2021 21st International Conference on Computational Science and Its Applications (ICCSA) | 978-1-6654-5843-6/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICCSA54496.2021.00035

# On Domain Ontology for Decision Support in the Treatment of Gait-related Diseases

Terrance Marthinus
*Department of Computer Technology Services*
*Cape Peninsula University of Technology*
*District Six, Cape Town, South Africa*
marthinust@cput.ac.za

Olawande Daramola
*Department of Information Technology*
*Cape Peninsula University of Technology*
*District Six, Cape Town, South Africa*
daramolaj@cput.ac.za

***Abstract* - In recent years, ontology has become the de facto standard for knowledge representation on the semantic web. The need to design and develop suitable ontologies that can support the operations and functionality of different types of intelligent systems is compelling. This paper presents the notion of decision support for healthcare practitioners in the treatment of gait-related diseases by using a domain ontology. The objective of the domain ontology is to create a knowledgebase artefact that can be leveraged for decision-making by healthcare workers during the prognosis, diagnosis and treatment of diseases that are associated with human gait impairment and gait abnormality. Gait impairment generally affects a patient's mobility and ability to walk normally. The impact of gait-related diseases can vary from old age to more severe neurological and physical disorders, which needs to be thoroughly examined and investigated for accurate diagnosis and prognosis. This paper discusses how a domain ontology, that can facilitate decision support to diagnose and treat gait-related diseases, can be developed. At completion, the ontology would be able to support intelligent operations such as semantic processing of data, intelligent reasoning, information search and retrieval, and intelligent recommendations that provide valuable support to healthcare practitioners in decision-making when dealing with gait-related diseases.**

***Index Terms* – *ontology, gait analysis, healthcare, knowledgebase, semantic web.***

## I. Introduction

The growing adoption and rapid surge of innovative technologies, have in general swung new doors wide-open, notably in the biomedical arena and digital sphere, to aid and assist human beings across several diseases and the treatment thereof. The principal intent of this paper is to explore the notion of domain ontology for decision support in the treatment of gait-related diseases. This will complement the efforts of healthcare practitioners that have to treat and manage patients with various gait impairments.

Gait analysis can be defined as the study and observation of human locomotive movement(s), which can be examined and measured, via computing equipment, at varying intervals of a specified individual. This analysis of gait impressions and assessment is used to evaluate and treat patients with medical conditions that hinder their mobility and ability to walk. The continual evolution in technology can generally help to improve the treatment and management of diseases.

Gait analysis is one of the hi-tech technologies that can help to achieve increased accuracy in treating diseases [1]. Leveraging technology advancements in areas of mobile computing, cloud computing, wearable sensors, and body markers that are interlinked to a computer (system), enables gait analysis to yield accelerated assimilation and analysis of (gait) data [2]. This technical affordance may allow healthcare practitioners to ostensibly make better-informed decisions, in near real-time, from within any location [3]. Moreover, it can be vital that healthcare practitioners detect, treat, and expedite decision-making to speed up a patient's well-being and overall health progress [4].

Historically, the word ontology refers to "the nature of being or existence" as (pro)claimed by philosophers, whose focus on knowledge of entities and how they are related within a hierarchy [5]. On the other hand, an ontology in Computer or Information Science denotes all entities that can be hierarchically represented, which are integrated and used across various applications. Therefore, the notion of an ontology that originally has its foundation in philosophy is conceived in Computer Science as a knowledge artefact that defines a certain reality and the nature of things [6]. Diverse knowledge areas or subject fields are categorised in their respective ontologies, which are fundamentally a representation of a knowledge domain with data, information and knowledge about that domain. An ontology can provide a common shared vocabulary as well as (syntax) rules for publishing data and can provide a semantic depiction of the data. One of the main motives to develop an ontology is information sharing, which can hopefully improve problem-solving within a domain. Henceforth, ontology in the ambit of Computer Science represents a structure for describing concept data and the demonstration of knowledge to aid decision-making and knowledge administration within a community of shared interest [7] [8] [9].

Biology or medical research, commonly referred to as biomedical, is where the concept of gait analysis predominantly exists. Contained by this medical purview, healthcare practitioners have their own vocabularies, terminologies and classifications that can be better represented when modelled and structured in a knowledgebase. Thus, a gait analysis ontology can assist healthcare practitioners and patients by delivering adequate decision support on issues of diseases that affect human gait.

978-1-6654-5843-6/21/$31.00 ©2021 IEEE
DOI 10.1109/ICCSA54496.2021.00035

This need for an accurate depiction of facts about gait-related diseases necessitates a proficient strategy to aggregate and organise knowledge on the topic of gait analysis and gait impairments, by using a structured vocabulary, in the form of a domain ontology. Users of an ontology publish and submit basically two types of data; ontology vocabularies and instance data [10]. Domain ontology offers and provides a structure of the data by illustrating how meaning can be represented and the relationships among entity elements in the data. Therefore, it enables relationships between entities and concepts to be defined.

