Using Motives and Artificial Emotion for Long-Term Activity of an Autonomous Robot

Paper 48

Autonomous Robots, Models of Emotion and Personality, Agent Architectures, Believability, Meta-Modeling and Meta-Reasoning

ABSTRACT

To operate over a long period of time in the real world, autonomous mobile robots must have the capability of recharging themselves whenever necessary. In addition to be able to find and dock into a charging station, robots must be able to decide when and for how long to recharge. This decision is influenced by the energetic capacity of their batteries and the contingencies of their environments. To deal with this temporality issue and based on research works in psychology, this paper investigates the use of motives and artificial emotions to regulate the recharging need of autonomous robots. A bipolar model of artificial emotion is presented, designed to be generic and not specifically configured for a particular task. The paper also describes the use of the approach in two specific applications, the AAAI Mobile Robot Challenge and experiments involving a group of robots share one charging station in an enclosed area.

1. INTRODUCTION

Continuous progress is made in designing autonomous capabilities for mobile robots, such as navigation in real environments [3] and map localization [19, 22], learning [5, 8], artificial vision [2], human-robot interaction [1], etc. These are all important capabilities to make mobile robots do useful tasks in the real world. But a more fundamental issue is the capability of a robot to stay "alive", e.g. to function. The autonomous existence of living entities is based on this capability. Maslow [7], in his Hierarchy of Needs Theory, has identified physiological needs (hunger, thirst, breathing, sleeping, etc.) as the most basic needs for human. For a robot, this means to have energetic autonomy.

To our knowledge, not much work have been conducted on long-term autonomy of robots. As early as 1964, early versions of the "Hopkins Beast" from Johns Hopkins University Applied Physics Laboratory were able to find wall outlets using a photocell eye, and where the robots would plug in to feed. Industrial mobile robots following predefined path also have the ability to recharge themselves. But the interest on energetic autonomy is rising. More recently, Yuta and Hada [25] addresses this capability as a benchmark problem to evaluate the autonomy of a robot. Localized using a map, the charging station is a housing in which the robot goes into to get recharged. The current of the battery is monitored to decide when to go back to the charging station and for how long. However, no results are presented on the robot's ability to recharge itself, and for how long it can survive in its environment. The MICRobES Project [15] is also interested in making robots recharge themselves autonomously and study their long-term adaptation in a social environment, but no results have yet been reported.

To conduct experiments that allow robots to autonomously recharge themselves, one useful device is to have a charging station that the robots can find and use. Such devices are still under development by most robot companies[1]. It is possible to simulate autonomous recharging by having the robots go to a specific location and have somebody replace batteries or manually plug the robot to a power supply. But situations such as a potential malfunction or sharing access to the charging station cannot be completely addressed. Also, since it is technologically feasible to design a charging station, we decided to build our own and to examine these issues in a real and complete setup.

Another important aspect related to having robots autonomously manage their energy is to decide when and for how long to recharge: the robots may need to recharge when they are accomplishing a critical task; charging stations may be already in use and many robots may be waiting to use them; it may be difficult to anticipate how long it will take to find a charging station, and how much energy is remaining, etc. In dynamic and unstructured environments, as it happens in the real world, efficient adaptation to these constraints is required by the robots. In fact, this is related to what have been qualified by Plutchik [16] as the problem of **temporality**, one of four **universal problems of adaptation**. Temporality "refers to the fact of the limited duration of an individual's life" [16]. Plutchik also suggests that "emotions are reflections of the adaptations that animals make to the universal problems". Based on this idea, this paper investigates the use of what can be qualified as being motives and artificial emotions, to regulate the recharging needs of autonomous robots.

The paper is organized as follows. Section 2 presents

[1]For instance, Activmedia inc. offers a docking station under special arrangements, and the iROBOT-LE robot from iRobot inc. is designed to be used with a *JuiceBar Charging Station* in which the robot can dock itself unassisted.

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a brief description of the roles played by emotion in autonomous decision making, and explains what can be characterized as 'artificial emotion' based on these roles. Section 3 describes the architectural methodology used to implement our model of motives and artificial emotions. Section 4 presents the experimental setup and our results, followed by Section 5 with conclusions.

