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Influence of the new trends in the economics on the military and industrial robot system design philosophy

Author's summary of the (PhD) Dissertation

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1. THE SCIENTIFIC PROBLEM

Robots are a part of everyday reality. Their presence and abilities are ever growing and they are transforming our future. Although much academic research has been done on the many challenging technical aspects of robots, little research is made on the social, geopolitical and economic factors that drive this industry ahead. The thesis will focus on the role and purpose of robots in human societies, both from an industrial and military perspective. The way industrial and military robots are positioned in 2010-2013 will allow making conclusions and identify trends forecasting about their future.

My research aims to determine how robots and their use - as part of flexible automation - have influenced society since their beginnings many centuries ago and how inbred human fear of machines is being dealt with. Also I look at how robotics is spreading within society and the various industrial sectors and how this will influence future development of industrial robots and linked sectors such as military robots. I limit the scope of my active research to the industrial and military robots, while only touching the areas of service robots, humanoids and androids, among others. My analysis of the various goals of the numerous types of military robots allowed me to draw up a clear segmentation matrix. This military driver matrix allowed me to define military robots within their groups and simplifying research on trend analysis, exposing limitations and predicting future development.

Technology is marching forward, and with it the field of robotics. To determine the future of industrial robots I used economic modeling tools like the Product life Cycle and Concentration Curve to base and test my research hypothesis. These models clearly show the maturity of the industrial robot, which will lead to its technological diversification. The experienced growth by industrial robots will likely continue while the high market concentration limits newcomers to niches. To understand the areas for growth within industry it is paramount to understand how robot-use grows within a company. For this I constructed a Robotics Growth Process model. This model approaches the adaptation by a given company with respect to the use and application of industrial robots. Based on the available usage data, experience and interviews it allows making predictions on future robot use within the various industrial sectors.

To analyze the current spread of robots and its trends I have used an approach using density charts. Large growth can be expected in many industrialized nations, as upcoming industrial nations need to close the density gap with the leading nations in order to stay competitive. Robots are not only changing the industrial landscape but also the competitiveness of countries and regions. To predict the competitiveness of regions I analyzed robot sales volume related to car manufacturing. The result shows clearly the automation gap in the United Kingdom, while investments and future growth in robotics by BRIC (Brazil, Russia, India and China) countries is evident. The data suggests that the rise of a national Chinese robot manufacturer can be expected. Germany makes up 50% of the European market and plays a crucial role in the old continent. The annual compounded growth rate since 2002 till 2012 in industrial robot sales amounts to 7%. A strong grow rate, which will continue for the future.

Most western societies face a growing share of a 60+ aging population. This group will in fact be one of the largest demographic groups, reducing the available work force. Part of my research has been dedicated to the correlation of the aging of the population in developed western countries as well as in upcoming powers like China with respect to robotics. To understand the implications of aging on the future trend of robotics I have designed a model where robot density and population aging are correlating. It pushes the emergence of the field of Service Robotics, which in 2013 is still in its infancy. Prototyping exists but large-scale commercial rollout has not yet happened. Either Japan or Korea would be the number one candidate here.

To understand the future of industrial and military robots it is necessary to analyze and understand which impacts it had on human societies. For this I reviewed the human fear for machines and intelligent life forms, as well as the effects of design on their acceptance. The uncanny valley analysis showed that a too human look-alike form has a negative impact on the adaptation. Also the ethical approach on how robots should behave has to be taken into account as it shapes their functionality and degree of autonomy.

The western capitalistic model drives manufacturing costs down by using flexible automation in the form of robotics. It is an unstoppable spiral, where machines and robots take over basic jobs massively. This implies possible high unemployment and the need for a new attitude on society and education. I analyzed the effect of the use of robots on the labor market. Although there is a direct negative effect on the share in manufacturing, the total employment is not (yet) effected. The welfare of humans comes under attack if no shift to higher education, R&D and creative innovation is undertaken. Artificial intelligence and robotics are not a threat, but should contribute to a more sustainable society.

