Developing and Maintaining an Ontology for Rehabilitation Robotics

Zeynep Dogmus, Gizem Gezici, Volkan Patoglu and Esra Erdem
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, like ontologies, 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 heterogenous 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, we have designed and developed the first formal rehabilitation robotics ontology, called REHABROBO-ONTO, in OWL, collaborating with experts in robotics and in physical medicine. We have also built a software (called REHABROBO-QUERY) with an easy-to-use intelligent user-interface that allows robot designers to add/modify information about their rehabilitation robots to/from REHABROBO-ONTO.

1 INTRODUCTION

Ontologies (like databases) 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 (e.g., rehabilitation robots, joint movements) 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; whereas an edge from a node that denotes "Rehabilitation Robots" to a node that denotes "Joint Movements" may characterize "targets" relation. Due to their flexible graph-like structure, ontologies (unlike databases) allow representation of incomplete knowledge, can easily be extended by new information (e.g., with new sorts/features of rehabilitation robots). Due to their formal representations, ontologies developed by different parties at different locations can be integrated, and reasoning (e.g., query answering) can be automated over concepts and their relations represented in these ontologies. Therefore, it is not surprising that more and more knowledge-intensive systems (including Semantic Web (Berners-Lee et al., 2001) 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.

As the number of rehabilitation robots increase, the information about them also increases, but most of the time in unstructured forms (e.g., as text in publications), which make it harder to access the requested knowledge (e.g., the flexion/extension range of motion (RoM) of ASSISTON-WRIST (Erdogan et al., 2011)) and thus reason about it (e.g., finding the rehabilitation robots that target shoulder movements and also have at least 60° RoM for the flexion/extension movements of the wrist). To facilitate access to requested knowledge about rehabilitation robots, we have designed and developed the first formal rehabilitation robotics ontology, called REHABROBO-ONTO. This ontology has been designed in a way that enables integration with other medical ontologies, such as ontologies that capture 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) (Horrocks et al., 2003; Antoniou and van Harmelen, 2004).

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Our goal is to make this ontology open-source so that every rehabilitation robotics researcher can easily add information about his/her robot to it, and every rehabilitation robotics researcher and every physical medicine expert can access information about all available rehabilitation robots. To facilitate such modifications and uses of REHABROBO-ONTO, we have developed a software (called REHABROBO-QUERY) with an intelligent user-interface. In this way, experts do not need to know logic-based representation languages of ontologies, like OWL, or Semantic Web technologies, for information entry, retrieval and modification.

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. On the one hand, robot designers can benefit from the system, for instance, 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. On the other hand, 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.

It is important to emphasize that the ontology REHABROBO-ONTO and the tool REHABROBO-QUERY introduced in this paper have been developed to initiate efforts in utilizing ontological technologies for the field of rehabilitation robotics. Therefore, by making REHABROBO-ONTO available open-source via REHABROBO-QUERY, it is our intention to continually update and enhance capabilities of these tools according to the feedback provided by the community.

2 RELATED WORK

Although there are some ontologies maintaining information about objects or environments (Chella et al., 2002; Yanco and Drury, 2004; Paolucci and Sycara, 2004; Wang et al., 2005; Suh et al., 2007; Johnston et al., 2008), developed for the use of robots, there are only several works in the literature that have proposed ontologies about robots.

In particular, Amigoni and Neri (Amigoni and Neri, 2005) 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 then 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 (Schlenoff and Messina, 2005) 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. (Juarez et al., 2011) 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.

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.

3 DESIGNING AN ONTOLOGY FOR REHABILITATION ROBOTS

We have designed the rehabilitation robots ontology REHABROBO-ONTO considering suggestions of the rehabilitation robotics researchers and physical medicine experts whom we collaborate with. As suggested in (Uschold and King, 1995) about designing an ontology, we have first identified the purpose, and then identified and defined the basic concepts and their thematic classes, and their relationships for the chosen subject domain.

