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RehabRobo-Onto: Design, development and maintenance of a rehabilitation robotics ontology on the cloud

Zeynep Dogmus, Esra Erdem*, Volkan Patoglu

Faculty of Engineering and Natural Sciences, Sabancı University, Istanbul, Turkey

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ABSTRACT

Representing the available information about rehabilitation robots in a structured form, as an ontology, facilitates access to various kinds of information about the existing robots, and thus it is important both from the point of view of rehabilitation robotics and from the point of view of physical medicine. Rehabilitation robotics researchers can learn various properties of the existing robots and access to the related publications to further improve the state-of-the-art. Physical medicine experts can find information about rehabilitation robots and related publications (possibly including results of clinical studies) to better identify the right robot for a particular therapy or patient population. Therefore, considering also the advantages of ontologies and ontological reasoning, such as interoperability of various heterogeneous knowledge resources (e.g., patient databases or disease ontologies), such an ontology provides the underlying mechanisms for translational physical medicine, from bench-to-bed and back, and personalized rehabilitation robotics. With these motivations, the first formal rehabilitation robotics ontology, called RehabRobo-Onto, is designed and developed, collaborating with experts in robotics and in physical medicine. A web based software (called RehabRobo-Query) with an easy-to-use intelligent user-interface is also built. RehabRobo-Query allows robot designers to add/modify information about their rehabilitation robots to/from RehabRobo-Onto. The ontology system consisting of RehabRobo-Onto and RehabRobo-Query is made available on the cloud, utilizing Amazon Web services, to provide a reliable environment for access, development and maintenance of RehabRobo-Onto by rehabilitation robot designers and physical medicine experts around the world.

1. Introduction

As the amount of information in digital formats increases, ontologies are becoming increasingly popular to represent and understand this information. Ontologies are formal frameworks for representing knowledge in a structured form, to aid access to relevant parts of the knowledge and automate reasoning over it. Unlike databases, ontologies allow representation of incomplete knowledge, can easily be extended by new information; ontologies developed by different parties at different locations can be integrated; and reasoning can be automated over concepts and their relations represented in these ontologies. Therefore, it is not surprising that an increasing number of knowledge-intensive systems (including Semantic Web [1] that is planned to provide automated services to Web by giving meaning to concepts) rely on ontologies to enable content-based access, interoperability, and communication across the Web. Along these lines, this paper presents the design and development of the first formal rehabilitation robotics ontology system, consisting of the rehabilitation robotics ontology RehabRobo-Onto and its Web-based software with an intelligent user-interface RehabRobo-Query.

Most of the digital information about robot-assisted physical rehabilitation and rehabilitation robots is kept in unstructured forms, typically as academic publications. This makes it hard to access the requested knowledge and thus automatically reason about it. Moreover, due to the interdisciplinary nature of rehabilitation robotics, requested knowledge commonly necessitates integration of further knowledge from other related disciplines. In addition to these challenges, due to the diversity and interdisciplinary nature of the field, there is a need for standardizing the terminology for rehabilitation robotics as emphasized by the European Network on Robotics for Neurorehabilitation. The formal rehabilitation robotics ontology system presented in this paper is an outcome of efforts to address these challenges.

RehabRobo-Onto represents knowledge about rehabilitation robotics in a structured form and allows automated reasoning about this knowledge. For example, using RehabRobo-Onto, users can retrieve "the flexion/extension range of motion (RoM) of AssistOn-SE [2]" and find "the rehabilitation robots that target shoulder movements and also have at least 210° RoM for the flexion/extension movements of the shoulder".

* Corresponding author.

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RehabRobo-Onto is open-access and available on the cloud, in order that rehabilitation robotics researchers can easily add information about their robot to it, and rehabilitation robotics researchers and physical medicine experts can access information about all available rehabilitation robots.

RehabRobo-Onto is designed in a way that enables integration with other medical ontologies, such as ontologies that capture physical rehabilitation protocols, patient data and disorder details. Considering the standards of World Wide Web Consortium (W3C), RehabRobo-Onto is represented in OWL (Web Ontology Language) [3,4]. This enables users to find answers to interdisciplinary queries, such as finding "rehabilitation robots that can be used to treat a patient with rotator cuff lesions".

RehabRobo-Onto promotes the standardization of terminology for rehabilitation robots. Given the growing number of different approaches introduced by various research groups and the variability of results available, the development of such a standardization is a critical step forward in the field, and can help robotic rehabilitation technology become widely understood and accepted as a useful tool.

