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Etho-robotics: What kind of behaviour can we learn from the animals?

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Abstract: The trends of robotics changes as service robots gain more ground and become part of our daily lives. Service or social robots have to function in less controlled and more dynamically changing environments than industrial robots, and the users of social robots are generally less technologically literate than the users of industrial robots, therefore social robots have to be able to interact naturally with humans and to fit in the human social environment. Social robotics faces new challenges that require an interdisciplinary approach. In contrast to previous approaches where the communication and behaviour of social robots were based on human-human interactions, ethorobotics offer a new direction. Today robotics is not advanced enough to reach the physical and cognitive capabilities of humans thus human-animal interaction can serve as a better model for designing the behaviour of social robots. Human-dog relationship is a good example for this paradigm as dogs have similar roles as social robots will have in the future. Dogs acquired social cognitive skills during domestication that enhances the interspecific relationship with humans and helps their interactions. Etho-robotics research uses ethological principles and methods to derive complex behavioural models which can be transcribed to mathematical form and implemented into robots. Human-robot interaction studies can be conducted to evaluate and refine the implemented models. Etho-robotics research was already used to create behavioural models for attachment and for multiple aspects of human-robot interactions. The application of Fuzzy Rule Interpolation methods fits well the conceptually "spare rule-based" structure of the existing descriptive verbal ethological models, as in case of the descriptive verbal ethological models the "completeness" of the rule-base is not required. The main benefit of the FRI method adaptation in ethological model implementation is the fact, that it has a simple rule-based knowledge representation format. Because of this, even after numerical optimization of the model, the rules are still "human readable", and helps the formal validation of the model by the ethological experts. On the other side due to the FRI base, the model has still low computational demand and fits directly the requirements of the embedded implementations.

Keywords: Autonomous mobile robots, Man/machine interaction, Fuzzy Control, Behaviour-based Control, Human-Robot Interaction, Etho-robotics.

1. INTRODUCTION

As the trends of robotics changes, the environment in which robots have to succeed also shifts. According to the report of Japanese Ministry of Economics and Trade (Ministry 2010) in the near future industrial robotics will be overshadowed by the constantly growing field of service robots (Figure 1).

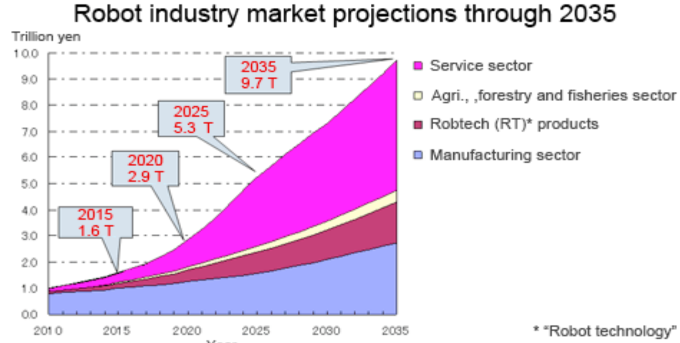

Fig. 1 Predictions of future robotics trends

Previously robots were mainly used by big companies in high volume manufacturing (i.e. car industry). Industrial robots were perfect to execute procedures simplified to tiny (angular) movements. It takes approximately 400 times longer to program a classical industrial robot in complex operations than to execute the actual task. The robots are programmed by robot specialists and are spatially separated from the workers.

Today the classical industrial robots have appeared in small and medium sized enterprises (SME), thus the efficiency of robot programming methods must be improved in order to avoid losses caused by frequent switches in small scale production. Since an SME cannot employ a robot specialist the robot is commissioned by third party system integrator and programmed by an engineer, who is not a robot specialist. One possible solution is virtual commissioning and remote operation via augmented reality, when a robot specialist operates real-time several robots working at different SMEs. Tele-presence is a big challenge during remote operation. Tele-presence is the psychological feeling of "being there" in an environment based on a technologically founded immersion

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environment. It should provide the ideal sensation, i.e. we get the necessary information fed back from the remote environment with no delay. Another solution can be the super flexible programing or supervisory system. The easiest and most natural way of programming a robot is to show the task, or just interactively instruct the robot for the task. The robot needs special visual and tactile sensors and special cognitive abilities to understand and learn the situation. The robot is considered as an apprentice with the physical strength, manipulation ability and learning capacity required for precise manufacturing. He/it has a special kind of intelligence but he/it is handicapped in some senses therefore he/it needs special treatment. We have to command him/it clearly in a special way and we have to supervise his/its work. If we can learn how to communicate with and train this "new worker" we can get a new capable "colleague". The long term goal is that the plant manager would be able to assign daily tasks to a robot as natural way as to the human workers. For example, using CAD documentation and some verbal explanations. If we have an unskilled worker the next step (challenge) is the skill acquisition. Most of the manipulations skill can be learned in a non-model based try and error method. The robots can learn tasks by mimicking the actions of a human operator but a skill transfer is necessary also since the end-effectors of the robots are different from the human hand. A skilled robot can identify the problem and select the necessary skill to perform the task, thus become an autonomous agent, a manufacturing robot assistant. The next step when the robot can work together with a skilled human worker, or more workers, and more robots (robot operation in shared space).

In recent years there has been an increased interest in the development of Human-Robot Interaction (HRI). Researchers have assumed that HRI could be enhanced if these intelligent systems were able to express some pattern of sociocognitive and socioemotional behaviour (e.g. Dautenhahn 2007a). Such approach needed an interaction among various scientific disciplines including psychology, cognitive science, social sciences, artificial intelligence, computer science and robotics. The main goal has been to find ways in which humans can interact with these systems in a "natural" way. Recently HRI has become very user oriented, that is, the performance of the robot is evaluated from the user's perspective. This view also reinforces arguments that robots do not only need to display certain emotional and cognitive skills but also showing features of individuality. Generally however, most socially interactive robots are not able to support long-term interaction with humans, and the interest shown toward them wears out rapidly.

2. SOCIAL OR SERVICE ROBOTICS

Robotics is facing a paradigm shift. From organized industrial environment robots are soon to step over into our complex daily life. To counterpoint the new use cases these non-industrial robots are called service robots in the corresponding ISO and IEC standards. Service robots need to have totally new functions and behaviour, which means that new problems of robot control are emerging and have to be solved. From the well-controlled manufacturing environment robots have to step out to less controlled and more stochastic environments. For service robots it is not enough to execute a pre-programmed action line. They must be able to adapt to changing environment, make their own decisions and in addition, they have to socially fit into the human environment. This requires a huge set of skills and attributes that industrial robots do not possess. We have to find a way to answer the new arising questions that emerge during the research and development of service robots. When can we say that a porter robot was polite? Or a police robot decided and professional? How can we describe politeness, attachments, affordance and other social behaviours in a mathematical way? These questions might seem remote however we need to think ahead. Along with the technical development of robots we also have to deal with their social integration. Similarly, we start the education of a child in childhood and not when she/he's already grown up.

