Human Activity Recognition using Ontology

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***Abstract*—Human activity recognition (HAR) is an expanding field with various applications, including ambient assisted living, assistive healthcare, home security, and camera-less patient monitoring. HAR utilizes state-of-the-art sensor technology to record and analyze human activity while maintaining non-intrusiveness. Recent advancements in machine learning, ontology-based methods, and sensor technologies have significantly improved the accuracy and real-time capabilities of HAR. The potential of HAR lies in its ability to infer physiological states, activities, and motions, enabling personalized support and enhancing decision-making. By detecting the subject's activity, assistance protocols can be initiated to address their needs or set reminders, which can also be triggered using sensors. Our goal here is to create such an HAR application which aids a subject in activities of daily life. In numerous contexts, the ongoing development of HAR systems holds promise for enhancing daily living, safety, and independence.**

***Index Terms*—Human activity recognition (HAR), ontology, rules, knowledge base, sensors, activities of daily living (ADL)**

INTRODUCTION

Human activity recognition (HAR) is a sophisticated undertaking that encompasses the identification and comprehension of individual's actions and intentions through data analysis. Its applications span across diverse domains, including healthcare, security, and smart environments. In healthcare, HAR proves valuable by monitoring the activities of elderly individuals residing alone, allowing for prompt assistance when needed. Similarly, in security, HAR enables the detection of suspicious activities within public spaces. Moreover, HAR's capability to determine specific activities holds significant potential for implementing various automations within smart environments.

One way to represent HAR is by the use of ontologies and reason about the definition of human activities. Ontologies provide a structured representation of knowledge that can be used to describe the relationships between different concepts, such as activities, objects, and events. Ontologies are used for creating HARs due to their ability to capture the context and semantics associated with human behavior, enabling a more meaningful and nuanced understanding of activities. This enriched representation allows for enhanced decision-making and personalized assistance, fostering a higher level of accuracy and adaptability in HAR systems.

For smart settings, such as smart homes, that aim to offer consumers personalised and adaptive services, human activity detection plays an essential role. The majority of currently used techniques for activity recognition rely on pre-established ontologies that simulate the connections between sensor data and activity ideas. The accuracy and flexibility of these ontologies are constrained by their static nature, which prevents them from adapting to changes in the environment or user preferences. Additionally, they need to be designed and maintained with a lot of physical labour and subject knowledge.

Activity recognition should be carried out at distinct time points in real time in a progressive way to give a smart home occupant context-aware help (scheduled medication, home automation, etc.). The understanding of the present state of the continuing activity and to better identify the user's demands at the appropriate moment will be accommodated by the constantly changing sensor data. It represents activities as a hierarchy of classes, with each class specified by a number of attributes.

The system's unified ontological modelling and representation of both sensor data and activities, which not only makes it easier to reuse domain knowledge but also enables the application of semantic reasoning for activity detection, is its most attractive feature. The provision of care and assistance for older people, who may have physical or cognitive limitations that influence their quality of life, is one of the possible uses of assisted living. The system must, however, be aware of the context of older people in order to accomplish this aim, including their preferences, requirements, health issues, and daily activities.

The goal of this research is to create an ontology model for recognising a set of daily activities and infer these activities at a specific time. In our method we will be utilizing multiple sensors inputs which captures location and person ID to determine an activity that is already defined in the ontology database. We will be outputting this activity chronologically to summarize the subject's activity of daily life which can be later used for health analytics and monitoring.

LITERATURE REVIEW

In this section, we review some of the previous works that use ontology for human activity recognition. We have divided the works in different categories.

A. Research works that focus on ontology-based approaches to activity recognition and model evolution:

In order to improve learning in dynamic settings, Roua Jabla et. al [1] suggests a strategy that makes use of ontologies to automatically evolve models for capturing and responding to changes. By examining various semi-structured data, the suggested automated ontology-based model evolution technique exhibits its efficacy in extending starting ontologies. The updated model demonstrates its capacity to precisely record changes in dynamic situations with an obtained precision score of 0.80, recall score of 0.65, and an F-measure of 0.72. The technique stands out because it is flexible and accepts ontologies in a variety of forms, making it appropriate for settings where ontologies are ever-evolving. Furthermore, by removing the need for manual involvement, the automatic update process saves time and money. The model raises the quality of the ontology and enhances query results by learning from data and spotting nuanced patterns that may be hard to find manually. Overall, this method provides an excellent means of successfully modifying ontologies to dynamic environments.