2. ARTIFICIAL EMOTIONS

What are emotions? Surely trying to answer this question is not without experiencing a variety of emotions! A survey of different definitions is given in [21], and for the sake of generality, here is the definition of Kleinginna and Kleinginna that tries to put everything together in one all-embracing definition:

> Emotion is a complex set of interactions among subjective and objective factors, mediated by neural/hormonal systems, which can (a) give rise to affective experiences such as feelings or arousal, pleasure/displeasure; (b) generate cognitive processes such as emotionally relevant perceptual effects, appraisals, labeling processes; (c) activate widespread physiological adjustments to the arousing conditions; and (d) lead to behavior that is often, but not always, expressive, goal-directed, and adaptive.

From this definition, we can understand why a lot of theories has been developed about emotions, and still no complete theory of emotion exist [17].

The concept of artificial emotion is increasingly used in designing autonomous robotic agents, mostly by making robots respond emotionally to situations experienced in the world or to interactions with humans [23, 1]. But it seems that there is more to it than that. Psychological evidences suggest that they can serve three important roles in designing autonomous robots [11]:

- *Emotion to Adapt to Limitations.* Emotion plays a role in determining control precedence between different behavior modes, coordinating plans and multiple goals to adapt to the contingencies of the world (under constraints of time and other limited resources), especially in imperfectly predictable environments [4, 14, 16]. Uncertainty prevents any complete dependence on predictive models in human planning – people typically think only a step or two ahead and they respond, moment-by-moment, to the new arrangements of the environment that their actions help to create [14]. The adaptation problems that emotion help solve are finding an equilibrium between the subject's concerns and the environment by signalling the occurrence of concern-relevant events, by recognizing the plan junctures that these events imply, and by instigating control shifts accordingly [4].

- *Emotion for Managing Social Behavior.* In relation to social behavior, Plutchik [16] interestingly points out that emotions are in direct association with four **universal problems of adaptation**, which are: **hierarchy** (Anger/Fear), **territoriality** (Exploration/Surprise), **identity** (Acceptance/Rejection) and **temporality** (Joy / Sadness). Plutchik's theory also suggests the possibility that emotions "are functional adaptations for establishing a kind of social equilibrium. This would imply that emotions enter into every social transaction and help to establish a balance of opposing forces. These balances are always temporary and frequently change as we move through life from one conflict to another" [16]. This is also suggested by Oatley and Johnson-Laird [14], especially in the context of creating mutual plans: "Mutual plans cannot be innately wired into the cognitive systems; they must be created in the minds of more than one individual by implicit or explicit agreement." These plans are partly under the control of both participants and partly governed by conventions of their society. One way to set up a mutual plan is to make a promise to somebody, creating an obligation and a corresponding expectation. Emotions are then used to communicate junctures in mutual plans among individuals in social groups.

- *Emotion for Interpersonal Communication.* In order for emotions to regulate behavior in social interaction, emotion also has a communicative role, as suggested in the previous paragraph. Ethologists believe that emotional expression have a communicative function and act as releasers for the coordination of social behavior. There are signals that promote group cohesion, signals to communicate about external environment, and intraspecific threat signals. It is to an animal's advantage to communication its intentions, and to be sensitive to such messages from others [13]. Emotional expression promotes individual isolation (as it may be necessary in defending something) or to promote group (as different social circumstances might require). In fact, the role of expression in emotion can be seen from three different views: the situation is evaluated by emotion that lead to an expression; expression may be a reaction to the situation that also produces the emotion; the expression may affect the emotion rather than the other way around [13]. Emotion then serves a dual purpose: it is a communication act and it is a sensed state.

Trying to summarize the various theories surrounding the notion of emotion, we could say that: (1) emotions are causes of action; (2) cognition can trigger emotions – emotions can trigger cognitive operations; (3) emotions can cause expressive actions; (4) emotions can affect purposive, goal-directed action; (5) emotions can become goals; (6) the behavior also affects emotion [13]. One interesting aspect is that emotional experience is the cause of emotional behavior, and the emotional experience is also response: it occurs in parallel to behavior and is part of its causes [17].

