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An Approach for Deigned Behavior of Robotics Based on Man's Imagination

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Abstract: Robotics has been named a key science of the 21st century. The methods of robotics are spreading to other engineering sciences, and to medical areas, offering huge chances for novel products. In order to build autonomous robots that can carry out useful work in unstructured environments new approaches have been developed to building intelligent systems. Robotics originated with the goal of building human like machines, but it has become much more than that. Even though we are still decades away from human like machines, the developing robotics technologies are proving useful in ways that nobody expected: robot assisted noninvasive surgery; disposal of roadside bombs; automated lab science for drug discovery; even auto focus features in digital cameras. Recent work has demonstrated the use of representations, expectations, plans, goals, and learning, but without resorting to the traditional uses, of central, abstractly manipulable or symbolic representations. Perception within these systems is often an active process, and the dynamics of the interactions with the world are extremely important.

Keyword: Robotics, AI, Biological, Neuroscience, Behavior.

I. INTRODUCTION

Robotic technology for manufacturing was originally developed in the United States, but the manufacturing robotics industry is now dominated by Asia and Europe, with serious consequences for US robotics and for US manufacturing. Behavior-based robotics is a branch of robotics that bridges artificial intelligence (AI) [1], engineering and cognitive science. Its dual goals are to develop methods for controlling artificial systems, ranging from physical robots to simulated ones and other autonomous software agents and to use robotics to model and understand biological systems more fully, typically, animals ranging from insects to humans. This article focuses mainly on work towards satisfying the first goal, giving a brief review of the key approaches and types of systems that have been implemented with a strong biological inspiration. Robotics is an area where a number of scientific fields meet, and this fact already is a source of attraction for the involved scientists, for users, and the public. Expectations run high and in diverse directions. The word “robot” itself comes from literature and was created in the twenties [2], in one of his plays, a play that ended tragically. In the forties, another writer, Isaac Asimov, made robots the leading figures in his utopian novels. Since these times, robots have been subjects of imagination. The reality of industrial robots only came in the sixties when Joseph F. Engelberger introduced the PUMA robot as a freely programmable, universal, handling device. With it came automation in manufacturing industry, economic issues, and social concern about human labour replaced by machines. The versatility of these robot machines has been increasing, largely due to their continuously increasing ability of information processing. The ultimate goal was the autonomous robot. However, as the application field for robots is widening, and the robot is coming out of the factory halls, new challenges are seen, and even a change of paradigm is taking shape. The robot is expected to be an extended, intelligent tool for the human, it should become a partner instead of being a “competitor” in fulfilling tasks, and there is a developing relation to biological systems. This development is illustrated by terms such as behaviour, emotions, or intelligence, taken out of their biological context and used to describe technical features and properties. For example, the term “intelligent” is being used to describe advanced robot behaviour, maybe still rather as a marketing term, but the idea certainly is to give it more meaning. It is obvious that there are high expectations as to the future potential of robotics, even euphoric ones and somewhat unrealistically utopic [6]. On the other side, there are sceptical views, seeing robotics as one of the most powerful technologies of the 21st century, together with genetic engineering and nanotech [8], threatening to make humans an endangered species. A more moderate and realistic, but still fascinating approach has been taken by a study group, consisting of experts from engineering, medical, philosophical and legal sciences, discussing the provoking question whether humans could be substituted by robots [4] . The paper will give examples of the actual state of the art by referring to nano-manipulation, human leg prosthesis, and by looking at developments in the medical area, and into embedded robotics. The paper will present some aspects and results discussed by that study group cited above, it will comment on robot intelligence, on expected benefits of future robot technology, as well as on socio-economic, legal and ethical constraints. In the field of robotics, 'control architectures' are methodologies that supply structure and impose constraints on the way that robots are controlled. The behavior-based approach is a methodology for designing robot architectures and controllers for endowing robots with intelligent behavior. The methodology is based on a biologically-inspired philosophy that favors parallel, decentralized architectures, and allows for some freedom of interpretation. The approach is general and fits well within other powerful frameworks such as schema theory.