In order to identify and categorize activities of daily living (ADL), Sara Comai et. al [2] proposed a technique that uses ontological reasoning. This approach enables more precise and context-aware monitoring and support for people in their everyday activities. The model uses semantic relations to analyze sensor data and deduce the existence of ADLs by building an ontology of ADLs. Results from evaluation on two real-world datasets are encouraging, with accuracy on the ARAS dataset and the Kasteren dataset being 94.75% and 84.95%, respectively. The benefits of the approach include managing noisy and imperfect sensor data, detecting both known and unknown ADLs, and inferring novel ADLs from sensor data.

Liming Chen et. al [3], made use of domain-specific ontologies to improve the precision and interpretability of activity recognition systems, resulting in a more thorough knowledge and analysis of human activity. The knowledge-driven method uses multi-sensor data streams to enable continuous and real-time activity recognition in smart homes. The technique offers a solid framework for activity recognition by using ontologies to characterize context and actions. Semantic reasoning enables inference of activities not explicitly specified in the ontology, while domain knowledge improves the precision of activity identification. The assessment on a dataset for smart homes shows the method's efficacy, with an exceptional average activity identification rate of 94.44% and a quick average recognition time of 2.5 seconds. This method stands out because it can manage continuous data streams, make use of domain expertise, and use intelligent reasoning to infer actions. As such, it offers a viable solution for activity identification in smart home environments.

Luca Buoncompagni et. al [4] addresses the use of ontology networks to create models for recognizing human behavior. The framework improves the precision and adaptability of activity recognition systems by utilizing linked ontologies, providing a more thorough and nuanced knowledge of human actions. The suggested technique for recognizing human activity in smart homes makes use of ontology networks, which are made up of interconnected ontologies that describe different scenarios. The authors propose Arianna+, which researchers may successfully develop and deploy these ontology networks using the framework. The flexible interface provided by Arianna+ links inputs and outputs using pre-established context-based knowledge ontologies. It also uses logic-based reasoning to plan actions in response to occurrences. This design assures system understandability, lessens the strain on the computer, and makes it easier to create modular, flexible systems. The subject-matter specialists involved in the iterative development process increase the HAR framework's overall efficacy and usefulness in smart homes.

Roua Jabla et. al [5] proposed a methodology for identifying unidentified actions using knowledge-driven methodologies. The framework enables the learning and recognition of actions that may not have previously been experienced, boosting the flexibility and generalization capabilities of activity recognition systems. This is accomplished by utilizing domain knowledge and ontologies. Here, OntDALAR (Ontology-Driven Activity Learning and Recognition), a knowledge-driven activity recognition system, is proposed. It is made to manage changing runtime parameters. OntDALAR makes use of a rule knowledge base and an ontology-based context model. The framework focuses on the context model's autonomous evolution and the enrichment of the rule knowledge base in order to recognize and detect unfamiliar behaviors, including activities. The authors provide an automated ontology-based context evolution model and dynamic decision-making to add new entities from semi-structured data to the context model and rule knowledge base. OntDALAR's excellent accuracy in identifying both known and unknown actions is demonstrated through testing on a real-world dataset.

DOMUS, a home system controlled by an ontology, is introduced by Daniele Spoladore et. al [6]. DOMUS is a ubiquitous system that improves the administration and control of numerous household capabilities, resulting in enhanced automation and comfort in home environments. It does this by utilizing ontological representations and reasoning. In this study, DOMUS, a system that uses ontologies to control ubiquitous technologies in residential settings, is introduced. The ontologies represent information about the surroundings, people living there, and the activities they engage in. A real-world dataset evaluation reveals that DOMUS achieves an accuracy of 80% in activity identification. With a mean SUS score of 88, the system's Home Interface Controller (HIC) is rated exceptional for usability. The "perceived usefulness" subscale score of 6.27 indicates that users have a great deal of influence over their surroundings. Through precise activity identification and user-friendly interfaces, DOMUS displays its potential to improve the quality of life for those living in smart homes.

