Networked Control Systems – Towards a Closer EU-Russian Collaboration

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Abstract

The paper presents the NESTER project "Networked Embedded and Control System Technologies (NECS) for Europe and Russia" funded by the European Commission under the 7th Framework Programme, aimed to identify opportunities for deeper strategic cooperation between Europe and Russia in the field of NECS. Four sectors with the highest potential for EU-Russian NECS R&D collaboration are analysed from the point of view of expected impacts and research challenges. Recommended axes for EU-RU research cooperation in the NECS area are presented as well.

Key words

Networked Control Systems, Europe, Russia, Collaboration

1 NECS in Europe and Russia

Software and electronics are now embedded in various devices and objects. At the same time pervasive data changes how these intelligent objects dynamically pool information, cooperate under numerous constraints and reliably interact and control the physical world. The networked control system, i.e. distributed hierarchical system of co-operating controllers and computing elements which are connected together, copes with failures and uncertainties with recovery through reconfiguration or self-restructuring. At the same time it uses more and more new sensors and sensor networks, emerging from micro and nanosystems technologies, leading to further improvements in performance and efficiency. These complex engineering systems, situated on the edge between several domains with 3 key elements (3"C") – communication, computer and control, are known under the name of Networked Embedded and Control Systems (NECS) [Hristu-Varsakelis and Levine, 2008; Wang and Liu, 2008].

One of the key elements of the research in the area of NECS is its multidisciplinarity. While individual contributions in the research and advances in the different application domains are of high level, there is very small interaction between the principal elements (3"C") and not enough of transversal research used in parallel in different domains. A better integration is required both at the technological level in order to avoid fragmentation and at the scientific level, where thorough and principled system-theoretic view is still missing. Even the meaning of the term "NECS" is ambiguous and still requires better definition as people coming from communication, computer and control communities have different understanding of NECS.

For example, despite the recent intersection between the application domains of network theory (communication) and control engineering (control), the necessary links for the transfer of ideas and tools between the two fields have yet to be established. This situation is largely due to fundamental differences between the methodologies and goals of the two communities. While control engineers build feedback systems to satisfy closed loop design specifications, network theorists seek models to explain the observed behaviour of existing networks. In fact, the starting points and objectives of a complex-network theoretician and a control engineer are reversed, even though they face the same problems in trying to understand their target systems. Despite the use of different analysis tools, network properties such as connectivity, efficiency, and robustness are critical to both control design and complex-network modelling.

Research on NECS has major strategic relevance for the European industry and society, since these systems form a key growth area in information and communication technologies with a broad range of applications that will affect the citizen in all aspects of their lives. Existing and emerging areas include, for example, automotive industry, energy management, biomedical and health care industries, environmental monitoring, factory automation, personal communication, process industry and transportation. Moreover, other information-based industries, such as telecommunications, are likely to benefit from advanced procedures for embedded decision making. Contrary to desktop computing where a few major players dominate the scene, NECS is still open field with enormous potential in the future markets of ambient intelligence.

In this situation, Europe should position itself as a major player, leading the development of intelligent and networked systems. Addressing these ambitious objectives requires merging of different system sciences and engineering as well as the mobilization of resources on a large scale. One of the urgent needs in the emerging area of embedded and networked control systems is to reinforce insufficient dialogue between the various NECS research groups. Indeed, one of the consequences of the present fragmentation

of efforts undertaken in different countries positioning in the NECS technologies is the situation where the methodologies are rediscovered from one area to another with more or less difficulties and more or less knowledge of the available or promising fundamental tools that can be used.

Russia is the "old" scientific partner of the European Union. Traditionally very strong in the fundamental physics and mathematics research, Russian researchers have outstanding competences in "hot" ICT topics such as software architecture, nanoelectronics components, robotics, infrastructures, embedded systems design. It is also expected that NECS fields will be developed rapidly in the nearest future. At this moment, Russia has significant world level research in numerous topics related NECS: (1) Compiler research on programming modern parallel systems; power saving compilation; (2) Reconfigurable heterogeneous multicore architectures, adaptive self-tuning software and machine learning; (3) Design of high-capacity network processors; (4) Real-time safety-critical embedded systems; (5) Applications of distributed embedded multi-agent systems; (6) Control of large-scale infrastructures; (7) Techniques of formalized system architecture representation and models of computation for embedded systems design; (8) Reconfigurable hardware based embedded system design; (9) Fundamental research in control theory etc.