With the integration of service robots into our everyday environment and the expansion of roles they can potentially fulfil, new types of users will be introduced to robots. Alongside with the classic users of robots, people can be divided to 4 main groups:

- robot specialist engineer
- engineer, but not robot specialist
- non-technical but technology literate end user like caregiver, employee of courier company, etc.
- non-technical not technology literate end user like elderly people

As we can see, with the divergence of robots from industrial settings the technical skill levels of users decreases even to the point where their potentially negative attitude towards robots can in itself cause difficulties in interacting with a robot. Consequently, there is an increasing need to make the training of robots more automated and at the same time to make them be able to fulfil more and more sophisticated tasks. This requires a more sophisticated robot control. Stepping away from SME the next landmark for robots is the workplace, such as offices, official institutes or health care facilities. These types of environments are much less controlled than manufactories and regular interaction with humans is required as a part of the robots' function. The main tasks of robots in workplace environments would be for example transporting items from different parts of the building, providing devices or supplies for the workers, cleaning, passing on messages and reminders, guiding visitors or serving refreshers. More special functions could be fulfilling the roles of doorman or guard.

In the future robots will become part of our daily life. We can also state it this way: robots are already part of our daily life, but not in a coexistent manner. Industrial and service robots are working for humans every day. However, as long as we think that robots only exist for following human orders, we are on the wrong understanding of the next-generation robotics. Today a communicational barrier exists between "robots" and humans. In order to fill this gap, we have to start in the beginning: how to create a system, which has actuators, sensors and intelligence in such manner, that people accept and interact with it without having any kind of challenge communicating/interacting with them.

Today's robot applications are mainly classified in the following categories:

- Manufacturing (industrial and service robots)
- Healthcare (medical robots)
- Outdoor (disaster management, agricultural, construction robots)

All above-mentioned sectors have their own specialties related to communication/interaction with robots. Up to now, most of the effort was to achieve higher user friendliness: to simplify communication interfaces, to ease programming and to develop artificial intelligence, which could react to sudden changes of environment, etc. However the main challenge is real autonomous operation in the non-industrial (non-standardised: e.g. outdoor, medical) environment and in the social behaviour these robots display. When service robots enter our homes they will have to succeed in the most complex and less controlled environment with almost constant shared space with humans. Additionally, the home environment is where robots have to satisfy the requirements of the most diverse of users, the general public. Service robots can also fulfil assistive roles, for example in caring for the elderly, in developing the abilities of autistic children or in rehabilitation. It cannot be expected from every possible user to gain insight into the technological background of robotics therefore these types of users will have generally speaking the less technical knowledge so this problem have to be solved by developing exemplary communicational skills for these robots. The first step to achieve is for robots to adapt to not just the physical but also the unique social environment of humans.

3. CHALLENGES IN HRI

The design of socially interactive robots has faced many challenges. Despite major advances there are still many obstacles to be solved in order to achieve a natural-like interaction between robots and humans.

The "uncanny valley" effect: Mori (Mori, 1970) assumed that the increasing similarity of robots to humans will actually increase the chances that humans refuse interaction (will be frightened of) very human-like agents. Although many take this effect for granted only little actual research was devoted to this issue. Many argue that once an agent passes 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 (Geller, 2008). 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 spite of the huge advances in robotics current socially interactive systems fail both with regard to motor and cognitive capacities, and in most cases can interact only in a very limited way with the human partner. We see this as a major discrepancy that is not easy to solve because there is a big gap between presently available technologies (hardware and software) and the desire for achieving human-like cognitive and motor capacities. As a consequence recent socially interactive robots have only a restricted appeal to humans, and after losing the effect of novelty the interactions break down rapidly.

The planning and construction of biologically or psychologically inspired robots depends crucially on the current understanding of human motor and mental processes. However, these are one of the most complex phenomena of life! Thus it is certainly possible that human mental models of abilities like "intention", "human memory" etc., which serve at present as the underlying concepts for control socially interactive robots, will be proved to be faulty. Because of the goal of mimicking a human, socially interactive robots do not utilize more general human abilities that have evolved as general skills for social interaction. Further, the lack of evolutionary approach in conceptualizing the design of such robots hinders further development, and reinforces that the only goal in robotics should be to produce "as human-like as possible" agents.

We do believe that robots should not be human like. We have to study their possible status in society. Some people might consider them family members who also faithfully serve their masters.

This is exactly what we expect from robots, but social companion animals, especially dogs fulfil a very similar role in the life of families. Dogs are regularly part of human families in which its members are emotionally attached to them. As dogs acquired social skills during domestication that help them in communicating with people and fitting in the human social environment, they can serve as suitable model animals for designing the behaviour of social robots. The adequate behaviour models that can be implemented into robots could be learned from dogs. The solution can be etho-robotics.

4. ETHOLOGICALLY INSPIRED ROBOTICS: ETHO-ROBOTICS

Etho-robotics is a new emerging interdisciplinary field which aims to bring together engineers who are building and programming robots and biologists who are interested in behavioural discipline. Ethology is the biological science of investigating animal and human behaviour in the natural environment. Robotics is slowly reaching a stage where autonomous behaviour and interaction with other robots or humans becomes a reality. Having "behaving" robots means that ethologists are needed both for studying human-robot interaction but also for cooperating in the design and modelling of robot behaviour. Etho-robotics claims that inter-specific interaction should provide the basis of human and robot cooperation. Accordingly, the embodiment and behavioural skills of social robots should suit their specific niche in their function and cooperation with humans.

Etho-robotics advises that robots must not be built on any pre-concept of being either human or animal-like but both the embodiment and the behaviour should be derived from the functional demand (Dautenhahn, 2007b; Miklósi and Gácsi, 2012). This means that the engineers and the ethologists have to determine together (1) the actual environment in which the robot "lives", (2) the performance which is expected from the

robot, (3) the optimal (and most simple) embodiment and behaviour skill which is needed for successful working, and (4) complexity to minimum social behaviour if the robot is working in a human (anthropogenic) environment. The etho-robotic approach also stresses the strong functional relationship between embodiment and behaviour. Embodiment should not elude a capacity which is actually not functional, and behaviour should not go beyond the actual skills needed for good performance. Implying higher capabilities through embodiment or behaviour than what the robot is actually capable of can result in disappointment, and a decrease in believability (Rose et al., 2010). The etho-robotic approach ensures that these robots are functional, show an acceptable performance, fit in the complex social human environment, and are cost effective.
The bio-inspiration for etho-robotics comes from detailed observation of inter-specific interactions in nature. Human-dog interaction provides the most dominant model for etho-robotics because robots in human environment and dogs share many functions (Miklósi and Gácsi, 2012; Topál et al., 2005). Dogs acquired various social skills during domestication that helps them fit in the human social environment (Kubinyi et al., 2007). Dogs had to reach a level of social competence where the behaviour of the dog corresponds to functionally analogous behaviours of the human, e.g. dogs understand some of the simple gestural cues that humans use during communication (Topál et al., 2009). The interaction between humans and dogs can serve as the basis of models for human-robot interactions and it presents a different approach from the widely researched human-human interaction centric view (Figure 2). Today social robots are far from reaching the cognitive capabilities of humans, therefore the communication between them and the humans should be developed accordingly, and be mainly based on simple social behavioural elements. As the research on human-robot verbal communication is still in its early stages, the development of communication should focus on the robot's capabilities to understand simple verbal commands and on the non-verbal aspects of communication. Similarly to dogs, the understanding of simple verbal commands supplemented with contextual and gestural information should be sufficient for communication (Pongrácz et al., 2001).