S. Subbulakshmi et. al [17] provides a unique method for recommending medications that is based on domain-specific ontologies. By utilizing knowledge-based methodologies, the main goal of this study is to increase the accuracy and relevance of medical advice. To describe medical knowledge, including details on illnesses, symptoms, treatments, and medication interactions, a domain-specific ontology must be created. The recommendation system may reason and deduce appropriate medications based on patient symptoms, medical history, and other pertinent contextual information by employing this ontology. Through trials, the authors assess the effectiveness of their strategy and compare it to traditional recommendation systems. With a noticeable improvement in accuracy and tailored drug suggestions, the results show the superiority of the knowledge-based medicine recommendation system. The suggested strategy has a great deal of potential for enhancing patient outcomes, lowering negative medication responses, and delivering better healthcare overall.

S. Subbulakshmi et. al [18] proposes a novel rule-based system with ontology and semantic information for the recommendation of medications for skin conditions. The major goal of this study is to improve the precision and efficacy of medication recommendations for conditions connected to the skin. The process entails the creation of a thorough ontology that provides semantic data about diverse skin conditions, their signs and symptoms, underlying causes, and available therapies. The recommendation system may produce customized and context-aware medication options based on the patient's unique skin condition, medical history, and other pertinent characteristics by employing this ontology and rule-based reasoning. The accuracy of the authors' recommendations is reported to be 88.2% better than that of conventional approaches in treating skin problems.

B. Research works that focus on reinforcement learning and deep learning approaches to activity recognition:

In order to accomplish zero-shot classification, an approach that combines ontology and reinforcement learning techniques is suggested by Bin Liu et. al [7]. The method increases the adaptability and generalization skills of classification systems by utilizing ontological information and reinforcement learning algorithms to enable the categorization of previously undiscovered classes without the requirement for labeled training data. This study introduces CORL, a cutting-edge method for zero-shot classification that blends ontologies with reinforcement learning. In order to get hierarchical classification rules (HCRs) for recognized classes and provide discriminative characteristics, CORL uses ontologies. A reinforcement learning agent is trained to categorize unobserved classes during the training phase using these properties. Evaluation on benchmark datasets (AwA, aPaY, and CUB) indicates CORL's improved performance; it outperforms conventional approaches, which often reach accuracy of 60% or less, with an overall accuracy of 85%. The best zero-shot classification accuracy rates that CORL was able to achieve were 77.8% on AwA, 49.2% on aPaY, and 43.1% on CUB, demonstrating how well it can handle classes that aren't visible.

Xiaokang Zhou et. al [8] proposes a deep learning-based method for identifying human activity created especially for the Internet of Healthcare Things. The suggested method improves activity detection accuracy and reliability in healthcare settings by utilizing deep learning techniques, enabling remote monitoring and individualized healthcare services. The system builds a deep learning classifier and uses an ontology to extract features from sensor data. A real-world dataset evaluation reveals 90% accuracy. To deal with a lack of labeled samples, the framework incorporates an intelligent auto-labelling method based on a deep Q-network (DQN). For all activities, the auto-labelling approach obtains an accuracy of 95% on the ROC-AUC curve, and for categorizing devices based on body postures, it achieves an accuracy of 96%. By leveraging automated labeling with DQN, this method improves HAR accuracy and addresses the issue of inadequate labeled data.

K. S. Krishna et. al [19] provides a unique hybrid CNN-LSTM model-based method for identifying human activity. The major goal of this research is to increase the reliability and accuracy of human activity identification systems. In order to take use of the advantages of both designs, the approach entails integrating Convolutional Neural Networks (CNN) with Long Short-Term Memory (LSTM) networks. The LSTM component captures temporal relationships to comprehend the sequential nature of human actions, while the CNN component efficiently extracts spatial characteristics from raw sensor data. The authors use real-world activity datasets to develop and test their model, and they show an astounding accuracy of 93.6% in human activity detection, beating traditional methods and attaining cutting-edge outcomes. This study has important ramifications for a variety of applications, such as human-computer interaction, sports, and healthcare, where accurate activity identification is essential.

