An Ontology for Dynamic Sensor Selection in Wearable Activity Recognition

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Abstract. A strong effort has been made during the last years in the autonomous and automatic recognition of human activities by using wearable sensor systems. However, the vast majority of proposed solutions are designed for ideal scenarios, where the sensors are pre-defined, well-known and steady. Such systems are of little application in real-world settings, in which the sensors are subject to changes that may lead to a partial or total malfunctioning of the recognition system. This work presents an innovative use of ontologies in activity recognition to support the intelligent and dynamic selection of the best replacement for a given shifted or anomalous wearable sensor. Concretely, an upper ontology describing wearable sensors and their main properties, such as measured magnitude, location and internal characteristics is presented. Moreover, a domain ontology particularly defined to neatly and unequivocally represent the exact placement of the sensor on the human body is presented. These ontological models are particularly aimed at making possible the use of standard wearable activity recognition in data-driven approaches.

Keywords: Ontologies, Activity Recognition, Wearable sensors, Sensor selection, Sensor placement, Human anatomy.

1 Introduction

In the recent years, an enormous interest has awaken in the human physical self-quantification. Particularly devoted to health and wellness improvement, the personal self-tracking and evaluation of people's wellbeing is flourishing as a key business in which hundreds of applications and systems are increasingly available at the reach of most consumers. Most of these systems build on mobile and portable sensor devices that are carried on, or directly worn, by their users. Generally named "wearables", these devices are capable of measuring important physical and physiological human characteristics such as body motion or vital signs, which are principally used to quantify physical activity patterns [7,11] as well as to determine abnormal vital conditions [15,14,9].

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By far, most of the effort in the personal self-quantification has been devoted to the analysis of human behavior by using wearable systems, also known as wearable activity recognition. Many solutions have been provided to that end, and although accurate systems are available, most of them are designed to work in closed environments, where the sensors are pre-defined, well-known and steady. However, real-world scenarios do not fulfill these conditions, since sensors might suffer from diverse type of anomalies, such as failures [6] or deployment changes [8]. Realistic dynamic sensor setups pose important challenges to the practical use of wearable activity recognition systems, which translate into specific requirements to ensure seamless recognition capabilities. One of the most important requirements refers to the support of anomalous sensor replacement to maintain the recognition systems operation properly. In order to enable sensor replacement functionalities in an activity recognition system, mechanisms to abstract the selection of the most adequate sensors are needed. To that end, a comprehensive and interoperable description of the available sensors is required, so that the best ones could be selected to replace the anomalous ones.

Although technical characteristics may be extracted from data or spec sheets, more practical definitions such sensor location or availability are required for an accurate sensor selection at runtime. Accordingly, models that may integrate these heterogeneous sensor descriptions are required. In this work, the use of ontologies is proposed to neatly and comprehensively describe the wearable sensors available to the user. Concretely, this work aims at defining ontologies to support the intelligent and dynamic selection of the best replacement wearable sensor in case an anomalous one is determined. To the best of the authors' knowledge, this is the first time that ontologies are used in this regard, which goes beyond the state-of-the-art utilization of these models to detect activities in a knowledge-based recognition approach. On the contrary, it can be said that, ontologies are used here to enhance the machine learning activity recognition used in data-driven approaches. The rest of the paper is as follows. In Section 2 an overview on the use of ontologies in activity recognition is provided. The key motivations for the use of ontologies in dynamic sensor selection is presented in Section 3. Section 4 thoroughly describes the ontology proposed for the sensor selection problem. Finally, main remarks and conclusions are provided in Section 5.

2 Related Work

The use of ontologies in activity aware systems is principally focused on the application of knowledge-based recognition techniques. In these approaches, the activities are described through ontologies and recognized using reasoning and inference methods. For example, Bae [4] presents an ontology-based smart home system that discovers and monitors activities of the daily living. Nguyen et al. [13] also propose an ontological approach using the outputs of binary sensors to detect office activities. A similar use of the ontologies is made by Cheng et al. [10] to both represent and reason activities based on the analysis of the user interaction with smart objects in pervasive environments.