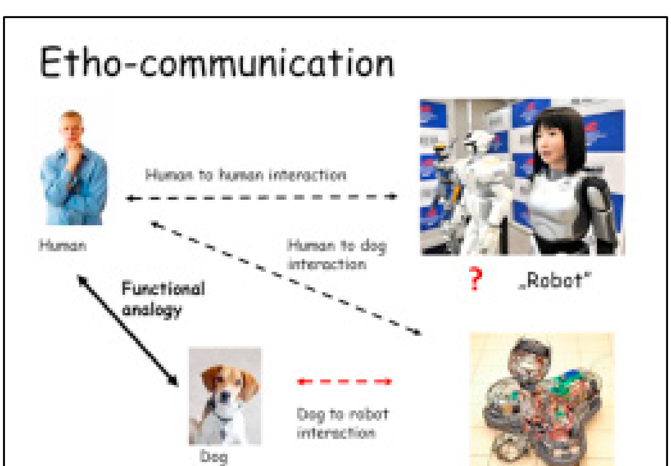


Fig. 2 Human-dog communication as a model for human-robot communication

Dogs excel in helping humans who are sightless, are disabled or suffer from mental disorders but dogs assist also people living with diabetes or epilepsy. Although it is unrealistic in short term that robots could replace dogs in these roles, dogs serve as a very useful model for planning and designing social and assistive robots. Dogs inspire important behaviours with functional consequences for human-robot interaction. This include attachment (Topál et al., 1998), social monitoring (Faragó et al., 2014), gaze contact (Passalacqua et al., 2011; Téglás et al., 2012), simple (non-linguistic) vocal communication (Pongrácz et al, 2005) etc.

5. ETHO-ROBOTICS RESEARCH

The ideal progress of etho-robotics research can be seen in Figure 3.

The process of etho-robotics research starts with the ethological observation of human-animal interactions through experiments. The interactions are chosen due to the proposed functional similarity of the behaviours displayed and the behaviours we wish to implement in the robot. Based on the behavioural analysis and the statistical results, a coherent behavioural model is formed which is usually a descriptive verbal ethological model. The next step is to find the key components of the model and translate them to a mathematical form. A robotic control model is built on the mathematical model. The implemented robotic control model is then used in human-robot interaction experiments corresponding to the starting experiments. After the analysis and evaluation the possible shortcomings of the model can be discovered, e.g. behavioural elements that were present during the initial human-animal interaction but were not implemented in the model. Therefore a feedback is created which helps in further research to refine the model.

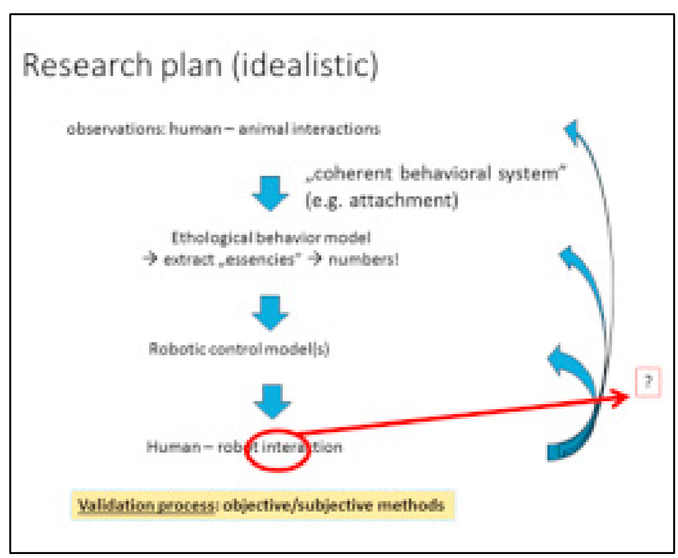


Fig. 3 The ideal progress of etho-robotics research

Etho-robotics studies have already explored some aspects of the behaviour of dogs as models for the communicative skills of assistive robots (Gácsi et al., 2013). Most assistive robots has been designed with human-like attributes in mind, but due to present-day technologies they fail to fulfil the expectations of the users that their human-like appearance and behaviour incites. Using the functionally relevant behaviours of assistance dogs as models for the behaviour of assistive robots could help us overcome this problem, and it could also facilitate the companion aspect of the robot. The restricted abilities of robots create an asymmetrical social relationship with the user, similarly to owner-dog dyads (Gácsi et al., 2013; Topál et al., 2005). In Gácsi et al. (2013) the researchers examined the behaviour and communicative signals of humans and their assistance dogs in typical every-day situations that require the help of the dog. They found that in an object fetch and carry task the interaction between the owner-dog pairs contained context-specific and also dyad specific features. Humans used both verbal and non-verbal communication during the interaction which is an indication that social robots are required to be able to recognize and process non-verbal communication alongside with verbal commands. Joint attention was necessary to initiate interaction, and humans draw the dogs' attention to them before giving instructions; the dogs also established eye-contact before performing a new action. Based on this result, social robots should orientate their body or head in the direction of the human in order to show their attentional state. In the second situation they examined, the dog was given an unsolvable task (the object to be fetched was not at the indicated location or could not be retrieved). In this case dogs looked at the owners not only when initiating the interaction but also when encountering the problem. The dogs did not resign easily from completing the task and kept trying with performing similar actions. They also vocalized and showed displacement activities. These behaviours and the commitment to the task was rated positively and if implemented into social robots it could facilitate empathy towards the robots. Another research based on the behaviour of assistance dogs investigated the attention getting and leading behaviour of hearing dogs when signalling a sound source to their deaf owners. The observed behaviours were studied with a social robot in human-robot interaction trials which were carried out with the Wizard of Oz method (Koay et al., 2013). The majority of participants were successful in understanding the visual communicational signals of the robot. The leading behaviour was implemented into a mobile robot, which consists of a mobile platform and a 2 DOF head part (Takahashi et al., 2015).

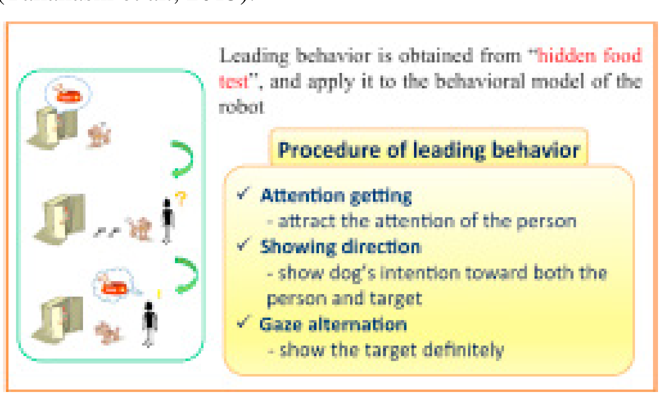


Fig. 4 The implemented behaviour (Takahashi et al., 2015)

In a recent study researchers described social monitoring of dogs as a behaviour which could potentially make long-term interactions easier with social robots (Faragó et al., 2014). Social monitoring occurs when the participants are not in active interaction at the moment, but the dog pays attention to the actions of the human by orienting towards him/her from time to time and showing low-level communicational signals. This behaviour indicates a readiness for interaction towards the human and make the initiation of interaction faster, without possibly disturbing the human with their presence. In long-term human-robot interactions when elderly people will live together with assistive robots in their home, these aspects can be crucial. There is currently ongoing research on implementing social monitoring into robots.

