Ethologically Inspired Human-Robot Interaction Interfaces

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ABSTRACT
This paper presents human-robot interaction interfaces based on ethological studies. An ethological test procedure was modeled with the application of a fuzzy rule interpolation based fuzzy automaton. This fuzzy automaton was loaded with rules formed from the extracted ethological knowledge. Using the behaviours supplied by the fuzzy automaton as conclusions, different interfaces can be defined for the incarnation of the model. The ethological test procedure and its modeling technique based on the fuzzy automaton will be shortly introduced in the paper, and then the various human-robot interfaces based on the former will be presented. These include interfaces of simulated environments and also interfaces as real robot hardware with their supplemental devices (sensors, cameras, etc.).

Categories and Subject Descriptors
I.2.9 [Artificial Intelligence]: Robotics - Operator Interfaces

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Design, Experimentation, Human Factors

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human-robot interface, ethologically inspired robotics, fuzzy automata

1. INTRODUCTION
There are many aspect of handling Human-Robot Interaction (HRI). One of them is based on a concept that some social robots should act like animal companions to a human being. Therefore - according to this paradigm - robots should not be human-like, and should not prefer human-to-human like communication. Instead robots should follow existing biological examples and form interspecies interaction. A good example for this HRI paradigm - representing the interaction of different species - is the 20 thousand year old human-dog relationship. One good reason of this approach in HRI is the lack of the 'uncanny valley' effect [13]: increasing similarity of robots to humans will actually increase the chances that humans refuse interaction (will be frightened). Although many take this effect for granted, only little actual research was devoted to this issue. Many argue that once an agent passes a certain level of similarity, as it is the case in the most recent visual characters in computer graphics, people will treat them just as people [16]. However, in the case of 3D robots, the answer is presently less clear, as up to date technology is very crude in reproducing natural-like behaviour, emotions and verbal interaction. Thus for robotics the uncanny valley effect will present a continuing challenge in the near future.

In order to overcome some of the challenges presented above ethologically inspired HRI models can be applied. This concept allows the possibility of studying of individual interactions between animals and humans. If one defines robots as mechanical...
or electronic agents that extend human capacities then the dog (which has been domesticated by humans) represent a similar agent because some time after domestication dogs were utilized as an aid in hunting, animal husbandry, warfare, protection, transport etc [12]. The long-term (for approx. 20,000 years) and successful human-dog interaction shows that humans have the ability to develop social interaction with very different agents.

According to this theorem, companion robots do not have to rely on the exact copy of human social behaviours, instead they should be able to produce social behaviours that provide a minimal set of actions on which human-robot cooperation can be achieved. Such basic models of robots could be improved with time making the HRI interaction more complex.

Ethologists can supply verbally defined rules for constructing a possible model, hence variables are not defined exactly and also the gathered expert knowledge is incomplete from the viewpoint of rule base construction of the whole system. As for the variables, it is plausible to use fuzzy description, where linguistic terms can be easily incorporated. To overcome the problem of rule base incompleteness, Fuzzy Rule Interpolation (FRI) models are applied because FRI can supply conclusions by design in these situations. In contrast, when using traditional fuzzy inference systems a considerable amount of redundant rules should be added to make the inference system complete, which makes fuzzy reasoning practically unusable in case of high input dimensions.

The paper is structured in the following way. First the structure of the fuzzy description of the laboratory procedure is discussed. Then the example ethological model, the original standard laboratory procedure developed for studying the dog-owner relationship is introduced briefly. The third chapter describes the Human-Robot Interaction (HRI) interfaces used for ethologically inspired applications, which can be either a simulated environment or a physically existing robot hardware.

2. ETHOLOGICALLY INSPIRED HRI
This chapter gives an overview of the whole model, first by shortly introducing the connection between ethological modeling and fuzzy rule interpolation, along with behaviour-based-control systems. Then the modeled ethological test procedure is described. After the structure and the test procedure are introduced, some sample rule sets of the working model will be examined.