Previous approaches rely on binary or very simple sensors to detect primitives or atomic activities, which are described in an ontological model and used for ontological reasoning to detect high level activities. However, they do no exploit the potential of data-driven approaches in activity recognition, where the sensor data is analyzed using machine learning techniques to detect patterns matching known activities. Therefore, and in order to move one step forward, knowledge-driven approaches have been combined with data-driven approaches to recognize activities. For example, BakhshandehAbkenar and Loke [5] define a hybrid model using machine learning techniques applied to body motion data and reasoning based on the ontological representation of the activities. Riboni and Bettini [16,17] utilize ontological reasoning to recognize complex activities based on simple actions, which are detected via supervised learning algorithms building on data from wearable sensors and mobile devices.

3 Motivation for the Use of Ontologies for Sensor Selection

In order to provide interoperability, heterogeneous sensors used in wearable activity recognition systems should be abstracted from the actual underlying network infrastructure. This of utmost importance to be able to replace a sensor suffering from anomalies with another one which could provide the activity recognition system with the same sensing functionality.

A semantic description is needed to define the wearable sensor capabilities; not only the information the sensor measures and its intrinsic characteristics, but also its location on the human body. In case the anomalous sensor selection and replacement were done by human users, it would be sufficient to describe the sensor with a number of keywords or tags. However, free-text tags are insufficient for any machine-based interaction, where the selection and replacement of anomalous sensors have to be executed by a machine. In this case, the syntax and semantics of the sensor description need to be clearly defined.

In the sensor description, the semantics could be implemented using different representations. For example a language with implicit semantics like XML or an ontology language that formally describes the semantics. XML descriptions do not provide the full potential for machines to acquire and interpret the emerging semantics from data, therefore the semantic meaning of the data has to be previously agreed between machines. Conversely, an ontology-based data representation solves these problems and enables efficient selection for heterogeneous sensors. The drawbacks of ontologies are the overhead in their representation and the complexity of defining the models. However, the interpretation of the semantics out of the data is a great advantage that overcomes these disadvantages. For all this reasons, ontologies one of the best options to capture the semantics in the sensor description.

Moreover, one of the properties of a formal structure like an ontology is the interoperability. Therefore, using ontologies the sensor descriptions provided for sensors of different vendors are sufficiently rich to be automatically interpreted by the activity recognition system to apply methods to select a replacing sensor. This work proposes an ontology to describe heterogeneous wearable sensors and which supports the replacement of anomalous sensors in activity recognition systems.

4 The Sensor Selection for Real-World Wearable Activity Recognition Ontology

An ontology to describe heterogeneous wearable sensors and which will enable the selection replacement of anomalous sensors in activity recognition systems is presented in this work. This ontology named Sensor Selection for Real-World Wearable Activity Recognition Ontology (SS4RWWAR Ontology) needs to have two main characteristics: extensibility and evolvability. These refer to the ability of the SS4RWWAR Ontology to support the description of new sensors not envisioned at design time and used in new application domains. Extensibility and evolvability require that the ontology is designed to assure that the mechanisms to select the best sensors for replacement are still valid and do not need to be re-implemented when new sensors are added and new concepts are included to the ontology.

The SS4RWWAR Ontology needs to be defined as an upper ontology which defines the basic common concepts and several plugable domain ontologies which inherit from the concepts in the upper ontology. New concepts, that could be required in future activity recognition applications, are defined in domain ontologies that extend these models. Extending the SS4RWWAR Ontology in a distributed fashion by generating the new concepts for the sensor descriptions in a decentralized manner could be achieved in the future using an approach based on Linked Data [2]. Moreover, in order to allow extensibility, existing ontologies have to be reused if possible, for example for the definition of the sensing magnitudes, units or body locations.

4.1 SS4RWWAR Upper Ontology

The SS4RWWAR Upper Ontology specifies the sensor description and includes the list of magnitudes that can be measured by the sensor, the location where the sensor is placed, the sensor internal characteristics and a human readable description of the sensor. The *WearableSensor* class is the main concept of the SS4RWWAR Upper Ontology and an instance of this class is the actual sensor description. In this work we use the well-known ontology language OWL2 as encoding for the sensor descriptions because of its expressiveness. The graphical representation of the SS4RWWAR Upper Ontology with all its classes and properties is shown in Fig. 1.

