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The beauty of theory that moves

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by

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The beauty of theory that moves

Meneer de Rector Magnificus,
Ladies and Gentlemen,

The world of robotics has fascinated mankind since the ancient days and has always inspired scientists and the fantasy of people.
As defined in the Wikipedia [1]:

> *"A robot is a mechanical device which can perform complex tasks either according to direct human control, partial control with human supervision, or autonomously (that is, fully under computer control)"*

The etymology of the word Robot comes from the Czech "robotnik" (slave) by itself coming from "robota" (forced labor, drudgery) and first used in the play R.U.R. (Rossum's Universal Robot 1921) by Karel Čapek, one of the most important Czech writers of the 20th century. It seems nevertheless that the word was invented by the brother Josef who used it initially in a short story.

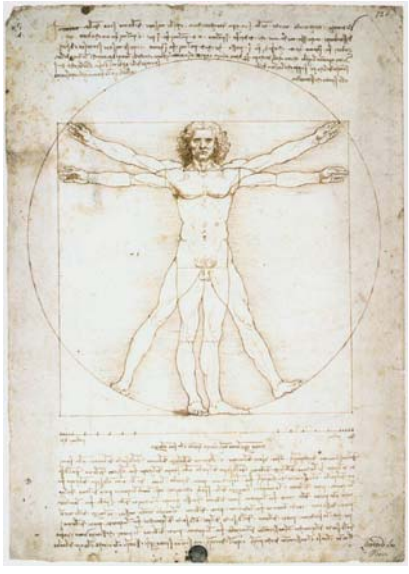
Karel Čapek 1890 - 1938

The first idea about a robotic device stems from the ancient Greek time and the work of Archytas (428 BC - 347 BC) a Greek philosopher, mathematician, astronomer, statesman, strategist and commander-in-chief, famous as an intimate friend of Plato, who was born in Taranto (Italy), which in those times belonged to the Magna Grecia. Archytas created a mechanical bird he called "The Pigeon" (350 BC), propelled by steam which actually was said to have flown for about 180 meters, probably suspended on a wire or pivot for its "flight".

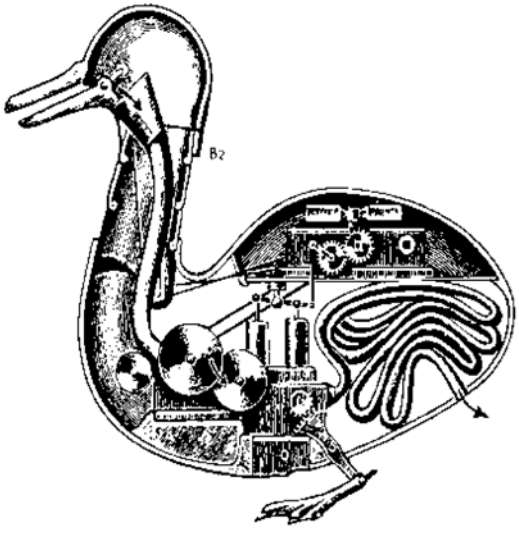
The first recorded design was made by Leonardo da Vinci around 1495, and it concerned a mechanical knight that was apparently able to sit up, wave its arms, and move its head and jaw. The drawings of this design were rediscovered around the 1950s in Leonardo notebooks and were likely based

on his anatomical research recorded in the *Vitruvian Man*.

The first working robot is instead said to be due to Jacques de Vaucanson, a French engineer and inventor from Grenoble (France). In 1737 he built his first automaton, *The Flute Player*, a shepherd that played the tabor and the pipe and had a repertoire of twelve songs. One year later he presented his creation to the Académie des Sciences. Later that year, he created two additional automatons, *The Tambourine Player* and *The Digesting Duck*, which is considered his masterpiece. The



Vitruvian Man (1490)



The Digesting Duck of Jacques de Vaucanson

duck had over 400 moving parts, and could flap its wings, drink water, digest grain, and defecate.

