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Robots for the Benefit of Humans

Contributions of our Lab and its Cooperation Partners

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Summary The article is a supplementary text going along with the Power Point presentation prepared for this lecture. The PP presentation can be accessed through the author's home page. The lecture starts with an outline of the speaker's interest and background in the field of robotics. It introduces more recent examples of work performed by his team and various cooperation partners over more than three decades, always at the continuously moving frontiers of robotics research and development. The lecture emphasizes the cross-disciplinary character of the area of robotics and its potential benefits for humans.

1. Introduction and Motivation

It is a great pleasure and a distinct honour for me to spend this afternoon together with you, the professors and students of Takamatsu High School. The idea for this lecture is due to my colleague and friend Professor Seiji Hata from Kagawa University, Takamatsu City. Professor Hata serves as the General Chair of this year's *International Conference on Instrumentation, Control and Information Technology – SICE 2007*, which is currently proceeding at Kagawa University, Fig. 3 (cited figures correspond to viewgraphs, videos etc of the PP presentation).

This year's visit to Takamatsu, which is actually my third, is not by chance. Professor Hata and myself are sharing several common interests. Some years ago we both initiated a closer academic cooperation between Kagawa University and my university, the Technische Universität München, Germany, abbreviated TUM. Because of a number of successful student and staff exchanges over the last years we had the pleasure to renew an earlier *Academic Exchange Agreement* during a ceremony at TUM in February 2007, Fig. 4 - 8.

To begin with let me briefly explain how I myself got interested in the area which is in the centre of today's lecture. It has a history of more than 50 years and starts at the time when I was about your age and a student at an institution called *Leibniz Gymnasium* in Wiesbaden, Germany, Fig 9. You will not be surprised that according to the name of the High School's patron, Johann Gottfried Leibniz (1646 - 1716), Fig. 10, the educational program emphasized maths, science and modern languages. Leibniz, the great German philosopher and mathematician was the inventor of determinants, the differential and integral calculus, and the binary number system, which all form an indispensable mathematical base for modern science and engineering.

During the 10th grade, my High School organized a study excursion to Munich, including a visit to the famous Deutsche Museum, Fig. 11, one of the first technical museums in the world. In its exhibits of historical technical master pieces I was fascinated among others by a prosthetic device, the multi-fingered Goetz hand (1504), Fig. 12, and an android artificial musician, the mechanical trumpet player (1810), Fig. 13. Starting from this experience I developed a broader interest in similar artefacts, which somehow emulate human or anthropomorphic abilities by use of available “modern” technology. After some research, I discovered that even in the very early ages of the Greek and Romans, there was already some interest in such devices, e.g. organs and clocks with movable figures. The same is also true for other cultures, like in Asia. Prominent examples are the Tea Serving Puppets developed in Japan during the Edo and Meiji periods, Fig. 14. A rather visionary science fiction automaton from the beginning of the last century is the artificial policeman *Robocop 1924,* Fig. 15, a figure that became also very popular by the movies.

After graduation from High School, followed by an obligatory one-year internship in the workshops of several mechanical and electrical engineering companies, I entered the *Technical University of Darmstadt,* Fig. 16. During my Electrical and Communication Engineering education I got acquainted with the first commercial computers and studied their application to motion control of machine tools, also called CNC machines. 50 years ago this subject area was at the real frontiers of scientific research and development. Imagine that at this time a computer with the power of less than a simple electronic calculator today filled a spacious air-conditioned office room.

From control of machine tools my interests shifted to motion control problems of vehicles, such as cars, trains and aircraft. As a postdoctoral Visiting Scholar at *Stanford University,* Fig. 16, about 40 years ago, I developed some theoretical approaches to minimum energy control of station to station motion of high-speed urban trains and to optimal transition control of VTOL-aircraft. Later, as an electronics and control engineer with the *Dornier Aerospace Company* at Friedrichshafen, Germany, I got involved in developmental and experimental work related to the VTOL transport aircraft *Dornier DO 31*, Fig. 17, and an unmanned teleoperated reconnaissance helicopter *KIEBITZ* (“peewit”, a curious bird), Fig. 18. By the way, Friedrichshafen, located at the Lake Constance, was the place where in the early 20th century the first commercial airships, the famous Zeppelins, and some years later the jumbo-sized transatlantic flying boat *Dornier DO X* where designed and manufactured, Fig. 19.

