Biofeedback Agents for Electromyocontroled Teleoperated Robots

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Abstract. Robot navigation and manipulation in unknown environments for non-autonomous applications is entirely dependant on the human controller and the data provided to control the robot. This task is complex and requires the development of specific skills and almost always alienates the human controller because it is linked to an interface that does not allow extending the user presence where the action is actually developing. On this paper we suggest a mixed technique to join virtual reality (VR) hardware and emulation techniques with biofeedback input to provide a suitable platform to tele-navigate a robot and an agent architecture that improves telecommunication and teleoperation. This approach suggests that it is possible to create intuitive and self-explained applications for robot navigation on which the users can explore the environment as if they were where the robot is and trough biofeedback, understand this environment better and extend the controllerś senses trough it. A biofeedback agent at the usersś terminal indicates the status of the teleoperated robot and using a hierarchical finite state machine it works as a link between the bare electronic response to the movement of the muscles and the robot movements and reactions.

1 Introduction and Previous Work

Robot teleoperation has been deeply studied by many areas of applied sciences like space exploration and medical surgery between many others. All these applications need a high degree of precision and interactivity between the operator and the remote site, but this represents an enormous challenge. [1] Many robot teleoperation systems have been developed based on visual feedback but they are strongly dependant of the transmission speed. This implicit delay can obstruct the biofeedback process because this process requires immediate correlation between cause (anoperator's action) and efect (change in the remote environment).

When we want teleoperated robots to interact with their environment in a more natural way, as if they had an animal instinct we think our implementation is capable of giving the robot an extra fluidness in its interaction. We can think of the specific case of soccer playing aibo robots, these robots act autonomously

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but an intelligence algorithm can be developed to transmit human movements and decisions over specific conditions and events into the movement algorithm at a learning state during programming. This would give autonomous robots the ability to execute movements referred to a human action autonomously during a game. This can also be implemented in other applications like searching and exploration while dealing with specific conditions that can detriment the outcome of the robot's activity.

In the following sections we will describe the design and implementation of a complete human-robot interface designed to improve the interaction between an operator and a device. We describe the bases used to develop a biofeedback agent, which links the operator and the robot. In future work these agents will be able to use an expert systemś database to learn and modify a feedback loop in order to achieve a better execution of the activity and allow autonomous completion of specific expert routines.

First we will describe biofeedback, biofeedback agent and electromyocontroller. Then we will talk about our implementation and current results.

2 Biofeedback

Feedback can be defined as the response in a system, molecule, cell, organism or population that influences the activity or productivity of the system. To understand this concept from the biological point of view we can extend this concept and form a new one: Biofeedback, which is in essence the control of a biological reaction by the means of the products of the action. These products represent the information given instantaneously to an individual by a physiological process taking place on himself.

By monitoring the data that reflects the state of the physical conditions of an individual as temperature, pressure, pulse, etc. and retro feed the person by a monitor of level, light or sound the individual can modify this activity regardless that this activities are ruled by the nervous system in an involuntary way.

Now, lets define biofeedback, with biofeedback. We learn about the external world and our internal processes and it is the key to link feedback with kinesthetic sensation. Neal E. Miller developed a theory about the control of the involuntary functions of the body in the early 60s. By the means of training these behaviors, several illnesses as high blood pressure, stress, phobias, etc. can be controlled and treated.

We learn about the world trough biofeedback, we control our idea of the world by sensing it and acting to change it with notion of the effect we want as a result. There have been many clinical cases where there is a change in the perception and even in the interpretation of these signals of the external world by modifying the way people receives that information.

Robots, just like humans, need to interact with their environment and compute the information they receive in order to perform a certain task. Lets compare the robot perception with the human perception. Feedback can be defined as a response in a system that influences the activity or productivity of the system itself, in robot control feedback is needed to determine the external conditions of the robot and it is interpreted and provided by the sensor fusion array. Is explained in [2] that it is difficult for a robot to correctly respond to a given environment so they integrate robot sensors and effectors to enable the robot or a group of robots to provide a desired response.