From an engineering point of view, autonomous robots would surely benefit from having mechanisms that play a similar role. One possibility is to use internal variables that have the same purposes as emotion, as outlined in the previous paragraphs. In addition, different mechanisms for implementing artificial emotions can surely be designed according to properties associated with the decision making approach used to control the robot. Taking all of this into consideration, our long term research goal in this project is to propose a model of artificial emotion that is suitable for the architectural methodology used in our research, and see how it

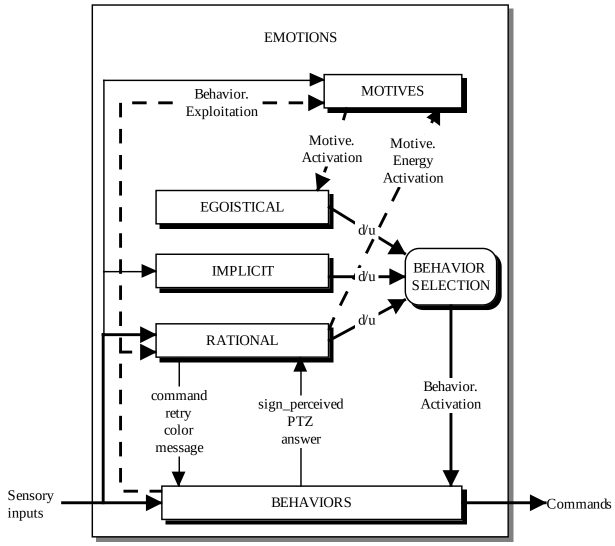

Figure 1: Architectural methodology followed in our robot designs.

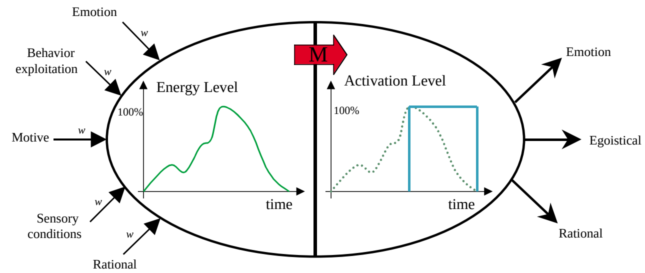

Figure 2: Schematic representation of a motive m.

can help a group of robots behave autonomously in its environment. But before we can do that, we have to address other aspects related to the capabilities necessary for making robot manage their energy autonomously, and these aspects are described in the following section.

3. ARCHITECTURAL METHODOLOGY

We program our robots following the guidelines of a hybrid reactive-deliberative architectural methodology [10, 12] that allows to combine various properties associated with intelligent behavior, like reactivity, reasoning and motivation, while still preserving their underlying principles. The architecture is shown in Figure 1 and is built on top of behavior-producing modules connecting sensory information to commands. To summarize briefly, *Behaviors* are selected dynamically according to influences coming from *Implicit* conditions determined only by sensory inputs, from a hierarchical organization of the goals of the robot (managed by the *Egoistical* module), and from reasoning done by the *Rational* module using knowledge innate or acquired about the task. Note that information can be exchanged between the *Rational* module and the behaviors. Processes for these three modules all run independently and in parallel to derive behavior recommendations d/u, i.e., behavior *desirability/undesirability*. This ensures that emergence is also preserved for the selection of behaviors. The *Behavior Selection* module simply activates behaviors that are more desirable than undesirable.

In our proposed artificial emotion model, *Emotions* are there to monitor the accomplishment of the goals of the robot over time, and these goals are represented using *Motives*. These abstractions are presented in the following subsections. Before explaining them in more details, note that one important source of information for motives is the observation of the effective use of the behaviors, which can serve as an abstraction of the robot's interactions within the environment. This last influence is related to the link called *Behavior.Exploitation*. An active behavior may or may not be used to control the robot, according to the sensory conditions it monitors and the arbitration mechanism used to coordinate the robot's behaviors. So, an active behavior is exploited only when it is releasing commands that actually control the robot.