In the early 1970s I became a Professor and Director of a Research Laboratory for Control and Automation at the TUM. Based on my earlier fascination with human-like mechanical devices and my more recent industrial and engineering experience, I decided to enter the area of robot research. Around this time, Japanese engineers were very successful in introducing robust robot arms at a broader scale in the car and electrical manufacturing industries, e.g. for pick-and place or welding tasks.

Different from ongoing industrial developments the scientific interest in our lab moved rather early to the application of ideas, concepts and technologies from industrial robotics to areas which were directed to the needs of humans. This leads me eventually to the actual topic of today’s lecture: *Robots for the Benefit of Humans.*

In the following, I will present sample examples from more recent research and development work performed in our lab, often in close cooperation with partners at universities and industries. In the course of the discussion you may note that a typical characteristic of respective research is the interaction between the human and some robotic device.

2. Robots for Amusement

The KUKA *Robocoaster*, rests upon robot arm technology developed for many decades by the KUKA Co. with the objective to increase productivity of industrial manufacturing. This technology, which must be considered a sophisticated combination of mechanics, electronics and computers, an engineering discipline that is also called *mechatronics*, has become so powerful, flexible and safe that the company recently decided to add a gondola to the robot's wrist, Figs. 21 - 23. This modification allows two seated persons to enjoy a Robocoaster ride by choosing from a wide range of ride profiles and speeds, varying from gentle to extreme. Naturally, this novel type of coaster could only start its operation in amusement parks, like LEGOLAND, after passing the necessary safety tests and inspections.

3. Autonomous Mobile Robots

The introduction of robot arms in factories led to major increase of industrial productivity and opened the way to more flexible forms of manufacturing. However, transfer and transportation of parts from workstation to workstation proved to be a major bottleneck. Therefore we got interested in overcoming the limitations of existing *Automatic Guided Vehicle* (AGV) technology, which requires for its safe operation an expensive and inflexible infrastructure, such as fixed guide-wires in the plant-floor.

3.1 Mobile Robots on the Factory-floor

As an alternative we proposed a type of Autonomous Vehicle, with the capability to *localize* itself (Where am I ?) by use of a map and natural landmarks in the environment, to *navigate* (How do I get from location A to B ?), and to *move* safely (avoiding collisions) by use of concurrent real-time information from various onboard sensors, such as ultra-sonic devices and different types of cameras, Figs. 25 - 26. The introduction of this kind of *Autonomous Mobile Systems* (AMS) leads to manufacturing with higher degrees of flexibility in transportation. In addition AMS technology offered the possibility to develop multi-functional vehicles for purposes of pallet transportation, forklift operation or even floor inspection tasks.

This experience opened also our mind for novel ideas, such as mounting a robot arm on top of an AMS, leading to a non-stationary *Autonomous Mobile Manipulator*. Such systems offer an increased number of degrees of freedom of motion and allow to perform manipulation tasks in extensive workspaces, as for example along the wing of an aircraft. Through introduction of AMSs and Mobile Manipulators major progress in implementing the concept of a real *Flexible Manufacturing System* (FMS) could be achieved.

3.2 Mobile Manipulator for Fetch-and-Carry Tasks

The experience with Autonomous Mobile Manipulators on the factory floor stimulated also the idea of developing a type of wheeled *Personal Robotic Assistant*. It comprises an omni-directional locomotion platform, a light-weight robotic arm with a two-fingered hand, the necessary localization, navigation and piloting capabilities and last but not least a voice input/output system as *Human-System-Interface* (HIS), Fig. 27 - 28.