When we talk about biological entities as cells, beings or populations the term used is Biofeedback, which is in essence the control of a biological reaction by the means of the products of the reaction. Integrating the information brought by our senses seems to be a very difficult task, but the brain can join all this information to give us an idea of what is near us. Biofeedback does not need to involve an ECG (Electro Cardio Graph) or EMG (Electro Myo Graph), for example, a mirror is a perfectly good biofeedback device for many aspects of gait retraining. Most of the records used in biofeedback are taken from the surface of the skin. The information recorded by surface sensors can be sent to a computer for processing and then displayed; in our case the biofeedback system will be provided by some muscle contraction sensors that will connect the user with the robot.

So, we can use Biofeedback providing real time information from psycho physiological recordings about the levels at which physiological systems are functioning Fig. 1. In this case we can use our own idea of position and direction to retrofeed the loop between the teleoperated robot and the human controller and get the correct kinesthesia between the robot and the human controller.

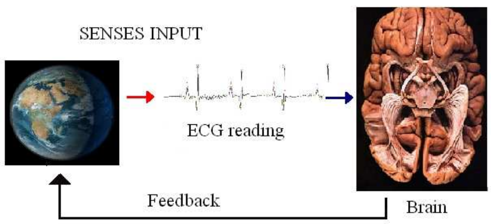

Fig. 1. Biofeedback process

Now we will move to the problem of motion control and kinesthetic sense compliance. First lets define kinesthesia as the sense of motion, the perception of body position and movement including muscular tensions, this classic definition is given by its greek roots kinesis (to move) and (esthesia) to perceive but some psychiatrists define it in a more complex manner considering it one of the somatic senses, (the somatic senses, also known as the somatosensory systems, include the skin senses of touch, temperature, and pain), responsible for the sensing of movement and the one that gives the relative position of objects and one self in a given place to the brain.

Kinesthesia, then, can be defined as the sense that tells the brain where the parts of the body are relatively to one another and where in the space we are. It is important to clarify that the vestibular system is the one that tells the brain about the position of the head in space not the kinesthetic one.

It is, then, possible to interconnect the human controller and the teleoperated robot in such a way that a biofeedback loop is attained. This biofeedback loop can be used to extend the senses and specifically the kinesthesia of the controller by reflecting the environment perceived by the robot into the perception of the human operator.

3 Biofeedback Agent

Now we will define some concepts to use them in the following section, first what is a biofeedback agent? We know so far that biofeedback is the process of control of a biological reaction by the means of seeing how it changes trough time; a biofeedback agent is the one that channels the biological information back to the source. It is an active agent with the potential for inducing both positive and negative changes in the interaction between the human operator and the robot. We define this biofeedback agent as both, a linking element that feedbacks the two edges of our system by signaling status levels to the user and the robot about the environment of the other, and as a control, decision and learning agent which can acquire information and modify the execution of the activity under certain constraints, a computational agent with adaptability capacities that work as medium to improve biofeedback. This biofeedback agent is in charge of merging both edges in the perception, sensation, action and interaction aspects.

4 Electromyocontrol

We can describe concept of an electromyocontroller as a human-computer interface built to sense the electrical activity in the muscles of a human user and traduce those signals into a pattern that can be analyzed and used for the purpose of controlling the execution of an activity by a certain device, in this case, the movement of an teleoperated Aibo robot. The objective of this electromyocontroller is to give the human operator the ability to manipulate the robot by moving his own muscles and to build a complete biofeedback interaction channel. The use of this type of controller enables us to give the robot humanlike decision taking and movement routines that the biofeedback agent can use to learn how to improve the execution of the activity.

As the fundamental concept behind the electrophysiological study of the human body is the detection of potentials in excitable cells, we decided to implement electromyosensors to detect the potentials generated at a certain muscle in the body of the human operator. These electromyosensors conform the recollection phase of our interface and integrate several elements in order to produce a detectable 5 Volts step output signal as the result of the registry of the pure myoelectrical signal generated at the muscle.

