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Enabling Reuse of Robot Tasks and Capabilities by Business-related Skills Grounded in Natural Language

(Ideas Paper)

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***Abstract*—Definition and reuse of robot instructions is still an art that requires extensive engineering, not only of the infrastructure but also of the adaptation of robot capabilities to the context and domain at hand. Technical approaches are numerous, but the lack of practical success is an indication of hidden difficulties, which we have experienced as complications over the last two decades. Based on recent insights we got the idea that it is insufficient to consider technical, economical, and human aspects separately; a new and more coherent type of integration is necessary. A key example is the notion of (robot) skills, which according to this idea should be defined such that the technical capabilities are encapsulated according to business values, and at the same time grounded in terms of knowledge such that human operation is facilitated.**

***Keywords*-Robotics; software composition; reuse; robot skill.**

I. Introduction

Robots are special and more difficult to instruct than other machines due to a combination of motion dexterity and uncertainty. The variations in the physical environment and necessary interaction with human operators make the situation complex, forming semantic systems [1] rather than standard software. Nevertheless, for non-experts to deal with robot motions, there must be a way to make use of (parts of) existing robot task definitions. Even if that requires a cognitive robot system for also being able to better deal with unforeseen situations, both the design of such systems and the techniques for refinement of robot tasks benefit from an understanding of fundamental engineering aspects.

Generally, efficient reuse and continual improvements of proven solutions is a necessary condition for the development of advances systems in the normal presence of scarce resources. That is, whereas a moon-landing project with a huge budget can result in an advanced system, most every-day developments have to build on earlier results (considering both technical, legal, economical, and human aspects). When such developments are within a set of engineering disciplines, there are methods worked out such as model-driven engineering (MDE) [2]. Also in classical industrial robotics the development of automation systems is an established engineering task, with the machine, the task, and the environment being both structured and well known (or unknown within known tolerances). A useful engineered system has an economic value, and for smart future robots that will then include both the cognitive platform as well as the learned or instructed robot tasks. We can call the reusable entities skills [3], but what would the motivation be for providing such robot skills for reuse by others, and what more is needed for skills to be truly reusable also when human interaction and uncertainties are considered?

II. Robot Skills

For developments to actually take place, there needs to be a driving force (motivation) and a process (way of working) towards some goal. The motivation is typically profitability (but could be political or community efforts, but still in need for the continual progress). That is, there are business reasons for developing products and complete systems. For product parts provided by suppliers, the same applies hierarchically down to the smalled purchased subsystem. Components will be used in other systems too, depending on and influencing the market value of it. The same clearly applies to robot instructions, so *the first part of our idea is to treat the business aspect as a primary concern for encapsulation of robot tasks and skills.*

The second part (formulated below in Section II-C) has to do with the principles of representation, which have to support the simplified but generic (not only wizards for predefined use cases) use of smart robots. Somewhat related to the business aspect, there is the aspect of management, on factory level but also on the shop floor in terms of machine usability (and understandability in case of problems); the value of a product of course depends on the users being able to manage it (installation, maintenance, reconfiguration, error handling, etc.) with the associated support options. The necessary user interaction is then part of the requirements in systems engineering. Programmable products in general comprise an interesting case with human interaction on both the system and the user level. Two examples are smartphones and programmable machine tools (so called CNC machines [4]), but what about robot capabilities from a human interaction point of view?

A. *Programming of robot motions*

At a first glance, a robot is just another type of programmable device with some operations having physical effect, like a PostScript printer or a CNC machine. A pick-and-place robot in a known environment and a specified task is also like that, and a so called PLC [5] would be sufficient. However, for (future) more advanced robots that are to perform in interaction with humans, that are to be configured with very limited system integrator support, that are to be productive in a manufacturing situation, and that are to adapt to an uncertain of partly unknown environment, we should be aware of some fundamental differences compared to other programmable machines:

1) The robot is generally not tailored to a specific application, and hence the flexibility/configurability demands are higher than for other programmable machines.
2) Since robot programmers typically are neither software experts nor working in the same organization as the robot application-package developers, normative engineering principles, such as in MDE, do not apply.
3) The combination of product, process, geometry and equipment data, together with code that is imperative, is not reusable in terms of the parts involved, in particular as uncertainties are implicit.
4) For reasons of performance tuning, there are multiple levels of system interfaces (joint space, c-space, etc.).
5) Adaptation, learning and mixed-initiative human interaction forms a cognitive system going beyond the explicit engineering of other machines.

B. *Skills as configured coordination*

The notion of skills relates to learned procedural knowledge, where learning refers to the use/ordering of instructions as well as to online adaption in a quite general sense. Skilled robots perform work when given a goal/task and necessary resources. When doing that, the robot can be perceived as skilled **and** assiduous. The robot is supposed to perform according to the intentions of the human master, and when properly configured the controls of the robot are coordinated such that the capabilities of the physical robot performs according to the intention. Thereby, we can refer to the *Intention space* and the *Capability space*.

Other notions for the intention space (within several of our projects tackling these issues) has been 'task space' or 'problem space', but a robot "task" in current practice too often specifies 'how' or 'what' in more detail beyond the actual intention, and 'problem space' assumes there is a problem, and engineering (rather than cognitive solutions) may follow. The notion of a solution space is also not appropriate since the solution is not the specific motions but the coordination that gradually (while instructing the smart robot) and temporarily (in a changing world) accomplishes the intended motions.

