Wear4pdmove: An Ontology for Knowledge-Based Personalized Health Monitoring of PD Patients

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Abstract

In the field of Parkinson's Disease (PD), wearable sensors are commonly used to collect movement data from patients for various purposes such as analysis, monitoring, and alerting. To ensure interoperability with other personal health data, such as PHR data, it is crucial to semantically describe this data. Our work focuses on reusing existing ontologies and introducing new conceptualizations to engineer Personal Health Knowledge Graph (PHKG) for PD patient monitoring and doctor alerting. We aim to address the specific knowledge requirements in personal health for PD and support rule-based high- level event recognition. Developing a PHKG can greatly assist health specialists in efficiently assessing patients' conditions, providing timely and cost-effective care for PD patients.

Keywords

Sensors, Wearables, Parkinson Disease, Ontologies, Knowledge Graph

1. Introduction

Parkinson's disease (PD) is a neurodegenerative disorder characterized by movement difficulties. With a projected global increase in PD cases, this study emphasizes the importance of utilizing smart devices and knowledge-based applications to collect and analyze real-time personal health data for improved PD patient care [1]. The focus is on rule-based recognition of high-level events, such as missed medication doses, based on low-level event detection, such as tremors and bradykinesia.

Wearable technology, smart apps, and semantic data integration techniques are used to address the challenge of representing and linking sensor data with PD-related personal health records. The goal is to gain a comprehensive understanding of disease progression and its impact on patients' daily lives. The proposed Wear4PDmove ontology incorporates existing ontologies and introduces new classes and properties to meet requirements. It aims to enable real-time monitoring, alerting, reasoning, and advanced data analytics for personalized healthcare in PD, as depicted in our proposed architecture (Figure 1).

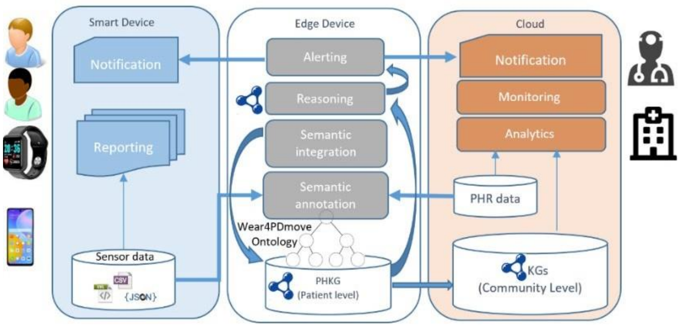

Figure 1: PHKG proposed architecture for PD monitoring and alerting.

The study aims to provide accurate clinical terminology to doctors for improved monitoring and decision-making. The results have the potential to significantly enhance the monitoring, diagnosis, and treatment of PD, a debilitating condition prevalent among the elderly.

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This research article presents the development of a new ontology in the field of PD patient monitoring and alerting, namely the Wear4PDmove ontology. This ontology is built by reusing and extending existing ontologies to fulfill specific requirements, as the related works do not fully address them, filling the semantic gap of high-level event recognition based on low-level events i.e., tremor and bradykinesia. To engineer the Wear4Pdmove ontology, a collaborative, agile, and iterative approach to ontology engineering (OE) has been used i.e., HCOME [7].

2. Related Work

Younesi et al. [2] introduced PDON, a standardized vocabulary for PD research, enhancing interoperability and data sharing. PDON improves accuracy and consistency in data analysis. PMDO is another valuable ontology for labeling and sharing PD data, focusing on movement disorders. Neither ontology represents wearable sensor data, limiting their applicability in PD monitoring. To address this, SSN and SOSA ontologies are commonly used. SSN describes sensors, observations, and data processes, while SOSA models sensor relationships and context, improving sensor data representation and integration in healthcare [3]. SAREF and SAREF4WEAR provide standardized vocabularies for wearables and IoT solutions, facilitating interoperability and data integration. Prior studies have utilized wearables to monitor PD symptoms and proposed semantic interoperability frameworks [5]. Monitoring PD patients during daily activities is crucial for understanding their motor state. Recent studies highlight the benefits of PHKGs and the need for integrating wearable and PHR data for PD monitoring [6]. Existing work explores semantic annotations and IoT data integration, but no studies have developed PHKGs for PD monitoring using commercial wearables and PHR data [2]-[7].