Many other scientists have contributed then to the development of robotics, such as Joseph Jacquard, who in 1801 developed the first automated Loom; Charles Babbage, who in 1822 proposed a design of the first programmable computer called the “Difference Engine”, and who is considered by many to be one of the founding fathers of computer science; and Nikola Tesla, mainly known for forming the basis of modern alternating current electric power (AC) systems, who created the Remote Controlled Boat in 1898 and is thus considered the first scientist to create a tele-manipulated robot.

Robotics has fascinated humanity for centuries: in 1941 Isaac Asimov, a Russian-born American Jewish author and biochemist, wrote a robot story entitled "Runaround," first published in the March 1942 issue of *Astounding Science Fiction*, in which he recited for the first time his Three Laws of Robotics [2], which became world famous afterwards.

Maria, Fritz Lang’s “Metropolis”

Hollywood has certainly also contributed to the interest and fantasy around the world of robotics, starting from Fritz Lang's movie "Metropolis" in 1926. "Maria", the female robot in the film, is the first robot to be projected on the big screen.

Application Fields

The application fields of robotics are many and will increase in the coming years without any doubts. Common fields of applications are Medical and Health Care, Service, Surveillance, Security, Space, and, last but not least, Entertainment.

In the Medical Sector, a successful story is the one of Intuitive Surgical (http://www.intuitivesurgical.com/) with the System “Da Vinci” which is

becoming widely spread in Minimally Invasive Robotics Surgery. Also other robotized systems are used for the treatment of tumors. In these systems, an x-ray beam is focused on a specific constant target point, while the beam constantly changes positions, in order to have maximum radiation only in the target region.

Intuitive Surgical DaVinci System

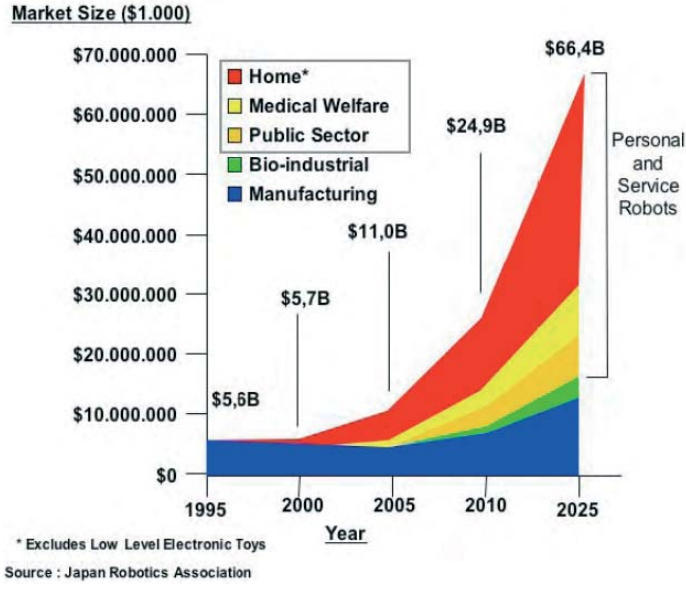
Service Robotics is an increasingly growing sector, where many different applications are being developed. Examples are the robot Manus, which supports disabled people, automatic tennis balls catchers, vacuum cleaners, swimming pool cleaners, and tanking machines.

In security and defense, one of the market leaders is IRobot, which, besides producing the very successful vacuum cleaner Rumba, has major contracts with the US Department of Defense and provides many of the robotics devices that have been used, for example, in operations in Iraq. Another recent and amazing development in military applications is the very robust quadruped Big-DOG, developed by Boston Dynamics, a spin off enterprise of MIT.

Space is one of the fields which really would not have existed without robotics. Many rovers of JPL and ESA have appeared, but also the ERA ARM developed by Dutch Space, which will be launched shortly, and the Robonaut of NASA are examples of nice applications of robotics in space.