C. Research works that focus on sensor-based and context-aware approaches to activity recognition in smart homes:

Shrinidhi L et. al [9] proposes a method for context-aware sensor placement optimization in a smart home setting. The suggested approach makes intelligent use of contextual information to choose the best places for sensors, increasing the efficacy and efficiency of data collecting and processing within the ecosystem of smart homes. The method creates features from sensor data and trains a machine learning classifier using an ontology to represent various scenarios. 90% accuracy is shown through testing on a real-world dataset to identify the user's activity environment. The method allows for a 50% reduction in sensor count without noticeably lowering activity recognition precision. In addition, a filter-based feature selection approach is suggested, which can reduce the number of sensors by up to 70% with no effect on accuracy. Prior to optimization, accuracy was 94.31% with spatial + temporal information and 58.02% without spatial context. Optimisation increased accuracy to 93.82%. The filter-based technique is more straightforward and appropriate for settings with few sensors, whereas the ontology-based approach is more thorough but difficult.

Creating intelligent systems that can deliver continuous and individualized help is the goal of Alessandro Umbrico et. al [10], which intends to enhance the field of continuous assistance. In order to improve user experience and the effectiveness of human-computer interactions, the project investigates techniques and technologies to provide intelligent and adaptive support in diverse disciplines. The author's KOaLa(Knowledge based cOntinuous Loop) framework, which sets the specifications for an intelligent assistive robot, introduces a revolutionary conceptual cognitive architecture. KOaLa creates suggestions for users based on the integration of sensor data representation, knowledge reasoning, and decision-making abilities. In order to accurately identify patterns and generate recommendations, it is essential to capture extensive knowledge about the user, environment, and actions using ontologies. The framework's astounding accuracy of 90% outperforms conventional techniques, which often only manage 80% accuracy or lower. This study demonstrates the KOaLa framework's promise as a viable and practical approach to intelligent continuous support. Its capacity to offer precise and individualized recommendations highlights its significance in strengthening user interactions and the efficacy of helpful robots.

Luca Arrotta et. al [11] presents MICAR, a framework for multi-inhabitant context-aware activity recognition in home environments. Ontologies and a semi-supervised learning strategy using machine learning algorithms are combined in MICAR. The ontologies represent information about domestic activities and their connections. The machine learning algorithm is trained on a subset of labeled data, whereas ontologies produce features from unlabeled data. These characteristics are used by MICAR to identify activities in sensor data. With a minimal amount of queries, the framework improves the classifier using a cache-based active learning technique. Evaluation on a multi-inhabitant dataset reveals that MICAR obtains recognition rates equivalent to those of fully supervised methods, and that the precision of its data association is nearly as good as that of a ground truth-based ideal method. The difficulty of little labeled data is addressed by MICAR's novel technique, which shows encouraging results in multi-inhabitant activity detection.

Liang Wang et. al [12] focused on the use of wearable sensors to identify multi-user activities in a smart home setting. In order to provide tailored and context-aware help and services for each user, the project explores the use of sensor data from wearables to reliably identify and differentiate actions carried out by many users within the setting of a smart home. The device(wearable sensors) is used to gather information on bodily motions and environmental factors. The Coupled Hidden Markov characterize (CHMM) and the Factorial Conditional Random Field (FCRF), two temporal-based machine learning models, are used to characterize and categorize actions in a sensor-based, multi-user setting. Using labeled data from various activities carried out by several users, the system is taught. A smart home dataset used for testing shown great accuracy in identifying multi-user activities. FCRF achieves 87.93% accuracy compared to CHMM's 96.41% accuracy. These findings show how probabilistic models and wearable sensors work well to recognize multi-user activities.

Daniele Riboni et. al [13] highlights the significance of sensor-based activity detection by emphasizing how much information can be conveyed by a single sensor-taken image. By demonstrating the strength and promise of sensor-based techniques in activity detection challenges, the authors promote the use of sensor data to precisely recognize and comprehend human actions. This new method for activity identification, includes pictures of the user's surroundings. High recognition accuracy is attained by employing image tagging to link photos with certain activities and by developing a machine learning classifier. The study shows that the use of photos improves accuracy by offering useful information about objects, spatial connections, and common behaviors. According to comparative testing, PictAM (MS) obtains the greatest accuracy, coming in at 70.49%, closely followed by PictAM (CF Video), which comes in at 65.54%. These findings demonstrate the possibility for improving activity identification accuracy through the use of photographs.