With these insights in mind, and considering coordination as a separate concern defining run-time behavior according to the configuration of the system [6], the topic is how to support reuse and compositionality of robot capabilities such that developments of robot tasks *build on earlier results* (as stated in the first paragraph and considering the mentioned business part of our idea).

C. *Skills as declarative knowledge*

The second part of our idea is that a skill should be declaratively defined as the configuration and coordination of capabilities according to the intentions, which for the robot system should have a grounding in related symbols as found in human natural language. To that end, our conceptual prototypes involve several interlinked graph structures [3], which on the highest level is grounded via an ontology [1], which should fulfill requirements on management and usability. Hence, the symbol grounding [7] needs to be coherent with the human notions, and recursively that should apply to the skill definition itself too.

By declarative definitions and the human notions as such, the system gets better prepared for managing unforeseen events (errors, now operator ideas, etc.). If this can form the basis for the definition of robot skills, we hope to have reached a new and intrinsically sound foundation [7] for cognitive robot systems. Human language reflect our way of thinking [8], with some regional differences, but if the notions for (human manageable) robot skills are independent of specific language, the approach is believed to be globally applicable.

D. *Invariant natural-language grounding*

The combination of skilled and assiduous does not appear to have a word of its own in English, like it has in other languages. Referring to the native languages of the four authors of this paper that are Swedish (se), German (de), Polish (pl), and Korean (kr) respectively, the following details the key notions in English and those other languages (in brackets [se/de/pl/kr]). We then have the word for skilled&assiduous being [duktig/tüchtig/wprawny/younenghan] in those languages. Missing the single-word term in English word is not crucial since we for robot control want to keep the goal (or more precisely the assiduous part) explicit and separate from the capability description. Question is, do the terminologies found in our natural languages (that reflects human thought) indicate (by invariance considering our native languages) that we actually found a definition of robot skills that match both human skills and the human notions for talking about those skills? If so, the above second stage of our idea means that the natural language terms should take the human notion as a basis for the definition of robot skills. Since our study including English and four other languages includes Asian and Slavic languages, we think our findings have a reasonable generality.

The skill-related adjective skilled [skicklig/geschickt/wykwalifikowany/halsooitnen] further adds perspective to the term skill [färdighet/Fertigkeit/wprawa/youyonghan], where the terms mean that a skill can be performed without a conscious cognitive process (and hence it is learned). Still, the performer can explain (knows meta-data) the steps included in performing a skill, possibly referring to the context in abstract/declarative ways. Example: Shifting gear when driving a car; the procedure uses knowledge about the location of the gears, which typically/better is expressed in a declarative way (where are the gears placed rather than telling how any version of gear location can be traversed/found for any type of driving).

Other words are knowledge [kunskap/wissen/wiedza/jisig] and (cap)ability [förmåga/Fähigkeit/zdolność/jinenitnen]. Relating these terms with skills, the skills could be efficient solutions to requested capabilities of the system/workers/robots (so a requested capability is in the *intention space* and the actually existing skills are in the *capability space*), but whereas the skills are learned (the implicit process during performing instances of them) a capability may very well include a cognitive process involving awareness (on-line usage of meta-data). That is, to further clarify the meaning of skills, the swedish term färdighet (en: skill) is complementary to kunskap (se: ”kunskap och färdighet”, i.e. the terms being mainly complementary), meaning that 'färdigheter' (and hence/possibly the abilities) exist (or can be used) without (using) explicit knowledge (about what is being performed), which in turn confirms the consistency of the presented idea and definitions so far.

E. Representation in software

Having skills (in the capability space) that can be performed efficiently (meeting productivity demands for robots in manufacturing, or handling a time-varying environment for the case of autonomous robots), does not mean there are no skills in the intention space. That is, a task can first have a specification such as an assembly graph, and then being detailed in terms of a state machine using the elementary/atomic operations, but after parameterization it can be promoted to a skill (an abstract skill not yet associated with its context, or a concrete skill that can be readily performed). Since a skill is learned (possibly by a human that then implemented it accordingly), there should be support for continual learning if needed, and again the need for skills being parametrized in declarative knowledge is apparent. Such knowledge will include state machine representations (forming an FSM if finite, today being imperative [5] rather than declarative [1] in both intention and capability space.

III. Conclusion

We bring forward the idea of redefining the notion of skills, for robots with the purpose of accomplishing the desired reuse of tasks and capabilities, such that

- skills comply with business aspects of components,
- skills interface between intended and actual motions,
- skills specify the configuration and coordination of actions by connecting the involved graphs representing the knowledge in a declarative manner,
- skills have a gradual instantiation reflecting the gradual configuration in terms of graph interconnections,

and a central part of the idea is to base the definition on terms used naturally in the human language. Skill is much related with knowledge, and thus better expressed in declarative context rather than in procedural context. Specifically, since skills are task-oriented, they have to be precisely represented by some processes organizing elementary/atomic/basic behaviors (or sub-skills) as in a form of graph-based declarative knowledge. The invariance with respect to the listed native human languages supports our idea that the suggested notion is inherent to human thinking.

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