Different behavioural models were created for various purposes based on dog behaviour and human-dog interactions. One of these models is an emotional engine model (Szabó et al., 2012) in which the authors used neurobiological and ethological data and principles in building a non-linear state space model, extended the emotional engine by emotion arbitration and used a hierarchical rule tree for the arbitrations. Other behavioural models investigated the implementation of clicker training in social robots (Kaplan et al., 2002) while other searchers used fuzzy-automaton to develop a model of the dog-owner attachment (Kovács et al., 2011) which model could be implemented into robots and tested in a laboratory, or with a simulation (Vincze et al., 2012) with the modified Ainsworth's Strange Situation Test (Topál et al., 1998). The dog-owner attachment behaviour was implemented into a mobile robot and evaluated through human subjects' impressions (Ichikawa et al., 2012).

The other role of etho-robotics is to design test beds for detailed quantitative evaluation of human-robot interaction, i.e. benchmarking the service outcome. This approach goes well beyond present day methods that are based on short human-robot interactions, and use mainly questionnaires for collecting data. The etho-robotic study of human-robot interaction aims for long (hours, days) interaction, automated data collection on human and robot behaviour, and the use of appropriate control observations and benchmarks for performance. This aspect of research is essential by providing more direct feedback to the engineers and the ethologists for improving the robot.

In the following chapters we would like to present a few research topics of service robots in which etho-robotics plays an important role.

4. ANIMAL TYPE MOVEMENTS

Both the human and animal like legged locomotion for robots is still big challenge. From the point of view of technology we need new locomotion designs, since the mass of the existing electric motors are relatively bigger than that of the muscles found in the bodies of humans or animals. The classical model-based control methods are not applicable for sophisticated motion.

Several types of mobile robots exists like tracked, wheeled, legged, wheeled-legged, leg-wheeled, segmented, climbing or hopping. The control methods of these robots are implemented individually for every construction. In most of the cases the control algorithms uses the virtual centre of motion method. The path of the motion describes the path of this point (Udengaard,and Iagnemma, 2007). We can consider the whole mobile robot as a point (the centre of gravity, virtual centre of motion). The velocity and the angular velocity of the centre of gravity define the motion of the robot (at constant speed). At the path of the motion we prescribe the velocity and the angular velocity of the robot in every moment.

The most often ways for mobile robot motion are the differential type drive and the steered vehicle concept. The path planning of these mechanical constructions can be extremely difficult (Arogeti, et al., 2012). Indoor environments increase the number of questions in this method (see in Figure 5).

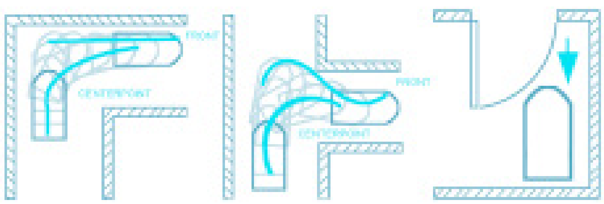


Fig. 5 Steered vehicle path planning

At different driven type mobile robots path planning is simpler, because the robot can turn around without the change of the position. The orientation of the robot is always the same with the moving direction. These robots (and the driven vehicles also) have only 2 DoF-s on the ground plane. In 1994 Stephen Killough invented omni wheels (Killough, 2011) These are wheels with small discs around the circumference which are perpendicular to the rolling direction. This type of wheel does not have a geometrical constrain perpendicular to the rolling direction. With this type of configuration we can get a 3 DoF holonomic system (x, y, rot z). The most of the overland animals can move in 3DoF: turning and moving in one direction in the same time. The ordinary drive systems (steered wheels, differential drive) cannot perform this.

One of the main characteristics of animal locomotion is that the body orientation and the velocity vector do not always point to the same direction. The holonomic robots have an additional property that the moving and looking direction can be different during reaching a target on a non-straight trajectory (see Figure 6).

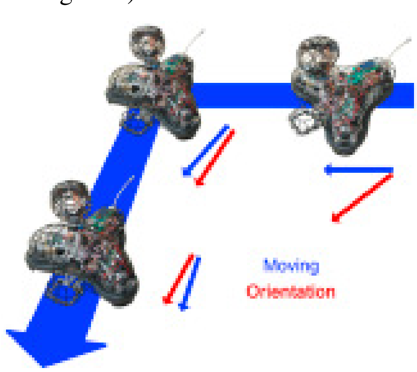


Fig. 6 Different direction of moving and looking during holonomic movement.

Therefore path planning algorithms were designed for a holonomic driven robot platform. Implementation was made on MOGI-ETHON (Figure 7), a holonomic drive mobile robot.

Fig. 7 MOGI-ETHON, a holonomic mobile robot. Its omnidirectional drive allows the implementation and measurements of path-planning algorithms including orientation information. A laser scanner is built on the top of the robot providing real-time distance measurement data.

5. ADAPTED ANIMAL MOTION ATTRIBUTES

This chapter points to three motion-related animal characteristics with communicative implications, which are proposed to be adapted to mobile robot path planning. People's interpretation of these animal motion attributes will be explained along with the proposed corresponding meaning in case of mobile robotics.

5.1. Object proximity-seeking

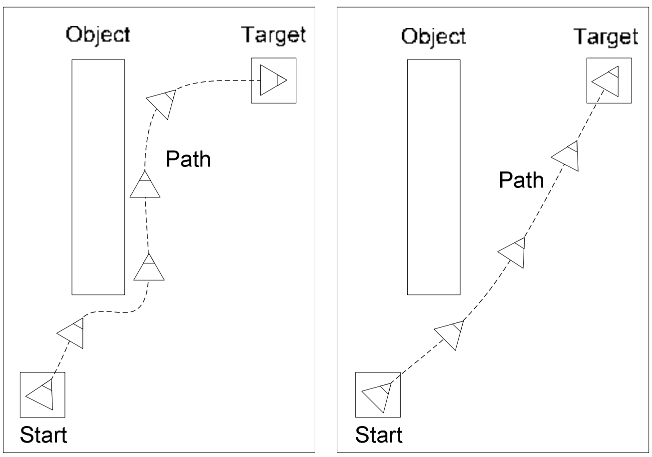
Objects often mean protection or hiding for animals. These are not just obstacles which have to be bypassed. Most visibly, cats often go close to the wall even if it results in a longer path as demonstrated on Figure 8. This antipredator behaviour specific to small mammals e.g. rodents is well described by ethological studies. It is affected by anxiety-related medicines, therefore medical companies also analyse it in the widely used animal tests called open field test (Lipkind et al., 2004).

People's interpretation of object proximity-seeking behaviour of animals is the avoidance of interaction. A mobile robot could behave in the same way if it does not intend to initiate an interaction, e.g. when the robot has an already defined task and does not expect new commands.