Magnitudes measured by the wearable sensors need to be clearly specified in order to support the definition of heterogeneous sensor modalities used in activity recognition. In the SS4RWWAR Upper Ontology the magnitudes are represented by the *Magnitude* class. In order to link the *Magnitude* class to the

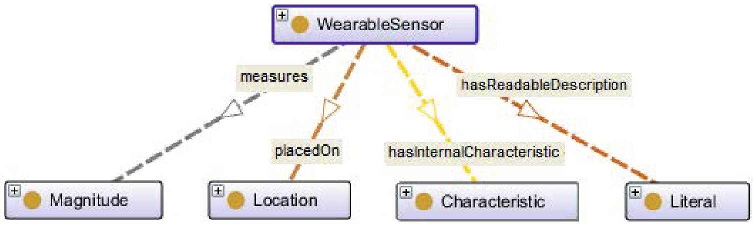

Fig. 1. SS4RWWAR Upper Ontology representing the description of Wearable Sensors

sensor description the *measures* property has been defined. This object property has as domain the *WearableSensor* class and as range the *Magnitude* class. The *Magnitude* class has to be further specified in a domain ontology in order to describe the details of each magnitude. At this moment, the ontology only defines three types of magnitudes measured by Inertial Measurement Units (IMU). The three subclasses of the *Magnitude* class are the *Acceleration* class representing the measurement of accelerometers, the *TurnRate* class representing the measurement of gyroscopes, and the *MagneticFieldOrientation* class representing the measurements of magnetometers. In the future we plan to provide a complete ontology with the most important sensor modalities which allows the description of the most common sensors.

Wearable sensors location affects the performance of the activity recognition systems. In order to allow sensor replacement, the locations of the sensors need to be well specified. In the SS4RWWAR Upper Ontology, the position where the wearable sensor is placed is described by the *Location* class. The link to the sensor description is established through the *placedOn* property which has as domain the *WearableSensor* class and as range the *Location* class. Since wearable sensors are placed on the human body, the actual location of the sensor will be a body part. In order to describe the human body parts and use them as sensor locations, the *HumanBodyPart* class, which is a subclass of the *Location* class, has been defined in the SS4RWWAR Human Body Ontology. This ontology, described in Section 4.2, is one of the main contributions of this work and is the key to support the selection of replacement sensors placed on closed by body locations.

Wearable sensors from different vendors have different characteristics, for example sensor dynamic range, bias, or offset, which have to be properly described in the ontology. The *Characteristic* class is used to describe these internal sensor characteristics. The link between the characteristics and the actual sensor description is done via the *hasInternalCharacteristic* property, which has as domain the *WearableSensor* class and as range the *Characteristic* class. The *Characteristic* class needs to be further specified in the future in order to comprehensively describe all the sensor characteristics.

The sensor description may contain some human readable information about the sensor. Examples of these descriptions could be "SHIMMER 3", "Fitbit Flex" or any other name that could identify the sensor. The property *hasReadableDescription* is used to link the human readable text, represented by the class *rdfs:Literal*, to the sensor description. The property *hasReadableDescription* has as domain the *WearableSensor* class and as range the *rdfs:Literal* class.

The SS4RWWAR Upper Ontology is quite simple since all the potential will be derived of the domain ontologies, like the SS4RWWAR Body Ontology presented in the forthcoming section. As any other ontology, the SS4RWWAR Upper Ontology is subject to any future extensions and revisions.

4.2 SS4RWWAR Human Body Ontology

Wearable sensors are placed on the human body, they are located on concrete body parts. In order to represent human body parts the SS4RWWAR Body Ontology has been defined. The possibility of using available ontologies to describe the human body parts has been analized. A candidate ontology was the Foundational Model of Anatomy ontology (FMA) [1], one of the most complete knowledge source for bioinformatics which represents the phenotypic structure of the human body. Another candidate was the Uber anatomy ontology (Uberon) [12,3], an anatomy ontology that integrates any type of animal species. These ontologies are too extensive for the purpose of this work since the location of the sensors does not require the definition of the internal organs, neural network, skeletal system or musculature. In fact, the FMA ontology is composed of over 75.000 classes and the Uberon of over 10.000 classes, which makes them too complex for reasoning on the selection of best wearable sensors. For these reasons, a new body ontology describing only the body locations where sensors can be worn has been created in this work. This ontology is based on the lessons learned from studying the well-known anatomical ontologies.