II. SYSTEM ORGANIZATION

The leading role of robotics is based on its inherent technology potential and, in particular, its relations to areas beyond technology. In comparison, the direct economic impact of robotics appears to be rather small. As robotics is a multidisciplinary area, expectations are very diverse as well. Subsequently some trends and potential benefits will be outlined for different areas. The organizational methodology of behavior-based systems differs from other robot control methods in its approach to modularity, that is, the way in which the system is organized and subdivided. The behavior-based philosophy mandates that behaviors are relatively simple, incrementally added to the system and not executed in a serial fashion. The systems are meant to be constructed in a bottom-up fashion, resembling evolution in its incremental refinement as well as its utilitarian exploitation of existing modules.

A. Technology

Robotics can be regarded as a typical and representative part of Mechatronics, as a cutting edge technology in this rapidly expanding research field [9]. Mechatronics combines in a synergetic way the classical engineering disciplines mechanical and electrical engineering and computer science, leading to new kinds of products. It can be stated that any technical progress in robotics will quickly spread over to products of everyday life and may eventually initiate further progress. Automotive technology for modern cars, for example, in making advanced use of sensors for controlling their dynamics and assisting in safe driving are following ideas from robotics [10]. In addition to that, the need for low-priced sensors in mass-produced cars has subsequently spurred the industrialization of micro technology in a very sustainable way. Methods of robotics and mechatronics serve, beyond the individual product, as guidelines for the development of complete systems. Thus, the name system robotics or embedded robotics has been coined, to describe the integration of sensors, control, actuators and information processing into a system. This can be a car, an automated traffic control system, a military air defense system, medical service and human care systems, or the safety and energy management system of a building. There are already names such as cartronics, or domotronics, characterizing these new fields [11]. The spread-over to smart machine technology, with self-calibration, self-diagnostics, and self-tuning control loops can already be seen. This will lead to improved safety, reliability, and maintenance procedures for such smart machines, and there the expected economic benefits are obvious.

Another important area that is profiting from the advances in robotics is the control of complex dynamical systems. Examples are humanoid robots, as well as vehicles, construction machinery, machine tools, or prostheses for limbs and hands. On one side, it is the non-linear, model based, adaptive control that makes novel machine tools with parallel kinematic structures feasible, together with hard real-time operating systems, being used already in mobile robots. On the other side, bio-inspired behavioural control will lead to intelligent mobile robots moving smoothly in unstructured environments. Ideas for such a kind of control architecture are derived from motor control in animals. The relation between robotics and biology, however, goes beyond that and will be considered subsequently.

B. Biological Implementation

Robotics has a very stimulating co-operation of mutual interest with biological information processing and neuroscience. On one side data processing in biological systems can play a role model for advanced robot systems, and on the other side, the proven methods and tools for modeling in robotics may help to better interpret and understand the rather descriptive input/output models usually being available in biology. Investigations on the walking of stick insects, the navigation of desert ants, the swimming motion of fish, and the flight techniques of bees are being related to mobile robots. This effort may be stimulated by the underlying assumption that the ability to master motions is an evolutionary component of intelligence. In particular when related to motor control, is using robotics to verify its models for walking or grasping motions. This will have implications for the better understanding of human motor control and the design of prostheses, technical replacements of sensory organs (techno-implants), and limbs (see chapter on knee prosthesis). The speculative question arises: will humans eventually be replaced by robots [12]. The subsequent consideration might contribute to an answer: Contrary to the passionately discussed potential of controlling human development by genetic engineering, the evolutionary change of humans and human life due to technical developments takes place in a dark spot of our realization. Our ability for information processing, moving around and conquering distance and remoteness, underwater and in space and overcoming biological deficiencies has dramatically changed just in the past one hundred years. Actually, it will be complemented now by gradually integrating intelligent robots as tools into our life, and by enhancing our life system by "spare part medicine", making use of techno-implants, i.e. artificial sensory organs, technical heart assist systems and prostheses. This development and its consequences is hardly reflected consciously. It can be assumed that humans will make the relevant decisions step by step within an evolutionary process.