RehabRobo-Query[1] is developed as a Web-based software that features an intelligent user-interface to facilitate modifications and uses of RehabRobo-Onto. In this way, it is not necessary for the experts to know the underlying logic-based representation languages of ontologies, like OWL, or Semantic Web technologies, for information entry, retrieval and modification. Amazon Elastic Compute Cloud (Amazon EC2),[2] which is a web service that provides resizable compute capacity in the cloud, is utilized for both developing and maintaining RehabRobo-Onto, and for querying RehabRobo-Onto via RehabRobo-Query.

The ontology system consisting of RehabRobo-Onto and RehabRobo-Query is of great value to robot designers as well as physical therapists and medical doctors. Robot designers can benefit from the system, to identify robotic devices targeting similar therapeutic exercises or to determine systems using a particular kind of actuation–transmission pair to achieve a range of motion that exceeds some threshold. Availability of such information may help inspire new designs or may lead to a better decision making process. The ontology can also be utilized to group similar robots by quantifiable characteristics and to establish benchmarks for system comparisons. Overall, an ontology designed to specifically meet the expectations of the overall rehabilitation robotics effort has the potential to become an indispensable tool that helps in the development, testing, and certification of rehabilitation robots. Similarly, physical therapists and medical doctors can utilize the ontology to compare rehabilitation robots and to identify the ones that serve best to cover their needs, or to evaluate the effects of various devices for targeted joint exercises on patients with specific disorders.

This paper extends the authors' earlier conference publications [5,6]. In particular, it includes a more detailed description of the design, implementation and maintenance of RehabRobo-Onto by providing explanations about the methodological strategies and the choice/use of technologies. The registration and authorization processes for accessing/modifying RehabRobo-Onto are described. The processes of adding/modifying information to/in RehabRobo-Onto using Semantic Web technologies are explained in more detail (including relevant SPARQL queries). In addition, the paper gives a much more detailed description of the implementation of the ontology system, providing explanations about the overall system architecture (explicitly showing workflow/dataflow for addition of information) and the use/choice of technologies. A wider range of related work is covered as well.

2. Related work

Although there are some ontologies maintaining information about objects, environments or processes [7–13], developed for the use of robots, there are only several works in the literature that have proposed ontologies about robots.

The importance of designing and developing ontologies for robotics is emphasized by IEEE-RAS Ontologies for Robotics and Automation Working Group.[3] The group has initiated the design and development of ontologies for several sorts of robots [14] (e.g., mobile robots [15], urban search and rescue robots [16]).

In particular, Amigoni and Neri [15] introduce two ontologies (in OWL): one to store general concepts and properties/relations about the movement capabilities of mobile robots (e.g., wheels and their properties) and the other to describe the high level tasks that these robots can perform (e.g., move, rotate). The idea is to allocate tasks and/or assign roles to mobile robots by means of querying these two ontologies using a description logics reasoner.

Schlenoff and Messina [16] introduce an ontology (in OWL) for urban search and rescue robots. The ontology captures structural characteristics (such as size), functional capabilities (such as locomotion capabilities) and operational considerations (such as display type) of the robots with a goal of assisting in the development and testing of search and rescue robot systems.

Juarez et al. [17] introduce a database (called RoboDB) for storing physical characteristics of robots; but also note that they plan to transform the knowledge stored in RoboDB into an OWL ontology to benefit from this "common" language of ontologies and related reasoners.

In a similar way, an ontology is developed in OWL to describe the components, like sensors and ports, of a surgical robotics setting [18,19]. The ontology is queried using Prolog.

However, none of these existing robot ontologies have been designed to target rehabilitation robots and, without further customization, they fail to capture many important aspects of rehabilitation robots, including the interoperability with the existing ontologies in physical medicine. Furthermore, none of them is open-access where the researchers are allowed to contribute and access. In that sense, the work presented in this paper contributes to the efforts towards designing and developing robotics ontologies.

3. Design of RehabRobo-Onto

Ontologies are formal frameworks for representing knowledge in a structured form, to aid access to relevant parts of the knowledge and automate reasoning over it. An ontology can be viewed as a graph where nodes denote concepts and the edges between the nodes denote relations between the corresponding concepts. For instance, an edge from a node that denotes "Upper Extremity Rehabilitation Robots" to a node that denotes "Rehabilitation Robots" may characterize the "is-a" hierarchy relation. An edge from a node that denotes "Rehabilitation Robots" to a node that denotes "Joint Movements" may characterize "targets" relation.

This paper introduces an ontology about rehabilitation robots, called RehabRobo-Onto, based on the suggestions of rehabilitation robotics researchers and physical medicine experts. As suggested in [20], the following steps are followed in the design of this ontology. First, the purpose of the ontology is identified.

[1] http://hmi.sabanciuniv.edu/?page_id=781.
[2] http://aws.amazon.com/ec2/.
[3] http://www.ieee-ras.org/industrial/standards.html.