilled. Humans respond favorably to the act that helps another while it also fills a need for them. This inter-relationship is being explored in a human-robot relationship. For example, Okada Michio developed a robot that does not pick up trash, but rather finds it and requests a human's help to accomplish its task [6]. In this instance, when the robot finds a piece of litter, it does not function autonomously, but rather indicates the location of the litter and with an angled bow, requests the help of a human to pick it up. The implication is clear; let's work together and see what we can accomplish. Okada believes this relationship creates a desire to nurture the robot echoing Sherry Turkle's study.

3.4 The Perfection of Imperfections

Another method of building a relationship may be in the creation of a robot whose characteristics are imperfect. Just an in human beings, some of the most unique and charming human characteristics are those that are seemingly imperfect –a gap tooth, a cowlick in the hair– an imperfect robot might be one that stutters occasionally, or develops a limp after moving for an extended period of time. As illustrated by the uncanny valley[2] research, human engagement is not in what is perfect, but rather in the abstract or the imperfect. Imperfection in all its unique qualities is endearing to humans. It would follow that we may like our robots to be more imperfect in order to bond emotionally with them.

[2] The uncanny valley was a term originally coined by Masahiro Mori in 1970 to describe the eerie and unsettling response of people when confronted with an android that is not quite human. The uncanny arises when one is confronted with something that transgresses the boundaries of our conceptions of normal, and thus seems to be one of the key responses invoked in confrontations with the border between humans and machines [8]

4 Conclusions

When developing robots that will help us in our day-to-day lives should we be looking at the mutual need humans and robots may begin to feel for each other? How will those relationships be expressed? How can we develop robots that spur our desire to connect with them in order to fulfill the individual's wishes and needs? Will a robot ever have a need for a human's emotional attention? These are all relevant questions for future research.

Given the proposition that the analysis of the human condition through performance is helpful, and even essential, in the development of social, attentive, emotional, and empathetic human beings, are performance techniques then essential to analysing the behavior and relationship between humans and robots in the arena of social intelligence?

Performance, connection, and authenticity are the gold standard that should be hoped for in the creation of the relationship between humans and robots. We can attain these goals through the specific application of understanding human behavior, gesture, shape and relationships. We must be specific in programming robots to respond to, and to eventually to learn from, the human relationships they will be a part of. Social intelligence and the attention to create, improve, and expand the understanding between humans and robots can be positively impacted by the research of performance styles and techniques, specifically internalized method work, and representational biomechanics.

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AURAL: Robots, Evolution and Algorithmic Composition

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Extended Abstract

Focusing on the interactiviness that a robotic interface establishes between the virtual and the real world, some sensory systems and mobile robotic platforms were developed for the AURAL project, a robotic evolutionary environment for sound production [1, 2].

In the AURAL environment, the sonification is generated by an evolutionary mapping of the robot trajectories into sound events. One issue addressed is the structure/novelty tradeoff [3]. By applying these ideas to algorithmic composition systems means that more knowledge and structure allows the creation of new pieces that are more tightly matched to the desired musical genre. However, the flipside of more structure is less new material. The highly constrained output will be less likely to stray beyond a genre's limitations or it may be surprising. Thus, the highly structured composition system will be less general, able to reach less 'music space' with its output.

In the AURAL, this tradeoff is treated by creating an interplay between sound, real-world artifacts, user and behavioral information. Through the interaction among the evolutionary sound process, the artificial vision system and the mobile robots [4]. The sound interface has a *Graphic Area*, the heart of the system, wherein the user may draw curves to be sent as trajectories to the robots. This area is associated with a conceptual sound space with two axis, the "red" one, or melodic, and the "blue" one, or rhythmic. The paths travelled by the robots in the arena are observed by the artificial vision system and sent, as sequences of points, to the sonification module. The red curves, sent as trajectories to the robots and the blue curves associated with the paths travelled guide the evolutionary sound process across different regions in the sound space.

AURAL was presented in an art gallery where the visitors could appreciate the sound output and the interaction among the robots, as a kind of choreography. The visitors drew curves in the graphic area, which were transmitted as trajectories to a master robot, the Nomad. While the robots (until 4) moved in the arena, virtually traveling along the conceptual sound space, people changed the orchestra, rhythm and pitch controls, investigating the sound possibilities. Both a process of man-machine interaction and parallel exploration occurred.

On the last day of the exhibition, a dancer, three musicians and the AURAL system itself, with four robots, performed an interactive concert called *Robotic Variations*. The performance of the robots was accompanied by the musicians, who knew the type of music that would be generated, but they had to be able to adapt the performance. At the same time, the dancer, tracked by her red hat, was interacting with the robots, all interfering in the music that was being generated.

One can see as an interesting aspect of the AURAL environment the possibility of different setups to explore distinct levels of interaction among humans and machines. AURAL supplies a platform for robotic experimentation and artistic creation exploring human and machine interaction and bringing about results that could not be obtained otherwise.

