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Publication date:
2008

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
Rasmussen, B., & Andersen, P. D. (2008). Technology foresight on cognition and robotics. [s.l.]: European Foresight Monitoring Network. (EFMN Brief; No. 125).
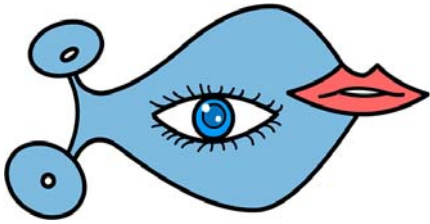
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Technology Foresight on Cognition and Robotics

Foresight Brief No. 125

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Sponsors:	Ministry of Science, Technology and Innovation (Denmark)	
Type:	A national technology foresight project with the purpose of identifying and motivating development agendas that seem particularly promising for Demark within a time frame of ten years.	
Organizer:	Risø DTU, Systems Analysis, Roskilde, Denmark (www.risoe.dk)	
	Birgitte Rasmussen, Per Dannemand Andersen	
Duration: Jan. 05-Feb. 06	**Budget:** € 147,000 **Time Horizon:** 2005-2015	**Date of Brief:** Dec. 2007

Purpose

This technology foresight project was motivated by the significant resources recently invested, both nationally and internationally, in the development of increasingly advanced and complex robots. There is a need to examine the perspectives, possibilities and consequences of development and utilisation of advances in robotics. The goal of the foresight project is to formulate a robust and broadly accepted foundation that can be used to identify opportunities for innovation associated with the development of robot technology that seem particular promising for Demark within a time frame of ten years.

Why Cognition and Robotics?

In recent years, significant amounts, in dollars, euro and yen, have been invested, both nationally and internationally, in the development of increasingly advanced robots that can, independently or in interaction with humans, perform increasingly complex tasks and functions.

The use of robots with cognitive capabilities will enable machines to operate and behave in different ways depending on their surroundings. Robots can interpret the meaning of information gathered from their surroundings; they can act under the guidance of rules or in response to sensory perceptions. Robot technology has an extremely wide range of applications, and users are formulating promising perspectives for innovation. Advanced robots are not only a question of technology and intelligence. Increased utilisation of robot technology may also necessitate debates on the ethical and societal aspects of relying on robots in our daily lives – both at home and at work.

Steering Committee and Target Groups

The project was undertaken by a steering committee appointed by the Danish Ministry of Science, Technology and Innovation, with eight members, including representatives from robotics, computer vision, psychology, learning, social science and industry. A project team from Risø National Laboratory[1], the University of Southern Denmark and the University of Aarhus acted as methodological advisers. The target groups for the study are the Danish Ministry of Science, Technology and Innovation, scientific advisory and grant-awarding bodies, research institutions and universities, as well as companies on both the development and user sides of the technologies.

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[1] Since 1 January 2007, Risø National Laboratory has merged with the Technical University of Denmark (DTU) with DTU as the continuing unit.

Methodology

Transdisciplinary Approach

The foresight project can be viewed in a transdisciplinary perspective. The goal is bridging, coupling and integrating concepts and theories from the fields of robotics and cognition in a problem-oriented context, including viewpoints and ideas from various groups of stakeholders, both scientific and non-scientific.

The overlap and intersection between robotics and cognition is a relatively unexplored research area. Therefore, the foresight project was of a more preliminary nature than other Danish technology foresight studies. The study did not attempt to set agendas for research and innovation in robotics, but focused only on the possibilities at the crossroads where robotics and cognition meet.

Mandate

The mandate for the technology foresight was:

> Formulation of three to five promising development agendas for Denmark. Development agendas are understood as long-term visions within selected application areas in which cognitive robots will promote innovation.

> Formulation of research, education and innovation policy recommendations.

Documentation and Knowledge Provisions

The process was conducted as a broad dialogue between users and producers of robot technology solutions, as well as researchers and experts in cognitive and robotics research. The goal was to lay down a robust and broadly accepted foundation that could be used to identify promising prospects for innovation associated with the development of robotics. Approximately 100 stakeholders and scientists participated in the process in one way or another.

The overall design of the foresight project is presented in the figure below. The key elements are:

> Through dialogue with users and experts, a broad survey was conducted of the prospects for innovation that robots with cognitive capabilities can help create.

> Five application areas were selected where the use of robots with cognitive capabilities appears particularly promising from a business and societal point of view. For each area, a development agenda was formulated.

> In extension of this, players with insight into the selected application areas were asked to formulate which user wishes and needs for robots and their cognitive capabilities would be crucial to realising the prospects of innovation within the different areas.