In the European research area (ERA), control systems are part of the ICT thematic area, but the word "Control" does not appear in this term. However, in Russia the situation is quite different. The commonly used term is "Informatics and Control Systems", both in the Russian literature and in the names of some faculties in Russian Universities. There even exists a Russian journal entitled "Control Systems and Information Technologies".

In the present situation when the control area is somehow "hidden" in the ICT terminology, many Russian specialists in the control area do not pay any attention to the ICT calls of the European Commission. From this point of view, FP7 awareness raising actions made toward third countries, in the field of control technologies, should particularly underline that this field of competencies is included within the ICT area of the FP7 [FP7 Work Program].

For these reasons, the European Commission decided to support the NESTER project, aimed to propose the collaboration priorities between Russia and Europe in the field of NECS, to bring closer the European and Russian researchers in the field of NECS and to foster joint collaboration opportunities driven by industrial demands.

2 The NESTER Project

NESTER project (www.nester-ru.eu) , funded by the European Commission under the 7th Framework Programme, was an Inter-national cooperation support action on NECS, one of the key priorities ICT areas defined in the ICT Work Programme (FP7-ICT-2). The project concept was designed by the consortium partners in order to approach the European and Russian researchers in the field of NECS and to foster joint collaboration opportunities driven by industrial demands. NESTER project succeeded in mapping existing competencies of relevant NECS technologies and in dissemination of information about such competencies in Europe, decreasing the gap between offer and demand from European and Russian side.

The project based its analysis on industrial sector needs in order to identify the four industrial sectors most propitious for cooperation. Developing common NECS classification, the NESTER project had screened Russian and European competences in the field of NECS technologies and mapped collaboration opportunities.

The building of the European and Russian NECS Network opened to researchers, industrials, and policy makers supported a constructive dialogue between Russia and the European Union. This created new ideas, concepts and technologies that helped to catalyze knowledge transfer and allow to progress beyond the current NECS technological state-of-the-art. Thus, NESTER was a great opportunity to build industrial and research partnerships between Europe and Russia in the NECS field.

3 Identification of four industrial "locomotive" sectors with highest potential for European-Russian NECS collaboration

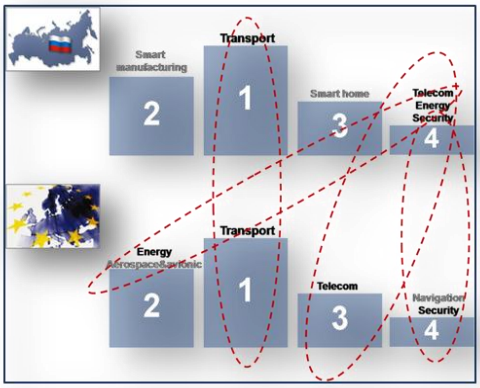
The NESTER project firstly aimed to identify four industrial sectors showing a high level of proclivity of the NECS technologies usage in which EU-RU NECS applied research cooperation would be the most promising, from a list of 10 preliminary selected industrial sectors, such as energy, aerospace, automotive, consumer electronics, manufacturing, and telecommunication. 20 interviews with experts in the field of NECS as well as bibliographical analysis served as an input for the process of 4 sectors' identification. The survey helped as well to reposition the industrial sectors that have been indicated to the ICT Work programme 2007-2008.

The following four sectors most propitious for NECS EU-Russian collaborations were identified through the analytical work and surveys:

(1) Transportation;
(2) Energy;
(3) Telecommunication;
(4) Public infrastructure security.

4 Four industrial "locomotive" sectors: key challenges for European-Russian NECS collaboration and expected impact

Figure1. Identification of four industrial



"locomotive" sectors with highest potential for EU-RU NECS collaboration

4.1 Transportation

The state of practice exhibited the following weaknesses:

- Safety and Quality of service are considered separately;
- Model based design is performed but the information flow between abstraction levels is not standardized;
- Conflicting requirements are detected manually;
- Modular certification is not yet done;
- Product time-to-market pressure does formal methods not applicable in practice;
- Academia programs target low educational skills in formal methods (scientific vs. engineering approach).

