Physical Human-Robot Interaction in Anthropic Domains: Safety and Dependability

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Abstract— In this paper we describe the motivations and the aim of the EURON-2 research project “Physical Human-Robot Interaction in Anthropic Domains” (PHRIDOM). This project, which moves along the lines indicated by the 1^{st} IARP/IEEE-RAS Workshop on Technical Challenge for Dependable Robots in Human Environments [1], is about “charting” the new “territory” of physical Human-Robot Interaction (pHRI). To ensure these goals, the integration competences in control, robotics, design and realization of mechanical systems, human-machine interaction, and in safety-dependability of mechatronic systems is required. The PHRIDOM Consortium is composed of 5 partners from 3 different European countries.

I. General Description and Scope of PHRIDOM

The PHRIDOM project is about exploring the relatively new research field of physical Human-Robot Interaction (pHRI). In writing the project, we have often used metaphorically the language of pioneering explorations of the nineteenth century.

Thus, we plan in this project to explore the uncharted “territory” of pHRI and contribute to prepare an “atlas” for it (see e.g. fig. 1). Its ”geographical features” mainly consist of

- Applications(*Destinations*): tens of examples of intelligent machines embedded in anthropic domains - i.e. environments shared by machines and humans, working together elbow-to-elbow, or even more closely;
- Requirements(*Viability Conditions*): safety, dependability, reliability, failure recovery, performance;
- Technologies(*Via Points*): sensors, actuators, mechanics, control, SW architectures;
- Systems(*Pathways*): connecting crucial components and leading to technological solutions to applications, while fulfilling the requirements;
- Competences(*Crews*): the centres of excellence among academic and industrial groups from which a successful research crew has been recruited.

The planned “atlas” will be useful in the near future to navigate in this new research field - using knowledge accumulated so far by pioneers to provide directions to new explorers who want to reach out for new, unexplored applications. It is in this sense a preparatory project, following which we would expect a large number of other projects to be able to make headway into the bushes of a difficult, high-responsibility, yet fascinating research domain.

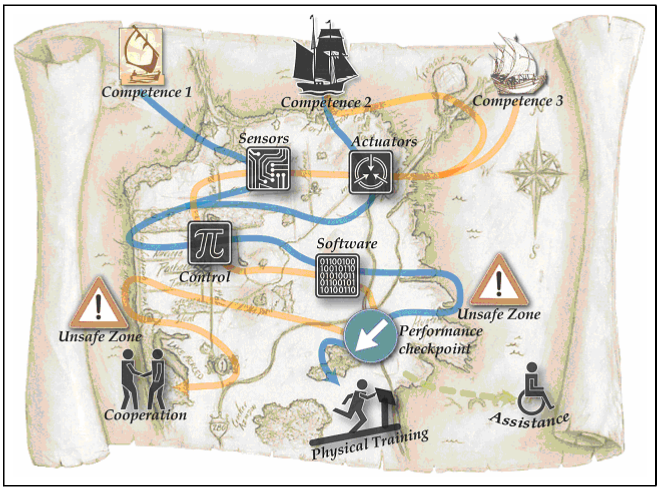

Fig. 1. The aim of the PHRIDOM project is to explore the new territory of physical Human-Robot Interaction.

A. Applications involving pHRI

Central to PHRIDOM is the highly challenging domain of human-centred robotics, where machines have to closely interact with humans. Applications of robotics in domains such as medical, domestic, public-oriented service, personal assistance and home care are often cited as examples of interesting avenues for development. Applications of intelligent machines that work in contact with humans are however more, and more general, involving e.g. haptic interfaces and teleoperators, cooperative material-handling, power extenders and such high-volume markets as rehabilitation, physical training, entertainment (see e.g. [2], [3],

[4], [5]). All the above applications involve human-robot interactions where the person may be a non-professional user or a bystander. Unlike the industrial robotics domain where the workspace of machines and humans can be segmented, machines of these types must, by definition, have physical contact and interaction with the user.

The PHRIDOM project will enquire in the above and other fields, scouting for new applications who promise the best return-on-investment, be such return in terms of societal wellness (as e.g. for assistive or public service robotics) or industrial markets (as e.g. in entertainment or training machines) reporting on the application-specific needs in terms of technology and requirements.

B. Requirements in pHRI

Robots designed to share an environment with humans must fulfil different requirements from those typically met in industry. It is often the case, for instance, that accuracy requirements are less demanding. On the other hand, a concern of paramount importance is safety of the robot system. "A robot may not injure a human being...", or, to rephrase the famous quote, under no circumstances should a robot cause harm to people in its surroundings, directly nor indirectly, in regular operation nor in failures. Failures in the mechanics or control should happen rarely, if ever. This entails degrees and standards of reliability that must be rethought.

From a system viewpoint, however, a pHRI machine must be considered as part of unpredictably changing anthropic environments. From this point of view, "failures" are events (e.g., contacts with a person, unexpected changes of an user's mind, even users' mistakes) that cannot be ruled out in principle, and must rather be faced by suitable policies. The need hence arises for fault detection, and for graceful fault management and recovery. In general, pHRI applications also raise critical questions of communication and operational robustness. All these aspects can be captured by the concept of *dependability* [1], a crucial focus of PHRIDOM.

The next most crucial requirement for pHRI systems after dependability remains with their performance, i.e., broadly speaking, in their accuracy and rapidity in performing tasks when required (see e.g. [6]). Requirements are a fundamental tool for engineering solutions, as they define which pathways through technologies towards applications are legal and viable. To be useful, however, requirements must be quantified and/or formalized. PHRIDOM will strive for providing unambiguous definitions of concepts such as safety, fault robustness, dependability, performance, in relation with the different application domains.