NASA Robonaut

Entertainment is becoming an important sector and many Japanese companies like Honda and Fujitsu are investing big capitals in these markets. Philips is also starting interesting activities in the study of human machine interaction with the ICat and the study of autonomous behavior and vision in their involvement in robotics soccer.



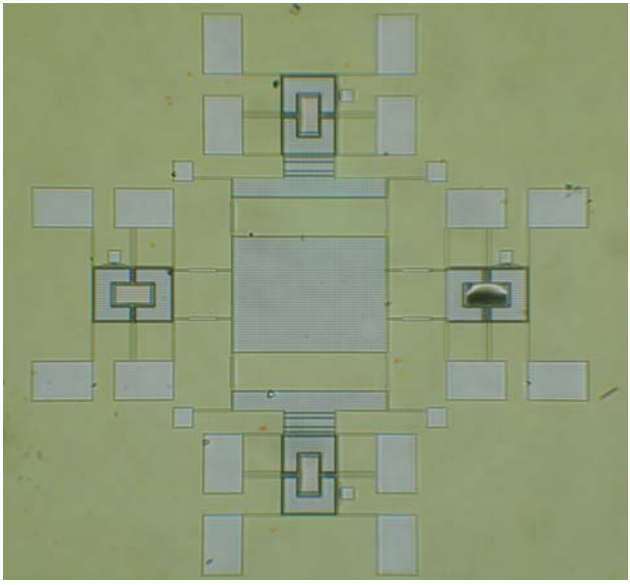
It is interesting to look at the forecasting of the Japan Robotics Association (http://www.jara.jp/), which foresees an incredible increase of the market size in the coming twenty years. This will mainly be the result of an increase in Personal and Service Robotics which is likely to become pervasive in our society.

Some Current Activities

After this extensive introduction I would like to present four projects and several other activities in which I am involved, in order to give a flavor of the robotics taking place in Twente.

Micro-robots can be useful for various applications, as sub-parts of bigger systems such as humanoids, or as devices used by themselves in medical, storage, security and many other applications. Beside miniaturization, one topic which has interested me for many years is the deep understanding of multi-body mechanics and its physical interaction with the environment and with control loops in order to achieve difficult motions [3,4].

I have tackled these problems so far making wide usage of the geometrical mechanics of Lagrangian and Hamiltonian systems, but especially of Port Hamiltonian Systems [5,6,7] as introduced by Prof. Arjan v.d. Schaft and Prof. Bernhard Maschke in 1992 [8].



µSPAM: Two DOF moveing plate for probe storage designed by ir. Mihai Patrascu.

Let me give some specific examples of projects I am directly involved in.

The goal of the STW micro-SPAM project, coordinated by Dr. Leon Abelmann, is to develop a new storage device with Gbytes per square centimeter density and access times below three milliseconds .
Within this setting, the mWalker originally designed and developed at the TST group led by Prof. Miko Elwenspoek has been modeled and characterized in details since it will form the main actuator for the final device [9.10]. Thanks to the insight gained during these studies new designs have been conceived and a novel 2D table has been fabricated that translates perfectly without torsion.

The IOP sponsored project MAMS, Multi Axis Micro Stage coordinated by Prof. Herman Soemers tries to develop a six degrees of freedom manipulator which should fit within the 2-3 mm of the magnetic lenses of a Transmission Electron Microscope (TEM). In the project two conceptual designs are investigated beside the study for methodologies to achieve accurate enough

MAMS: 6 dof platform designed by ir. Dennis Brouwer.

measurements. One design uses a two stage motion [11] and the other tries to develop a silicon parallel structure.

The goal of the NWO sponsored project LOPES, Lower Limb Powered Exo-Skeleton coordinated by Dr. van der Kooij is to develop a novel exoskeleton for the rehabilitation of stroke patients. The novelty of the approach is to control the system with variable impedances in order to adapt to progress of the patient during a rehabilitation program.