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AURAL$_2$: Robots and a Generative System in an Algorithmic Composition Process

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Extended Abstract

An artificial vision system, mobile robots and a generative process were applied for sound production in AURAL$_2$, a robotic art installation [1]. Generative systems have many similarities with systems found in various areas of science; they may provide order and disorder, as well as a varying degree of complexity, making behavioral prediction difficult. However, such systems still contain a definite relation between cause and effect. The artist (or creator) generally provides basic rules, and then defines a process, random or semi-random, to work on these elements. The results continue to happen within the limits domain of the rules, but also may be subjected to subtle changes or even surprises [2].

In the AURAL$_2$, synthetic, game and everyday sound fragments are inserted into a database, the memory of the system. Each sound fragment is associated with a cell in a virtual grid, projected on a winding format platform (3m x 3m wide, 0.3m high), or stage (Figure 1). A hole inside the platform creates tracks that may be travelled on by only one robot or two robots. The robots have a border sensor, they stop when they detect the border. In the other regions of the platform, three or four robots can move around. This design cases conflicts among the robots when they try to escape from confined areas. The robots are tracked by a vision system which evaluates the position (x, y) of the robots on the stage; associates a cell in the matrix with that position and plays the sound fragment associated with it. The movement of the robots through the different regions of the stage triggers the sound of the associated cells, (re)creating soundscapes in the installation environment.

On a TV, the virtual grid is shown in several angles, as well as the cells activated by the robots (Figure 6). The visitors may interact with the system by talking, singing or screaming at a microphone, starting the intervention process: sound fragments are extracted from the interventions of the visitors and randomly inserted into the environment matrix; there is a possibility of the segments to be triggered and played again by the movement of the robots. A spectral analysis is applied on the fragment that caused the intervention, and two visual effects may be perceived by the visitors.

When there is more energy in the upper partials of the sound fragment, the following actions take place: the color of the cell associated with that fragment is changed to red on the TV, otherwise to blue. A rotation is applied on the grid. Finally, the sound fragment is inserted into the sound data base, i. e., the memory of the system, superposing a previous one, enhancing a recycling acoustic process. Thus the AURAL$_2$ intervenes in the sound ecology, generating new aural trajectories with the everyday sounds.

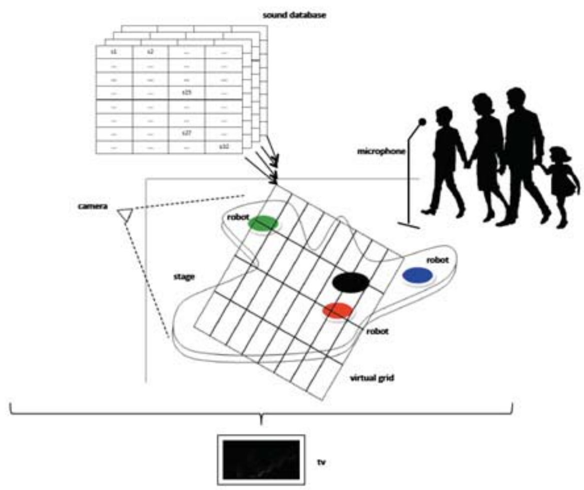

Fig. 1 The components of AURAL$_2$: sound database, camera, microphone, robots.

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COLUMN: Core Less Unformed Machine

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1 Introduction

Fig. 1. Appearance of Core Less Unformed Machine (COLUMN).

The concept of a self-configurable (transformable) robot is versatile and effective in space applications, entertainment, natural disasters, and developing and controlling such robots is really challengeable [1]. Exist mechanism are attempting to connect their modules as external parts, as well as try to maintain their structural shape as snake or walker [2][3]. Always challengeable to design the motion mechanism and autonomous capability for such kind of novel architectural artifact which is entirely different from the existing.

In this video, we presented a transformable artifact (COLUMN) which becomes a social mediator in the proposed context. The COLUMN is a soccer ball-shaped interactive artifact consisting of eight modules that are connected to the twelve servomotors (Figure 1). We can transfer the COLUMN body shape by moving the actuators with modules, and these actuators can be controlled by a wireless communicator called a "COLUMN Gear." Each of the users (three participants) can control the 4 servo-motors of the COLUMN, and a user can swing the COLUMN gear to change its body shape (transfer its modules). Users have to coordinate with each other to boost its transformable behaviors while preserve their co-action in the dynamic interactions. In contrast to the previous utilization of robot as a social mediator [4][5], in this study interactive users have to understand what/how they are controlling the robot, and necessitate inferring the way of connecting with others, and also understand essential in-time coordinate in the dynamic interaction. This type of synchronization with each other's swing (toward achieving their goal) can be defined as the interpersonal coordination in the context. Therefore, by using the patterns of interpersonal coordination, our motivation is to explore users invent transformable behaviors for the COLUMN.