3.3 Mobile Manipulator in Hospital Environment

A next step was the adaptation of the before-mentioned Personal Robotic Assistant to the needs of people in a senior citizen home or of patients in a hospital, Fig. 29 - 30. It may be noteworthy, that *acceptance* of such a robotic helpers by patients or people in general plays a key role. This means that technology developers have to be seriously concerned with human factors and psychology in order to come up with innovative and successful products for this growing market segment. For the end-user it is not robotics that counts, it is rather the safe service and convenience that technology can provide. In contrast to the factory environment, where engineers and skilled workers deal with robots, in the service area non-expert and sometimes even handicapped people are expected to cooperate with such systems. This means that it may be wise to “hide the robot under the hood”, thus that users are not scared by technology, which they often don’t understand. From this example we can conclude that the application of robot technology in service environments, such as in hospitals, our homes or supermarkets needs much more sophistication and sensitiveness to human needs and demands compared to the classical application of robots in the factory. Thus, “embedded robotics” may become an important trend in the near future.

4. Robots and Robotic Approaches in Medicine

Medicine offers many opportunities for application of robotic devices and techniques. The table in Fig. 32 presents just a few examples: organ function replacement systems, support systems for various classes of users or novel educational and training systems. We will discuss examples for each of these application areas.

4.1 LOKOMAT – A Driven Robotic Gait Orthosis

The LOKOMAT, Fig. 33 - 36, supports functional training of neurological patients in activities of daily living, like ambulation or walking. The LOKOMAT is a motor-driven exoskeleton, i.e. sort of an active brace. This *robotic gait trainer* comprises robotic arms attached to each of the patient’s legs. The arms guide the legs mimicking normal human gait. The system assures a precise synchronization between the speed of the driven limbs and the motion of the treadmill. LOKOMAT relieves therapists of the manual labour during manually assisted training. Therefore, training sessions can be longer and more repeatable.

4.2 A Patient-driven Gait Neuroprosthesis – WALK

This feedback controlled neuroprosthetic system was developed for motion restitution of patients with spinal cord injury, leading often to partial or complete loss of all motor and sensor functions in the lower extremities, Figs. 37 - 43. Since muscles and the peripheral motoneurons remain untouched, muscle contractions can be initiated by a neurostimulator together with skin attached electrodes through focused functional electrical stimulation (FES). The actually achievable benefit for the patient, i.e. an increase in quality of life, depends heavily on the efficiency and intelligence of the control system within the neuroprosthesis. Both are key objectives of our cross-disciplinary and robotics’ inspired research efforts.

4.3 Virtual Orthopaedic Reality – VOR

There is a growing need for more sophisticated forms of training of medical students, for example for the diagnosis of the various types of knee joint diseases, Figs. 44 - 49. Together with medical partners we developed for this purpose a multi-modal (involving various human senses) orthopaedic training simulator. The system is based on formal bio-mechanical models, industrial robot technology and techniques adopted from *virtual reality* (VR). The simulator supports the user in realistic learning of specific orthopaedic examination methods, while results achieved during operation are monitored and evaluated. Note the similarity of this approach to the well-known pilot training by use of flight simulators.

5. Telepresence and Teleoperation

Teleoperation is required were a direct physical interaction of an operator with a *“remote”* environment is not possible because of distance, hazards, size etc. Early forms of this technology were developed during World War II with respect to servicing of nuclear facilities. More recent examples of teleoperation are also found in space, deep-sea or even medical applications, like *computer-assisted surgery*. The basic idea of teloperation is putting a *teleoperator* at the remote site and to interconnect the operator with the teleoperator by a *communication link* and a *human-system interface*. *Telepresence* is a more recent extension of teleoperation allowing the operator to experience the remote environment with a few or all his/her senses (multi-modality) while interacting indirectly with the physical environment. Telepresence techniques have the potential to enhance operator or user immersiveness into the remote environment and to increase operator efficiency in task execution, Figs. 50 - 51.

5.1 Guiding of a Remote Mobile Teleoperator

In this application a user located in city K is interconnected via Internet with a mobile teloperator in city M, Figs. 52 - 53. Through a head mounted display (HUD) the operator can look into the remote environment. Simultaneously, the user's locomotion in the user environment is transmitted to the teleoperator, thus controlling platform locomotion and view direction of an onboard camera. By moving around in the user environment the user feels somehow realistically immersed into the remote environment.

5.2 Walking About a Virtual Museum

In this application the remote environment is a synthetic, i.e. virtual or computer-generated, and not a physical environment. By fusing the visual feedback and his/her motion impressions the user feels immersed in walking about a museum, Figs. 54 - 55.