C. Communication

The interaction between human and computer is seen today as one of the topics in computer science [6], and these approaches certainly will form an essential part of the communication methods between human and robot as well. In addition to that, safety aspects will be of much more importance, as a misunderstanding or a mistake in the communication can have most serious consequences. Furthermore, the activity and mobility that can be exerted by a robot will allow a wider range of communication modalities. The robot can turn its attention actively to points of interest, it can explore strange situations, and it can actually "bring" information or objects. The observer, seeing a real, moving robot will get different impressions than just by looking at some animated simulation from virtual reality. A nice example is the toy dog from Sony as shown Figure 1. It is even supposed to express "emotions", for example by wagging its tail. Emotions may play an important role for man-machine communication, expressing expectations, summarizing rational thinking, condensing information and representing it in an easily understandable way. This desire to generate human-like communications may be an argument for building humanoid robots whose body motion could carry "emotional qualities" that might be more easily interpreted by humans.

Figure 1: Robotics with emotional behaviours

D. Responsibility of Work

Another issue in designing the cooperation between man and machine is the allocation of work and the authority to make decisions when man and machine are jointly solving a task. Our capabilities to use automated machinery for carrying out complex tasks is increasing, and at the same time, we are aware of the limitations in the autonomy with which machines can or should perform these tasks. It therefore appears natural to design machines that can co-operate in an "intelligent" way with their human users, thus extending the range of the human and making best use of the capabilities of the machine. Such human oriented machinery will have novel features in their behaviour, related to their interaction with humans. The allocation of work between human and machine is a problem that is being discussed and will influence the way of automation and the design of future machines. We will need machines which can work in an autonomous way up to a certain degree of complexity, and in critical situations or on a higher level of autonomy the necessary interactions with the human operator or user have to be facilitated and structured. The design of a machine and its motion control heavily depends on the degree of automation, i.e. how function and authority is allocated to man and machine. There are a number of criteria for allocation, briefly characterized, for example, by the terms left over, economic, comparison, and complementary. In the left over scenario, the degree of automation is as high as is technically feasible and only the tasks that can not be automated are left over for the humans. Following only economic criteria means that for each partial task the cheapest solution will be chosen. In the case of comparison, a task will be allocated to the one, machine or man, who performs it best. The complementary approach assumes that man and machine have basically different capabilities that complement each other. The idea is to combine positive capabilities, the versatility of man and the consistency of the machine. Thus, the objective is to assist the operator by providing him with an intelligent tool, and not to replace him by an automated machine. At the Institute of Work Psychology of the ETH a concept for the co-ordination of the three areas Man Technique Organization has been derived. A number of projects have already shown the advantages of this approach for soft automation, and one example, the user oriented automation of flexible sheet bending, will be briefly presented subsequently. The manufacturing cell for flexible sheet bending was developed at the ETH Center for Integrated Production. The cell consists of a laser cutting machine, press brake, conveyor belts, and a robot. The work has been jointly pursued by the Institutes of Work Psychology, Forming Technology, and Robotics. The robot system for charging the press brake has to fulfill the requirements of the MTO-concept. It has to offer user friendly and application-tuned task level programming for interactive program optimization and error correction, as well as interaction facilities to intervene in decisions on every system level. Thus, for example, the cell can be used for manual manufacturing of single, complex products during daytime, and for fully automated operation during night shift. In this way the expert knowledge and the responsibility of the press brake operator can be maintained and even enhanced. The human worker and the robot are sharing the same work space. Not only can the contents of work be shared between man and machine, the authority, as well. The different levels for the complementary allocation of authority, i.e. who is in control of a process, are shown in Figure 2. The range spans from full human control (manual mode of operation) to the fully automated process. Of course, safety is a dominant issue in designing the appropriate man-machine-interaction. It can be improved by making best use of the "intelligence" of the machine.