The main class of the SS4RWWAR Body Ontology is the *HumanBodyPart* and represents each one of the body parts (see Fig. 2). The main division of the body is done in four parts: head, trunk, upper limbs and lower limbs. Therefore, four classes are defined as subclasses of the *HumanBodyPart*: the *Head*, the *Trunk*, the *UpperLimb* and the *LowerLimb*. Moreover, each of the main body parts can be further partitioned in subdivisions, which are also parts of the human body and therefore subclasses of the *HumanBodyPart* class. The *HeadSubdivision* class has been specified to define the subdivisions of the head: face and scalp. The *TrunkSubdivision* has been specified to define the subdivisions of the trunk: thorax, abdomen and back. The *UpperLimbSubdivision* class has been specified to define the subdivisions of the upper limbs: shoulder, arm, elbow, forearm, wrist, and hand. The *LowerLimbSubdivision* class has been specified to define the subdivisions of the lower limbs: hip, thigh, knee, leg, ankle, and foot.

In order to set the links between the each of the main body parts and their corresponding subdivisions, the *hasPart* object property has been defined, as well as its inverse property the *partOf* property which relates the subdivisions to their containing main body part (see Fig. 2). The link between the *HeadSubdivision* class and the *Head* class is created by using the *partOf* property and defining the *HeadSubdivision* as a subclass of the axiom *partOf some Head*. Similarly, the inverse property *hasPart* links the *Head*class to the *HeadSubdivision* class. In the same way, these properties are used to establish the relations between the

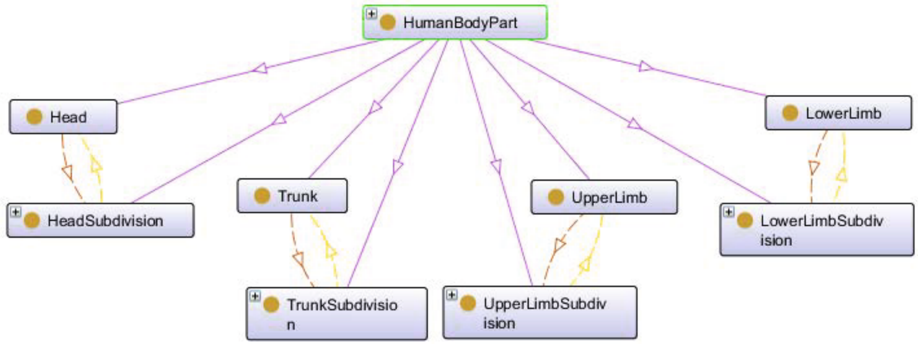

Fig. 2. Top part of the SS4RWWAR Body Ontology defining the body and its four main parts - head, trunk, upper limb and lower limb - represented by the *HumanBodyPart*, the *Head*, the *Trunk*, the *UpperLimb* and the *LowerLimb* classes, and their subdivisions represented by the *HeadSubdivision*, the *TrunkSubdivision*, the *UpperLimbSubdivision* and the *LowerLimbSubdivision* classes. The continuous purple arrows represent the *has subclass* property, which links the *HumanBodyPart* class with its eight subclasses. The dashed brown arrows represent the *hasPart* property, which relates the main body parts to their corresponding subdivisions. The dashed yellow arrows represent the *partOf* property, which relates the subdivisions with the main body parts.

rest of body parts. The link between the *TrunkSubdivision* class and the *Trunk* class is created by using the *partOf* property and defining the *TrunkSubdivision* as a subclass of the axiom *partOf some Trunk*, and the inverse property *hasPart* links the *Trunk* class to the *TrunkSubdivision* class. The link between the *UpperLimbSubdivision* class and the *UpperLimb* class is created by using the *partOf* property and defining the *UpperLimbSubdivision* as a subclass of the axiom *partOf some UpperLimb*, and the inverse property *hasPart* links the *UpperLimb* class to the *UpperLimbSubdivision* class. The link between the *LowerLimbSubdivision* class and the *LowerLimb* class is created by using the *partOf* property and defining the *LowerLimbSubdivision* as a subclass of the axiom *partOf some LowerLimb*, and the inverse property *hasPart* links the *LowerLimb* class to the *LowerLimbSubdivision* class.