Our goal of developing an ontology for rehabilitation robotics is mainly to maintain a knowledge repository containing information about all rehabilitation robots and relevant references, to facilitate access to

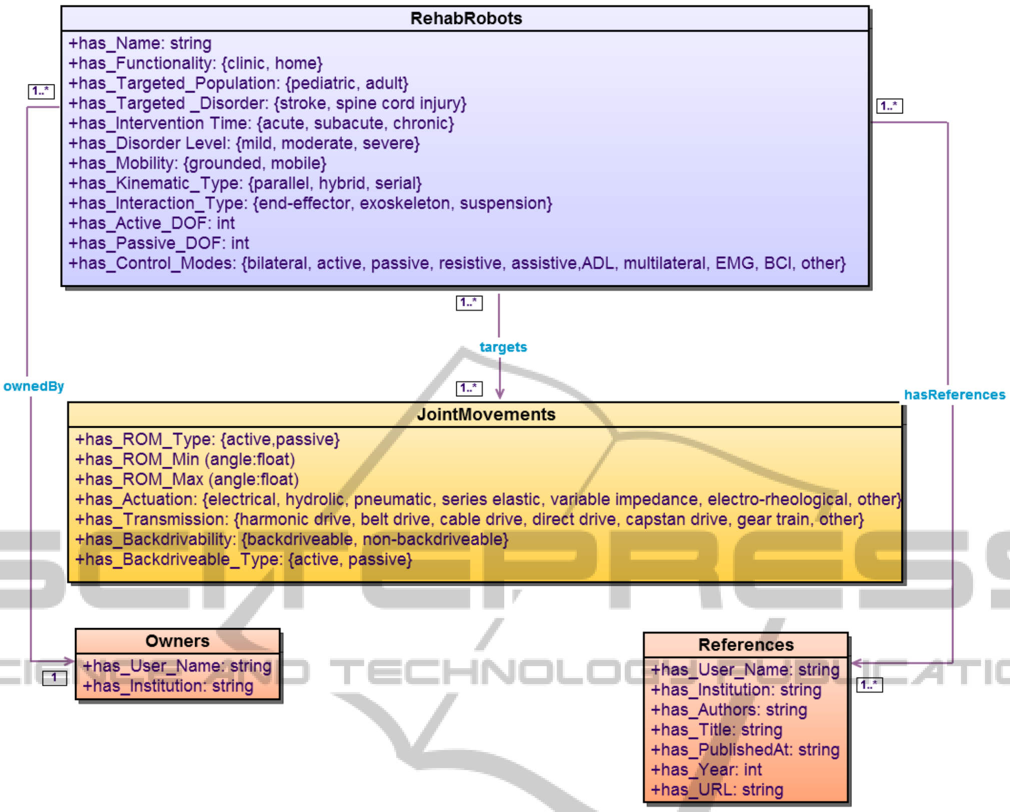

Figure 1: REHABROBO-ONTO with main classes.

requested information in this repository for both robot designers as well as physical medicine experts. In this way, not only it will be easier for robot designers to improve the state-of-the-art in rehabilitation robotics but also it will aid translation from bench-to-bed and back, and personalized physical medicine by allowing the physical medicine experts to choose the right rehabilitation robots for specific patients/therapies.

Along these goals, next comes the question of what kind of information should be maintained in such an ontology about rehabilitation robots.

We have designed our ontology (Figure 1) considering four main concepts (or thematic classes):

- `RehabRobots` (representing rehabilitation robots and their properties),
- `JointMovements` (representing targeted joint movements and their properties),
- `Owners` (representing robot designers who add/modify information in the ontology about their own robots),
- `References` (representing publications related to rehabilitation robots).

These concepts are related to each other by the following relations:

- a rehabilitation robot `targets` joint movements,
- a rehabilitation robot is `ownedBy` a robot designer,
- a rehabilitation robot `hasReferences` to some publications.