Using the economic life cycle modeling I could determine the factors that prolong the growth cycle of industrial robots and I have identified three new design application areas being the lightweight robots, the 7 axis articulated robots and the 6 axis delta robots. To make valid statements and predictions about these innovations and to better understand these shifts in market and technology, I needed to define a new market model. This robotics matrix tool allows me to better understand the constraints and opportunities in the quadrant where robots and humans interact fully and freely together. This segment has so far been out of reach of robotics. Industrial robots typically do not cooperate with humans. The robotics driver matrix identifies the growth paths of industrial robots. With the entrance of robots in the new area of human-robot cooperation a broader view is necessary. Aside from the technical aspects on the robots themselves, adaptation of the workplace and the spectrum of interaction, or communication with the robots are new factors and fields for further investigation.

When I analyzed the constraints and limitations on the military side, it shows that there is a complete lack of functionality when it comes to the ethical side of their use and responsibility in the case of autonomous assault robots. This could possibly trigger an adaptation in their technological development. Technical limitations like energy supply, target discrimination and environment complexity also shape their future design.

2. RESEARCH AIMS

My goal was to research the influence of broad economic trends on the future design philosophy of military and industrial robots. In this context I apply a holistic approach of the economic impact, growth and market characteristics.

I have set out the following tasks:

1. To analyze the application and history of industrial and military robots to determine their current market structures and properties in order to identify new innovation trends.

2. To determine the effects that industrial and military robotics has had on human societies. Identify the relationship between these effects and future use and application.

3. To examine, model and realize a new segmentation of military robots that could identify limitations, common functionality and research waypoints based on the desired objectives of these robots.

4. To examine the effects of aging populations in societies on the adaptation and use of robotics correlated to the competitiveness of countries.

5. To investigate the effects that robotics has on the labor market.

6. Utilizing a new matrix model for industrial robots, identify the new design philosophy paths and propose future human-robot interface possibilities and workplace adaptations.

3. RESEARCH METHODS

For analyzing the numerous professional references and publications found in libraries, magazines, business publications and Internet, I used the method of analysis, cross-referencing, modeling, synthesis and deduction. Working as a professional in the robotics industry gave me in many cases the opportunity to verify claims and statements in real applications.

The creation of hypothesis and research questions were based on my professional experience in the matter of robotics and the raw statistical data provided. I have visited various international trade fairs on robotics and automation, like 'Automatika' in Munich (D), where all international robot manufacturers, robot sensor and robot peripheral companies and experts expose, confer and gather.

I have conducted interviews with various high-level executives and experts of many of robotics related companies and research institutes to get qualified input on the direction of their research and to test my hypothesis. On top I have conducted interviews with well-known scientific robotics researchers. Over the last 15 years I have participated in various international scientific and industrial conferences and platforms, often as a speaker, pertaining to the subject of my dissertation.

As a result I have gained a deep knowledge of the subject, able to draw conclusions based on both verifiable quantitative data combined with qualitative input. Hence my achievements have been published by various professional technical academic journals, as listed in the list of publications.

4. THE EXECUTED RESEARCH WORK IN CHAPTERS

The following fundamental scientific questions are to be posed:

- **Question 1:** Can a complete new design of industrial robots be expected? (Related research covered by Chapter II, III and IV)
- **Question 2:** Is there a future for Light Weight Robots? (Related research covered by Chapter IV)
- **Question 3:** Is Robotics creating or destroying Labor? (Related research covered by Chapter I and II)
- **Question 4:** Is there a fundamental economic proof that supports future growth of industrial robots? (Related research covered by chapter III)
- **Question 5:** Can military robots work fully autonomously? (Related research covered by Chapter III)

5. SUMMARISED CONCLUSIONS

Industrial robots are tools to transform the manufacturing strengths of companies, industries, countries and regions. It allows sustainable economic growth, partly offsets aging related problems and can create jobs. While current industrial robots are only in 10% capable of sensing their environment, the entry into the human-robot collaboration segment will be a paradigm shift in the world of flexible automation. The aging industrialized societies face an additional challenge on remaining competitive and robotics, especially human-robot collaboration, is the key to its solution. Workspace sharing between humans and robots will transform our factories and manufacturing.