This type of myosensors has been previously used to build monitors of the human behavior as intent detectors used to complete danger measures during the evaluation of a dangerous real-time situation in human-robot interaction [3] [4] and to conform other systems like psychological therapy approaches.

5 Teleoperation and Electromyocontrol

To feel and see the changes in the environment where the robot is, as experienced by the sensors of the robot will make the navigation close looped giving the idea to the user that is the one exploring the distant location. To achieve that, we need to submerge the human controller into the reality of the robot, providing suitable controls and visual feedback to attain the sense of position and orientation from the robotś point of view. In the application shown in this paper we use the video stream provided by the robotś camera, a 3D model of the robot (local model) and intuitive muscle motion sensors at the userś side to control the reactions of our target. As we can see in the work of [5] [6] [7] [8] teleoperation has been successfully used in applications that require extreme precision successfully.

The myosensors give the user the idea of a really moving inside the environment because the controller relates movement directly with movement, he/she can see the result of their actions by watching the changes in the virtual reality environment where the 3D model exists and finally, the operator has a perspective of the remote scenario from the robotś point of view as seen in the camera stream. All these elements interlace to modify the perception of the user and change the way the operator senses the remote environment.

6 Implementing Biofeedback AGENTS

Hierarchical finite state machines, as traditional finite state machines, consist of states and transitions between states. The big difference is that HFSMś allow mixed states where there can be shared variables, functions and even transitions providing a higher level of abstraction impossible in common FSMś. These capabilities make them more efficient and a HFSM can need only the half states than its equivalent FSM.

We take lot of care on defining the kind of agentś brain so we can define a correct HFSM which describes the reactive motivation and objective that will allow the user to get a more adequate idea of the status of the remote robot, allowing the agent to be a biofeedback path ensuring correct reaction and interaction and avoiding problems surging from localized motion control, network latency and time delays.

We need to correlate the real movement of the AIBO with our biofeedback agent movements to describe on real time the interactive reactions of the robot allowing a realistic interaction. In this case we give our agent a 3D modeled body to allow instantaneous visual feedback, allowing reactive action to the interaction and make corrections and apply controls.

On this case we have to design the reactive control of a graphic agent equipped with external sensors that allows the identification of the current state which will depend on the user actions, the AIBO status, the interpretation of the AIBO environment and the previous state.

We want this agent to be capable of giving the correct controls to our AIBO robot, to achieve a more natural interaction of the AIBO in its environment, so the agent must acquire a reactive behavior that will act as the animal instinct provided by the input of the user and translated by the agent trough behavioral patterns into AIBOs movements.

There are many ways to implement a HFSM witch supports behavior models, one way to do it is to use HGSs to represent the behavioral unit or using PaT-Nets(Parallel Transition Network) [9] [10], but using behavioral primitives in our HFSM description optimized worked to our propose see Fig.2.

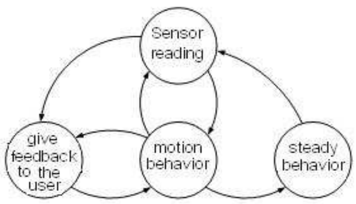

Fig. 2. Biofeedback process

As we can see on Fig. 3 our system consists of two main phases, the first one consist in capturing the action-reaction scheme of the teleoperation of the robot in an specific environment, the second one uses the motion-time tables to describe a series of robot controls that can be used to generate autonomous programs to solve specific tasks when there is no user connected to the system.

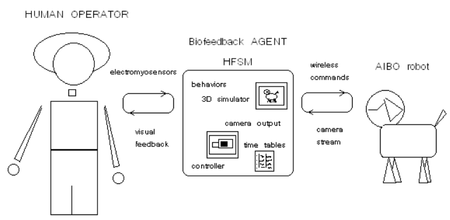

Fig. 3. Biofeedback Agent Simulation

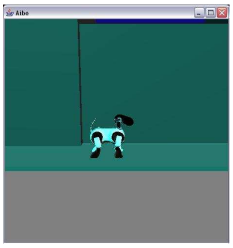

Fig. 4. Virtual Aibo

Fig. 5. Real Aibo

7 Results

We tested the operation of the biofeedback loop system we have described during the previous sections using two human operators and an AIBO robot as the teleoperated device. We achieved an important degree of involvement between the operators and the robot but the response time of the system was not good enough (around 4 seconds). To ensure biofeedback we need response time under 1 second. Here our agent plays a vital role covering the missing time space commands, returning faster visual response to the user improving the biofeedback mechanism and saving operatorś responses and controls executed on the robot on time tables. With a good amount of recorded behaviors and control sequences our agent can provide a more natural and better response to the actual reaction of the robot to the controls and foresee commands to enhance the navigation system.