### *A. Background*

In order to implement an intelligent system by using ontologies, the Web Ontology Language (OWL), which is the standard language semantics that was adopted by the World Wide Web Consortium (W3C), is often used. This allows for smooth procedural interchange of information between applications within the framework of the semantic web. The implementation of an ontology, based on OWL, consists of classes as domain entities, sets of individuals, which are the instances of classes, and properties that define the relationships between these entities. OWL ontology can be demonstrated by using open-source ontology editors to create the knowledge artefact, and to infer knowledge from the knowledgebase. The thriving expansion of the semantic web makes it more straightforward for humans, as well as machines, to implement ontology-based knowledge structures that can be useful for all appropriate actors, when competently designed and effectively deployed [11]. The semantic web is basically an extension of the existing web that gives structure and meaning to information, which promotes enhanced machine to machine interoperability [12].

In recent years, ontologies have gained considerable attention and traction in various fields of research. Evidently, in the present day, ontologies are extensively applied in different domains like knowledge engineering, artificial intelligence, natural language processing, e-commerce, digital information sharing, database management, bioinformatics and various other disciplines [13]. The importance for healthcare practitioners having access and insight to (clinical) gait analysis and information have become increasingly pertinent, especially in the age of huge data volumes and innovative novel technologies. Now, more than ever, the need to develop and design a suitable domain ontology, in an attempt to assist healthcare practitioners with informed decision-making and recommendation of more advanced treatment ideas, is becoming a necessity [14].

At present, the Ontology for Biomedical Investigation (OBI), which is built on W3C principles, can be used with other available data on the semantic web. OBI is an integrated ontology that offers concepts with clearly defined definitions to describe all dimensions of how investigations in the biological and medical domains are conducted [14]. This in turn, would facilitate knowledge-sharing and decision-making in the medical landscape. Successively, this will ultimately ensure the well-being and general health improvement of patients.

Domain ontologies for gait analysis, on issues of clinical gait are rare, and has made the treatment of gait-related diseases cumbersome and labour-intensive for healthcare practitioners [15] [16]. Healthcare practitioners find it difficult to draw inferences and interpret gait (analysis) data, which has affected the treatment of gait-related diseases. Hence, healthcare practitioners have limited access to decision support in the handling of gait-related diseases [17]. Consequently, this affects the reliability of data analysis, the potential for improved knowledge-sharing, the accuracy of diagnosis and individually-assessed treatment solutions specifically tailored towards a patient's gait impairment [6] [16].

Decision support for healthcare practitioners, in the treatment of critical gait-related diseases and knowledge-sharing amongst practitioners, has not been maximised due to a lack of domain ontology for gait analysis, linked with a limited quality of decision support. Thus, this paper will discuss how a domain ontology can be utilised for decision support in the diagnosis and treatment of gait-related diseases. At completion, the research will be significant for improving the decision-making process and advancing the treatment of diseases associated with human gait. This will be done through support for semantic processing of data, intelligent reasoning, information search and retrieval, and intelligent recommendations.

## II. LITERATURE REVIEW

In this section, we present a theoretical background by discussing the relevant topics of gait analysis and ontology engineering. We also provide an overview of related work.

### *A. Gait Analysis*

Human gait or locomotion are characterised by, but not limited to, temporal movements, which include cadence, speed, stride (length), foot impressions, skeletal joint and muscle movements, along other postural bodily functions. Gait impairments can be analysed by virtue of assessment, monitoring, and progress to provide practical diagnosis, treatment administration that is further catalogued as neurological, muscular or skeletal [18]. This categorisation of quantifiable assessment and evaluation of gait deviations is known as gait analysis. [4], purport that technology has made it possible to quantify and assess human-motion or gait via sensory configurations, through computer-aided technology innovations, in order to produce clinical gait analysis. Moreover, the authors in the research community define gait analysis as structured human-motion movements that can be measured and characterised with the acquisition of gait data. Gait data acquisition is the process where a patient's gait numerical measurements are obtained in acquisition sessions.

Gait disorders and impairment are more prevalent among the elderly and is linked with loss of autonomy, limited mobility, and a lesser quality of life [19]. Cognitive decline, which is a major contributor and an underlying factor, has a direct association in the severity of gait impairment and abnormality in older and younger demographic groups [19]. Gait features and variability are more complex compared to just age-related locomotive stride lengths and shuffling footstep cadence, as studies have shown that neural connectivity and function play an integral part in the mechanisms of gait [20].

Recent advancements, in the field of gait analysis, enable quantifiable gait to be categorised in order to determine the specific improper gait exhibited by a patient, such as Hemiplegic Gait, Diplegic Gait, Neuropathic Gait, Myopathic Gait or Ataxic Gait [17].