Not only are the different body parts subdivided in a hierarchical manner, they are also connected to other parts. Several object properties have been defined in the SS4RWWAR Body Ontology to describe the connections between body parts. The top property is the *connectedTo* property and has eight subproperties which define the connections of body parts according to the standard human directional terminology: superior or inferior, anterior or posterior, medial or lateral, proximal or distal. The *superiorlyConnectedTo* property relates a body part with another which is located towards the top of the body or human head. Its inverse, the *inferiorlyConnectedTo* property relates a body part with another which is located towards the bottom of the body or feet. The *anteriorlyConnectedTo* property relates a body part with another which is located towards the front of the body. Its inverse, the *posteriorlyConnectedTo* property relates a body part with another which is located towards the back of the body. The *laterallyConnectedTo* property relates a body part with another which is located towards the lateral of the body. Its inverse, the *mediallyConnectedTo* property relates a body part with another which is located towards the middle of the body. The *proximallyConnectedTo* property relates a body part with another which is located towards the main mass of the body. Its inverse, the *distallyConnectedTo* property relates a body part with another which is located more distantly of the main mass of the body.

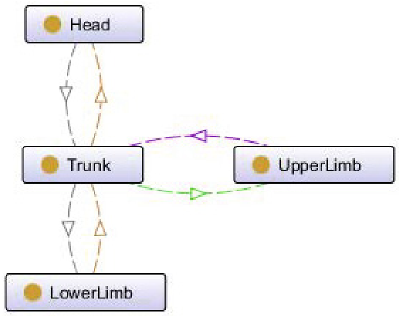

Fig. 3. Representation of the connections between the main body parts - head, trunk, upper limb and lower limb -. The dashed red arrows represent the *superiorlyConnectedTo* property, which relates the *Trunk* class to the *Head* class, and the *LowerLimb* class to the *Trunk* class. The dashed blue arrows represent the *inferiorlyConnectedTo* property, which relates the *Head* class to the *Trunk* class, and the *Trunk* class to the *LowerLimb* class. The dashed green arrow represents the *laterallyConnectedTo* property, which relates the *Trunk* class to the *UpperLimb* class. The dashed purple arrow represents the *mediallyConnectedTo* property, which relates the *UpperLimb* class to the *Trunk* class.

The connections between the main body parts can be established through the eight subproperties of the *connectedTo* property as shown in Fig. 3. Since the head is the top of the body and has located the trunk below, the connection between the *Head* class and the *Trunk* class is created by using the *inferiorlyConnectedTo* property and defining the *Head* as a subclass of the axiom *inferiorlyConnectedTo some Trunk*. Inversely, the connection between the *Trunk* class and the *Head* class is created by using the *superiorlyConnectedTo* property and defining the *Trunk* as a subclass of the axiom *superiorlyConnectedTo some Head*. The same reasoning applies to the connection between the trunk and the lower limbs, since the trunk is on top of the lower limbs. Thus, the connection between the *Trunk* class and the *LowerLimb* class is created by using the *inferiorlyConnectedTo* property and defining the *Trunk* as a subclass of the axiom *inferiorlyConnectedTo some LowerLimb*. Inversely, the connection between the *LowerLimb* class and the *Trunk* class is created by using the *superiorlyConnectedTo* property and defining the *LowerLimb* as a subclass of the axiom *superiorlyConnectedTo some Trunk*. Finally, the trunk is in the middle of the body and the upper limbs are in a lateral position from the trunk. Thus, the connection between the *Trunk* class and the *UpperLimb* class is created by using the *lateralyConnectedTo* property and defining the *Trunk* as a subclass of the axiom *lateralyConnectedTo some UpperLimb*. Inversely, the connection between the *UpperLimb* class and the *Trunk* class is created by using the *mediallyConnectedTo* property and defining the *UpperLimb* as a subclass of the axiom *mediallyConnectedTo some Trunk*.

In order to complete the the SS4RWWAR Body Ontology definition, the subdivisions of the main body parts need to be specified and the connections between these subdivisions need to be established. Fig. 4 shows the classes and properties related to the body subdivisions.

The *HeadSubdivision* class (see Fig. 4(a)) has two subclasses, the *Face* and the *Scalp*, which inherit from the *HeadSubdivision* class being a subclass of the axiom *partOf some Head*. The face is the anterior part of the head and the scalp the posterior part of it. Thus, the connection between the *Face* class and the *Scalp* class is created by using the *posteriorlyConnectedTo* property and defining the *Face* as a subclass of the axiom *posteriorlyConnectedTo some Scalp*. Inversely, the connection between the *Scalp* class and the *Face* class is created by using the *anteriorlyConnectedTo* property and defining the *Scalp* as a subclass of the axiom *anteriorlyConnectedTo some Face*.