We made our first experiment by exploring a local environment where the operators could have direct visual biofeedback of the movements of the robot.

Our next approach involved a remote location where the visual biofeedback elements took critical importance. The actions of the operators were successfully interpreted by the biofeedback agent, allowing a good performance in the exploration of the remote environment. The operators showed anxiety and uncertainty at the beginning while trying to communicate their commands through the myosensors, but the biofeedback elements helped reduce these emotions with time. The level of immersion in the remote location was acceptable but the use of other biofeedback elements, which interact with other senses different from sight, might increment greatly the operatorś awareness of the elements in the remote site.

Muscle	**Command**
Right Biceps Operator 1	Front movement / Stop front movement
Left Biceps Operator 1	Side movement left / Stop side front movement left
Right Biceps Operator 2	Side movement right / Stop side movement right

Table 1. Actions and Commands.

The previous table describes a model situation in which the operator commands the AIBO robot to move forward, stop, initiate forward again and move left.

Time	**Command**	**Biofeedback agent correction**	**Biofeedback agent's action to reflect condition on simulation**	**Source of action**
4 sec	Front movement	None	Initiate 3D model's front movement	Operator
10 sec	Stop front movement	Smooth transition between real and simulated stop.	Wait for Robot real stop time	Operator
11.5 sec	Stopped	Smooth transition between real and simulated stop.	Initiate 3D model's stop front movement	Robot
13 sec	Front movement	None	Initiate 3D model's front movement	Operator
16 sec	Side movement Left	Stop front movement Smooth transition between real and simulated direction change.	Wait for Robot real direction change time	Operator
17 sec	Stop front movement	Smooth transition between real and simulated direction change.	Wait for Robot real stop time	Agent
17.5 sec	Stopped	Smooth transition between real and simulated direction change.	Initiate 3D model's stop front movement	Robot
18.3 sec	Side movement Left	None	Initiate 3D model's side movement left	Agent

Fig. 6.

The compensations made by the biofeedback agent ensure that the simulation reflects accurately the user commands and the robotś real state, making transparent the delay times between the execution of commands and absorbing the intermediate steps required to execute them according to the robotś constraints.

The operator tends to think of less constrained movements by idealizing the robot as an holonomic device but this is not true, so the agent must fill the void between the desired movement and the actual movements required to achieve de robotś preferred configuration.

8 Conclusions

On this paper we have described how to use biofeedback to improve navigation in teleoperated robots, by enhancing the kinesthetic feeling to create better and faster responses to changes in the environments.

To measure how this navigation is improved we have to generate goal based excercises which rely on the human-controller's reactions and actions and measure time using a chronometer, we have to emulate diferent scenarios and tasks to see the efectiveness of our method and use virtual reality hardware to build a complete biofeedback loop between the robot and the user.

Using biofeedback to navigate remote robots can be useful in applications where the human user instinct is basic to correctly scan the area, in other words, when the place of exploration is completely unknown and has potential dangers and many bifurcations and obstacles.

Fig. 7. Human controlling an Aibo

A normal camera video can provide the necessary data to navigate remotely but it can not give the user the kinesthetic feedback needed to improve reactions where an immediate action is important.

9 Future Work

We want to extend our work using other methods to extend other senses of the user besides the kinesthetic one. We plan to make electromyo-stimulating modules to transmit to the user physically the existence of boundaries in the remote location detected by proximity or contact sensors in the robot. In further work it may be possible to coordinate multiple extensions for different senses using different biofeedback channels.

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