> Finally, based on these wishes and needs, a selection of proposals was formulated for transdisciplinary research themes and innovation initiatives, which would need to be initiated in order to promote the development and utilisation of robots with cognitive capabilities.
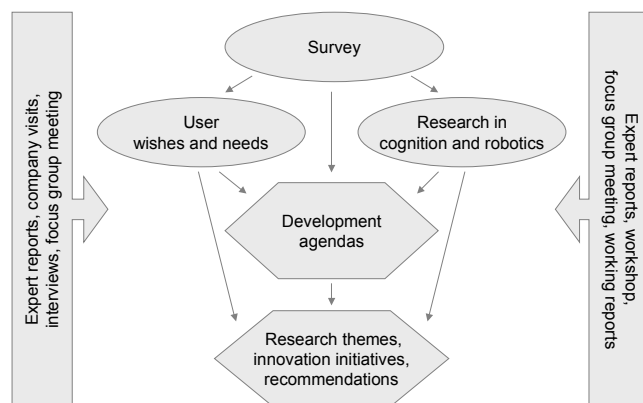
Project design

Findings and Lessons Learned

Development Agendas

Ten areas were identified at the outset where cognitive robots could promote innovations relevant in a Danish context: industrial automation; agriculture, horticulture and forestry; entertainment, play and learning; personal service and care; health and hospitals; handling of hazardous substances; offshore and underwater systems; building, installation and construction; military, defence and contingency; transport.

According to the mandate, a significant deliverable was the formulation of three to five promising development agendas. The steering committee adopted the following four criteria for priority-setting:

> *Megatrends* – understood as general international trends for social development that will influence promising application- and business-related potentials.

> *General importance of area to society* – that is, areas where the use of robots with cognitive capabilities can alleviate critical, societal problems or challenges.

> *User needs in the area* – refers to application areas where robots with advanced cognitive capabilities can lead to improved problem-solving and quality of life for users.

> *Research and business opportunities* – in terms of the competitiveness of Danish companies, there are three underlying criteria: new products, new markets, and new production systems. Special consideration is given to areas where Danish companies utilise existing technology and already lucrative niche markets.

The steering committee identified five particularly promising development agendas for Denmark.

> *Industrial automation* – including flexible robots and production systems for various types of automation in the manufacturing and food industries; for instance materials finishing, pallet picking, welding, painting, cutting and item handling.

> *Agriculture, horticulture and forestry* – including robots for plant and animal production in conventional and organic agriculture, horticulture, nurseries, tree plantations, and cultivation of crops for energy production or for medicinal purposes.

> *Entertainment, play and learning* – covering leisure and entertainment activities for both children and adults, including cognitive robots for services in relation to quality of life, leisure activities, home entertainment, play and education.

> *Personal service and care* – including care for the elderly, assistance for people with physical disabilities, personal care and services, home security and domestic cleaning.

> *Health and hospitals* – including diagnostics, surgery, rehabilitation, laboratory analyses, patient care and internal transport at hospitals.

Research Themes and Innovation Initiatives

A transdisciplinary perspective balancing the interaction between needs-driven and research-driven innovation was recommended by the steering committee. Instead of the highly ambitious 'man-on-the-moon' focus seen in many international robot technology initiatives, the Danish initiative instead focused on user needs and practical experiences and on the need of research to be able to regularly define its research agendas and redefine its critical problems.

The steering committee found it useful to distinguish between short-, medium- and long-term initiatives as well as between initiatives that focus on innovation, application orientation and basic research:

> *Short-term:* Innovation initiatives in which robots with simple cognitive capabilities can be used to help solve concrete known and well-described problems in specific applications. These are robots that function as parts of systems with well-structured surroundings and high predictability, as well as robots with pre-programmed reaction patterns and limited interaction with users/operators. In the short term, these initiatives are expected to be geared primarily towards industrial applications. Innovation initiatives: new vision and sensor technology; production cells; standard solutions and systems; toys and games; improved user interfaces; user studies in robot development; working environment and safety.

> *Medium-term:* Research and development in which robots with cognitive capabilities are incorporated into specific applications with semi-structured surroundings and a certain degree of unpredictability in the robot's tasks. Application-oriented research: mobile robots that can navigate outdoors and indoors; robot technology for varied one-off production tasks; cognitive robots; multimodal user interfaces; role division between user and robot; robots in organisational interaction.