2.1 Structure of the Model
Expert knowledge in ethological modeling mainly exists in the form of expert’s rules. Most of them are descriptive verbal ethological models. The knowledge representation of verbal expert’s rules can be very simply translated to the structure of fuzzy rules, transforming the initially verbal ethological models to a fuzzy model. On the other hand, in case of the descriptive verbal ethological models, the ‘completeness’ of the rule-base is not mandatory (as the model has a descriptive manner), which makes implementation difficulties in classical fuzzy rule based systems, and classical fuzzy reasoning methods (e.g. the Zadeh-Mamdani-Larsen Compositional Rule of Inference (CRI) [23] [11] [9] or the Takagi - Sugeno fuzzy inference [17] [18]). Classical fuzzy reasoning methods are assuming the completeness of the fuzzy rule base. If there are some rules missing i.e. the rule base is “sparse”, observations may exist which hit no rule in the rule base and therefore no conclusion can be obtained. One way of handling the ‘fuzzy dot’ knowledge representation in case of sparse fuzzy rule bases is the application of the Fuzzy Rule Interpolation (FRI) methods, where the derivable rules are deliberately missing. Since FRI methods can provide reasonable (interpolated) conclusions even if none of the existing rules fires under the current observation.

The application of FRI methods in direct fuzzy logic control systems gives a simplified way for constructing the fuzzy rule base. The rule base of a fuzzy interpolation-based model, is not necessarily complete, it could contain the most significant fuzzy rules only without risking the chance of having no conclusion for some of the observations. In other words, during the construction of the fuzzy model, it is enough to concentrate on the main actions (rules could be deduced from the others could be intentionally left out from the model).

Numerous FRI methods have been proposed [22]. The fuzzy reasoning method ‘FIVE’ (Fuzzy Interpolation based on Vague Environment, originally introduced in [3], [4] and [5]) was developed to fit the speed requirements of direct fuzzy control, where the conclusions of the fuzzy controller are applied directly as control actions in a real-time system.

The main idea of the ‘FIVE’ is based on the fact that most of the control applications serve crisp observations and require crisp conclusions from the controller. Adopting the idea of the vague environment (VE) [1], FIVE can handle the antecedent and consequent fuzzy partitions of the fuzzy rule base by scaling functions [5] and therefore turn the fuzzy interpolation to crisp interpolation.

For implementing ethologically inspired HRI models, in this paper the classical behaviour-based control structure is suggested. In behaviour-based control systems (a good overview can be found in [15]), the actual behaviour of the system is formed as one of the existing behaviours (which fits best the actual situation), or a kind of fusion of the known behaviours appeared to be the most appropriate to handle the actual situation. This structure has two main tasks. The first is a decision, which behaviour is needed in an actual situation, and the levels of their necessities in case of behaviour fusion. The second is the way of the behaviour fusion. The first task can be viewed as an actual system state approximation, where the actual system state is the set of the necessities of the known behaviours needed for handling the actual situation. The second is the fusion of the known behaviours based on these necessities.

The ethological test procedure introduced in the next chapter is modeled using a fuzzy automaton, by giving the rules of the state-transition Fuzzy Rule Interpolation (FRI) models (see more details in [7]). This fuzzy automaton controls the behaviours and the behaviour fusion of the model.

2.2 The Ethological Test Procedure
The ethological test procedure used in this paper has been developed for studying the affiliative relationship between a dog and its owner. The procedure is made up from seven episodes, each lasting 2 minutes, where the dog is in different situations: first with the owner, then with a stranger, or alone (according to a pre-defined protocol). Through the test, the dog’s behavior is evaluated mainly focusing on dogs’ responses related to their proximity seeking with the owner [19].

In the first episode of the test, the dog and the owner are in the test room. First the owner is passive, and then he/she stimulates
playing. The second episode is where the stranger comes into the room and starts to stimulate play with the dog. Then the owner leaves the room, so in the third episode the dog is separated from the owner; the stranger tries to play with the dog then sits for a while and offers petting. The owner comes back in the beginning of the fourth episode, this is the first reunion. Meanwhile the stranger leaves the room and the dog is with the owner for two minutes. Then the owner also leaves, so in the fifth episode the dog is alone in the room. In the next episode the stranger returns and tries to stimulate playing or comfort the dog by petting it. The return of the owner marks the beginning of the last episode. The stranger leaves the room, the owner interacts with the dog for two minutes and the test ends.

During evaluation, ethologists record pre-defined behavioral variables for describing the dogs’ responses related to both the owner and the stranger and they analyze data to reveal significant differences in behaviors showed towards the two persons.