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Drum Circle

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Extended Abstract

Machines are often displacers. In factories, they displace human workers; in construction projects, they displace natural objects to make way for buildings and roads; in communication, they displace previous means of social interaction. Machines are often big and powerful. Such attributes are necessary in order to move heavy and/or large objects in order to reshape the landscape. Some may interpret these activities as machines *over*powering parts of the land. Machines are often noisy. This quality, in part, defines the sonic identity of contemporary city life and has been reflected in art, for example in George Antheil's composition *Ballet Méechanique* (1924).

Drum Circle challenges the idea of machines as displacers that are big, powerful, and noisy. Here, the robots, CADI (modular percussion arms) and MADI (a snare drum with fifteen strikers), depart from their familiar man-made surroundings and venture into the woods of Virginia. The robots tuck themselves peacefully into the landscape, arranging themselves on top of logs and covering themselves with leaves. Once comfortable, they sonify their physical surroundings by playing a diverse percussion ensemble that includes found nearby objects, such as beer bottles, as well as more traditional instruments such as woodblocks, metal bowls and drums. In some sense, this contextualization of machine in nature strikes us as a juxtaposition of unlike things. Indeed, machine / nature interactions often result in dramatic transformations where nature is displaced and transformed into some unlike object(s) of human will. *Drum Circle* is not such a story: here, we see and hear robots not as imperialist amalgams of electromagnets and plastic, but rather as agents that are governed by the kinetic and acoustic characteristics of our[1] physical world that can cooperatively interact and coexist with surrounding objects. Their stature is small; their movements are subtle. Their materials are translucent, allowing images of their surroundings to pass through their bodies in recognizable but altered ways. Their utterances are quiet and, at times, sparse in order to allow us to hear nature's responses. They communicate in the spirit of harmony, not hegemony. They present themselves in a way that invites us to question our assumptions about the line between nature and machine.

Musically, the relationship between machine and nature in *Drum Circle* is one of collaboration: a mechanically regular input is filtered through a system characterized by natural components, physical forces, and pseudo-randomness to produce a temporal sequence that reflects a synthesis of these various elements. The piece begins with a sequence of falling rocks that is the product of mechanical regularity and physical randomness. One of the robotic percussion arms is attached to a box, filled with small rocks, with a hole on the bottom of it. The arm shakes the box at regular intervals, which reconfigures the rocks and allows some to fall through the hole. The rocks strike a sensor-equipped metal plate and the temporal intervals between these strikes are stored in a software program. The resultant rhythm from this sequence of intervals is iteratively transformed rhythmically and orchestrationally throughout sections of the work, thus this statement and its means of production are conceptually and musically foundational. Over the course of the work, these musical ideas are stated, absorbed, re-interpreted and stated again to create a cyclic yet developing story.

Drum Circle was composed in 2010 by Scott Barton and Steven Kemper for the robotic instruments MADI (multi-Mallet Automatic Drumming Instrument), CADI (Configurable Automatic Drumming Instrument) and assorted found percussion instruments. MADI and CADI were designed and built by Expressive Machines

[1] 'Our' in a shared sense: not a possessive one.

Musical Instruments (EMMI), founded by Troy Rogers, Steven Kemper and Scott Barton. A video of the work is featured on the 2011 EcoSono DVD *Agents Against Agency.*

Rehearsal for the (Robot) Revolution

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Abstract.
This paper considers the use of tele-operated and autonomous robots in live performance. The word "robot" traces its lineage to theatre, and theatre has proved a conducive site for studying what makes robots compelling. Theatre is a narrowly defined domain in which robots can excel; however automated performances that merely substitute robotic actors for human ones are not always engaging. While some plays explore ambivalence to robots or "misbehaving machines" thematically (like *R.U.R.*), the exigencies of live theatre (unlike film) do not allow for editing or special effects. This means that robots must be highly calibrated and run the risk of appearing like over-rehearsed actors. How do artists create engaging performances while ensuring reliable and robust performances?

This paper considers design and approaches to staging robots in live theatre and interactive art. Citing examples of machinic performances absent of human actors (*Le Cour de Miracles*; *Stifter's Dinge*), interactive robotic art (*Telegarden*; *Six Robots Named Paul*), human-robot opera and musicals (*Death and the Powers*; *King Kong*), puppetry (*Pygmalion Project*; *Savanna*; *How to Train Your Dragon*), and traditional spoken-word plays (*I, Worker*; *Sayonara*; *All in the Timing*; *Fremtiden*), we demonstrate how creative approaches to robot dramaturgy and puppetry-inspired control techniques create compelling and interactive performances. Theatre performances function as authentic sites of human-robot interaction staged in fictional landscapes that both exaggerate and occlude the capabilities of robots.

Keywords. Art Robots Performance Uncanny