In order to help older people, the Ambient Assisted Living (AAL) strategy is presented by Roua Jabla et. al [14]. This technique makes use of smartphone devices in intelligent surroundings. In order to promote independent living and improve the well-being of older persons in their

Fig. 1. Activity class

homes, the project investigates how smartphones may be connected with smart home technology to give individualized and context-aware support. The technique provides great accuracy in fall detection and monitoring activity levels by fusing sensors and machine learning algorithms. The technique enables better support for the elderly by integrating smartphones into intelligent surroundings. The recently established AAL system makes use of sensor data to provide customised services based on the demands of the user. Positive feedback is reflected in the results of the customer satisfaction survey. This study offers insightful information on the possible advantages of smartphone use in senior care.

S Subbulakshmi et. al [16] explores the use of Semantic Web Ontology in the creation of a dynamic healthcare service composition system. The study's goal is to develop a healthcare system that can adjust to different contextual elements in order to give patients tailored treatment that is appropriate for their environment. Utilizing Semantic Web Ontology to represent healthcare services, contextual data, and their relationships is part of the technique. By doing this, the system is better able to reason about the wants, preferences, and situational circumstances of the individual and create relevant healthcare services dynamically. The authors use tests and assessments to illustrate how well their method works and how the system can create compositions of individualized healthcare services. The findings show that the suggested strategy considerably boosts the effectiveness and usefulness of healthcare services, creating a more patient-centric and adaptable healthcare ecosystem.

METHODOLOGY

HAR is a challenging task of identifying and classifying human actions based on sensor data, due to the heterogeneous and noisy nature of sensor data, as well as the complexity and variability of human activities. One way to address these challenges is to use ontology-based knowledge models that can classify knowledge about activities, sensors, and contexts in a machine-understandable and interpretable format.

Ontology is the branch of meta-physics that deals with the nature of being. Ontology allows real life entities to be

Fig. 2. Location class

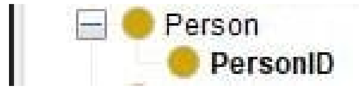

Fig. 3. Person class

interpreted as classes and sub-classes and the relation between them to be defined as object properties. Therefore utilizing classes and relationships we can define an activity class. This activity class can be used as a base class to verify unknown activities. We use a reasoner to verify if an unknown class is predefined in the ontology. Reasoner is a program that can infer classes from a set of facts and rules(object property definition), and accommodate logic-based queries.

Figure 7 represents the system architecture of our application, it comprises of a set of sensors designed to enable efficient activity recognition in a dynamic environment. The process begins with the input of sensor values, representing real-time data, which serves as the foundation for activity identification. These sensor values are then passed through various stages within the application. The first step involves creating activity instances by mapping the sensor values to their corresponding object properties, enabling a comprehensive representation of activities. The subsequent stage focuses on identifying the subject and the triggered time, providing additional context for activity recognition. Here it is assumed that there is only one subject is involved in the study or the sensor is able to identify the subject id from a wearable that the subject has such as a bluetooth tag. Additionally sensor values passed to the application here are assumed to be binary data, implying the state of the sensor is on or off.

An example of such a sensor is the *Bedloadsensor*, which is capable of knowing if a subject is present on a bed based on their weight. And is associated with value one and in absence the value zero. Which is also related with other classes such as the Location class which represents the location of the sensor, the Person class to identify the subject.