3. Engineering the Wear4Pdmove ontology

The proposed Wear4Pdmove ontology captures knowledge of PD patient monitoring, integrating movement data with PHR data for real-time event recognition and alerting. The ontologies we reuse (Figure 2), such as DAHCC [11], SOSA [12], SAREF [13], SAREF4WEAR [14], and PMDO [15], provide a solid foundation for representing various aspects of sensor and PD-related data, and knowledge about wearables in the context of healthcare monitoring, which aligns with our objectives. While SNOMED-CT is an essential healthcare terminology widely used in the medical domain, our primary goal is to leverage existing ontologies that specifically address the challenges and intricacies of PD patient monitoring and alerting. Nevertheless, we acknowledge the importance of SNOMED-CT and other related healthcare ontologies in broader healthcare contexts, and their potential relevance for interoperability and data integration beyond the scope of the Wear4PDmove ontology [10].

Figure 2: Reused ontologies in Wear4PDmove ontology

The imported ontologies play a pivotal role in enhancing the core Wear4PDmove ontology by incorporating a rich set of concepts and relationships that facilitate the modeling of various aspects, including data analytics, sensor technologies, smart appliances, wearable devices, and medical equipment used by patients. This comprehensive ontology framework empowers the representation of complex healthcare scenarios, enabling seamless integration of smart devices, sensors, and medical equipment in the healthcare domain. Within this context, the Wear4PDmove ontology is designed to support a wide range of

critical tasks, including continuous patient monitoring, precise low-level event detection (e.g., tremor analysis), and the generation of actionable recommendations for healthcare professionals.
An agile and collaborative ontology development workflow based on the HCOME methodology is employed, incorporating the latest recommendations in ontology engineering. It includes collaborative tools, iterative evaluation, reuse of ontologies, and modular development in a shared workspace. The HCOME methodology comprises three phases: specification, conceptualization, and exploitation. The specification phase captures ontological requirements efficiently. The conceptualization phase involves design choices and preparations. In the exploitation phase, the modular ontology supports decision-making and analysis in the PD domain, with continuous evaluation and refinement based on stakeholder feedback [7].

3.1. Ontology Specification

The Wear4PDmove ontology integrates stream data from wearables and static/historic data from PHR databases to create a PHKG. Its purpose is to enable health apps to reason about high-level events, such as 'missing dose' or 'patient fall'. The ontology has specific requirements that need to be met. Our approach encompasses a comprehensive representation of patient data, including movement patterns, daily activities, and personal health records. By integrating data from diverse sources like wearables and personal health records, we create a unified, real-time view of an individual's health. This integration enables continuous monitoring and timely alerts for healthcare professionals. To analyze and interpret this integrated data, we employ a scientific methodology and structure it uses a PHKG. This logical framework supports informed decision- making.

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Prefixes:
      rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
      rdfs: <http://www.w3.org/2000/01/rdf-schema#>
      sosa: <http://www.w3.org/ns/sosa/>
      dahcc: <https://dahcc.idlab.ugent.be/Ontology/SensorsAndWearables/>
      w4pd: <http://w3id.org/Wear4PDmove/onto#>