As seen in Figure 1, each class has its own properties. For instance, `RehabRobots` has the "functionality" property to be able to describe that a rehabilitation robot can be used at home or in clinic. `JointMovements` has a property to describe the "RoM type" of the robot: a rehabilitation robot can be used in active mode, where some effort from the patient is required while the robot guides the patient, or in passive mode, where no effort is required from the patient while the robot guides the patient's movements. We also keep information about the owners (e.g., names, institutions) and the related references.

Considering various sorts of rehabilitation robots and various sorts of joint movements, `RehabRobots` and `JointMovements` classes have subclasses; some of these subclasses are illustrated in Figures 2 and 3. Maintaining such a hierarchy aids not only compact representation of knowledge about rehabilitation robots (by avoiding repetitions) but also efficient reasoning about it. Currently there are 93 classes represented in REHABROBO-ONTO.

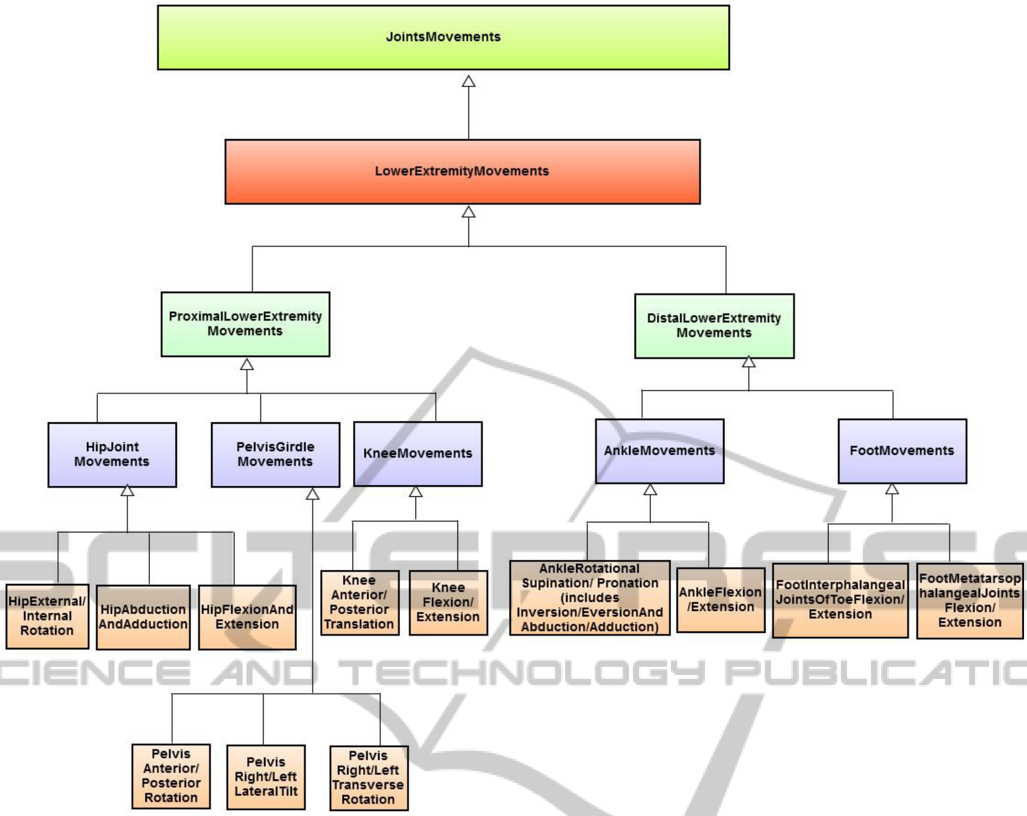

Figure 3: Hierarchy of lower extremity joint movements targeted by rehabilitation robots.