5.2. People approach

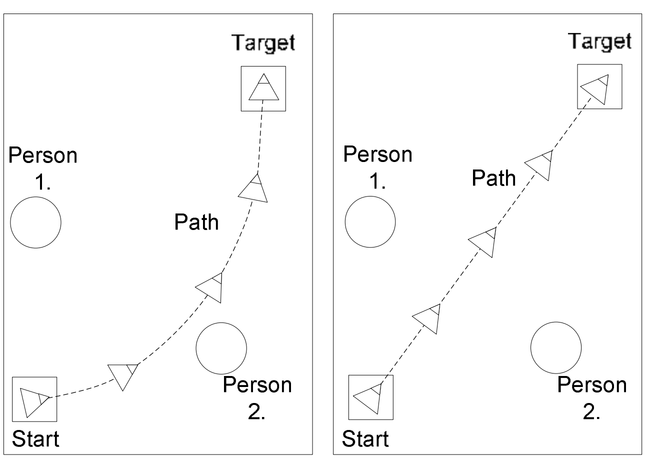
As ethological research points out (Kerepesi et al., 2014), dogs distinguish between their owner, familiar people, and strangers. Dogs stay in closer proximity with their owner, and are more likely to interact with familiar people (Faragó et al., 2014).

People intuitively perceive the dog's approach or avoidance, and expect interaction according to it. In case of robotics, this motion characteristic could be used to express that the robot expects getting a command from a specific person while doing its task and the robot is ready to process the new task, or it could express the opposite, that the robot does not accept a command from a specific person. Therefore, we suggest assigning artificial values to people, which we have called people approach value. This value could be assigned to each person individually by a higher level algorithm. Based on that, our proposed path planning algorithm can behave towards different people using different degrees of approximation. Figure 9 shows the effect of this parameter on the resulting path.



(a) (b)

Fig. 8 The path (a) with and (b) without the object proximity-seeking motion characteristics. This nature is specific especially for small mammals, like rodents, as they often stay close to objects for hiding and protection.



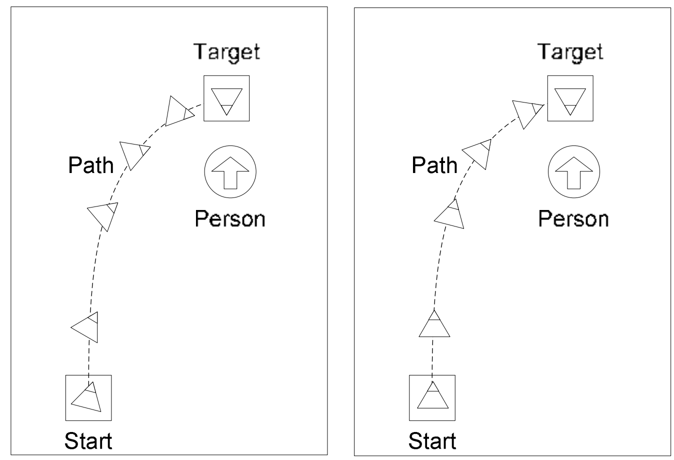
(a) (b)

Fig. 9 Demonstration of different paths specific to dogs in case of (a) Person 2 has a more important role (e.g. Person 2 is the owner), (b) people approach does not differ.

5.3. Target pointing orientation

Movement of animals is holonomic in the sense that animals can move to any direction and change orientation at the same time, independently. Angle difference between velocity and orientation often shows the intent or attention of the animal (Faragó et al., 2014). For example, Figure 10 (a) shows a typical path and orientation of a dog, which comes from behind a person to the person's front for initiating interaction, while Figure 10 (b) shows the same path without any difference between orientation and velocity direction.

Based on orientation information, people can get a concept about the target, attention, or future movement of the animal. Mobile robots could do the same to provide feedback to people about their objective and future movement. For example, if a robot is waiting for a person to initiate an interaction, it could indicate this intent by continuously facing that person even if the robot has to follow him or pass to the person's other side.



(a) (b)

Fig. 10 (a) A typical path and orientation of a dog, which comes from behind a person to the person's front for initiating interaction. Orientation and direction of movement are different, indicating the dog's objective. Fig. 10 (b) The same path in case of a not natural, non-holonomic movement, in which the movement of the dog would not indicate the robot's intent before reaching its target.

6. ETHOLOGICALLY INSPIRED HRI MODEL

According to (Kovács, et. al., 2009), in order to overcome some of the challenges presented above ethologically inspired HRI models can be applied. The concept of ethologically inspired HRI models allows the study 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 the first biological robot because some time after domestication dogs were utilized as an aid in hunting, animal husbandry, warfare, protection, transport etc (Miklósi, 2007). The long-term (since cc 20.000 years) and successful human-dog interaction shows that humans have the ability to develop social interaction with very different agents. The human-dog relationship rests critically on our ability to produce and understand various forms of communicative cues that are emitted in an inter-specific relationship in which the two members' signalling behaviour overlaps only to certain extent. Human behaviour evolution has selected for increased ability to form social contact with any creatures, which originates in the very social nature of nursing (parental) behaviour in humans which is unique in the Primates. Humans also show a preference to use social relationship for joint action in cooperative settings. Finally, humans have the mental capacities (and the preference) to attribute certain human-like mental capacities to other agents (even to non-living things) which also facilitates the interaction between them.

Therefore robots do not have to rely on the exact copy of human social behaviour (including language etc) but 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.

7. FRI IN HRI MODEL

According to (Kovács, et. al., 2009), in ethological modeling, mass of expert knowledge 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 required (thanks to the descriptive manner of the model), 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) (Zadeh, 1973) (Mamdani, 1975) (Larsen, 1980) or the Takagi - Sugeno fuzzy inference (Sugeno, 1985) (Takagi and Sugeno, 1985)). 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. FRI methods can provide reasonable (interpolated) conclusions even if none of the existing rules fires under the current observation. From the beginning of 1990s numerous FRI methods have been proposed (Wong, et. al., 2006).

8. THE "FIVE" FRI

According to (Kovács, et. al., 2009), an application oriented aspect of the fuzzy rule interpolation emerges in the concept of "FIVE". The fuzzy reasoning method "FIVE" (Fuzzy Interpolation based on Vague Environment, originally introduced in (Kovács, 1996), (Kovács and Kóczy 1997a) and (Kovács and Kóczy 1997b)) 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 serves crisp observations and requires crisp conclusions from the controller. Adopting the idea of the vague environment (VE) (Klawonn, 1994), FIVE can handle the antecedent and consequent fuzzy partitions of the fuzzy rule base by scaling functions (Kovács and Kóczy 1997b) and therefore turn the fuzzy interpolation to crisp interpolation.

The idea of a VE is based on the similarity (in other words: indistinguishability) of the considered elements. In VE the fuzzy membership function $\mu_A(x)$ is indicating level of similarity of x to a specific element a that is a representative or prototypical element of the fuzzy set $\mu_A(x)$, or, equivalently, as the degree to which x is indistinguishable from a (Kovács and Kóczy 1997b). Therefore the α-cuts of the fuzzy set $\mu_A(x)$ are the sets which contain the elements that are $(1-\alpha)$-indistinguishable from a. Two values in a VE are ε-distinguishable if their distance is greater than ε. The distances in a VE are weighted distances. The weighting factor or function is called *scaling function (factor)* (Kovács and Kóczy 1997b). If VE of a fuzzy partition (the scaling function or at least the approximate scaling function (Kovács, 1996), (Kovács and Kóczy 1997b)) exists, the member sets of the fuzzy partition can be characterized by points in that VE (see e.g. scaling function s on fig. 1). Therefore any crisp interpolation, extrapolation, or regression method can be adapted very simply for FRI (Kovács, 1996), (Kovács and Kóczy 1997b).