Example triples:
<Acc22-sensor>        a    dahcc: Accelerometer;
      sosa:observes       <Wearable_Acceleration_for_PD_movement>.
<Wearable_Acceleration_for_PD_movement>    a    dahcc: WearableAcceleration.
<PDpatient-001>          a          sosa: FeatureOfInterest.
<PatientMovement>        a          sosa: FeatureOfInterest.
<PD-patient-Observation-001>   a  sosa: Observation;
      sosa:hasFeatureOfInterest        <PDpatient-001>;
      sosa:hasFeatureOfInterest        <PatientMovement>;
      sosa:madeBySensor                <Acc22-sensor>;
      sosa:observedProperty            <BradykinisiaUpperLimpForPDpatient>;
      sosa:observedProperty            <TremorForPDPatient>;
      sosa:observedProperty            <Wearable_Acceleration_for_PD_movement>;
      sosa:resultTime                  "2022-07-06T12:36:12.150Z"^^xsd:dateTime;
      w4pd:hasTremor                   false;
      w4pd:hasRigidity                 false;
      w4pd:hasPosturalInstability      true;
      w4pd:hasFreezingOfGait           false;
      w4pd:has Akinesia                true;
      w4pd:hasDepression               false;
      w4pd:has Anxiety                 true;
      w4pd:hasSleepDisturbances        false;
      w4pd:hasFatigue                  false;
      w4pd:hasDysphagia                false;
      w4pd:hasBradykinisiaOfUpperLimp  false.
```

Figure 3: Example triples of Wear4PDmove ontology

Based on the aim and requirements of the ontology, a number of competency questions (CQ) have been shaped in collaboration with the domain experts. The following is a selective list of such questions, which have been transformed to SPARQL queries in the evaluation phase: (**CQ1**) retrieve activities performed by patients for behavior analysis and disease progression monitoring. (**CQ2**) identified patients performing Sketching Activity and their performance level for personalized treatment plans. (**CQ3**) retrieve recorded observations for specific patients to analyze disease progression and adjust treatment plans. (**CQ4**) retrieve patient's PHR and relevant information for personalized treatment plans and dosing.

3.2. Ontology Conceptualization

Following the specification of the aim and requirements of the ontology, and the generation of the competency questions, the subsequent phase involves the design and development of the related ontology. The Wear4PDmove ontology aims to provide an inclusive and fused model for PD patients' personal health information, supporting customized monitoring, alerting, advanced data analytics, and decision-making. It incorporates/reuses related ontologies and introduces novel classes and properties to meet specific requirements.

In Figure 3 an example set of triples describing an inferred PD patient observation is presented, including information about the accelerometer sensor, patient movement features, observed properties (e.g., tremor, wearable acceleration), and observation result time. To be able to define the triplified knowledge presented in [10] and in Figure 3, a number of new (w4pd prefix of Wear4PDmove namespace) or reused (other prefixes/namespaces) classes and properties have been defined.

3.3. Ontology Exploitation and Evaluation

The Wear4PDmove ontology presented in this paper is encoded in OWL using Protégé 5.5. The latest version is publicly available with a permanent URL at https://w3id.org/Wear4PDmove/onto for further evaluation and criticism by related communities of interest and practice. The ontology is evaluated with OOPS! [8] and documented with WIDOCO [9], and is available under the license CC0. The engineered ontology was evaluated by transforming competency questions into SPARQL queries and executing them on inferred knowledge. The knowledge was obtained from a PHR database and a .csv file of sensor data from a smartwatch used in PD patient experimentation. Pellet reasoner and Snap SPARQL plugin were used to query the inferred knowledge for 'missing dose' event observations.

The ontology files, example SPARQL queries (Qx), and SWRL rules are available at https://github.com/KotisK/Wear4PDmove. SPARQL queries Q1, Q2, Q3 and Q4 are in correspondence with CQ. In Wear4PDmove ontology, SWRL rules identify missing dose high-level events by analyzing low-level events (such as tremor or bradykinesia) in patients.

Boolean data types are used to represent low-level events such as a patient with tremor or bradykinesia. Event values (true/false) are derived from raw sensor/wearables data analysis performed with a custom API which is currently under development as part of an ongoing research project [16]. The following SWRL rules, manually generated based on the analysis of scientific literature and in consultation with experts specializing in the field of healthcare, represent knowledge related to the recognition and notification process for doctors regarding missing dose high-level events of PD patients.

Rule 1: If tremor is observed after dosing in a PD patient, a missing dose event is recognized, and a notification is sent to the doctor via the sendNotification function. Instances of PD patient observations are automatically classified as "PD patient Missing Dose Event Observations".

SWRL syntax: *Observation(?obs), obsAfterDosing(?obs, true), observedProperty(?obs, 'Tremor for PDpatient'), hasTremor(?obs, true) -> sendNotification('Missing Dose Notification', true), 'PDpatient Missing Dose Event Observation'(?obs)*

Rule 2: Similar to Rule 1, this rule detects missing dose based on the low-level event of bradykinesia in the upper limb of PD patients. If an observation for bradykinesia of the upper limb is made after dosing and bradykinesia is detected, a missing dose event is recognized. A notification is sent to the doctor using the sendNotification function.

SWRL syntax: *observedProperty(?obs, 'Bradykinisia Upper Limp for PDpatient'), Observation(?obs), obsAfterDosing(?obs, true), hasBradykinisiaOfUpperLimp(?obs, true) -> sendNotification('Missing Dose Notification', true), 'PDpatient Missing Dose Event Observation'(?obs)*

These rules aim to identify missed medication doses in PD patients and promptly notify doctors, but their effectiveness requires testing and validation. The evaluation process involves assessing the accuracy of observations, sensitivity and specificity of the rules, and usability of the notifications. Collaboration between domain experts and data scientists is necessary, and real- world patient data may be collected and analyzed for this purpose.

4. Conclusion and Future Work

This research is a first step towards engineering the Wear4PDmove ontology for monitoring and alerting PD patients, integrating personal health data sources for high-level event recognition such as a missing dose event. While it introduces necessary new classes and properties for personalized health monitoring, we are aware of potential limitations in terms of scalability and resource constraints when deploying efficient PHKGs in real-time PD patient monitoring platforms/systems. On the other hand, the scenarios and rules presented in this paper are only a first indication of what is possible to be represented in this domain. For example, we acknowledge that tremor is one of the main symptoms of PD, but even when taking medication (e.g., levodopa) consistently, the effectiveness of the medication may vary based on factors such as recent meals, sleep patterns, and minor changes in health conditions. Our future work will address these challenges, including experiments with scalable OWL reasoning engines on edge devices like Raspberry Pi or Arduino.

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