3.1 Motives

Works on motivational systems [6, 1] have shown that a good balance between planning and reactivity for goal-management can be achieved using internal variables that get activated or inhibited by different factors. So we use a similar approach for motives. Each motive is associated with a particular goal of the robot. The word 'motive' is used because it refers to something that prompts an agent to act in a certain way. The activation level of motives are used by other modules of the architecture to affect the overall behavior of the robot. As shown in Figure 2, a motive m is characterized by an energy level E and a mapping function M that are used to determine its activation level A, according to the formula: $A_m = M(E_m)$. The energy level and the activation level of a motive range between 0 and 100%. The energy level can be influenced by various factors: sensory conditions, exploitation of behaviors associated with the motive, activation of other motives, *Rational* influences, emotions, and time. The energy level is computed by the equation $E_m = \sum_{j=1}^{n} w_j \cdot f_j$, where f represents the occurrence of n influencing factors, weighted by w, affecting the motive. This equation can also be interpreted has having different increment or decrement values w associated with particular events n. The influences are computed every processing cycles, i.e., at 10 Hz. For factors that occur for long period of time and that must not influence the motive for the entire period, we use a habituation function [20] to modulate its influence. Equation 1 presents the habituation strength $h(t)$ calculated for an input j, and α represents the habituation rate. The habituation strength is used to modulate the weighted input that influence the energy level of the motive. Higher the habituation rate, less influence the same weighted input have over a consecutive period of time. Finally, mapping from E to A can be directly transposed, determined using thresholds, or triggered according to the energy level of other motives.

$$v(t) = (1-\alpha) \times (w_j \cdot f_j) + \alpha \times v(t-1)$$
$$h(t) = (1-\alpha) + \alpha \times v(t-1) \qquad (1)$$

In the case of the recharging need of the robot, the motive named *Energize* is used to decide when and for how long recharging is required. The activation level of *Energize*

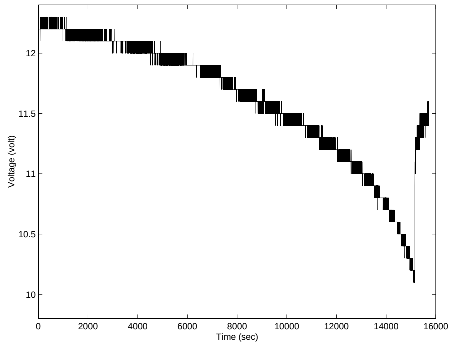

Figure 3: Voltage level of the batteries over time.

is derived from the energy level using a linear mapping function, i.e., the activation level equals the energy level. The *Needs* module examines the activation level of this motive to recommend the use of behaviors, like the *Recharge* behavior that makes the robot find and dock to the charging station, according to the following rules:

- If the activation level of *Energize* is greater than 50%, the *Recharge* behavior is desired. The *Recharge* behavior makes the robot dock into the charging station based on information given by the docking mechanism.

- If the activation level of *Energize* equals 100%, behaviors that might interfere with the detection of the charging station are set to be undesirable. Other behaviors that might help in finding the charging station, like *Follow-Wall*, are set to be desirable.

When the robot is not docked to the charging station, the energy level of *Energize* is influenced by the following factors:

- Battery voltage level. The voltage level of the batteries does not decrease with a fixe amount over time, as shown in Figure 3. So the amount of energy left can only be roughly approximated by looking at the voltage level over time. We observed that our robots have an autonomy of approximately 2 hours when their batteries are fully charged and in movement, and 4 hours if they remain still. Table 1 gives the weights (increment values) derived empirically to characterize the influences the battery voltage level should have on the energy level of *Energize* to allow this motive to get activated soon enough for the robot to find the charging station in time.

- Sensing of the charging station. The robot has the capability sensing the presence of the charging station. In that case, the energy level of *Energize* is incremented by 0.05% but weighted by a habitation with $\alpha = 0.6$. The habituation effect on this signal avoids constantly increasing the energy level of the motive during the time the robot is perceiving the charging station. Combined with the decision mechanism used by the *Needs* module to recommend behavior, the robot can opportunistically use the charging station if the energy level of *Energize* is sufficient.

Table 1: Increment values for different voltage levels

Voltage Level (Vdc)	Increment %
[12.1, ∞[	0.0
[11.9, 12.1[	0.001
[11.7, 11.9[	0.004
[11.5, 11.7[	0.015
[11.3, 11.5[	0.025
[11.1, 11.3[	0.05
[10.9, 11.1[	0.1
[10.7, 10.9[	0.2
[10.5, 0[	0.5

- *Rational* module. Depending on the task and on commands given by a user, this module may increment or decrement the energy level of *Energize* to make the robot recharge its batteries before starting to accomplish a long task or to allow the robot to complete a critical task before it goes recharge.