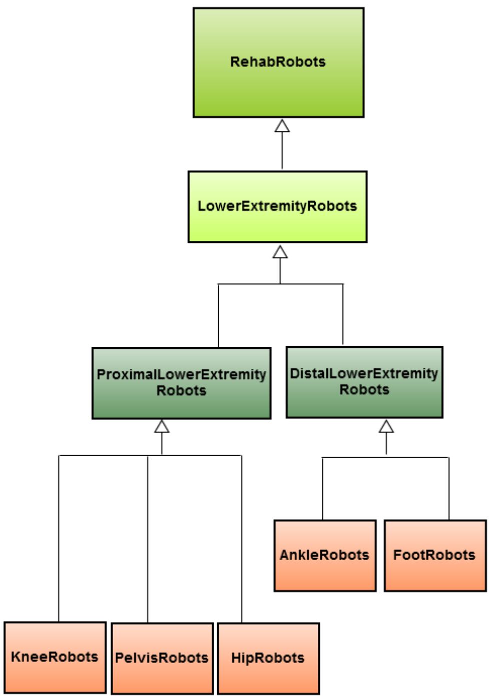

Figure 2: Hierarchy of lower extremity rehabilitation robots.

4 DEVELOPING AND MAINTAINING REHABROBO-ONTO

Ontologies represented formally in a language, such as OWL, are based on variations of Description Logics (DL) (Baader et al., 2008). DL provides the logical formalism not only for such formal ontologies but also the Semantic Web.

DL terminology consists of concepts, roles, and objects. Objects denote entities of our world with characteristics and attributes; concepts are interpreted as sets of objects; and roles are interpreted as binary relations on objects or concepts. According to a formal ontology terminology (e.g., in OWL), concepts are called classes, attributes of classes are called data properties, roles are called object properties, and objects are called individuals. For instance, a concept/class named `RehabRobots` may represent all rehabilitation robots, whereas an object/individual named ASSISTON-SE represents the particular shoulder robot introduced in (Ergin and Patoglu, 2012; Yalcin and Patoglu, 2012). A class (e.g., `RehabRobots`) may have subclasses (e.g., ShoulderRobots); then subclasses inherit properties of classes. Such a possibility of representing hierarchical classes allows compact representation as well as efficient reasoning over it.

Due to the common logic-based formalism that underlies formal ontologies and Semantic Web, different ontologies developed by different parties around the world can be integrated for deep automated reasoning. In that sense, considering also the possibilities of integrating information about rehabilitation robotics with other information (e.g., patient information, disease information, genetic information), maintaining information about rehabilitation robotics as formal ontologies is well-decided.

Once we identify classes, their properties, subclasses, relations between classes, and define them precisely as in the previous section, we can represent the ontology formally using a logic-based ontology language. Considering the standards of W3C, we have decided to represent the ontology in the logic-based ontology language OWL; then we need to use description logic reasoners to find answers to experts' queries. We have represented the OWL ontologies that describe general concepts and their properties/relations using the OWL ontology editor PROTÉGÉ (Gennari et al., 2003).

Once we represent general concepts and their properties/relations about rehabilitation robots in OWL, we are not done yet. As discussed above as a part of our goals, we would like the rehabilitation robotics ontology to be shared by researchers so that robot designers can add/modify information about their robots, and both rehabilitation robotics experts and physical medicine experts can ask queries over it. Therefore, we would like to allow researchers to add information about specific rehabilitation robots by "assertions" (like, "the rehabilitation robot whose name is ASSISTON-WRIST is a wrist robot and it has clinic use") as well.

Such assertions about specific individuals can be added to REHABROBO-ONTO using PROTÉGÉ. However, since PROTÉGÉ downloads the whole ontology to be able to add new information, ensuring that the users add information to REHABROBO-ONTO without letting them modify other parts of the ontology may be problematic. Also, assuming that the existing robotics experts and physical medicine experts know about DL and logic-based ontology languages, that they have experience in using DL reasoners or Semantic Web technologies, and that they keep track of the most recent versions of these software, may not be reasonable along our goals for an effective use of the rehabilitation ontology. To facilitate the effective use of the rehabilitation ontology