Industrial robots continue their advance throughout industries worldwide. While in the past they were mostly used in automotive related industries, in 2013 new branches like food, medical and aeronautics and SME are opening up. With these sectors come the demand of having robots respond to an even higher degree of flexibility to overcome the new applications and need to handle shorter production batches and higher change overs. With the many inexperienced users in these new industries and sectors new robot design in terms of application and form need to address the barriers.

Now new innovations on the basic concept for articulated and delta robots allow also for new growth. Lightweight modular robots have found their start in general industry, medical applications and aerospace manufacturing. By adding more degrees of freedom, a 7th axis in the case of articulated robots and the addition of a wrist to delta robots, a new range of applications is being fulfilled by using these innovations on the conventional robots. Dual arm robots complete the set of new growth areas for industrial robotics in the new era. Design follows function. This new design philosophy must be supported by clear safety norms and regulations. Such a requirement is not yet fulfilled by the industry. So not only does functionality shape the new design, so does regulation. Using lightweight materials in the design enables the robots to be mobile or to be moved round easily. This is yet another noteworthy difference between current industrial robots, which operate in general from a fixed position. In addition the human-robot collaboration segment robots need to allow for adaptive teaching, a requirement to enter the huge market of SME's. Human-robot collaboration entails also a different human-machine interface. A redesign of the workplace where 3d camera systems can track human presence and intent, and where humans can interact with the robots using predefined gestures are identified. The market size for these new robots is sizable and attractive as it is a new segment untapped by current available robots. The segment of human-robot collaboration can benefit from the already high acceptance rate of normal industrial robots.

R&D Investments in automation can improve a countries competitive position while remaining a high cost country, like Germany. China's star is rising, with large growth numbers in investments, robot density, but is also facing the growing share of elderly. It is to be expected that China will equal Japan in the future when it comes to yearly installed robots. China has no own robot manufacturing but indications show that in the near future this is likely.

Although fear for robots exists, society should fear more the social and economic impacts that this expanding growth of robotics will bring. Unemployment can rise to enormous heights, and lead to an unsustainable social model where large part of human society cannot participate in the capitalistic model anymore, as there will be a surplus of human labor. The welfare of the people comes under attack if no shift to higher education, R&D and creative innovation is undertaken. Artificial intelligence and robotics are not a threat, but should contribute to a more sustainable society.

As sensing and perception of its environment is crucial in human-robot cooperation, a focus on the workplace and human-robot interface must be addressed. Not only from a mere standardisation viewpoint but also with regards to the way the robot is programmed and interacts with its human operator counterpart. Adaptive learning plays a key role in this development. Single or dual arm lightweight robots will be used in close cooperation with humans. Such robots produce high productivity output while working on high complex assembly tasks. Major elements identified are: low power consumption, low weight and modular build, torque sensing or error compensation to allow controlled collisions with human operators, 7 or 14 DoF. Adaptive learning as a way to program the robot will allow entering a new mass market. To reach maximum output in this new segment a focus on robot hardware design is not sufficient. The following areas need to be addressed: co-design of the workplace and in specific the way the human operator interacts with the robot. Body gestures, intent, voice commands are to be included. Standardization on programming language and safety related issues become a priority with the development of human-robot interaction automation.