Once docked, the robot must decide how long it should remain on the charging station. Using the voltage level is not appropriate to determine when the batteries are sufficiently charged, because the voltage level is influenced directly by the charging station. First, the voltage level rises quickly, and then slowly stabilizes. Also, our charging station optimizes the charging process by considering the amount of current generated by the power supply, and this also influences the voltage level readings of the batteries. So, what we need to do is to let the robot remain long enough to get its batteries charged, but to be ready to leave as soon as possible when sufficient energy has been accumulated to let others use the charging station when necessary.

To determine the amount of time to remain at the charging station, the energy level of *Energize* is used to approximate the maximum time required for charging. Our approach is simply to decrement the energy level of *Energize*, using the energy level as an approximation of the amount of recharging required. When it is low, the robot needs to recharge for a shorter period than when it is high. Our charging station is able to recharge the batteries of a robot in 2 hours. We empirically set a decrement value of 0.001% when the energy level is greater than 50%, and of 0.003% otherwise. The first phase is to give a minimum time of 83.33 minutes for the robot to recharge its batteries without being allowed to leave. The second phase uses a greater increment because when the robot is not recharging, the *Recharging* behavior is not activated on this interval of energy level of *Energize*. This signifies that the robot has sufficient energy to operate, and if the robot finds the charging station not long before having activated *Recharging*, it will stay less time on the charging station (27.78 minutes for this second phase). This allows the robot to continue doing tasks that got interrupted when it opportunistically found the charging station. These values were found empirically and work fine in our experimental setups.

3.2 Artificial Emotion Model

As shown in Figure 1, the emotional capability is incorporated into the control architecture like a global background state, allowing emotions to influence and to be influenced by all of the architecture's modules. This is to take into consideration the multiple effects emotions can have on the behavior of the system, as described in Section 2. In our design, emotions can be used to change some of the parameters of behaviors, adapting the way the robot response to stimulus. They can also change the goals pursued by the robot. This is related to research conducted by Oatley and Johnson-Laird [14], indicating that emotions provide a biological solution to certain problems of transition between plans in systems with multiple goals and in unpredictable environments, by maintaining these transitions and by communicating them to ourselves and to others.

In addition, our goal is to derive an emotional model that is generic and not specifically configured for a particular task. We would like the mechanisms that derive emotional states to be the same whatever the goals pursued by the robot. For instance, we try to avoid having to make a direct connection with an emotion like pain and the event of having the robot collide with an obstacle, if in some cases making contact with an object is desired. This cannot be valid in all situations, and it could be done using a cognitive approach [21] to emotion (via the *Rational* module), to specify explicitly what influences can be considered in specific conditions. For our research and trying to complement other research works on artificial emotion, we are interested in finding a model that allow emotions to be influenced by all possible situations, and not specifically to particular states and conditions. Also, the model of emotion we proposed to study differs from other emotional representation in that the behavior of the system is not oriented toward satisfying particular emotional states.

To do so, the energy level of motives is used as an abstraction of the progression toward the accomplishment of the goal associated with activated motives. Monitoring the energy level of motives make the approach generic, since the emotions can be used in different contexts (i.e., goals) according to the motives activated and their priority. Note that we are not excluding in the future the possibility of having direct influences on emotions, instead of only relying on analysis of energy level of motives.

Our model is a two-dimension bipolar model with four emotions: *Joy/Sadness* and *Anger/Fear*. *Joy* and *Anger* are positive emotions, while *Sadness* and *Fear* and negative emotions.

- *Joy.* Monitors a decrease in the energy level, indicating the accomplishment of the goal associated with the motive.
- *Sadness.* Monitors an increase in the energy level, indicating difficult progress in the accomplishment of the goal associated with the motive. A high level of this emotion may suggest to the robot that it is unable to accomplish its goal, and it should try to get some help or to do something else. This can be done by deactivating the motive in question.
- *Anger.* Monitors oscillations in the energy level, indicating difficult progress in the accomplishment of the goal associated with the motive.
- *Fear.* Monitors constant energy level, indicating no progress in the accomplishment of the goal associated with the motive.