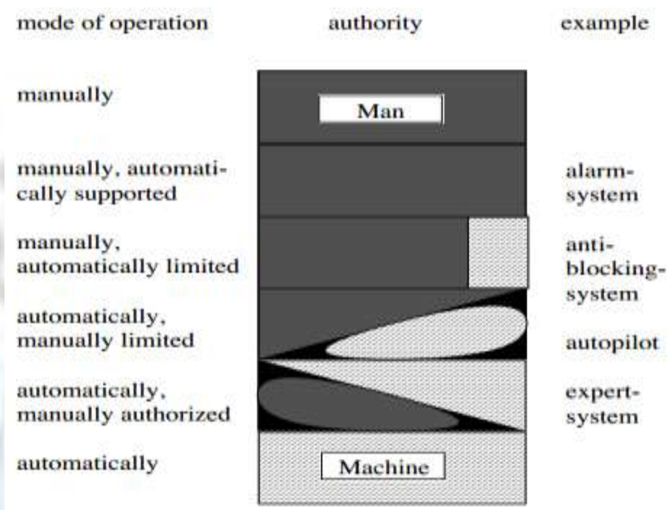

Figure 2: Different levels for the allocation of work authority between man and machine

III. METHODOLOGY

A methodological constraint of behavior-based systems is their use of state and representation of information is not centralized or centrally manipulated. Instead, various forms of distributed representations are used, ranging from static table structures and networks, to active, procedural processes, providing a rich medium for innovative interpretations. Behaviors can be designed at a variety of levels of abstraction. In general, they are made to be higher than the robot's atomic actions (that is, typically above 'go-forward by-a-small-increment' or 'turn-by-a-small-angle'), and they extend in time and space. Effectively, this elevates the representational level of the system, which has been shown to facilitate higher-level cognition and learning. Some commonly implemented behaviors include 'go-home', 'find object', 'get-recharged', 'avoid-collisions' and 'pick-up-object'. More specialized behaviors include: 'avoid-the-light', 'aggregate-with-group', 'find-mate', 'follow-edge', etc. The internal behavior structure of a system does not necessarily need to mirror its externally manifested behavior. For example, a robot that flocks with other robots may not have a specific internal 'flocking' behavior; instead, its interaction with the environment and other robots may produce flocking. Typically, behavior-based systems are designed so that the effects of the behaviors interact in the environment, rather than internally through the system, so as to take advantage of the richness of the interaction dynamics. These dynamics are sometimes called 'emergent' because they result from the interactions and are not internally specified by the robot's program.

A. Coordinating multiple behaviors

A key issue in behavior-based systems concerns the coordination of the multiple behaviors, thus making 'arbitration' (deciding what behavior to execute at each point in time) one of the central challenges. For the sake of simplicity, most implemented systems use a built-in, fixed priority ordering of behaviors. More flexible solutions, which can be less computationally efficient and harder to analyze, have been suggested, commonly based on selecting a behavior by computing some function of the behavior activation levels, such as voting or activation spreading.

B. Learning and adaptation

Learning has been called the hallmark of intelligence; thus, achieving adaptive and learning capabilities in artificial systems is one of the greatest challenges of AI. Learning is particularly difficult in robotics, because sensing and acting in the physical world involve a great deal of uncertainty, owing to incomplete and noisy information and dynamically changing environment conditions. It is often difficult for robots to perceive correctly (owing to limited sensory technology) and act on (owing to limited effectors) the variety of situations that arise in the physical world. Nonetheless, robot learning is an active branch of robotics, and is one of the variations and adaptations of standard machine learning techniques (in particular reinforcement learning) that have been applied effectively to robots. Behavior-based robots have learnt to walk, navigate, communicate, divide tasks, behave socially and even identify opponents and score goals in robot soccer. Reinforcement learning is the most popular method for learning in mobile robotics. It refers to a set of problems (rather than methods), in which the robot must improve its behavior based on rewards or punishment from the environment. The reinforcement learning model is based on early conditioning work in psychology, and recently an increasing number of robot learning systems have used related concepts from biological reinforcement learning, most notably shaping and operant conditioning. Supervised learning methods using neural networks have also been used. Some of the most effective demonstrations of learning in mobile robots have been inspired by biological learning systems.