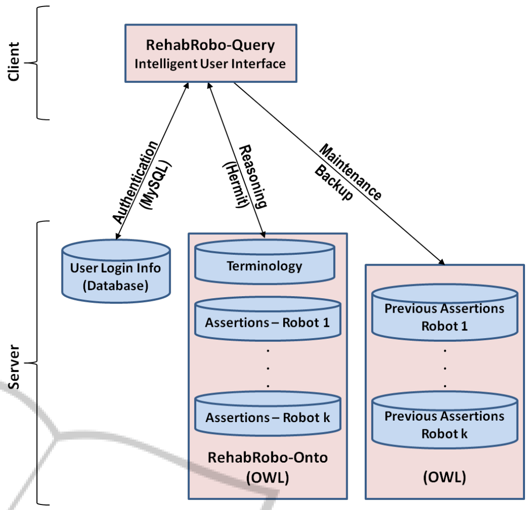

Figure 4: An overview of the system architecture of REHABROBO-QUERY.

by different users, we have designed a tool (called REHABROBO-QUERY) with an easy-to-use intelligent user-interface.

REHABROBO-QUERY (Figure 4) is a software that allows rehabilitation robotics researchers to add/modify information to REHABROBO-ONTO about their robots by following consecutive tabs of the intelligent user-interface and allow experts to ask queries about the existing robots, without having to know about DL or logic-based ontology languages, and without possessing any experience of using the existing description logic based reasoners or Semantic Web technologies. Some snapshots of the user interface of REHABROBO-QUERY for adding new information to REHABROBO-ONTO ontology about the rehabilitation robot ASSISTON-WRIST (Erdogan et al., 2011) are shown in Figures 5 and 6.

As the registered user describes the robot by navigating the tabs, the information is held in the system in a structured way, as temporary objects. Therefore, the user has the chance to return to any tab to change the information. After entering all properties of the robot, in the End tab, all the information entered by the user is displayed as a summary for the last time. After the user checks the information and confirms its addition to REHABROBO-ONTO, the information about the rehabilitation robot is transformed into assertions in OWL to be added to REHABROBO-ONTO. Assertions about each rehabilitation robot is stored in a separate file, to make it easy to modify/delete REHABROBO-ONTO as well as for efficient query answering planned as part of future work.

A user can modify or delete his/her own robots only. First the relevant robots are found by querying REHABROBO-ONTO using the DL reasoner HER-

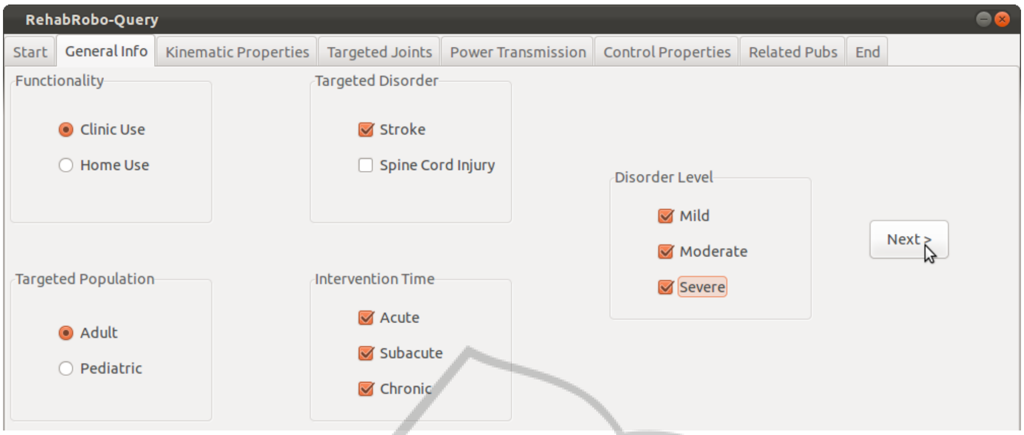

Figure 5: REHABROBO-QUERY: Adding to REHABROBO-ONTO general information about the rehabilitation robot ASSISTON-WRIST.