The influences from the analysis of the motive's energy level are also based on the amount of energy level and the priority of the motives. The priority of motives are attributed following the guidelines of Maslow's Hierarchy of Needs Theory [7]. As the energy level of the active motive with the highest priority increases, its influences on the emotion variables increases too. Theorically, we can illustrate the mechanism behind our model of artificial emotions with the following example involving Energize. As the voltage level of the batteries decreases, the energy level of *Energize* increases, causing an increase in the level of *Sadness*. When the energy level of Energize reaches 100%, *Fear* is also generated to indicate that the robot is now operating in dangerous conditions. *Fear* can be useful to help determine the robot with the highest need for recharging if more than one robot is waiting to recharge. As the robot starts to dock and has difficulties detecting the station, variations of the energy level generates *Anger*, which could help indicate to others to leave an area or to change the velocity of the robot to facilitate the detection of the charging station. And as the robot is recharging, the energy level of *Energize* decreases which influences *Joy*. If the robot leaves the station early, the amount of *Joy* would be less than if it leaves the station fully charged. This could indicate the amount of compromise the group must make to ensure the survival of the most individuals.

Figure 4: Back of the robot, showing the infrared ring.

4. EXPERIMENTAL SETUP AND RESULTS

To conduct experiments on long-term activity of autonomous robots, we have to our disposal six Pioneer 2 robots, three indoor and three outdoor models. Each robot is equipped with 16 sonars, a compass, a gripper, a pan-tilt-zoom (PTZ) camera with a frame grabber, a RF Ethernet-modem connection and a Pentium 233 MHz PC-104 onboard computer. The programming environment is Ayllu [24], a development tool for multi-agent behavior-based control systems.

Each robot is also equipped with a ring of seven infrared detectors, located at its back as shown in Figure 4. This allows the robot to detect the charging station, which emits an infrared signal. The charging station is shown in Figure 5. Five infrared detectors are oriented directly at the back of the robot, and the other two are located on each side to allow to detect the charging station when the robot passes in front of it. The robot docks into the charging station by backing up so that the charging pins located above and

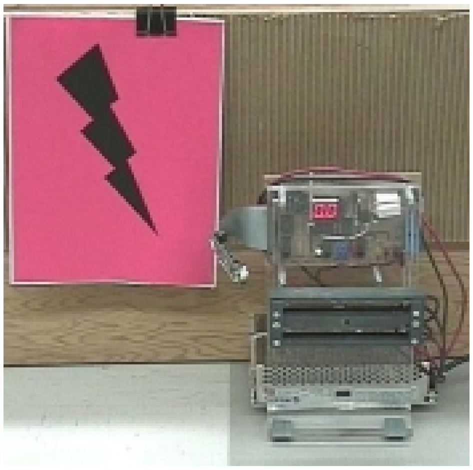

Figure 5: Charging station.

Figure 6: Lolitta H, our Pioneer 2 robot that participated in the AAAI'2000 Mobile Robot Challenge. The robot is shown next to the charging station symbol, and is docked for recharge.

below the infrared ring make contact with the charging station. A PIC microcontroller is used to change the amount of current generated in order to recharge the batteries as fast as possible.

Concerning the autonomous recharge capabilities of the robot, only the *Joy/Sadness* emotions are used. Two experiments have been conducted so far. The first involves a robot entry to the AAAI Mobile Robot Challenge, making the robot attend the National Conference on AI. The second involves a group of robots share one charging station in an enclosed area. In both of these experiments, behavior-producing modules using Subsumption [3] as the arbitration mechanism are used. As indicated in Section 3.1, the *Recharge* behavior is responsible for making the robot recharge its batteries. When activated, infrared signals sensed using the back ring of infrared detectors will influence the velocity and rotation of the robot (as long as no higher priority behaviors like *Avoid* to avoid obstacle, are exploited). When an infrared signal is detected, *Recharge* makes the robot slowly back up and orients the robot for proper docking. Readings from the back sonar ring are use to measure the proximity of the charging station. Once docked, the robot is able to detect the voltage applied to the external connectors for recharging, and stop the motors and the sonars. When not enough current is generated by the power supply, it means that the batteries are fully charged, and the charging station automatically shut down to signal to the robot that it may leave. Not sensing voltage level from the charging station may also indicate a power failure of some sort, and the robot should not remain docked. In this case or if the robot decides intentionally to leave the charging station, the *Recharge* behavior is programmed to make the robot leave the charging station safely, moving forward and turning in one direction until no infrared signal are detected.