9. FRI BASED FUZZY AUTOMATON FOR HRI

According to (Kovács, et. al., 2009), 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 (Pirjanian, P., 1999), 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.

In case of the suggested fuzzy behaviour based control structures both tasks are solved by FRI systems. If the behaviours are also implemented on FRI models, the behaviours together with the behaviour fusion modules form a hierarchical FRI system.

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 and/or? could be intentionally left out from the model).

10. THE SUGGESTED FRI BEHAVIOUR-BASED STRUCTURE

According to (Kovács, et. al., 2009), in case of pure FRI based fuzzy behaviour-based control structures all the main tasks of the behaviour-based control are implemented on FRI models.

Such a structure is introduced on Figure 11 The three main tasks, the behaviour coordination, the behaviour fusion, and the behaviours themselves are FRI models.

For demonstrating the main benefits of the FRI model in behaviour-based control, in this paper we concentrate only on the in? many cases most heuristic part of the structure, on the behaviour coordination. The task of behaviour coordination is to determine the necessities of the known behaviours needed for handling the actual situation. In the suggested behaviour-based control structure, for this task the finite state fuzzy automaton is adapted (Figure 11) (Kovács, 2000), where the state of the finite state fuzzy automaton is the set of the suitabilities of the component behaviours. This solution is based on the heuristic, that the necessities of the known behaviours for handling a given situation can be approximated by their suitability. And the suitability of a given behaviour in an actual situation can be approximated by the similarity of the situation and the prerequisites of the behaviour. (Where the prerequisites of the behaviour is the description of the situations where the behaviour is applicable). In this case, instead of determining the necessities of the known behaviours, the similarities of the actual situation to the prerequisites of all the known behaviours can be approximated.

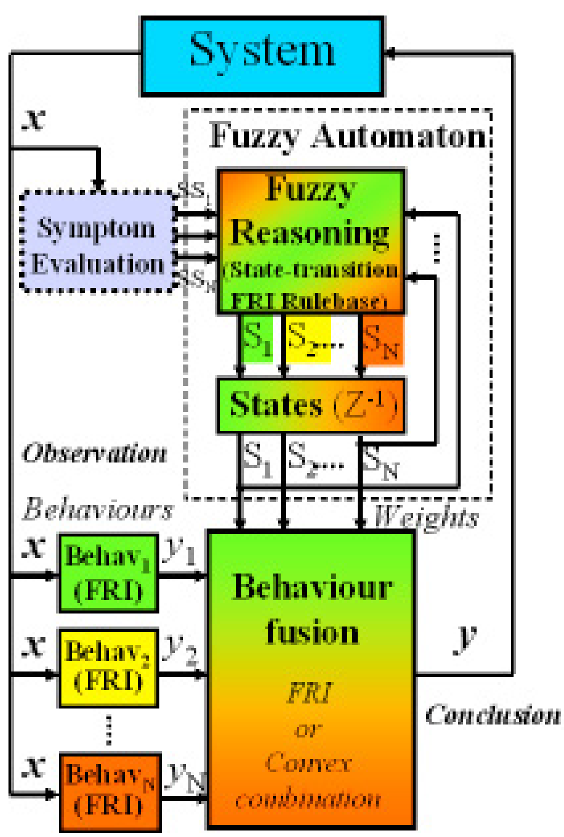


Fig. 11 The suggested FRI behaviour-based structure.

Thus the first step of the system state approximation is determining the similarities of the actual situation to the prerequisites of all the known behaviours – applying the terminology of fault classification, it is the symptom evaluation (see on Figure 11). The task of symptom evaluation is basically a series of similarity checking between an actual symptom (observations of the actual situation) and a series of known symptoms (the prerequisites – symptom patterns – of the behaviour components). These symptom patterns are characterising the systems states where the corresponding behaviours are valid. Based on these patterns, the evaluation of the actual symptom is done by calculating the similarity values of the actual symptom (representing the actual situation) to all the known symptoms patterns (the prerequisites of the known behaviours). There are many methods for fuzzy logic symptom evaluation. For example fuzzy classification methods e.g. the Fuzzy c-Means fuzzy clustering algorithm (Bezdek, 1981) can be adopted, where the known symptoms patterns are the cluster centres, and the similarities of the actual symptom to them can be fetched from the fuzzy partition matrix. On the other hand, having a simple situation, the fuzzy logic symptom evaluation could be an FRI model too.

One of the main difficulties of the system state approximation is the fact, that most cases the symptoms of the prerequisites of the known behaviours are strongly dependent on the actual behaviour of the system. Each behaviour has its own symptom structure. In other words for the proper system state approximation, the approximated system state is needed itself. A very simple way of solving this difficulty is the adaptation of fuzzy automaton. This case the state vector of the automaton is the approximated system state, and the state-transitions are driven by fuzzy reasoning (Fuzzy state-transition rule base on Figure 11), as a decision based on the previous actual state (the previous iteration step of the approximation) and the results of the symptom evaluation.

For demonstrating the simplicity of defining the rule base for the FRI model, a small example will be introduced in the followings.

11. EXAMPLE

According to (Kovács, et. al., 2009), the example is a tiny fragment of a more complex ethological model of a dog behaving in an unfamiliar room in interaction with its owner and an unknown human ("Owner" and "Human2" on Figure 12).

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 an unknown environment (see the "ellipsoid" track on Figure 12). The "`DogGoesToDoor`" is a simple dog activity, in which the dog goes to the door, and than stands (sits) in front of it.

The example is the definition of the related state-transition FRI rules of the fuzzy automaton acts as behaviour coordination.

The states concerned in the example are the following:

"Missing the owner mood of the Dog" (`DogMissTheOwner`) and "Anxiety level of the Dog" (`DogAnxietyLevel`): "hidden" states, which have no direct task in controlling any of the above mentioned behaviours, but has 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`): states, which have also direct task in controlling the corresponding “`DogExploresTheRoom`” and “`DogGoesToDoor`” behaviours.

As a possible rule base structure for the state-transitions of the fuzzy automaton, the following is defined (a tiny fragment of a more complex rule base):

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** `Human2ToDogDistance=`*High* **Then** `DogAnxietyLevel=`*Decreasing*

If `OwnerToDogDistance=`*High* **And** `Human2ToDogDistance=`*Small* **Then** `DogAnxietyLevel=`*Increasing*

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:

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

If `ThePlaceIsUnknown=`*Low* **Then** `DogExploresTheRoom=`*Low*

If `DogAnxietyLevel=`*High* **Then** `DogExploresTheRoom=`*Low*

where the text in Italic are the linguistic terms (fuzzy sets) of the FRI rule base.

Please note that the rule base is sparse. It contains the main state-transition FRI rules only.

A sample run of the example is introduced on Figure 12 and Figure 13 At the beginning of the scene, the owner is in the room and the Human2 is outside. The place is unknown for the dog (“ThePlaceIsUnknown=*High*” in the rule base). according to the above rule base, the dog starts to explore the room. At around the step count 17, the owner of the dog left the room, than “Human2” enters and stay inside. As an effect of the changes (according to the above state-transition rule base), the anxiety level of the dog and the “missing the owner” is increasing, and as a result, the dog goes and stays at the door, where the owner has left the room. See example run tracks on Figure 12 and state changing on Figure 13.