The *TrunkSubdivision* class (see Fig. 4(b)) has three subclasses, the *Thorax*, the *Abdomen* and the *Back*, which inherit from the *TrunkSubdivision* class being a subclass of the axiom *partOf some Trunk*. The thorax and the abdomen conform the anterior part of the trunk and the back the posterior part of it. Thus, the connection between the *Thorax* class and the *Back* class is created by using the *posteriorlyConnectedTo* property and defining the *Thorax* as a subclass of the axiom *posteriorlyConnectedTo some Back*. Similarly, the connection between the *Abdomen* class and the *Back* class are created by using the *posteriorlyConnectedTo* property and defining the *Abdomen* as a subclass of the axiom *posteriorlyConnectedTo some Back*. Inversely, the connection between the *Back* class and the *Thorax* class is created by using the *anteriorlyConnectedTo* property and defining the *Back* as a subclass of the axiom *anteriorlyConnectedTo some Thorax*. Also the connection between the *Back* class and the *Abdomen* class is created by using the *anteriorlyConnectedTo* property and defining the *Back* as a subclass of the axiom *anteriorlyConnectedTo some Abdomen*. Moreover, the thorax is located on top of the abdomen in the anterior of the trunk. Thus, the connection between the *Thorax* class and the *Abdomen* class is created by using the *inferiorlyConnectedTo* property and defining the *Thorax* as a subclass of the axiom *inferiorlyConnectedTo some Abdomen*. Inversely, the connection between the *Abdomen* class and the *Thorax* class is created by using the *superiorlyConnectedTo* property and defining the *Abdomen* as a subclass of the axiom *superiorlyConnectedTo some Thorax*.

The *UpperLimbSubdivision* class (see Fig. 4(c)) has six subclasses, the *Shoulder*, the *Arm*, the *Elbow*, the *Forearm*, the *Wrist* and the *Hand*, which inherit