Also, note that in both experiments and in addition to the information sensed from the infrared ring, the robot can also detect the charging station visually by recognizing the charging station symbol placed next to it, as shown in Figure 6. The behavior for recognizing symbols is set to be desirable when the activation level of *Energize* reaches 50%. If so, when a charging station symbol is perceived, the robot positions itself in front of the charging station by going at a specific distance of the symbol and turning on itself to perceive the infrared signature of the charging station with the infrared ring on its back. Otherwise, if the activation level of *Energize* is lower than 50%, the robot just continues its path without responding to the symbol.

4.1 AAAI'2000 Mobile Robot Challenge

By participating to this robot challenge, our goal was to design an autonomous robot capable of going through a simplified version of the entire task from start-to-end, by having the robot interpret printed symbols to get useful information from the environment, interact with people using visual cues (like badge color and skin tone) and using menus screens and graphics displayed on a touch screen, memorize information along the way in a HTML report, and recharge itself when necessary [9].

We found that the integration of all of these capabilities gives a real sense that the robot is autonomous in its decision making for accomplishing the Challenge. The recharging capability greatly contributes in that regard. Since only one robot was involved in these experiments, artificial emotions did not play a fundamental role in the decision process of the robot. Motives were sufficient in deciding when to recharge and for how long. Instead, we used the Challenge as a study case of our generic model of emotions to study how it can benefit the robot in making self-assessment of its situation in the environment and of the accomplishment of its goals. The different plan states to accomplish the Challenge were also represented using motives to allow them to be monitored by our emotional model. To observe the evolution of the robot's artificial emotions, we used the screen to generate simple facial expressions as shown in Figure 7. These facial expressions, inspired by [18] were generated using the following settings: the orientation and the size of the mouth are determined by *Joy/Sadness*, while *Fear/Anger* are used for the eyebrows. The color of the face is determined based on a comparison between the amplitude of *Joy/Sadness* with *Anger/Fear*: if both groups have the same big amplitude, the resulting color is black; if *Anger/Fear* is predominant, the face is red; if *Joy/Sadness* prevails, the face is green.

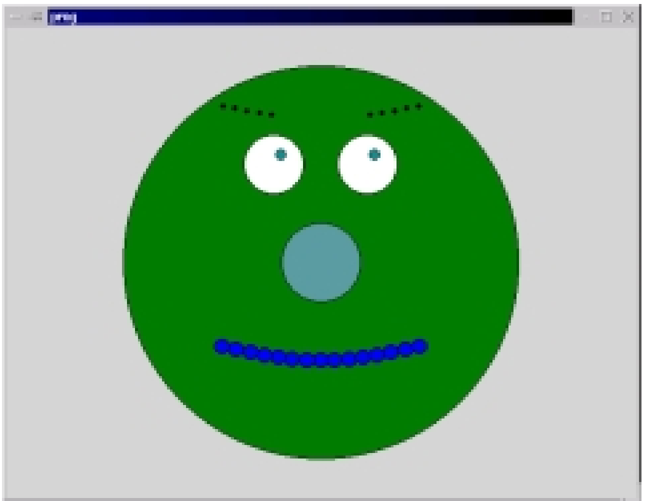

Figure 7: Face use to express the emotional state of the robot.

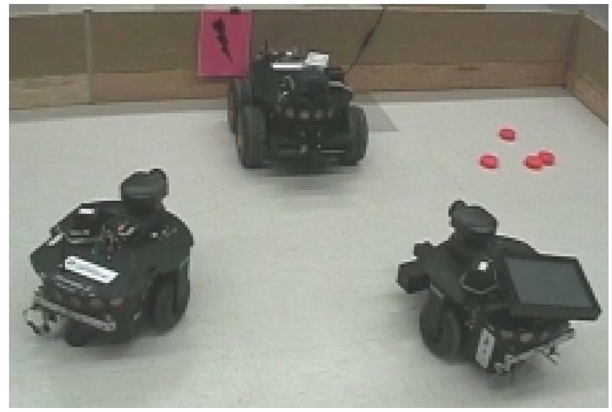

Figure 8: Group experiments having robots share one charging station.