2.3 Sample Rules from the Model

This chapter shows some parts of the model, which is only a small fragment of a more complex ethological model. This models the ethological test described in the previous chapter. The example behaviour is built upon two component behaviours, namely DogExploresTheRoom and DogGoesToDoor built separately. The 'DogExploresTheRoom' is an exploration dog activity, in which the dog 'looks around' in a not yet familiar environment. The 'DogGoesToDoor' is a simple dog activity, in which the dog goes to the door, and upon reaching it, stays in front of it, because the door separates the dog from the owner.

The following states concerned here are the following: 'Missing the owner - mood of the Dog' (DogMissTheOwner) and 'Anxiety level of the Dog' (DogAnxietyLevel). These are hidden states, which have no direct task in controlling any of the above mentioned behaviours, but have an importance in the state-transition rule base. ‘Going to the door mood of the Dog’ (DogGoesToDoor) and ‘Room exploration mood of the Dog’ (DogExploresTheRoom): 'normal' states, which have also direct task in controlling the corresponding 'DogExploresTheRoom' and 'DogGoesToDoor' behaviours.

In the followings, some sample FRI rule bases are listed which define the related state-transitions of the fuzzy automaton, which in result acts as behaviour coordination.

State-transition rules related to the missing the owner mood (state) of the Dog:

If OwnerInTheRoom= False Then DogMissTheOwner= Increasing

If OwnerInTheRoom= True Then DogMissTheOwner= Decreasing

State-transition rules related to the anxiety level (state) of the Dog:

If OwnerToDogDistance= Small And HumanToDogDistance= Small And DogAnxietyLevel= High Then DogAnxietyLevel= Decreasing

State-transition rules related to the going to the door mood (state) of the Dog:

If OwnerInTheRoom= False And DogMissTheOwner= High Then DogGoesToDoor= High

If OwnerInTheRoom= True Then DogGoesToDoor= Low

State-transition rules related to the room exploration mood (state) of the Dog are the following:

If DogAnxietyLevel= Low And OwnerStartsGame= False And ThePlaceIsUnknown= High Then DogExploresTheRoom= High

If ThePlaceIsUnknown= Low Then DogExploresTheRoom= Low

where the text with italic type setting are the linguistic terms (fuzzy sets) of the FRI rule base.

It is important that the rule bases are sparse by design, containing only the main state-transition FRI rules.

3. HRI INTERFACES

This section presents the human-robot interfaces for the previously system.

3.1 Simulated Environments

3.1.1 The original 2D interface

The original interface for the test procedure (introduced in [6]) is a simple two dimensional plan view displaying the test room and the participants. It was intended only for testing and development purposes for engineers.

The main area is the test room with a door leading outside. The two human participants are symbolized by the two filled rectangles, the blue one is the owner and the magenta is the stranger. The circular shaped object is the dog, which also has a head and tail sub-object. The head is used for determining the orientation of the dog. Also a toy object is defined, which can be used for interaction between the participants. The objects can be controlled using conventional personal computer input devices (e.g. mouse and keyboard). And of course according to the ethological test procedure the humans can be controlled automatically based on a text script file defining the scenario to be played. This way the dog will act according to the model, in realtime.

The user interface of the simulation application also incorporates ways to give information on the inner states of the model, which is useful for engineers. The various states of the fuzzy automaton are shown in real-time on sliders, also a text-box can be found in the center which logs the occurred events.
To help in easier testing for ethologists, an object control and movement recording feature was incorporated. An ethologist at a remote location can record the exact coordinates and movement of the objects, this way ethologists can exactly show where and what adjustments are required to improve the model and also in case of errors, those will be reproducible.

Also the application has a sophisticated observer module, which evaluates the behaviour of the dog based only on data which can be observed from the outside, without knowing any information of the states of the model. This observer module is a key part in the evaluation of the whole model’s correctness.

A screenshot of the application screen is shown in Figure 1.

3.1.2 The 3D Virtual Collaboration Arena interface

The Virtual Collaboration Arena (VirCA) [20] is a modular, easy to use 3D framework supporting the development of augmented reality applications. The augmented reality, the mixture of real and virtual environments, gives the unbeatable chance for experiencing the most realistic direct personal interaction with a virtual entity available only in a virtual environment.