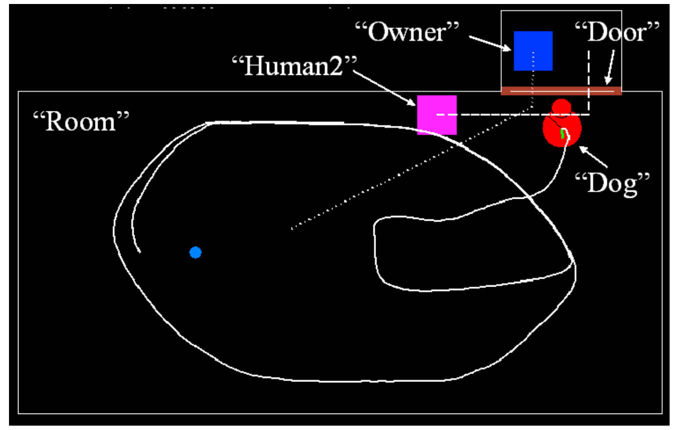


Fig. 12 Tracks of a sample run. Continuous line for the for the dog, dotted for the owner and dashed for the Human2.

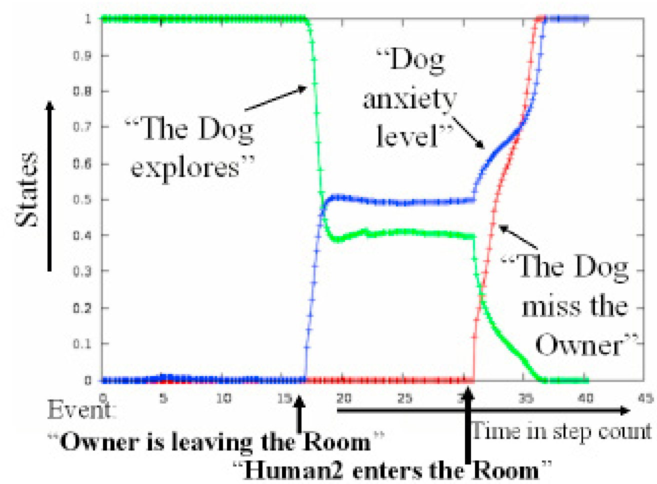


Fig. 13 Some state changes during the sample run introduced on Fig.3.

12. CONCLUSIONS

Robots will undoubtedly step outside of their classic roles in the industry into workplace environments and people’s homes. The new environments requires new solutions for challenges that industrial robots did not have to face. Service and assistive robots will have to perform their tasks according to their functions in a dynamically changing environment and they have to be able to interact with humans in a socially acceptable way. The function of social robots and the required social competences are in many aspects similar to what roles dogs fulfil in our lives. Dogs acquired specific social skills during domestication which assisted their integration into the human social environment. Human-dog interactions can serve as models for designing the behaviour of social robots, while ethological methods can be used to examine human-robot interactions and to get feedback on the performance of the robot or the implemented behavioural model.

The goal of this paper was to describe some of the research topics of social robotics in which etho-robotics can play an important role. The etho-robotics approach can be used to create behavioural models such as attachment, or behaviours that help the communication and interaction between human and robot, e.g. leading behaviour or social monitoring. Animal behaviour can also serve as a model for the path planning of social robots in various contexts. The paper also presents a behaviour-based structure built from Fuzzy Rule Interpolation (FRI) models and FRI automaton for handling Human-Robot Interaction (HRI) placed on ethological model basis. The suggested structure is simple and could be implemented to be quick enough to fit the requirements of direct real-time HRI applications. It is an easily built and simply adaptable structure for many application areas (see e.g. (Kovács, Sz., 2002) as an application area in user adaptive emotional and information retrieval systems).

The implementation of FRI reasoning methods in HRI applications simplifies the task of fuzzy rule base creation. The FRI rule base is not needed to be complete, so it is enough to concentrate on the main control actions, or even the rules can be added simply piece by piece.

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REFERENCES

Arogeti, S.A. Danwei Wang, Chang Boon Low, Ming Yu,(2012) Fault Detection Isolation and Estimation in a Vehicle Steering System ," IEEE Trans. on Industrial Electronics, vol. 59, no. 12, pp. 4810-4820.

Bezdek, J.C., (1981). Pattern Recognition with Fuzzy Objective Function. *Plenum Press*, p.256.

Dautenhahn, K., (2007)(a). Methodology and themes of human-robot interaction: a growing research field. *International Journal of Advanced Robotic …*, 4(1), pp.103–108.

Dautenhahn, K., (2007)(b). Socially intelligent robots: dimensions of human-robot interaction. *Philosophical transactions of the Royal Society of London. Series B, Biological sciences*, 362(1480), pp.679–704.

Faragó, T., Miklósi, Á., Korcsok, B., Száraz, J. & Gácsi, M., (2014). Social behaviours in dog-owner interactions can serve as a model for designing social robots. *Interact. Stud*, in press.

Gácsi, M., Szakadát, S. & Miklósi, Á., (2013). Assistance dogs provide a useful behavioral model to enrich communicative skills of assistance robots. *Frontiers in Psychology*, 4(December), pp.1–11.

Geller, T., (2008). Overcoming the Uncanny Valley. *IEEE Computer Graphics and Applications*, 28, pp.11–17.

Ichikawa, T., Yuki, M., Korondi, P.P., Hashimoto, H., Gácsi, M., Niitsuma, M. & Member, S.S., (2012). Impression evaluation for different behavioral characteristics in ethologically inspired human-robot communication. *Proceedings - IEEE International Workshop on Robot and Human Interactive Communication*, pp.55–60.

Johanyák, Z. csaba, Tikk, D., Kovács, S. & Wong, K.W., (2006). Fuzzy Rule Interpolation Matlab Toolbox - FRI Toolbox. In *International Conference on Fuzzy Systems*. pp. 351–357.

Kaplan, F., Oudeyer, P.-Y., Kubinyi, E. & Miklósi, Á., (2002). Robotic clicker training. *Robotics and Autonomous Systems*, 38(3-4), pp.197–206.

Killough Stephen (2011) 1997 Discover Awards. Discover Magazine, Retrieved 22, September.

Kerepesi, A., Dóka, A. & Miklósi, Á., (2014). Dogs and their human companions: The effect of familiarity on dog-human interactions. *Behavioural Processes*.

Klawonn, F., (1994). Fuzzy sets and vague environments. *Fuzzy Sets and Systems*, 66(2), pp.207–221.

Koay, K.L., Lakatos, G., Syrdal, D.S., Gácsi, M., Bereczky, B., Dautenhahn, K., Miklósi, Á. & Walters, M.L., (2013). Hey! There is someone at your door. A hearing robot using visual communication signals of hearing dogs to communicate intent. In *2013 IEEE Symposium on Artificial Life (ALife)*. IEEE, pp. 90–97.

Kovács, S., (2002). Fuzzy Reasoning and Fuzzy Automata in User Adaptive Emotional and Information Retrieval Systems. In *Systems, Man and Cybernetics …*.

Kovács, S., (2000). Interpolative Fuzzy Reasoning and Fuzzy Automaton in Adaptive System Applications. In *Proceedings of the IIZUKA*. pp. 1–4.