The "Military Robotics Driver Matrix" proves that the objectives for these robots are economic and humanistic or a given scaled combination of these two factors. The industry for military robotics is growing, and will continue to grow pushed by national and geopolitical interests. Military robots will follow a similar growth path as their industrial cousins, but will take less time to reach the same level. Here proper segmentation will serve as a start point for gathering data. Depending on their impact on human cost and or impact on an economic benefit all military robots can be classified as: logistics robot, reconnaissance robot, prevention robot and assault robots. Military prevention robots have a larger history coming from the de-mining area and find attention in academic circles. The logistic and reconnaissance robots are becoming a new growing segment. The steady growth of UAV deployment will continue and will lead the way to acceptance of other military robotics. Constraints currently exist and will determine the future development challenges for military robots. Technical issues like energy supply and suitable algorithms for vision target recognition and motion over unknown terrain prevent full autonomy in 2013. Aside from technical constraints is the fact that autonomous use of Assault Robots is not possible. Assault robots can work in the future autonomously from a technical viewpoint but probably should not as they do not operate from any moral point of view. The military robots in operation in 2013 are mostly are remote controlled and hence have a man-in-the-loop. This human factor brings the morality that the machine lacks. My analysis showed that there is concern among society surrounding this fact, but no steady answers are available. Assault robots should be equipped with some sort of moral intelligence or rules of engagement.

6. NEW SCIENTIFIC RESULTS

The new scientific results of my dissertation are the next:

1. I examined and analyzed the types of industrial and military robots used worldwide, and with this basis, I proved based on economic modeling that industrial robots will continue their growth despite their maturity status.

2. I proved the viability of new developments like 7 axis articulated robots, 14 axis dual arm robots and Light Weight robots as they create new growth areas within the Product Life Cycle.

3. I researched the negative attitudes and concerns about the use of robots and the human fear for machines. These fears and attitudes can be overcome by a push in R&D, creative innovation and focus on higher education.

4. I analyzed the impact of using industrial robots on labor. I proved that there is indeed a negative impact on the manufacturing share, but not a significant impact on total labor, disclaiming popular Luddite's theorem.

5. I designed a framework for industrial robots to understand their evolution. I systematized them according to production flexibility and assembly complexity. It highlights the emergence of a whole new sector for industrial robots.

6. I determined that for the human-robot collaboration segment a mere focus on robot hardware design is not sufficient. Enhanced robot functionality itself is not enough to fully benefit from the efficiency possibilities if the workplace and interaction are not taken into account. Essential is the co-design of the workplace and robots. In addition the way in which the human operator interacts with the robot is relevant. I determined that body gestures, intent, voice commands are to be included.

7. I concluded that standardization on the programming language and safety related issues become a priority with the development of human-robot collaboration automation.

8. I analyzed the currently deployed military robots, based on their manifold objectives. I systematized them according to their level of impact on the human and economic side. Through the Military Robotics Driver Matrix I developed a workable classification for military robots. The designed model can be used for trend evaluation, limits evaluation and can be applied in further academic research surrounding the topic.

9. I analyzed the position of military robots in society. I determined it to be 'acceptance' as a direct consequence of the industrial progress and positive experiences of military robots in

the latest war theatres. I concluded that military robots would follow a similar growth path as industrial robots, albeit accelerated.

10. I analyzed the constraints on military robots, combined with the experiences gained over time with industrial robots.

11. I have determined some basic requirements concerning the technical necessities that will drive the future design of military robots.

12. I have determined that the ethical aspects of future military assault robots is a concern that needs to be tackled if full autonomous deployment is pursued.

7. PRACTICAL AVAILABILITY OF THE NEW SCIENTIFIC RESULT

The thoughts and results of my thesis can be used both in the theoretical and practical phases of academic research programs and industrial development for military and industrial robots.

The researched issues can affect the design and functionality of future robotics systems targeted in the new innovation sectors like close human-robot cooperation and assault robots. The data support:

- Market attractiveness for human-robot collaboration;
- Robotics manufacturers can map their R&D investments based on the practical usability of the research results. Technical research institutes should take the lead in providing a new interface language for robots using visual and acoustic signals from humans. In this respect the workplace itself has to be taken into account during robot system design. This further investigation should lead to a common standard to be used by all robot manufacturers active or becoming active in the human-robot cooperation area;
- Strategic information on regions and applications on which further trend analysis can be used for design purposes and research areas.