> *Long-term:* Research into complex cognitive capabilities and their potential for robot technology. A number of basic research topics are essential in the long-term for developing robots that can evolve, are flexible and which interact naturally with their surroundings. Basic research: new materials; shape-changing and self-repairing robots; adaptability, stability and dynamics; the robot as a system component; system integration; intelligent user interfaces; organic cognition; embodied cognition; contributions to cognition through robotics research; cognitive taxonomy.

Transdisciplinary Approach

The study focused on the overlap and intersection between robotics and cognition, which is a relatively uncharted transdisciplinary area. Consequently, a key question concerns the attractiveness and incentives for becoming involved in this new transdisciplinary area. The concept of 'boundary objects' (Bowker and Star, 1999) was considered. Boundary objects are objects that inhabit several communities of practice and satisfy the informal requirements of each of them. They represent topics of sufficient common interest to form a meeting point. The formulation and selection of promising development agendas for Denmark can be considered as the first step in the boundary object identification process.

Successful transdisciplinary work is highly dependent on the existence of strong, but permeable, disciplines. Further, transdisciplinary initiatives ought to be problem- or topic-driven. During the foresight project, substantial disagreements arose and conflicting scientific paradigms from different scientists within the cognitive science community were encountered. Although these differences were discussed and reflected upon in the various activities of the foresight process, they also caused difficulties in identifying a strong permeable core discipline in cognitive science, which would make it attractive for a robotics/cognition transdisciplinary initiative. This would also have been uncomfortable for researchers outside the field of cognitive science, who would have been forced to take sides in controversies about which they had little knowledge or understanding. These experiences are not only a Danish phenomenon. A EU review (Andler, 2005) also identified barriers to the involvement of cognitive science in transdisciplinary initiatives.

Another challenge is the coupling of disciplines with significantly different research traditions and progression structures. Robotics tends to be interdisciplinary and problem-oriented, whereas cognitive science is monodisciplinary and more focused on epistemic research. Participants from different scientific traditions may have different ideas about how transdisciplinary research should be framed and how the different sci-

entific objects should be investigated and interfaced. Framing is action-oriented and plays a crucial role in forming a perspective from which a situation can be understood and acted upon. In this study, the overall objective was to develop robots with new cognitive properties, thus placing robotics in a core position and establishing an advantage for the field of robotics in the transdisciplinary framing process.

Robotics is a very active field worldwide. Recent developments in human factors, sensory perception and computing are opening up many new potential application areas for robotics. Thus, the robotics-cognition domain can be characterised as an emerging field with potential for the establishment of new networks and scientific communities including technological, medical, humanities, and sociological research and disciplines. Consequently, there has been no long-term cooperation and common understanding of the field between the robotics and the cognition science communities to serve as a basis for the technology foresight project. To cope with the absence of a common basis of understanding, the foresight project proceeded in an explorative manner, attempting to identify promising future applications involving both robotics as well as cognitive science, in a Danish context.

Policy Impact

The results have been disseminated among relevant advisory and grant-awarding bodies within research and innovation, relevant institutions and universities, and companies on both the development and user sides of the technologies.

The following actions are specifically recommended.

> *Improving opportunities for transdisciplinary research*: The Board of the Danish Councils for Independent Research and its scientific research councils are recommended to improve the prospects of transdisciplinary-research-initiated (bottom-up) projects to obtain funding.

> *Strengthening transdisciplinary strategic research*: The setting up of future ICT-related strategic research programmes for transdisciplinary projects on cognition and robotics is recommended. The Danish Council for Strategic Research should also incorporate cognitive robotics into its innovation-accelerating research platforms.

> *Incorporating cognitive robotics as an element in ICT strategy*: The Danish High Technology Foundation is recommended to include cognitive robotics as an element in its ICT strategy.

> *Improving opportunities for networking and innovation*: The Danish Council for Technology and Innovation is encouraged to consider how to support networking and innovation within the development and utilisation of cognitive robotics.

> *Exploiting funding options, forming networks and formulating specific transdisciplinary research projects*: Organisations within the five application areas need to consider how to support networks among users, researchers and manufacturers of robot technology solutions.

> *Debating possibilities within cognitive robotics and considering educational initiatives*: The Danish Board of Technology is recommended to initiate a project on the ethical and societal aspects of cognitive robotics, and the managing bodies and staff of universities and research institutions should discuss the needs and possibilities in terms of research and educational initiatives within and across cognitive and robotics research.

> *Establishing a separate research and development programme in the longer term*: Earmarked funding is recommended, as an extension of the Danish Government's globalisation strategy, for a separate research and development programme in robot technology and cognition.

The study contributes to European experiences on national-level foresight exercises. The conceptual findings of the case study are of value to science and innovation policy makers, foresight practitioners and scholars within the field.

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