### *B. Ontology and Ontology Types*

In conventional terms, ontology traditionally focuses on the philosophical discipline of how a set of thoughts, within a subject area, relate to each other for existing or their reason for being. In the purview of Artificial Intelligence (AI), and for knowledge representation, ontology has attracted attention in the field of Computer Science. Subsequently, to constitute a formal vocabulary to model a set of objects or categories, from within a domain, and depicting the properties and relationship between them. This is done in an effort to make domain assumptions explicit and to promote a shared understanding of a knowledge-domain. In an area where conceptualisation is often the abstract model of a real-world phenomenon, (domain) ontology is an explicit and formal specification of concepts and intelligent semantic relationships [15].

The primary purpose of the domain ontology is to enable (systematic) information extraction in order to provide "real-time" monitoring and recommendations, to help patients bounded by the limitations, which is constrained by the domain scope. According to [15], domain ontologies are feasible solutions to manage large data volumes, especially over recent years, where research projects are aimed to monitor patients in healthcare. They further concede that decision-making and disease management depend on healthcare professionals' competencies, which may impede on a healthcare practitioner's ability to successfully diagnose a patient's health issue or the provision of timely interventions [15]. Therefore, ontologies in healthcare are modelled to provide professional management of treatment suggestions and progress advancements made in the domain.

The introduction and inception of the semantic web have made ontology development more achievable. It empowers humans to construct (interrelated) datasets in the worldwide web, shape lexicon vocabularies, and formulate rules for the administration of data [10].

The semantic web is basically a "web of data", which offers a collective framework that enables data to be shared and (re)used across applications, in a standardised manner predominantly on the world wide web [21] [22]. The semantic web is a stack of technologies and language syntaxes, capable of making data and information more computer or machine-understandable on the internet, which is useful for ontology development in the biomedical domain. Computer-readable ontologies need to be syntactically sound and human-understandable, which is attainable since the arrival and support of the semantic web [22]. The advancements made in the semantic web signify indexing, annotating and reasoning using semantically enriched data where an ontology features as a pivotal part in the biomedical domain [23].

### *C. Ontology Development Methods*

Ontology engineering development is nearly similar to software engineering, as both yield an artefact after being developed, conform to a system's life cycle, and follow a specific methodology. Different methods and methodologies exist for various applications, and some are built from scratch or can be derived from another. Hence, there is no standardised methodology or one-size-fits-all approach. The practice of ontology development is a meticulous process as it involves systematic specifications and thorough collaboration of information sharing by several actors involved in the construction of the ontology [24]. In order to apply the most applicable methodology from proposed methodologies, the desired output needs to be meticulously considered. The process of ontology development has become quite significant in recent years, as ontologies have become the pillar of the semantic web, and the methodologies for ontology building determine which ontology is more suitable, for a knowledge domain, over another [25]. In certain instances, based on specific requirements, a hybrid or adapted methodology might be useful. Existing methodologies such as "Methontology", Toronto Virtual Enterprise (TOVE), Uschold and King Enterprise Ontology, Modular Ontology Engineering (MOE) as well as Agile Methodology for Ontology Development (AMOD), are prime examples of ontology development methods [26].

### *D. Ontology Languages*

Part of the ontology engineering process is to employ a suitable methodology to apply the right tools and techniques by implementing the appropriate ontology language that it supports. Various ontology development languages denote reasoning and logic for formal language ontology representation of concepts, taxonomies, relations, and axioms [27] [28]. Some of the most common ontology languages are; Web Ontology Language (OWL), Ontoligua, Ontology Markup Language (OML), Knowledge Interchange Format (KIF), and the standard Rules Interchange Format (RIF) language for the semantic web, amongst several others that can be considered for ontology development.

### E. Ontology Development Tools

Development tools of ontologies are intended to provide support for the ontology engineering process by expanding the scope of the ontology language. In order to achieve this, an editing environment and subsequent deployment for (automatic) updating can be enabled by an ontology editor [29]. It can be common practise for ontology editors to use one or more ontology language. Examples of ontology editors like; Protégé, WebOnto, OWL Editor, Ontolingua and Swoop are designed to facilitate in the construction and amendment of an ontology. Diverse ontology methodologies, languages and tools, that may possibly be of purpose, will better enable the researchers to investigate and identify which ones are better suited for development [30].

### F. Ontology Evaluation

Ontology evaluation is a relatively important process in establishing if the ontology is of decent and sustainable quality, especially for developing and maintaining an ontological knowledgebase, which can also assist ontology developers. Ontology evaluation and quality assessment involve various maintenance concerns in order to verify and validate updates, amendments, integrity of knowledge, consistency and domain information [31].

According to the authors in [31], numerous ontology evaluation and software tools like OntoQA, OntoAnalyzer, OntoClean, OntoKeeper, OntoGenerator were surveyed and evaluated as well as web-based ontology evaluation tools, against a set of self-imposed criteria, and concluded that OntoKeeper performed slightly better as an application tool for ontology evaluation in the biomedical domain. Ontology evaluation is based on measurements and set of criteria that are mainly clustered into four categories; "gold standard", "corpus-based", "task-based", and lastly "criteria-based" approaches [32] [33]. These evaluation approaches ensure that ontologies are of the highest calibre and embrace system interoperability and ontology alignment with the modularisation of ontologies.