C. Biologically Inspired Imitation

Our most recent work with behavior-based systems extends the control spectrum from planar mobile robots to articulated, anthropomorphic bodies. Again inspired by certain neuroscience theories of motor control (which demonstrate evidence of a finite set of additive force fields controlling the movement repertoire of frogs and rats), we are developing behaviors for the control of three-dimensional movement. As with our work on group behavior, we are using 'basis-behavior' primitives as a substrate for a broader repertoire of higher-level behaviors, obtained by sequencing and combining the basis set. Our current basis set includes behaviors for movement to a destination point, posture maintenance and oscillatory movements, all based on theories of human motor control, with the eventual goal of modeling learning by imitation. Acquiring new skills by imitation is a well-known robotics problem. It is usually classified as learning by demonstration, where the robot uses vision sensors to interpret the behavior of a human user and thus acquire a new task. Historically, assembly tasks have been learned by demonstration, without an effort to model precisely the observed behavior, but focusing on achieving the demonstrated goals. More recently, imitation learning between two mobile robots has been demonstrated, as has skill learning between a human demonstrator and an articulated robot arm with human kinematics, such as learning to balance a pole and play. The latter was an instantiation of the bidirectional theory of motor control, another example of a robotic implementation of a neuroscience model. Modeling human skill acquisition, while a tremendously challenging task, is gaining popularity in robotics. It has recently been approached from a Piagetian perspective, using developmental stages in order to simplify the complex learning problem. Computational modeling of motor control and learning is an active research area outside the scope of this review. Inspired by data from neuroscience and psychophysics that provide evidence for combined perceptual and motor activation during movement observation and imagination, we are developing a set of behaviors that not only produce movement, but also facilitate its perception. These behavior primitives simultaneously recognize and plan movements, thus combining perception and generation. Furthermore, the primitives facilitate prediction, in that they represent complete movements and when presented with an incomplete visual input, can complete it based on their own model of the movement. Practically, the system functions by continuously classifying the observed movements into its known repertoire, thus enabling imitation. Inspired by developmental psychology work providing evidence for infant prediction of goals implied in observed incomplete and incorrect actions, our primitives infer movement goals by internally matching, predicting and completing the observed movements. The ultimate goal of this work is dual, in a manner typical of behavior-based work, namely to provide insight into the animal/human imitation process, and facilitate automated programming of new tasks and skills in robotic systems.

IV. CONCLUSION

Robotics is a key science of this century. The development of robots into "intelligent" machines and systems will offer chances. However, challenges will have to be overcome. Intelligent robots should be able to communicate with users and work as intelligent tools in a co-operative way in the same work space. Here, "intelligence", and in particular the intelligence of robots, has been defined in a rather anthropocentric way, according to the needs of humans co-operating with such robots and using them as intelligent tools. Subsequently, trends and expected benefits of such intelligent robots are addressed. Technology related to and growing from robotics has been discussed. It includes areas such as mechatronics, automotive concepts, micro- and nano techniques, smart machine technology, soft computing, embedded robotics, and dynamics and control of complex, bio-inspired motion systems. Relations to biology and neuro science play an important role in defining robotics trends, and in giving an answer to the question: will humans be replaced by robots some day? The arguments converge to the conclusion that humans will make use of advanced robotics tools in an evolutionary way. The relation between man and machine will be a most important issue. It will require efforts in the technology of communication, and in the discussion of socio-economic, legal and ethical issues. Suggestions are being made for the simultaneous optimization of "Man, Techniques and Organization ". Examples for allocating authority, the decision making, in joint tasks of man and machine are shown. The classical objective of robotics, to build a robot which can work autonomously and which can do the work of man, is undergoing a change of paradigm: Instead of building machines that can do the work of humans, we should build machines that can do the work which humans can not do, or do not want to do.

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