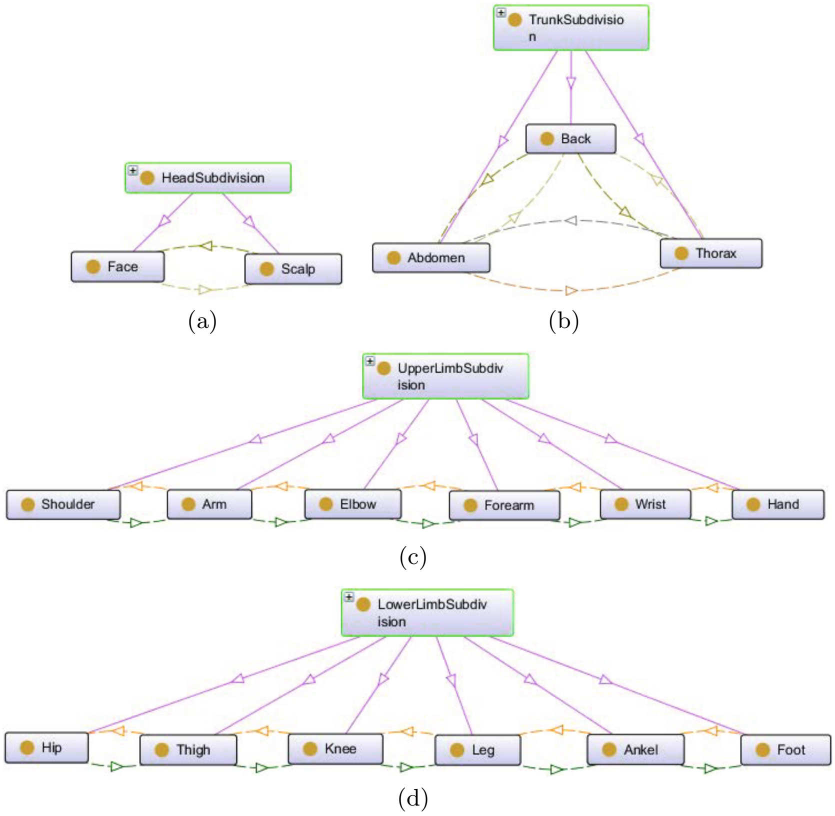

Fig. 4. SS4RWWAR Body Ontology for (a) the *HeadSubdivision* class, (b) the *TrunkSubdivision* class, (c) the *UpperLimbSubdivision* class, and (d) the *LowerLimbSubdivision* class. The continuous purple arrows represent the *has subclass* property. The dashed red arrows represent the *superiorlyConnectedTo* property. The dashed blue arrows represent the *inferiorlyConnectedTo* property. The dashed dark gray arrows represent the *anteriorlyConnectedTo* property. The dashed light gray arrows represent the *posteriorlyConnectedTo* property. The dashed orange arrows represent the *proximallyConnectedTo* property. The dashed green arrows represent the *distallyConnectedTo* property.

from the *UpperLimbSubdivision* class being a subclass of the axiom *partOf some UpperLimb*. The shoulder is connected to the arm, the arm to the elbow, the elbow to the forearm, the forearm to the wrist, and the wrist to the hand. From these upper limb subdivisions, the hand is the most distant from the trunk, which is the main mass of the body, and the shoulder is the closest to it. The connections between upper limb subdivisions are created by using the *distallyConnectedTo* property and defining the *Shoulder* as a subclass of the axiom *distallyConnectedTo some Arm*, the *Arm* as a subclass of the axiom *distallyConnectedTo some Elbow*, the *Elbow* as a subclass of the axiom *distallyConnectedTo* *some Forearm*, the *Forearm* as a subclass of the axiom *distallyConnectedTo some Wrist*, and the *Wrist* as a subclass of the axiom *distallyConnectedTo some Hand*. The inverse property *proximallyConnectedTo* is used to create the inverse connections by defining the *Hand* as a subclass of the axiom *proximallyConnectedTo some Wrist*, the *Wrist* as a subclass of the axiom *proximallyConnectedTo some Forearm*, the *Forearm* as a subclass of the axiom *proximallyConnectedTo some Elbow*, the *Elbow* as a subclass of the axiom *proximallyConnectedTo some Arm*, and the *Arm* as a subclass of the axiom *proximallyConnectedTo some Shoulder*.

The *LowerLimbSubdivision* class (see Fig. 4(d)) has six subclasses, the *Hip*, the *Thigh*, the *Knee*, the *Leg*, the *Ankle* and the *Foot*, which inherit from the *LowerLimbSubdivision* class being a subclass of the axiom *partOf some LowerLimb*. The hip is connected to the thigh, the thigh to the knee, the knee to the leg, the leg to the ankle, and the ankle to the foot. From these lower limb subdivisions, the foot is the most distant from the trunk, which is the main mass of the body, and the hip is the closest to it. The connections between lower limb subdivisions are created by using the *distallyConnectedTo* property and defining the *Hip* as a subclass of the axiom *distallyConnectedTo some Thigh*, the *Thigh* as a subclass of the axiom *distallyConnectedTo some Knee*, the *Knee* as a subclass of the axiom *distallyConnectedTo some Leg*, the *Leg* as a subclass of the axiom *distallyConnectedTo some Ankle*, and the *Ankle* as a subclass of the axiom *distallyConnectedTo some Foot*. The inverse property *proximallyConnectedTo* is used to create the inverse connections by defining the *Foot* as a subclass of the axiom *proximallyConnectedTo some Ankle*, the *Ankle* as a subclass of the axiom *proximallyConnectedTo some Leg*, the *Leg* as a subclass of the axiom *proximallyConnectedTo some Knee*, the *Knee* as a subclass of the axiom *proximallyConnectedTo some Thigh*, and the *Thigh* as a subclass of the axiom *proximallyConnectedTo some Hip*.

5 Conclusions

Human physical self-quantification systems for health and wellness improvement build on mobile and portable sensor devices. Body-worn sensor devices are subject to changes that may prevent the correct functioning of wearable activity recognition systems. Accordingly, mechanisms to support the selection of adequate sensor replacements are required in real-world scenarios. In this work, a novel use of ontologies for dynamic sensor selection has been presented. The ontological model is composed by an upper ontology describing wearable sensors and their main properties, as well as a supportive domain ontology particularly defined to neatly and unequivocally represent the exact placement of the sensor on the human body. Next steps of this work include the extension of the presented models towards the magnitude and sensor characteristics domains, as well as the application of ontological reasoning techniques to automate the selection of the most adequate sensors.

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