Substantially, most ontology evaluation tools consist of metrics and attribute to determine ontology quality and can be classified as; "domain task fit", "error checking", "libraries", "metrics" and "modularisation" [13].

- *Domain/Task fit*: Identification of how the ontology can be created or selected based on application.
- *Error Checking*: Determining correctness and the removal of errors.
- *Libraries*: Formulation of repositories for ontology sharing a mutual domain or ontology language.
- *Metrics*: Creation of metrics to evaluate the consistency of ontologies on particular attributes.
- *Modularisation*: Ontology modules or sub-ontology components that are built independently, but can be integrated to function as a more extensive ontology.

### G. Ontology Evaluation Approaches

i) *Gold standard*

This type of evaluation aims to equate the knowledgeable ontology to a reference ontology that already exists, which is identified as the "gold standard". This gold standard is the idealised result of the intuitive algorithm. However, it may be challenging to find an acceptable gold-standard ontology since it should be one that has been established in comparable situations with related objectives towards the intended ontology [32].

ii) *Corpus-based*

A corpus-based technique is driven by data. It is invoked to assess the extent to which an ontology sufficiently encapsulates a specified domain. The idea is to evaluate the quality of an ontology in terms of completeness and coverage of a domain based on a text compilation that extensively covers a given domain. The method compares an ontology with a corpus, rather than the similarity of an ontology with an existing ontology [32].

iii) *Task-based*

Task-based methods aim to quantify how much an ontology is helping to enhance the outcomes of a given mission. This assessment method assumes that a given ontology is designed for a specific operation and is assessed in this activity only according to its results, irrespective of all the structural elements [32].

iv) *Criteria-based*

Criteria-based approaches measure the extent to which an ontology or classification meets definite preferable criteria. These enable capabilities to differentiate between processes relating to ontology construction and more complex performances [32].

### H. Related Work

The advent of domain ontology has been generally recognised and applied in (human) gait and gait analysis. The author in [34] demonstrated how a domain ontology could be implemented with the process to construct a decision support data warehouse architecture. The domain ontology mainly focuses on the musculoskeletal lower limbs, which can be mapped to data warehouse models for generic data mining. They explored data-mining as a method of foundation in their construction process as their area of concern is an ontology of lower-limbs gait disorders. Contending to the size and complexity of biomedical ontologies, the authors opted to adopt OSMMI (Ontologie du Systeme Musculo-squelettique des Membres Inferieurs) as an ontology for their project. Since the authors based their model on OSMMI, it did not comprehensively satisfy the gait analysis requirements because it was too generic. Still, it could highlight other aspects of posture, ligament and articular contact well.

Assorted research studies have been conducted on ontology implementation for gait or gait analysis. An example of, gait recognition using fuzzy ontologies and sensor data was proffered by [35]. The authors' main aim was to exhibit the interoperability and reuse of applications and data using semantic web technologies for human gait motions. Instead of using conventional ontology mechanisms, the authors proposed fuzzy ontologies in an effort to substitute exact numerical figures with more flexible fuzzy (data)sets. According to the authors, "fuzzy logic" is commonly disbursed to handle non-specific and vague knowledge. The authors claim that some knowledge is not always clear and precise, with fuzzy data or datasets that have to be considered, and can be better represented in fuzzy ontologies as opposed to conventional ontologies. The use of Microsoft Kinect with the sensor was principally used for recording human subjects for gait analysis. Gait data acquisition and data extraction procedures were set out in order to aggregate data values. These data imprecisions were represented in a fuzzy ontology. In order for the authors to gain insight into human gait from human subjects, who participated in a controlled environment, an algorithm was deployed to determine the gait patterns of subjects for gait (pattern) recognition that could be useful in security surveillance.

[17] explored automatic gait analysis in neurodegenerative diseases in order to demonstrate the neurological and physical link to certain gait disorders. Neurodegenerative diseases such as Parkinson's, Alzheimer's, Huntington's and Dementia were among those diseases evaluated to detect postural changes during gait observations. The author implemented wearable sensors, floor sensors, and image processing as mechanisms to acquire and measure gait data. Gait datasets acquired were evaluated against existing datasets in three (3) databases in an effort to determine gait abnormality for improved accuracy and enhanced analysis.

Despite the fact that research studies advocate for domain ontology on diverse gait issues, there are particularly few studies that concentrate on developing domain ontologies for decision support to healthcare practitioners who primarily focus on the treatment of gait-related diseases. Some of the proposed approaches merely focus on gait and the analysis thereof, but almost none emphasise on a knowledgebase that can assist with decision making. Furthermore, this research would concentrate on creating a modular domain ontology for decision support that enables integration with (other) ontologies by making the ontology extendable to accommodate future expansion.

## III. METHODOLOGY

In this section, we give an overview of the research methodology, research strategy, and research design that will be adopted to realise the objectives of the study.