C. Technologies for pHRI

As a consequence of the wide gap dividing application specifications and requirements in pHRI systems from those of conventional, industry-oriented robots, the usage of technologies employed in the latter devices for anthropic environments is far from optimal. For example, while accuracy requirements in industrial arms call for rigidity, safety may well require compliance.

The inherent danger to humans of conventional machines can be mitigated by using advanced sensing capabilities: these must address not only the interactions with the environment of an end-effector, but of the whole mechanism. Distributed force/torque, tactile, proximity sensors will have to be considered in this light, along with more general environmental sensors (e.g., application of real-time visual servoing as shown in [7] to whole-arm collision).

Mechanical design of machines is of course of paramount importance to safety and performance: while the elimination of pinch points and sharp edges can reduce the potential for laceration or abrasion injuries, careful and light-weight design of moving parts and introduction of compliance on purpose can reduce the effects of impacting loads in case of collisions (cfr. [8]). Actuators and mechanical transmissions are a crucial issue for safety, and the most recent results on radically new approaches to design actuators for intrinsically safe machines (cfr. [9]) will be reviewed and generalized.

State-of-art control algorithms (such as techniques for flexible arms and compliant joints (cfr. [10], [11]), impedance and force control [12], fault detection and isolation) will have to be characterized and rethought in this framework. Completely new control techniques may have to be devised, in the changed light of the requirements for pHRI applications, where safety and reliability are, probably for the first time, at a premium.

SW architectures and engineering should be revisited as well, dependability being now a must, and adaptivity to unpredictable fault conditions having high priority.

D. pHRI Systems

A "system" is a functional assembly of technologies to fulfil an application's requirements. A system is obviously much more than the collection of its components, as such, it requires a specific study.

To achieve dependability, a complex strategy should be employed involving all aspects of manipulator design, including the mechanical, electrical, and software architectures. One of the most salient aspects in considering dependability in relation to human-friendly robotics relates to the multifaceted interactions between the human and the machine (dialog, contact, etc.). In this sense, pHRI is the indivisible alter-ego of cHRI (cognitive Human-Robot Interaction) (see e.g. [13]). The need arises to encompass very difficult issues, some of them being conceptually different from those defining dependability in other domains. At a system level, indeed, dependability implies:

- programmability: a machine should be able to achieve multiple tasks in different situations, described at an abstract level;
- autonomy and adaptability: it should be able to refine or modify the task and its own behaviour according to its goals and to the execution context;
- reactivity: it must take into account events and timing to achieve a hierarchy of requirements and goals;

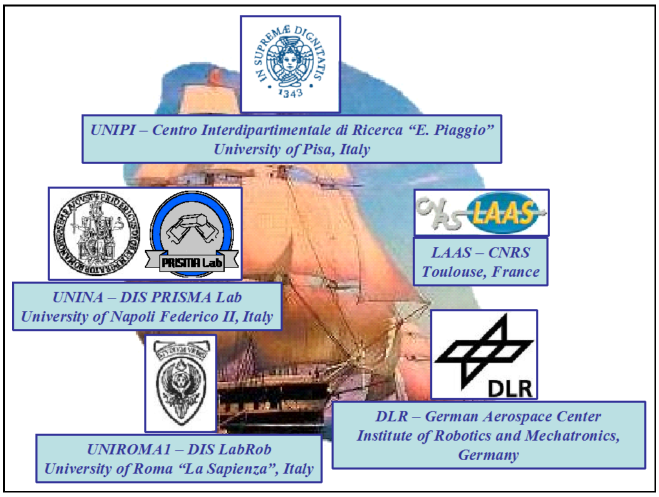

Fig. 2. The PHRIDOM Consortium.

- consistent behaviour: its (re)actions must be congruent with its tasks;
- extensibility: integration and learning of new functions and definition of new tasks should be possible and easy.

We contend that all the issues raised above cannot be considered independently from the decision-making processes of the system. These decision-making processes include those that are classically considered as related to dependability and safety issues. Therefore the validation of the architecture itself and of its components becomes a central issue for dependability. The architecture should provide tools to help the designer not only to integrate and develop the global robot system, but also to validate it both in its logical properties and temporal operations.

PHRIDOM considers standardization activities as an important ingredient of a system-oriented view to pHRI. The RIA committee has defined a new standard (T15, [14]) by which humans and robots can interact directly, and share a workspace (previously, under the R15 standard, robots had to be reliably switched off before a person may come near them). The new T15 is now getting to be an ANSI standard, and there are industrial pHRI robots going into various plants around the world, which comply with that new standard. Europe is interested in not lagging behind in the work necessary to define new standards that apply to more general pHRI systems, and PHRIDOM aims at providing an important contribution in this direction.

E. Competences in pHRI

The initial "crew" composed by the members of the Consortium is composed by four european Universities and one advanced research center, as illustrated in fig. 2. Although this group includes some important competence to fulfil the exploration goals, it is clear that the ambitious long-term goals of research in pHRI cannot be accomplished by such a limited number of partners. One of the open possibilities of PHRIDOM is to enlarge its crew, identifing where the competences can be found in different research field as computer science, aerospace, and other disciplines that are clearly needed to fulfil the specifications of different pHRI applications. Beyond the PHRIDOM consortium, we hope that the reults of this project will be useful to the robotics community at large to gather in a collective effort towards effective and safe human–robot collaboration.

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