We also associated the position and the size of the eyes with the position of the PTZ camera. When facial expressions showed that the robot is experiencing some sadness for instance, we were able to see that some need of the robot is not met, and using the touch screen menus we were able to find out why.

Since our approach for the Challenge used very limited amount of knowledge about the environment, it took a relatively long time to make the robot go through the phases of the Challenge from start-to-end. It all depended on the amount of symbols encountered to go to a particular place and on interactions with people. For instance, it took close to 10 minutes for the robot to go from the entrance of the convention center to the registration desk. Considerations of the time required by the robot for going through the different phases of the Challenge have a direct impact on the energy level of the robot. One complete trial could last around one hour and a half, and counting the time to set up the color segmentation in ambient lighting condition this could easily goes up to almost 3 hours. It was inevitable that the robot needed to recharge along the way. Our charging station, the *Recharge* behavior and the *Energize* motive revealed to be greatly valuable in that regard, giving the robot the ability to autonomously decide when it needed to recharge. Even during fine tuning of our approach the robot surprised us by suddenly starting to back up when we expected it to read a symbol, to then understand that the robot sensed the charging station at its back and needed to recharge.

4.2 Resource Sharing in Group

Having a group of robots share one charging station in an enclosed area is a rich experimental setup to study the usefulness of an emotional model. It involves making the robot adapt to their limited knowledge on the remaining energy, on the time required to have access to a charging station on the needs of others in the environment. Artificial emotion may then be exploited to communicate the general state of each robot to the group, and regulate the social behavior in a distributed fashion.

The overall objective of this type of experiments is to have the highest number of Pioneer 2 robots share one charging station in an enclosed area, while doing a foraging task. The idea is to make dynamic role selection in order to find the appropriate number of robots to do the task and share the charging station over time, with highest number of robots being able to survive. With robots having 2 hours of autonomy in constant movement when they are fully charged, and 4 hours if they remain still, and since full recharging requires 2 hours, the survival time of the robots will surely be affected by the number of robots in the pen. Observations will be made starting with two robots in the pen, to six robots. The experimental setup is shown in Figure 8.

As of now, some tests have been made with two robots, and the difficult part is to adjust the influence coming from the energy level of motives on the emotional variables. We are also elaborating rules to be used by the *Rational* module that exploit emotional states communicated by the robot to make a robot using the charging station decide when to leave the charging station, to ensure that other robots can survive. Overall, as suggested by [25], such experiments on robot autonomy can serve as a good testbed for algorithms for distributed autonomous robotics systems.

5. CONCLUSIONS

Research contributions of this paper address the issue of providing robots with energetic autonomy. This is a challenging problem because autonomous robots must determine when to find the charging station and decide for how long it is appropriate to recharge based on energy, task and group requirements. The proposed solution involves the use of a motive to manage the recharging need of the robot over time. Since the robot has limited information on its remaining energy, on the time required to find the charging station and on other constraints of the world (like the needs of other robots sharing the same environment), this paper suggests that a concept related to emotions might be useful. Three important roles of emotion, derived from a survey of the literature in psychology, have been outlined, i.e., adapting to the limitations of a system, managing social behavior and communicating interpersonal information. We believe that these characteristics must be taken into consideration to formalize the concept of artificial emotion, concept increasingly used in the design of autonomous robots and agents, but still a delicate subject to address. The usefulness of artificial emotion is going to be revealed in complex adaptation problems, like the temporality adaptation problem of energetic autonomy of a group of robots. Such problems require the integration of different capabilities for autonomous decision making based on internal and external considerations by the robot, and artificial emotions may just be the 'glue' required to make everything work.

6. ACKNOWLEDGMENTS

This research is supported financially by the Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Foundation for Innovation (CFI) and the Fonds pour la Formation de Chercheurs et l'Aide à la Recherche (FCAR) of Québec.

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