### *A. Research Methodology*

We plan to adopt a mixed-methods approach for the study, which will entail the application of both deductive reasoning and inductive reasoning to realise the goal of developing a domain ontology for gait-related diseases. The combination of quantitative and qualitative methods will be used for data collection and data analysis. Thus, qualitative data and numerical data will be generated at various stages of the research.

### *B. Research Strategy*

Since a domain ontology artefact will be constructed, the research will adopt a Design Science Research (DSR) strategy. Therefore, the DSR strategy that is adopted can be envisioned in the following five (5) stages:

- *Awareness of the problem*: At this phase, the problem is identified and core requirements defined.
- *Suggestion*: In this phase, ontology design pattern representation is conceptualised with a modular design library.
- *Development*: In this phase, modular ontology modelling and engineering, which are pattern-based, will be developed until modular ontology artefact is created.
- *Evaluation*: After artefact implementation, the ontology will be evaluated with ontology evaluation tools and techniques.
- *Conclusion*: Remarks and recommendations are derived for the adoption of the artefact and research findings.

### C. Research Design

The research design provides the framework for answering the research questions and achieving the target objectives. In addition, the research design applies a combination of tools, strategies and techniques in an effort to solve the research problem. Primarily, an ontology is a conceptual model, which is a definitive deliverable of the ontology development life cycle. The ontology itself is a design (science) artefact that is technology-oriented. The adoption of the Modular Ontology Engineering (MOE) approach will be incorporated as an ontology development method proposed by [36]. This will ensure that ontology modules or sub-ontologies, for specific diseases can be developed at any future stage, and still be integrated into the existing domain ontology.

The schematic in Fig. 1 depicts the research design process that the study will use.

*Awareness of the problem* (Phase 1): Semi-structured interviews and cross-sectional survey research from a representative sample of healthcare practitioners and knowledge experts to establish the domain ontology requirements and identify the right competency questions on gait-related diseases, will be carried out. Survey research involves the systematic collection of information to produce comprehensive data, in order to gain better insight from participants. A purposive sampling technique will be implemented since there will be a need to gather information from healthcare practitioners, who specialise in gait-associated illnesses, as well as from domain experts that demonstrate expertise in the given knowledge domain. The two main distribution options that the researchers will explore to conduct the survey are; telephonic and online surveys. Responses from the survey research questions will ultimately be codified to convert them into numerical values that can be useful for data analysis. We shall also use document review by referencing online documentation and medical publications to define the scope and granularity in the domain ontology. Multiple data collection methods, which are mainly survey research and supplemented by document review, will enhance credibility, validity, and broader understanding of the research findings. These different data collection methods ascribe to methodological triangulation since interviews, survey questionnaires, documents review, and experiments will be appropriated.

*Suggestion* (Phase 2): Here, the design of the domain ontology for gait analysis will be conceptualised by using Ontology Design Patterns (ODP), which are modularised and supported by Modular Ontology Engineering methodology [36].

*Development* (Phase 3): In this phase, the domain ontology artefact will be developed in the form of a modular ontology that facilitates a decision support system for healthcare practitioners. The example use cases of the domain ontology are depicted in Fig. 2.

The different operations that the domain ontology can support, in relation to the treatment of gait-related diseases, as shown in Fig. 2, are the following:

i) *Semantic Processing* – to define and structure semantic relationships in a shared vocabulary, for gait-related diseases, via semantic web technologies to users. This will enable the semantic analysis of textual data.

ii) *Intelligent Reasoning* – to provide reasoning about facts and inferencing capabilities for clinical gait analysis. This enables inferencing and knowledge generation from data.

iii) *Information Search and Retrieval* – to enable domain searching functionality, on gait-related issues, and facilitate domain-knowledge information retrieval.

iv) *Recommendations* – to intelligently recommend information based on predefined gait-related data using rules and cases to support decision-making.

*Evaluation* (Phase 4): During this phase, the domain ontology will be evaluated based on the evaluation attributes; domain task fit through feedback from relevant stakeholders by answering the competency questions, content richness based on standard metrics, and error checking for correctness.