8. RECOMMENDATIONS

The industrial robot industry is on the brink of opening a new segment, the move into human-robot collaboration. For the new design philosophy of these robots to be successful and sustainable, the following areas need to be addressed:

- A thorough market research of the segment where these robots are to be applied; industrial assembly lines throughout the geographic and business segments. It will form the basis for directing R&D investiture, pushing from prototyping to market ready robots;

- A proposal for a common programming language, to ensure high acceptance throughout the end customers;

- New safety norms regulating human-robot collaboration;

- A basic understanding of the new workplace design, taking into account a man-machine interface based on gestures, intent, voice commands;

- The application of this basic understanding in the realization of business economic thinking and action taking in all fields and on all levels.

Military robots are in there introduction phase, except for UAV. Based on the military driver matrix I recommend a thorough definition of the four identified categories. It will allow ease of comparing of international developments. Second an international standardization has to be set-up, like exist for industrial robots. Proliferation of technology could be considered, but a minimum experience share platform could be erected as many states invest in own R&D. The following preconditions for a successful and sustainable application of autonomous military assault robots would have to be fulfilled:

- To develop the field of military robot-ethics, i.e. Robotics Rules of Engagement, encourage the thinking and development of rule sets, linking it to international law on war like the Geneva Convention, and or UN Charters;
- A translation of these ethics into solid software and hardware controlled safeguards within the robots;

- A continuous improvement of energy supply sources for military field robots.

Lastly a focus on the ethical issues surrounding the deployment of assault robots is needed. The use of robot technology and applied level of autonomy of assault robots form an ethical boundary that is not even discussed. Awareness of the issue could be raised on an international military robotics forum.

9. RELATED PUBLICATIONS

A. Peer reviewed article in journal – Hungarian journal, in foreign language

1. Struijk, Bob "*Robots in Human Society and Industry*", International Journal in Academic and Applied Research in Military Science AARMS, Vol. 10, Issue 1, 2011, pp(183-195), HU ISSN 1588-8789.

2. Struijk, Bob *"Robot Economics Positioning up to the 2008 Crisis"*, Bolyai Szemle, Vol. 2/2011, pp(167-183), ISSN 1416-1443 http://portal.zmne.hu/portal/page?_pageid=34,46876&_dad=portal&_schema=PORTAL

3. Struijk, Bob "*Changes in Human Society led by Robots*", Debreceni Műszaki Közlemények 2011/1 pp.(25-34) *(HU ISSN 2060 6869)* http://www.mfk.unideb.hu/userdir/dmk/docs/20111/index.html

4. Struijk, Bob "*Robotics in the New Era – Challenges on Robot Design*", Debreceni Műszaki Közlemények 2011/3, pp(15-25,) (HU ISSN 2060-6869) http://www.mfk.unideb.hu/userdir/dmk/docs/20113/11_3_03.pdf

5. Struijk, Bob "*Robot Production Volume Data Trends and Analysis*", Debreceni Műszaki Közlemények 2012/1 pp(1-10) (HU ISSN 2060-6869) http://193.6.145.139/userdir/dmk/docs/20121/12_1_01.pdf

6. Struijk, Bob "*Robotics in Human Society – Challenges on Employment*", Katonai Logisztika, 2012/2, XX. Évf., pp(81-99), (HU ISSN 1789-6398) http://www.honvedelem.hu/containter/files/attachments/33019/kl2012-2_ok.pdf

7. Struijk, Bob "*A new understanding of modern robotics*", HADMERNOK, VII. Volume 2, 2012/6, pp(248-259) (HU ISSN 1788-1919), http://hadmernok.hu/2012_2struijk.php

8. Struijk, Bob "*New Design Philosophy in Military Robotics*", Repüléstudományi Közlemények, , XXIV. évf., szám July 2012. pp(119-135) (HU ISSN 1789-770X) http://www.szrfk.hu/rtk/folyoirat/2012_1/Bob_Struijk.pdf