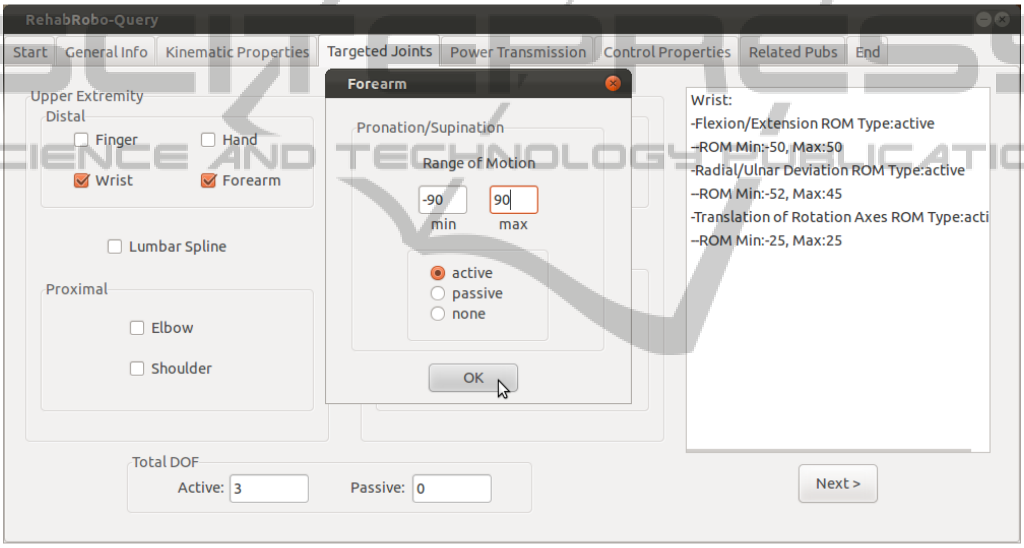

Figure 6: REHABROBO-QUERY: Adding to REHABROBO-ONTO information about the RoM of targeted joint movements of the rehabilitation robot ASSISTON-WRIST.

MIT (Motik et al., 2007) via OWL API, and listed in a pull-down menu. For modification, after the user chooses a robot from the list, the user interface that we have seen earlier for adding information appears but now with tabs filled with the robot's properties. The user can make changes via this interface and the updated information can be saved as a set of assertions in OWL, in a new file while keeping the previous version as "modified". For deletion, after the user chooses a robot from the list, the relevant file containing assertions about that robot is marked as "deleted". Note that in both cases, we keep the information about the robot before modification/deletion as well; these files may be needed if the user accidentally deletes his/her robot from REHABROBO-ONTO, or modifies it incorrectly.

5 CONCLUSIONS

We have designed and developed the first formal rehabilitation robotics ontology, called REHABROBO-ONTO, to represent information about rehabilitation robots. The benefits of having such an ontology can be summarized as follows:

- It provides structured formal representation about rehabilitation robots and their properties. This further allows easy access to the requested information, integration with other knowledge resources (e.g., patient databases, or disease ontologies), as well as reasoning (e.g., answering complex queries) over all these knowledge resources.
- It allows the selection of right rehabilitation

robots for a particular patient or a physical therapy. In particular, it helps finding available resources (e.g., rehabilitation robots and related publications that may involve results of clinical studies) that address a specific need. This further paves the way for translational physical medicine (from bench-to-bed and back) and personalized physical medicine.

- It aids exchange of information across rehabilitation robots researchers over the world, and thus to improve the state-of-the-art.
- It allows to identify "gaps" in functionality of rehabilitation robots, that can further improve research efforts.

We have also built a software, RehabRobo-Query, with an easy-to-use intelligent user-interface that allows robot designers to add/modify information about their rehabilitation robots.

Along these directions, our ongoing work involves extending RehabRobo-Query with the functionality of answering queries over RehabRobo-Onto using a DL reasoner. For instance, using RehabRobo-Query, we will be able to find

> the rehabilitation robots that has targeted population "adult" and that targets "shoulder scapular elevation/depression movements".

Our ongoing work also includes making RehabRobo-Query available to researchers by a web-service, and integration of RehabRobo-Onto with the existing related ontologies.

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