The last project I will discuss, which I have coordinated myself since 2002 for the European Commission, is called Geoplex: Geometric Network Modeling and Control of Complex Physical Systems [12,13,14]. The goal of Geoplex is to study various physical systems using port Hamiltonian theory. The usage of Port Hamiltonian Systems is extremely powerful both for the modeling and control of micro- and macro-systems and will be perused further in the coming years.

GEOPLEX: *The Robot Dribble made by ir. Gijs van Oort and ir. Edwin Dertien, and the 3D Tracker.*

It is my strong believe that properly distilling a problem and describing its essence in a good mathematical and geometrical language, without forgetting essential practical issues, is the only way to achieve conceptually new systems.
It could be argued that many tasks or control algorithms may be ``learned" by Fuzzy, Neural Networks or Genetic Algorithms like methods, but it is my believe that, even if nice results can be obtained with these methods, the essence of why a solution is obtained can not be grasped and further insight is often lost.
I believe that a beautiful area in robotics, where geometrical and analytical mechanics can help in tackling a fundamentally difficult problem, is the robust control of energy efficient bipedal machines. In this context we developed the robot Dribble, a planar biped robot which can walk with approximatively 6W.

Beside scientific projects, I am involved in local and international activities, some of which are the coordination of the Strategic Research Orientation on Smart Devices and Material of the IMPACT institute of our University, the membership of the advisory board of the IEEE Robotics and Automation Society which holds more than 6000 members worldwide, the Editor in Chief office of the IEEE Robotics and Automation magazine, fourth journal worldwide in robotics, and the Twente coordination of the to be formed Dutch Care Technology Institute.

Last but not least, in the framework of the new national developments around the new Center of Excellence of the 3TU Institute of science and Technology, I will have the pleasure to structurally collaborate with competent colleagues in Delft and Eindhoven to further encourage existing collaborations.

Valorisation of Researcch

Let me say few words on my view on valorization of research.

There are two types of valorization of research. The first one is related to the almost direct applicability of research results. This is often the semantic which is associated to the word valorization. The second form of valorization is instead the real long term innovation, creativity and progress which can result solely by the collaborations of Universities and Industry in a long term window. This second kind of valorization is the one which can keep the knowledge economy to an acceptable level for the years to come and should

be continuously stimulated.
We have the fortune in Twente of having groups of enterprises like the Mechatronica Valley Twente (MVT) which understand this view and people like Dr.ir. Dennis Schipper who really see the added value of strong collaborations without too much emphasis on short term results specific to the realization of a product, but rather to the essence of collaboration and exchange of knowledge and expertise.

Scientific Dreams

Science is driven by dreams which motivate enthusiasm and creativity and I now want to talk about one of my own dreams.

To justify what follows I would like to give a brief overview of the evolution which has taken place in robotics. This overview is due to the president elect of the IEEE Robotics and Automation society, dear colleague, and friend Prof. Bruno Siciliano. Originally, the need for helpful machines has brought the development of industrial robotics, and, as a consequence, manufacturing applications. After that, the strongly growing field of service robotics and space applications have entered. Nowadays, robots have come even closer to humans, with medical and clinical applications toward personal robotics. The trend and evolution over the past years shows furthermore the Humans' dream of replicating themselves and this justifies the increasing interest in humanoid robotics.

Besides the technological challenges that are involved, there will also be social acceptance problems. Nevertheless, in my opinion, it is not a matter of WHETHER humanoids will be used on a large scale, but rather WHEN this will happen.

"Hi, I'll be performing your surgery tomorrow."

But what is the next step? What is still missing? What should we work on?

What should the new generation humanoids be like? A new humanoid should be R.I.S.E.: Robust to walk stably and to be able to recover from stumbling, Intelligent to adapt to the environment and achieve situation

awareness, Soft to ensure safe interaction with humans [15], and, last but not least, Energy efficient to make it to a usable system in practice.