B. Non reviewed journal, abroad, in foreign language

1. Struijk, Bob *"Automation for Spanish car industry"*, La Vanguardia, Feb 2007. http://publicacionesymedios.net/ADMIN/upload/ind001fanuc4_maq.pdf

2. Struijk, Bob "*Robots and Reliability* " TechniPublications, Auto Revista, No 2.209, pp (82-87), March 2007,
   Purchase via Link:
   http://www.tecnipublicaciones.com/tienda/producto.aspx?idProducto=954

3. Struijk, Bob "*IRS Tokyo"*, i-Motion No.10, pp (6-7), Dec 2010,
   http://www.fanucrobotics.es/~/media/FRIB/Files/Magazines/i-motion%20n10.ashx

4. Struijk, Bob *"Robots – Food for thought"*, Next Generation Food, GDS Publishing, April 2010 http://www.nextgenerationfood.com/article/Robots-Food-for-thought/

C. Foreign Language Lecture in International Conference Proceedings

C.1 Peer reviewed

1. Róbert SZABOLCSI – Gerald MIES – Bob STRUIJK – Péter ZENTAY: *FANUC Robotics Project at Miklós Zrínyi National Defense University*, CD-ROM Proceedings of the VI[th] International Conference „New Challenges in the Field of Military Sciences, ISBN 978-963-87706-4-6, 18-19 November 2009, Budapest, Hungary.

C.2 Non reviewed

1. Struijk, Bob, Lecture on '*Robot Automation*', Auto Parts Makers Conference, Rabat, Morocco, March 2007.

2. Struijk, Bob, Lecture on '*Trends in Automation Technology*' Portorosj, Slovenija, 10-11 Feb 2005; Blok II (http://www.svet-el.si/tita/program.html).

3. Struijk, Bob, Lecture on "*Robotics for the future"*, 4[th] Conference of the Framework Programme: "EU Framework Programmes: From Economic Recovery to Sustainability" . April 13&14, 2010 Valencia, Spain. Reference via Spanish Ministry of Science and Innovation, P6, Session III, *Factory of the Future*
   http://www.micinn.es/stfls/MICINN/Presidencia%20Europea/Ficheros/Presi_ES_Conferencia_Valencia_Informe_FinalR2S.pdf

4. Struijk, Bob, Lecture on "*Flexible Automation"*, Conference "Inspiring Day" organised by technological Research Center *Tecnalia*, Industrial Systems Unit, May 16[th] 2012, Madrid, Spain. www.inspiring-day.com

10. ASPIRANT'S PROFESSIONAL SCIENTIFIC CV

Bob STRUIJK – CURRICULUM VITAE

30 October 1965	born in Amsterdam, The Netherlands (Dutch citizenship)
1972-1977	Elementary school Oosterhout, The Netherlands
1978-1982	Secondary school Oosterhout, The Netherlands
1982-1986	Technical college (electronics) Breda, The Netherlands
1986-1989	Higher Education, Business Engineering, Eindhoven, The Netherlands
1989-1990	Military service, Royal Dutch Air Force, ret. 2nd Lt. 1995
1989-1993	Master in Business Administration, Catholic University of Leuven, Belgium
1990	NIMA-B Marketing Manager degree, Utrecht, The Netherlands
1990-1995	Merlin Gerin BV, Utrecht, The Netherlands, Marketing and Sales Executive
1995-1998	Doorman BV, General Manager, Rotterdam, The Netherlands
1998-2003	FANUC Robotics Benelux, General Manager, Antwerp, Belgium
2003-2005	FANUC Robotics Czech sro, General Manager, Prague, Czech Republic
2007-2012	FANUC Robotics Magyarország Kft. General Manager, Budaors, Hungary
Since 2005	FANUC Robotics Iberica SL, General Manager, Barcelona, Spain
Since 2008	FANUC Robotics Europe SA, Luxembourg, Vice-President Europe
Since 2012	FANUC Nordic, General Manager, Stockholm, Sweden