Part of the gap existing between the current state-of-practice and state-of-the-art could be filled by the following achievements:

- New integrated platforms combining functional and non-functional properties
- New concepts of robustness and diagnosability
- Methodologies and tools coping with increasing system complexity
- Integration of formal methods and tools in development environments at different levels of detail according to domain/problem safety constraints.
- Modification of existing training practice

The European-Russian NECS cooperation should be structured in order to address these needs and shall provide techniques, methods and tools to improve safe mobility, to integrate diagnosability aspects in order to optimise life cycle costs and cover all transportation domains (e.g. advanced driver assistance systems, advanced braking systems, flight management systems; power management systems, cost-efficient implementation…).

Main challenges include : (1) Improvement of cross fertilisation between transport domains to leverage globally the excellence of engineering of NECS for transportation; (2) Development time reduction despite increase of systems and software complexity; (3) Increasing quality and reliability of products and services with novel functionalities for end user.

4.2 Energy

Expected impact from EU-RU collaboration includes:

- Energy saving (low energy consumption)
- Distributed energy management & optimisation
- Energy efficiency
- Higher performances with reduced energy consumption (Energy/performance trade-off)

Main challenges include:

- Energy management especially for sensors, actuators and wearable or portable devices
- Design of energy autarkic mobile embedded devices
- Reduce emission and energy consumption through better situation awareness and improved vehicle global efficiency
- Reduce energy consumption of home, office and mobile equipment
- Increased requirements for energy consumption for supporting security functions especially in battery-constrained embedded devices.
- Low energy/power electronics design with various requirements.

4.3 Telecommunication

The telecommunication sector is one of the most active in the Russian market. It is sufficiently financed and the use of NECS technologies in this sector is really high and has excellent potential.

Expected impact from EU-RU collaboration includes:

- Development of new network interconnections which will allow better interoperability of services and forester the reduction of telecommunication costs and the introduction of new technologies.
- Creation of new software network applications which will enable interoperation across the EU-Russia ICT community
- Contributing to the promotion of common standards and certification methods

The main challenge for NECS in the area of telecommunication is the provision of ubiquitous wireless connectivity under the constraints of minimum power consumption and limited bandwidth for real-time, secure and reliable communication. A particular focus appears in the development of systems with advanced properties:

- Tracking and wireless identification systems: These systems allow application and services based on the location of users and objects.
- Wireless Control Networks: These networks

are constituted by sensors and actuators providing the infrastructure necessary for the realisation of ambient intelligence.
- Autonomous systems with context sensitive self properties that enable the efficient construction of self-organising embedded systems
- Interoperable service oriented architectures play an important role in order to get full interoperability among heterogeneous resulting in fully autonomous plug and play behaviour
- Integration of heterogeneous communication technologies.

4.4 Public infrastructure security

Expected impact from EU-RU collaboration includes:

- Provide interconnected Embedded Systems based solutions satisfying new needs (financial, medical, public safety, …)
- Create common standards for devices and protocols approaching the homeland security market
- Increase the market of Critical Infrastructure Protection
- Advanced security of the common transport system increasing business opportunities in all market domains
- Increase the market of methods, tools and services to support cost effective processes for designing secure and dependable applications

Research challenges for joint European-Russian research include:

- Development of secure NECS at node level: secure software, scalability of the management of a large number of interacting devices, integrated security techniques that use modulation, encoding, encryption and interleaving technologies…
- Secure real -time networking for NECS and critical infrastructures and secure, trusted, dependable and efficient data transfer: frequency agility and flexible transmission, flexible communication protocols providing trade off between performance (latency, jitter, throughput…, and security parameters: determinism, reliability, security….
- Secure NECS services and applications: enhanced intrusion detection and prevention, large scale secure, dependable and resilient distributed NECS, continuous and upgradeable security assessment of large scale distributed NECS, automatic security management in presence of limited resources of embedded nodes.
- Design tools and methodologies for large scale distributed NECS: support for security as built -in feature, develop generic modelling, simulation and analysis methodologies, develop tools to evaluate security, privacy and dependability/composability
- Architectures, designs and processes: security/privacy specs: common framework, completeness evaluation, architectures: intrusion proof, upgradeable, trusted, dependable, architectures for reliable fault tolerant and resilient ES