I believe that the key to achieve this goal is a deep knowledge of analytical mechanics and dynamics, together with good engineering expertise. Furthermore I am convinced that the power and insight that port based techniques give will play a key role in solving many of these challenges. Last but not least, I have the pleasure and fortune to be surrounded by many competent and pleasant colleagues and this is an indispensable ingredient for success.

Let me just say a few words about teaching.

In my opinion, there are three ingredients which are essential to teaching:

1. Keep the quality of the material high to what you believe students must learn and do not adapt the level as a consequence of bad results;
2. Keep a friendly informal relation with students, since that is a cataliser for motivation and interest;
3. Show enthusiasm, which is more contagious than many biological viruses!

Also among students, the field of robotics is very popular. In the last four years, the number of students has steadily increased and this has also resulted in many projects for a final M.Sc. assignment.

I believe that in teaching robotics, the usage of many animations is essential to convey intuition on difficult concepts.

Furthermore, I believe that, also in an engineering education, it is fundamental for students to learn the logic of mathematical reasoning, including mathematical proofs, and to enforce the abstraction level with which they should be able to work by distilling a problem to its essence. That is why I seriously test these capabilities during exams.
Attractive examples are also fundamental in order to show that complex

mathematical modeling and abstractions are not useful by themselves, but that they allow to easily tackle problems which would be too difficult otherwise. An example is the kinematical analysis of mechanisms.

I believe that geometrical models which can be pictured can be illuminating. One typical example is the explanation of the stability or instability of rigid body rotations using the geometric intersection in body momentum space of the kinetic energy ellipsoid and the momentum sphere.

Conclusions

Let me finally draw some conclusions.

I believe that one of my best strengths is a strong mathematical background, combined with a good vision and feeling for engineering and a strong intent to construct real devices. I will invest my time, efforts, and enthusiasm in the years to come in order to work toward the achievements of many robotic dreams.

I am looking forward to encourage pleasant and fruitful collaborations within the University of Twente and outside and I will keep on being active in the international arena to promote the University of Twente as a leading and stimulating research and educational institution.

The robotics arena is one of the scientific fields where a good analysis and nice geometric tools can flower in real devices. These devices can help society in many different application domains, a real *beauty of theory that moves*.

Acknowledgments

The fact that I am here today is not only due to personal commitments and investment of time but is also thanks to many people who have contributed either on the personal or scientific level to achieve this important milestone in my life.
To name all the people who directly or indirectly have helped me would take too long and it is inevitable that I will leave some out.
I would like to thank Prof. Job van Amerongen for his continuous support and trust, all my students for the valuable help, collaborations and contributions to my research and all people of Control Engineering and Control Lab Products for the nice working atmosphere.

I would like to thank Prof. Alfred Bliek and ir.Peter Vroegop for their trust and their nice and pleasant attitude during my recent involvement as SRO in IMPACT.
I would also like to thank the dean of our faculty Prof. Tom Mouthaan and the Rector Magnificus Prof. Henk Zijm for their continuous support and enthusiasm in the management of the Faculty and University.
Gijs, Miko, Herman, Leon: thanks for letting me discover the beauty and challenges of the micro-world, I am sure we have many fun years ahead!
Peter, thanks for introducing me to the power of port based modeling.
Arjan and Bernhard: I still consider you as probably the most inspiring people in my academic career, thanks for everything!
Thanks to all people of the University of Twente for making this University such a pleasant environment to work in.

Beside the academia there are few people that I would like to thank in my personal life.

Joke en Rijk, het is nu al veertien jaar dat ik in Nederland woon en vanaf het eerste moment hebben jullie mij altijd geholpen, ondersteunt en als jullie zoon behandeld, hartelijk bedankt daarvoor.