The main idea of VirCA is to place physical devices in a computer generated virtual space, where objects can interact. These objects are called CyberDevices and can be either representations of physically existing objects or completely virtual objects. VirCA is a mixture of different technologies. For visualization it uses a 3D engine called OGRE 3D (Object-Oriented Graphics Rendering Engine), which is a scene-oriented, flexible 3D engine designed to make it easier and more intuitive for developers to produce applications utilizing hardware-accelerated 3D graphics. Also a component called Bullet is integrated, which is an open source physics engine featuring 3D collision detection, soft body dynamics, and rigid body dynamics. VirCA can connect research groups and distant laboratories (devices) over the Internet using standard protocols. For communication between the components the Robot Technology Middleware (RTM) is applied. RTM communication is based on the well-known CORBA middleware, but can also make use of the flexible communication channels of the Internet Communication Engine (ICE) [8]. According to the RTM concept, the VirCA is also an RT-Component, which brings the components together and provides a simple to use visualization and user interface by utilizing the aforementioned technologies.

This way VirCA can provide a solution for the users to collaborate with each other to control physically existing devices remotely in an easy to use mixed real and virtual 3D environment. For example when industrial robots are working in dangerous environments the presence of human operators is an unnecessary risk. In this case the devices can be controlled with methods close to real world methods, avoiding direct human presence. (The VirCA package is available at [24].)

To apply the services provided by VirCA, special VirCA interfaces (RTM) are needed in the actual programming environment. The original simulation application was implemented in MATLAB, which has no native RTM interface (could be used for direct VirCA communication). Hence an intermediate adapter was developed, which acts as a proxy between the two systems. For communication between the proxy and the simulation application, the standardized User Datagram Protocol (UDP) over IP (Internet Protocol) was chosen to be used.

As described earlier, the three participants of the test procedure are the dog, the owner and the stranger. On the original 2D interface these are represented with very simple objects. The two human objects can be freely controlled by the operator of the application, but it can be also controlled by the simulation application based on the pre-defined commands stored in a simple script text file. The movement and behavior of the dog object is strictly controlled by the application, as this is the main purpose of the implemented model.

These objects we are referring to are called CyberDevices in the VirCA terminology. Each CyberDevice has its own function and ports. For example, the dog component is responsible for receiving and processing messages from the MATLAB simulation program, and then it has to send the rescaled and recalculated coordinates to the VirCA component via RTM protocol.

In the original standalone MATLAB model the dog is composed from two circular objects, the body and the head (see Figure 1). However in VirCA, the dog is one solid detailed dog shaped object with head, torso, legs and tail. The position of the dog’s head and the dog’s body from the 2D space is used for calculating the orientation of the dog. This additional value is required for displaying the 3D dog object properly.

The owner and stranger components are like the same from the viewpoint of CyberDevice communication, but the reverse directions also have to be handled. This latter means that users can interact with these objects in the VirCA augmented space and the new positions should be transferred back to the MATLAB model. The dog component communicates only one-way, from MATLAB to VirCA. The new coordinates of the dog object are calculated by the model based on the observations and the inner system states. The toy component is somewhat different, in addition to handling the coordinate conversions between the two environments. The toy object can be picked up, dropped and thrown by the other participants.

The virtual room in the augmented VirCA environment was constructed resembling to the real laboratory room used for conducting the real test. Figure 2. shows a screenshot of the model running in the VirCA environment. For more details on the interface between MATLAB and VirCA see [21].
3.2 Intelligent Space

Intelligent Space [10] reverses the traditional concept of robot development. Traditionally the control logic, sensors, etc. are built into the robot hardware itself. Intelligent Space instead embeds sensors into the environment, centralizes the control logic, and the robot hardware itself becomes only an actuator. This makes robot hardware simpler, more complex processing and more resources can be allocated for the control logic, cooperation can be also simpler, because it can be coordinated centrally. The drawback could be that robots lose their independentness this way, and also Intelligent Spaces are not easy to mobilize, and could not be used in every environment (e.g. open air spaces).

Two interfaces using the Intelligent Space concept have been developed. These will be described in the followings.

3.2.1 ‘MOGI robi’

The ‘MOGI robi’ is a robot hardware especially built as an interface for the presented ethological test procedure simulation [2]. Connecting the ‘MOGI robi’ and the simulation application together, takes the incarnation of the model to a higher level. Ethologists can conduct real-life tests in a real test room, with real human participants, exactly as the same way they would do it with a real dog.