5. Recommended axis for EU-RU research cooperation in the NECS area

The implementation of NESTER project helped to define the following R&D areas, confirmed as areas representing high immediate interest for EU-RU research collaboration:

- Design
- Architecture
- Sensors & Actuators
- Distant control and monitoring

All these research collaboration axes perfectly correlate with technology demands expressed by the locomotive sectors and address key technical challenges.

5.1 Transportation

- Design of new integrated platforms
- New robustness and diagnosability concepts
- Standardization of the model based tools and design processes
- New solutions for modular certification
- Tools and methods for safety critical systems

5.2 Energy

- Energy management especially for sensors, actuators and wearable or portable devices
- Design of energy autarkic mobile embedded devices
- Reduce emission and energy consumption through better situation awareness and improved vehicle global efficiency
- Increased requirements for energy consumption for supporting security functions especially in battery-constrained embedded devices.
- Low energy/power electronics design with various requirements, such as extreme low power for wireless devices that needs to operate for years without maintenance, possibly exploiting energy scavenging techniques, low power solutions for sensors that are powered by the limited power supply from field-bus technology;
- Suitable power design to enable medium and

high performance devices and controllers to operate in industrial environment without any active cooling like fans and with the ability to be mounted in the limited space available for control system equipment in existing plants

5.3 Telecommunications

- Ubiquitous and secure wireless connectivity (end-to-end) to the service
- New high-functionality terminals with energy management techniques
- Network architectures and protocols for secure and dependable communications
- Integration of heterogeneous communication technologies
- Management of uncertainties in communication and node activity

5.4 Public infrastructure security

- Development of Secure embedded systems both at the node and the network level
- Development of Secure software (operating systems, etc) and integrated security techniques
- Network architectures and protocols for secure and dependable communications
- Enhanced intrusion detection and prevention
- Development of tools to evaluate security and privacy
- Development of intrusion proof, trusted architectures

6 Recommendations for strengthening EU-RU collaboration in the NECS filed

The results of NESTER actions proved that there is mutual benefit for Europe and Russia to collaborate in the NECS field. However, these benefits need to be promoted and explained. Following an in-depth analysis of the cooperation priorities in the area in both regions, the NESTER project underlined the following recommendations:

1. Promote the EU-RU research cooperation especially on the axis representing an immediate mutual benefit.
2. Support joint research projects in the areas representing potential interest for EU and RU side.
3. Support application-oriented research projects aiming at development of "high-tech" NECS prototypes for selected locomotive sectors
4. Increase the visibility of Russian NECS
5. R&D competences and research results in visibility of European NECS research results in Russia.
6. Provide hands-on support to Russian and European teams in order to overcome the cultural differences
7. Provide continuous hands-on support to the partnership building.
8. Support exchanges of young researchers and strengthen joint graduate schools and exchange programs.
9. Develop common open source tools
10. Organise joint EU-Russian FP7 calls in the field of NECS, and in particular in monitoring and control (joint calls have been already launched for other topics outside the ICT Work programme).

7 Conclusions

Russia has been one of the important ICT strategic partners of EU for many years; therefore, it was vital to undertake activities which would stimulate win-win co-operation between the two regions, crossing European "application" strengths and Russian "technological" strengths.

Joint EU-RU projects in the area of NECS would be beneficial for both European and Russian partners. The NESTER initiative underpinned the development of a strong EU presence in Russia, which had huge economic and scientific potential.

European research community would be able to use a great portfolio of technological developments, existing in Russia in respective area for decades and adopt scientific knowledge for practical scenarios of advanced control systems. Russian partners would gain an access to a broad range of proven developments and would be able to tailor their solutions to European standards in the areas of safety and compatibility.

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