Kovács, S., (1996). New Aspects of Interpolative Reasoning. In *Proceedings of the 6th. International Conference on Information Processing and Management of Uncertainty in Knowledge-Based Systems*. pp. 477–482.

Kovács S, Vincze D, Gácsi M, Miklósi Á, Korondi P (2009) Interpolation based fuzzy automaton for human-robot interaction, 9th IFAC Symposium on Robot Control. Konferencia helye, ideje: Gifu, Japán, 2009.09.09-2009.09.12. Gifu:IFAC, 2009. pp. 317-322.

Kovács, S. & Gácsi, M., (2011). A novel, ethologically inspired HRI model implementation: Simulating dog-human attachment. *2nd International Conference on Cognitive Infocommunications: CogInfoCom*.

Kovács, S. & Koczy, L.T., (1997). Approximate fuzzy reasoning based on interpolation in the vague environment of the fuzzy rulebase. *Proceedings of IEEE International Conference on Intelligent Engineering Systems*, pp.144–149.

Kovács, S. & Kóczy, L.T., (1997). The use of the concept of vague environment in approximate fuzzy reasoning. *Fuzzy Set Theory and Applications*, 12, pp.169–181.

Kubinyi, E., Virányi, Z. & Miklósi, Á., (2007). Comparative social cognition: from wolf and dog to humans. *Comp. Cogn. Behav. Rev*, 2, pp.26–46.

Larsen, Martin, P., (1980). Industrial applications of fuzzy logic control. *International Journal of Man-Machine Studies*, 12(1), pp.3–10.

Lipkind, D., Sakov, A., Kafkafi, N., Elmer, G.I., Benjamini, Y. & Golani, I., (2004). New replicable anxiety-related measures of wall vs center behavior of mice in the open field. *Journal of applied physiology (Bethesda, Md. : 1985)*, 97, pp.347–359.

Mamdani, E.H. & Assilian, S., (1975). An experiment in linguistic synthesis with a fuzzy logic controller. *International Journal of Man-Machine Studies*, 7(1), pp.1–13.

Ministry of Economics and Trade (METI). (2010). 2035nen ni muketa robotto sangyou no shourai shijou yosoku (Market forecast of robot industryin 2035). Retrieved:http://www.meti.go.jp/press/20100423003/20100423003-2.pdf

Miklósi, Á., (2007). *Dog Behaviour, Evolution, and Cognition*, Oxford University Press.

Miklósi, Á. & Gácsi, M., (2012). On the utilization of social animals as a model for social robotics. *Frontiers in psychology*, 3(March), pp.1–10.

Mori, M., (1970). The uncanny valley. *Energy*, 7(4), pp.33–35.

Numakunai, R., Ichikawa, T., Gácsi, M., Korondi, P.P., Hashimoto, H. & Niitsuma, M., (2012). Exploratory behavior in ethologically inspired robot behavioral model. *Proceedings - IEEE International Workshop on Robot and Human Interactive Communication*, pp.577–582.

Passalacqua, C., Marshall-Pescini, S., Barnard, S., Lakatos, G., Valsecchi, P. & Prato Previde, E., (2011). Human-directed gazing behaviour in puppies and adult dogs, Canis lupus familiaris. *Animal Behaviour*, 82(5), pp.1043–1050.

Pirjanian, P., (1999). Behavior Coordination Mechanisms By. *Ethology*, 1(213), pp.1–49.

Pongrácz, P., Miklósi, Á. & Csányi, V., (2001). Owner's beliefs on the ability of their pet dogs to understand human verbal communication : A case of social understanding. *Current Psychology of Cognition*, 20(1-2), pp.87–107.

Pongrácz, P., Molnár, C., Miklósi, A. & Csányi, V., (2005). Human listeners are able to classify dog (Canis familiaris) barks recorded in different situations. *Journal of comparative psychology*, 119(2), pp.136–144.

Rose, R., Scheutz, M. & Schermerhorn, P., (2010). Towards a Conceptual and Methodological Framework for Determining Robot Believability. *Interaction Studies*, 11(2), pp.314–335.

Sugeno, M., (1985). An introductory survey of fuzzy control. *Information Sciences*, 36(1-2), pp.59–83.

Syrdal, D.S., Koay, K.L. & Gácsi, M., (2010). Video prototyping of dog-inspired non-verbal affective communication for an appearance constrained robot. *RO-MAN, 2010 …*, pp.632–637.

Szabó, C., Roka, A., Faragó, T., Gácsi, M., Miklósi, Á. & Korondi, P., (2012). Building a human-dog interaction inspired emotional engine model. *IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society*, pp.5516–5522.

Takagi, T. & Sugeno, M., (1985). Fuzzy identification of systems and its applications to modeling and control. *IEEE Transactions On Systems Man And Cybernetics*, 15(1), pp.116–132.

Takahashi, S., Márta, G., Korondi, P., Hashimoto, H. & Niitsuma, M., (2015). Leading a Person Using Ethologically Inspired Autonomous Robot Behavior. In *Proceedings of the Tenth Annual ACM/IEEE International Conference on Human-Robot Interaction Extended Abstracts - HRI'15 Extended Abstracts*. HRI'15 Extended Abstracts. New York, NY, USA: ACM, pp. 87–88.

Téglás, E., Gergely, A., Kupán, K., Miklósi, Á. & Topál, J., (2012). Dogs' gaze following is tuned to human communicative signals. *Current biology : CB*, 22(3), pp.209–12.

Topál, J., Lo, M.M.I.K., Gácsi, M., Miklósi, Á., Virányi, Z., Kubinyi, E. & Csányi, V., (2005). Attachment to humans: A comparative study on hand-reared wolves and differently socialized dog puppies. *Animal Behaviour*, 70(Kummer 1982), pp.1367–1375.

Topál, J., Miklósi, Á., Csányi, V. & Dóka, A., (1998). Attachment Behavior in Dogs (Canis familiaris): A New Application of Ainsworth ' s (1969) Strange Situation Test. *Journal of Comparative Psychology*, 112(3), pp.219–229.

Topál, J., Miklósi, Á., Gácsi, M., Dóka, A., Pongrácz, P., Kubinyi, E., Virányi, Z. & Csányi, V., (2009). *The Dog as a Model for Understanding Human Social Behavior*,

Udengaard, Martin, Karl Iagnemma, (2007) Kinematic Analysis and Control of an Omnidirectional Mobile Robot in Rough Terrain" in Intelligent Robots and Systems, San Diego, pp. 795-800,

Vincze, D., Kovács, S., Niitsuma, M., Hashimoto, H., Korondi, P., Gácsi, M. & Miklósi, Á., (2012). Ethologically inspired human-robot interaction interfaces. *Proceedings of the 2012 Joint International Conference on Human-Centered Computer Environments - HCCE '12*, p.51.

Wong, K.W., Tikk, D., Gedeon, T.D. & Kóczy, L.T., (2005). Fuzzy rule interpolation for multidimensional input spaces with applications: A case study. *IEEE Transactions on Fuzzy Systems*, 13(6), pp.809–819.

Zadeh, L. a, (1973). Outline of a New Approach to the Analysis of Complex Systems and Decision Processes. *Systems, Man and Cybernetics, IEEE Transactions on*, SMC-3(1), pp.28–44.

The FRI Toolbox is available at: http://fri.gamf.hu