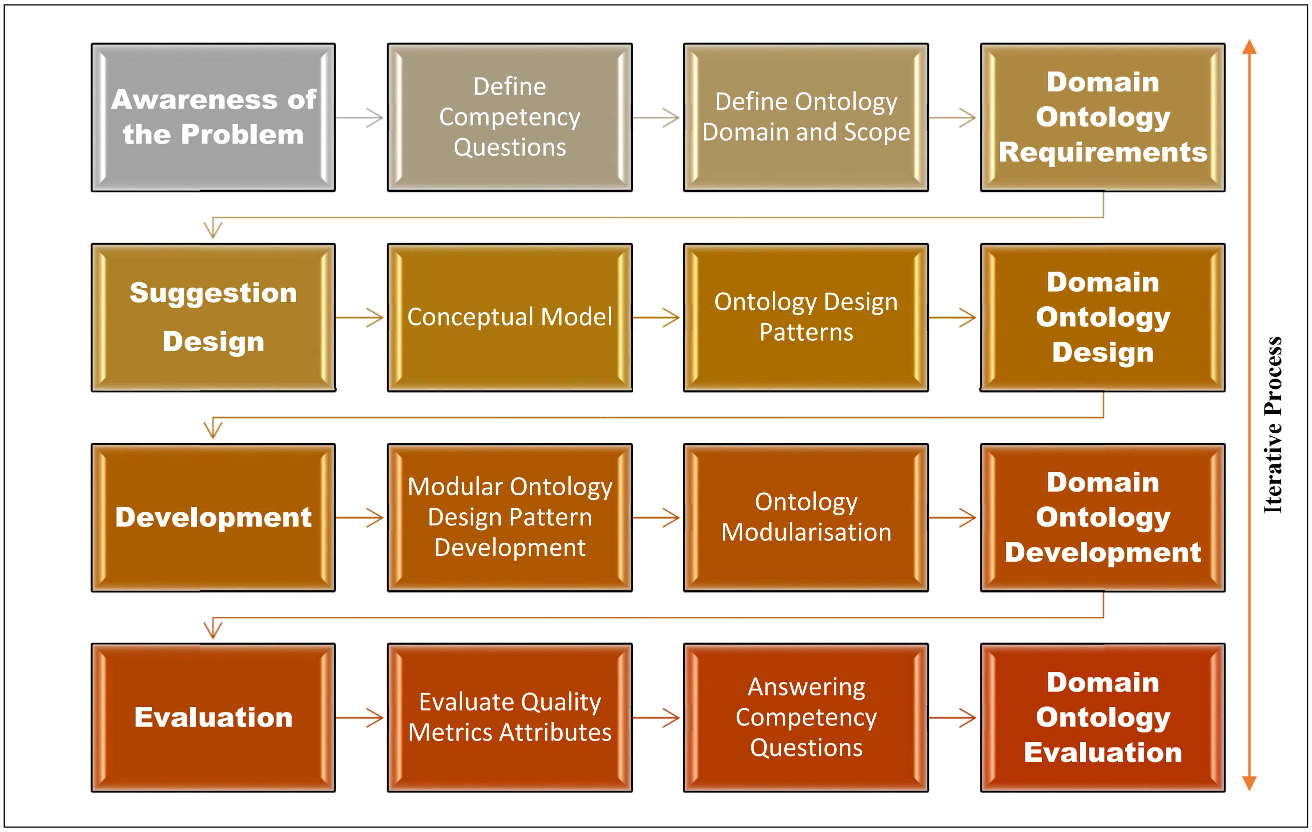


**Fig. 1**. Overview of the Adopted Research Design Process

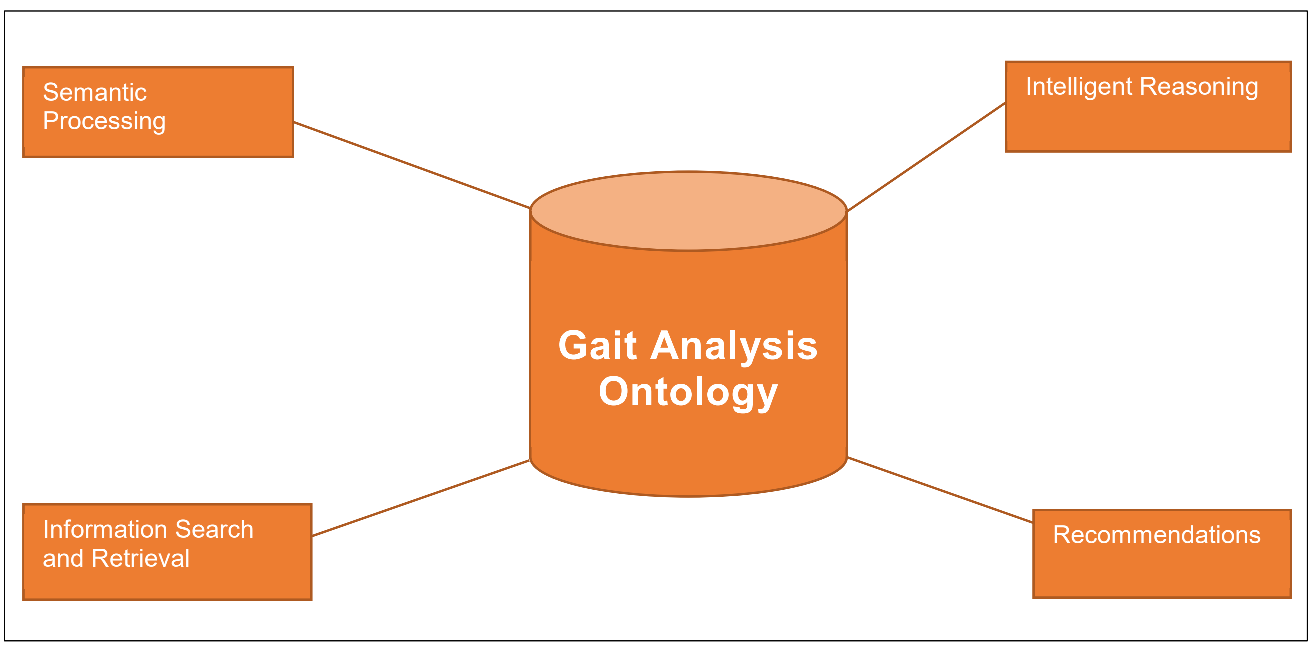


**Fig. 2.** Use Case of a Gait Analysis Ontology

## IV. CONCLUSION

In this paper, the vision to develop a domain ontology that can provide decision support for healthcare practitioners in the treatment of gait-related diseases is presented. The outcomes that could emanate from this study will have a significant impact on healthcare practitioners in the treatment of gait-related diseases by:

- allowing a shareable knowledge-domain ontology artefact to be referenced during intelligent system operations;
- provide access to artificial intelligence reasoning and semantic capabilities and;
- providing support that can augment decision support.

In future work, we undertake the development and the evaluation of the envisioned domain ontology for decision support in the treatment of gait-related diseases.

## ACKNOWLEDGMENT

The authors appreciate the support of the Cape Peninsula University of Technology (CPUT) in South Africa, and the National Research Foundation (NRF) of South Africa.

## REFERENCES

[1] Younesi, E., Malhotra, A., Gündel, M., Scordis, P., Kodamullil, A.T., Page, M., Müller, B., Springstubbe, S., Wüllner, U., Scheller, D. & Hofmann-Apitius, M. 2015. PDON: Parkinson's disease ontology for representation and modeling of the Parkinson's disease knowledge domain. Theoretical Biology and Medical Modelling, 12(1): 1–17. http://dx.doi.org/10.1186/s12976-015-0017-y.

[2] Nguyen, A., Gardner, L. & Sheridan, D. 2019. Towards Ontology-Based Design Science Research for Knowledge Accumulation and Evolution. Proceedings of the 52nd Hawaii International Conference on System Sciences, (April).

[3] Nguyen, T.H., Grundy, J.C. & Almorsy, M. 2016. Ontology-based automated support for goal–use case model analysis. Software Quality Journal, 24(3): 635–673.