5.3 Disposal of Explosives and Demining

Because of the hazards involved in disposal of explosive ordnances or in demining this is a highly relevant application area for introduction of novel teleoperation and telepresence technologies. A two-arm telerobotic system enables an expert to perform disposal operations from a control station in a safe environment, using in addition to a visual a display some sort of haptic display system, Figs. 56 - 59. The latter allows the operator to input position and force control commands to the remote teleoperator and to experience force and touch sensations transferred from the remote site to the operator's arms and hands.

5.4 Advanced Virtual Prototyping

This application is associated with digital product development, as practiced in the automotive and aerospace industries. The remote environment is replaced by a synthetic computer-generated world. By use of a novel human-system interface the user cannot only see and hear the radio in a virtual instrument panel, but he/she can also move it around and touch it, Figs. 60 - 61. By means of a complex hand/arm display a user can feel the weight of the radio when lifting it, experience the smoothness, roughness and temperature of its housing and eventually even feel the force required while inserting the radio into the instrument panel. The various modalities are rendered by sophisticated software systems and so-called *rendering engines*.

6. Humanoid Robots

The development of humanoid, human-like, robots has made significant progress in recent years. In Japan, research institutes and companies have presented a variety of humanoid robots with amazing locomotion, dancing and even artistic capabilities. However, their abilities to interact intelligently with the environment are still rather limited. Major constraints result from a lack of cognitive capabilities, such as environmental perception, intelligent decision-making and action, and deficiencies in combining locomotion with dextrous manipulation, which are all basic human competencies. Therefore, recent research in our group and in partner institutions is directed to overcome some of these limitations and to bring us closer to our vision of a humanoid robot, showing at least some modest intelligent behaviour while interacting with an environment made for humans, Fig. 62.

6.1 Intelligent Humanoid Robot Walking

Intelligent, i.e. continuous, goal-oriented and safe, walking of both, humans and robots, requires interaction of locomotion and perception. After studying some of the related problems together with experts from biology, psychology, medicine and engineering we developed a vision-guided biped robot JOHNNIE, which demonstrates some degree of intelligent behaviour, when walking along a 3D environment made for humans, Figs. 63 - 68.

6.2 An Advanced Humanoid Two-arm Robot

Complementary to our interest in intelligent biped walking, our partners at DLR, Oberpfaffenhofen, Germany have focused the problems of dextrous manipulation. They recently presented a human-like upper body system, the torso JUSTIN, comprising two arms with 4-fingered hands and a head with eyes, allowing intelligent manipulation, Figs. 69 - 71. The combination of the torso JUSTIN with an intelligent biped locomotion platform like JOHNNIE would certainly bring us closer to the vision of a “real” humanoid robot.

7. Final Remarks

As a person being active for more than half a century as an engineer, scientist and educator, it is my hope that this lecture succeeded in transferring some of my fascination with engineering and robotics to you, a promising generation of bright young men and women.

Considering the topic “Robotics for the Benefit of Humans” it is my understanding that we are still at the beginning of a longer-term development. This impression is also documented by some recent articles, written by people from Microsoft, foreseeing *Personal Robotic Helpers* in any home, Fig. 73.

There is a famous word by Thomas A. Edison: *“To invent you need a good imagination and a pile of junk”*. This may be still correct. However, one of the major challenges today is to convert an *invention* into an *innovation*, i.e. a socially accepted and economically successful product. This process requires ambitious and creative young people with a solid basic education not only in maths and the natural and computer sciences, but also a good understanding of social developments, psychology, economics or marketing and last but not least an openness to *cross-disciplinary team work*, Fig. 74.

While in the past technology proved to be the major driver of economic development, we are expecting for the future (i) a dominance of awareness for customer demand, in particular for the demands of an *aging society*, and (ii) the emergence of a broader *assistance business*. In this context robotics on the *macro-scale*, as discussed during this lecture, as well as on the *micro-scale*, e.g. for the life sciences and biotechnology, and even on the *nano-scale*, e.g. for drug application and nano-size machine tools, may play a key role, Fig. 75

Thank you for your kind invitation to this lecture and for your patience in listening to me.

Your comments and questions will be highly appreciated.

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