Luca e Mamma, vi ringrazio per il supporto e l'amore che mi avete dato e dal momento della mia nascita fino ad ora, senza il vostro continuo aiuto non sarei mai arrivato dove sono ora. Purtroppo papa' non puo' essere fisicamente presente, ma e' sicuramente a lui che devo la passione per la tecnica e l'amore a cui ho dovuto rinunciare purtroppo troppo presto.

Fiona: being married to a scientist is not easy; being married to an enthusiastic scientist is difficult; being married to a workaholic enthusiastic scientific is a real challenge. Without your personal support, patience, motivation, love, and help in difficult moments this would never have been possible.
The achievement of this personal goal has cost a lot of our family time and I hope I will one day be able to slow down my addiction for my work and find a good balance between my time investments.

Robin en Emily: waarschijnlijk vonden het jullie het erg vervelend, maar ik hoop dat het beeld van papa in z'n gekke jurk op jullie netvlies zal blijven. Het is zo ver!

References

[1] Wikipedia, http://www.wikipedia.com

[2] Asimov, I., "Runaround" (originally published in 1942), reprinted in I, Robot (a collection of short stories originally published between 1940 and 1950), Grafton Books, London, 1968, pp. 33- 51.

[3] Stramigioli, S. (1998), From differentiable manifolds to interactive robot control, PhD thesis, Delft University of Technology, Delft, The Netherlands. ISBN 90-9011974-4.

[4] Stramigioli, S. (2000), 'Intrinsically passive control and the ipc-supervisor architecture', MIROS Journal, Special Issue on "Force Control of Advanced Robotic Systems" 2.

[5] Stramigioli, S. & Duindam, V. (2004), 'Port based modeling of Spatial Visco-Elastic Contacts', European Journal of Control 10(5), 505–514.

[6] Stramigioli, S., van der Schaft, A., Maschke, B. & Melchiorri, C. (2002), 'Geometric scattering in robotic telemanipulation', IEEE Trans. on Robotics and Automation 18(4), 588–596.

[7] Stramigioli, S., Secchi, C., van der Schaft, A. & Fantuzzi, C. (2005), 'Sampled data systems passivity and discrete port-hamiltonian systems', IEEE Transactions on Robotics 21(4), 574–587.

[8] B. Maschke, A.J. van der Schaft, "Port-controlled Hamiltonian systems: modelling origins and system theoretic properties'', pp. 282-288 in Proceedings 2nd IFAC Symposium on Nonlinear Control Systems (NOLCOS 2004), Ed. M. Fliess, Bordeaux, France, June 1992.

[9] Ligterink, N. E., Patrascu, M., Breedveld, P. & Stramigioli, S. (2005), 'An energy-based electro-elastic beam model for mems applications', Sensors and Actuators A 117, 500–507.

[10] Patrascu M., S. Stramigioli and J. van Amerongen, "Modeling, Design and Control of the µWalker, a MEMS-based Storage Medium for µSPAM", Proceedings of the IMST 2004, Workshop on IMST 2004, RWTH, Aachen, pp H05, 2004

[11] de Jong, B.R., Brouwer, D.M., Jansen, H.V., de Boer, M.J., Lammertink, T.G., Stramigioli, S. and Krijnen, G.J.M., "Planar 3 DOD Sample Manipulator for nano-scale characterization", MEMS 2006, Instanbul, Turkey.

[12] S.Stramigioli (2004), Geoplex: A systematic approach to mechatronics, in 'VDI-Berichte 1842', Vol.1842, VDI, Darmstadt, pp. 1–8.

[13] Diolaiti, N., Melchiorri, C. & Stramigioli, S. (2005), 'Contact impedance estimation for robotic systems', IEEE Transactions on Robotics 21(5), 925–935.

[14] Duindam, V. & Stramigioli, S. (2004b), 'Port-Based Asymptotic Curve Tracking for Mechanical Systems', European Journal of Control 10(5), 411–420.

[15] Bicchi, A. & Tonietti, G. (2004), 'Fast and "soft-arm" tactics', IEEE Robotics and Automation Magazine.

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