[4] Agibetov, A., Gutierrez, K.E.T., Catalano, C.E., Patanè, G., Hurschler, C. & Spagnuolo, M. 2016. GaitViewer: Semantic gait data analysis and visualisation tool. CEUR Workshop Proceedings, 1748.

[5] Rapaport, W.J. 2005. Philosophy of computer science: An introductory course. Teaching Philosophy, 28(4): 319–341.

[6] Lu, J. & Xu, Q. 2017. Ontologies and Big Data Considerations for Effective Intelligence. http://www.igi-global.com/book/ontologies-big-data-considerations-effective/171688.

[7] Sanfilippo, E.M., Kitamura, Y. & Young, R.I.M. 2019. Formal ontologies in manufacturing. Applied Ontology, 14(2): 119–124.

[8] Daramola, O.J. 2010. A process framework for semantics-aware tourism information systems. In International Conference on Web Engineering Springer Berlin Heidelberg: 521–532.

[9] Uschold, M. & Gruninger, M. 2004. Ontologies and semantics for seamless connectivity. SIGMOD Record, 33(4): 58–64.

[10] Salvadores, M., Alexander, P.R., Musen, M.A. & Noy, N.F. 2013. BioPortal as a Dataset of Linked Biomedical Ontologies and Terminologies in RDF. Semantic Web, 4(3): 277–284.

[11] W3C. 2020. Semantic Web - W3C. W3C.Org. https://www.w3.org/standards/semanticweb/.

[12] Baker, T. 2005. Introduction to Semantic Web. International Journal of Advanced Research in IT and Engineering, 2(6): 90–101.

[13] McDaniel, M. & Storey, V.C. 2019. Evaluating Domain Ontologies. ACM Computing Surveys, 52(4): 1–44.

[14] Bandrowski, A., Brinkman, R., Brochhausen, M., Brush, M.H., Bug, B., Chibucos, M.C., Clancy, K., Courtot, M., Derom, D., Dumontier, M., Fan, L., Fostel, J., Fragoso, G., Gibson, F., Gonzalez-Beltran, A., Haendel, M.A., He, Y., Heiskanen, M., Hernandez-Boussard, T., Jensen, M., Lin, Y., Lister, A.L., Lord, P., Malone, J., Manduchi, E., McGee, M., Morrison, N., Overton, J.A., Parkinson, H., Peters, B., Rocca-Serra, P., Ruttenberg, A., Sansone, S.A., Scheuermann, R.H., Schober, D., Smith, B., Soldatova, L.N., Stoeckert, C.J., Taylor, C.F., Torniai, C., Turner, J.A., Vita, R., Whetzel, P.L. & Zheng, J. 2016. The Ontology for Biomedical Investigations. PLoS ONE, 11(4): 1–19.