The ‘Intelligent Space’ setup consists of three separate parts in this case: the robot hardware, a vision system, and the simulation application itself. See Figure 3. for a schematic diagram.

The robot hardware, ‘MOGI robi’ is based on holonomic wheel drive (three separate wheels), hence it can move in 3DoF (3 degrees of freedom). The robot has a separate head part, which can be controlled also in 3DoF. Another important part of the robot is a gripper, which is used for grabbing and releasing the toy. It is also equipped with a sophisticated mechanical tail for mood expression. Figure 4. shows the ‘MOGI robi’.

The vision system uses ordinary video cameras to gather samples of the environment. The participants have to be tagged with independent light sources, so they can be identified and positioned in the given space by the vision system.

The simulation application has been extended to be able to communicate with the vision system and to control the robot hardware.

As for the vision system, the communication is only one way. The vision system periodically sends the actually sensed positions of the various objects participating in the simulation. This is achieved by sending data encapsulated in User Datagram Protocol (UDP) over Internet Protocol (IP), similarly to the VirCA interface described earlier. The simulation application checks for the received UDP packets periodically (at a lower rate than the packets are sent). As only the newest position information is required, in case of multiple packets are received, all of them are dropped except the latest one.

As for the robot hardware the communication is bi-directional, which is physically realized by communicating via a Bluetooth adapter. The simulation application sends the desired position to the robot via the Bluetooth adapter, which is accessed as a simple serial port (RS-232) device. The desired position cannot be always reached in time because of several possible reasons, e.g. small unseen obstacles, rough terrain, not enough acceleration, etc. In this case ‘in time’ means the time till the execution of the next iteration cycle of the simulation application. In every
iteration, data from the vision system are received, this way the simulation application can check whether the robot reached the desired position or not (or maybe overrun on it). Based on the new data the application can recalculate and send the new desired direction to the robot hardware.

The mechanical tail of the robot is also controlled by the simulation application, based on the output of the model, the actual wagging rate and the length of the dog’s tail is sent and interpreted by the robot.

The gripper has to be activated by the simulation application also. When the robot gets into the correct position and orientation the simulation application activates the gripper (open/close) to grab the toy. Releasing the toy is a simpler task, because it can be done practically in any position, but considerations have to be made, because after opening the gripper, the robot has to move backwards to free the toy.

Data can be received from the robot hardware also. This is mainly used for checking that the robot is online, ready for duty, charge level of the batteries, etc. The current estimated position (based on a reference starting point and the occurred movement since the start) can be queried from the robot, which can be useful in some temporary cases when the robot cannot be seen by the vision system.

3.2.2 A Monitoring System for Home-Care Support

To further demonstrate ethologically inspired robotics, another robot hardware working in Intelligent Space is presented in this section. This system is not intended to be used by ethologists, but a real-life application of the concept of ethologically inspired robot design.

A monitoring system intended for home-care was developed [14], which applies an ethologically inspired approach for human-robot communication. The main task of this monitoring system is to monitor elderly people, and in case an unusual event occurs (e.g. person lying on floor, person is at a forbidden location), alert a caregiver person.

The system is based on the concept of the model presented earlier, of course with different rule bases.

As opposed to ‘MOGI robi’, instead of using a vision system with cameras for gathering the positions of the participants in Intelligent Space, an ultrasonic positioning system was constructed. This overcomes the problem of tagging participants with constant light markers, which can be uncomfortable for them. The ultrasonic transmitters can be worn hanging in the neck without disturbing the comfort of the subject.

The robot hardware consists of a Pioneer3-DX platform and a Nabaztag, see Figure 5. This robot is used to deliver alerts to a caregiver person. Alerts can be expressed in different ways. For more details on this monitoring system see [14].

4. CONCLUSIONS

The goal of the paper was to introduce the various interfaces developed for ethologically inspired modeling and robotics, also with a brief overview of the fuzzy automaton used for modeling the behaviour of the dog in a given situation. The interfaces also define communication methods and protocols between the components. These interfaces are mainly for an application which simulates an ethological test procedure, which is useful for ethologists and also for testing and validating the ethological-inspired human-robot interaction concept. Finally a project based on the former is briefly presented, which aims toward a real-life application. These together suggest that ethologically inspired HRI applications, which can be used in real-life for every day tasks are getting into focus.

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6. REFERENCES