[15] Ajami, H. & McHeick, H. 2018. Ontology-based model to support ubiquitous healthcare systems for COPD patients. Electronics (Switzerland), 7(12).

[16] Daramola, O. & Moser, T. 2021. Towards Semantic Data Integration in Resource-Limited Settings for Decision Support on Gait-Related Diseases.: 236–256.

[17] Manosperta, L. 2019. Automatic Gait Analysis in neurodegenerative diseases., (February).

[18] Baker, R., Esquenazi, A., Benedetti, M.G. & Desloovere, K. 2016. Gait analysis: Clinical facts. European Journal of Physical and Rehabilitation Medicine, 52(4): 560–574.

[19] Auvinet, B., Touzard, C., Montestruc, F., Delafond, A. & Goeb, V. 2017. Gait disorders in the elderly and dual task gait analysis: a new approach for identifying motor phenotypes. Journal of NeuroEngineering and Rehabilitation, 14(1): 1–14.

[20] Mirelman, A., Bonato, P., Camicioli, R., Ellis, T.D., Giladi, N., Hamilton, J.L., Hass, C.J., Hausdorff, J.M., Pelosin, E. & Almeida, Q.J. 2019. Gait impairments in Parkinson's disease. The Lancet Neurology, 18(7): 697–708. http://dx.doi.org/10.1016/S1474-4422(19)30044-4.

[21] Blondé, W., Antezana, E., De Baets, B., Mironov, V. & Kuiper, M. 2009. Metarel: An Ontology to support the inferencing of Semantic Web relations within Biomedical Ontologies. Nature Precedings: 2–5.

[22] Blondé, W., Mironov, V., Venkatesan, A., Antezana, E., De Baets, B. & Kuiper, M. 2011. Reasoning with bio-ontologies: Using relational closure rules to enable practical querying. Bioinformatics (Oxford, England), 27: 1562–1568.

[23] Ochs, C., Geller, J., Perl, Y. & Musen, M.A. 2016. A unified software framework for deriving, visualising, and exploring abstraction networks for ontologies. Journal of Biomedical Informatics, 62: 90–105. http://dx.doi.org/10.1016/j.jbi.2016.06.008.

[24] Barton, A., Rosier, A., Burgun-Parenthoine, A. & Ethier, J.-F. 2014. The Cardiovascular Disease Ontology. In FOIS.

[25] De Nicola, A., Missikoff, M. & Navigli, R. 2009. A software engineering approach to ontology building. Information Systems, 34(2): 258–275.

[26] Abdelghany, A.S., Darwish, N.R. & Hefni, H.A. 2019. An agile methodology for ontology development. International Journal of Intelligent Engineering and Systems, 12(2): 170–181.

[27] Maniraj, V. & Sivakumar, R. 2010. Ontology Languages – A Review. International Journal of Computer Theory and Engineering, (January 2010): 887–891.

[28] Sireteanu, A.N. 2013. A survey of web ontology languages and semantic web services. Analele Stiintifice ale Universitatii Al I Cuza din Iasi - Sectiunea Stiinte Economice, 60(1): 187–198.

[29] Yadav, U., Narula, G.S., Duhan, N., Jain, V. & Murthy, B.K. 2016. Development and visualisation of domain specific ontology using protege. Indian Journal of Science and Technology, 9(16).

[30] Peffers, K., Tuunanen, T. & Niehaves, B. 2018. Design science research genres: introduction to the special issue on exemplars and criteria for applicable design science research. European Journal of Information Systems, 27: 129–139.

[31] Amith, M., Manion, F., Liang, C., Harris, M., Wang, D., He, Y. & Tao, C. 2019. Architecture and usability of OntoKeeper, an ontology evaluation tool. BMC Medical Informatics and Decision Making, 19(Suppl 4): 1–18. http://dx.doi.org/10.1186/s12911-019-0859-z.

[32] Raad, J. & Cruz, C. 2015. A survey on ontology evaluation methods. IC3K 2015 - Proceedings of the 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management, 2(June 2017): 179–186.

[33] Raad, J. & Cruz, C. 2018. A Survey on Ontology Evaluation Methods to cite this version: HAL Id: hal-01274199 A Survey on Ontology Evaluation Methods. HAL archives-ouvertes.

[34] Turcin, I., Ergovic, V. & Lackovic, M. 2013. Ontology Driven Decision Support System Architecture for Gait Analysis. In Y. Dekhtyar, A. Katashev, & L. Lancere, eds. International Symposium on Biomedical Engineering and Medical Physics, 10-12 October, 2012, Riga, Latvia. Berlin, Heidelberg: Springer Berlin Heidelberg: 78–81.

[35] Huitzil, I., Dranca, L., Bernad, J. & Bobillo, F. 2019. Gait recognition using fuzzy ontologies and Kinect sensor data. International Journal of Approximate Reasoning, 113: 354–371. https://doi.org/10.1016/j.ijar.2019.07.012.

[36] Shimizu, C., Hitzler, P. & Krisnadhi, A. 2020. Modular Ontology Modeling: A Tutorial.