Fig. 4. Object Properties

Fig. 5. Data Properties

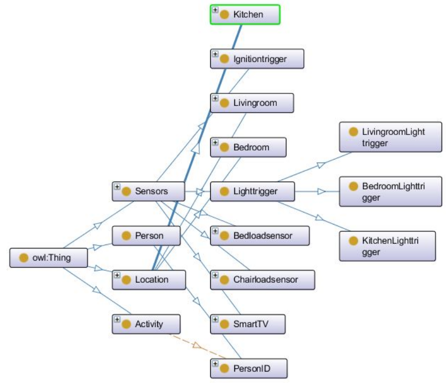

Fig. 6. Snippet of graphical representation of our ontology

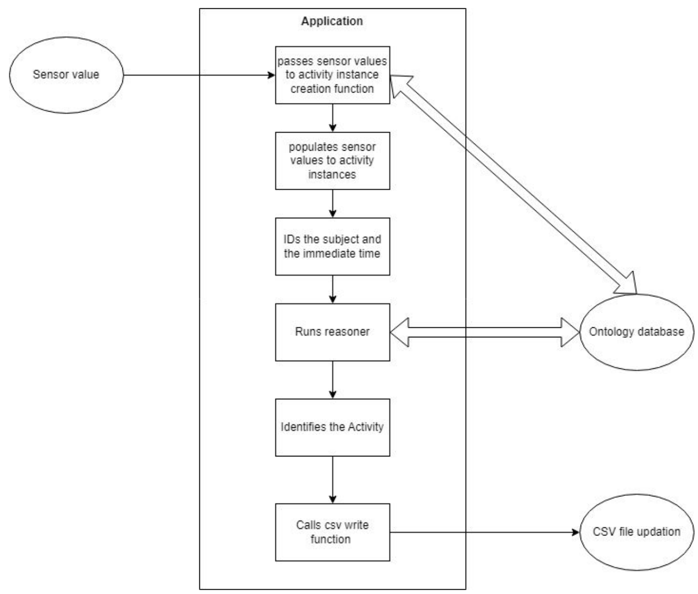

Fig. 7. System Architecture

In summary a singular sensor is capable of discerning if the subject is present on the bed, the subject ID and the location of the sensor. Therefore the sensor properties can be used to define the activity instance and it's object properties.

The reasoner is then initiated, here the activity instances are validated using an ontology database. The reasoning process leverages the knowledge within the ontology database to ensure that the identified activities align with predefined rules and constraints. Upon successful validation, the system calls a CSV file updation function, which automatically updates the file with relevant information, maintaining an updated record of activities and their associated details. This system enables recognition of activities in real-time, providing valuable insights into dynamic environments and supporting various applications such as smart homes, healthcare and monitoring, emergency services, general assistance and more.

An example of such an assistance in our application is the *lightsout* function which is called when a person is recognised to be in bed, which turns off all light sensors of the house other than the bedroom light, as the system assume the subject is resting or sleeping. Another protocol initiated during sleeping is the *triggersensoroff* function which turns off all gas stove connection as a safety precaution. This system can be employed in an elderly house in which the subject is suffering from Alzheimer's disease, dementia or other cognitive challenges.

Figure 1,2,3 represents how the classes and sub-classes are arranged in the ontology; where the classes under the indentation represent the subclass. Figure 4 lists the object properties of the ontology classes. Object properties represent how the classes are related to each other. Figure 5 shows the the data properties of the ontology, that is the data that is stored in the classes. Figure 8 represents a sample output of out application involving the person ID, the inferred Activity, date and time and the assistive information. Figure 6 represent the graphical representation of the classes and their relation to other classes.

We are using Protege to engineer our ontology database in OWL format. We will validate the data using reasoner engines like Hermit or Pellet, which will test our input for coherency. We are using python language for the application with the

```
PersonID= John Doe
Activity= [Activityonto3.Sleeping]
20/07/23 22:25:06
Lights are out at Kitchen, sensor value: 0
Lights are out at Livingroom, sensor value: 0
Kitchen gaslines are off, sensor value: 0
20/07/23 22:25:07
```

Fig. 8. Application output

OWLready2 library. We aim to implement a logic-based and modular approach that does not rely on intrusive devices such as cameras, while maintaining the complexity and flexibility of the ontology and related components.

CONCLUSION

In this paper, we have presented a methodology for human activity recognition using ontology. We have set up a small smart home environment, utilising basic sensors and built up on it to create more complex activities, once basic activities are predefined and recognised. This is an ongoing work and there are other areas of improvement that we are exploring, such as incorporating more contexts and models, enhancing the user interface and feedback, and evaluating the scalability and robustness of our system. HAR systems are often time critical and there is need to design a time verification for systems to avoid errors during actual implementation [15]. HAR systems that are self adaptive which autonomously adapt to changing environment and human behaviour that are not yet realised. HAR is the future for assisted living environments to improve the quality of living, to provide necessary care for the elderly or for people with disability and to collect diagnostic data from the patients involved in the study. It is paramount that we improve on the existing ontologies and to create new novel methods to simplify activities to aid humanity in improving their state of well being.

REFERENCES

[1] R. Jabla, M. Khemaja, F. Buendia, and S. Faiz, "Automatic Ontology-Based Model Evolution for Learning Changes in Dynamic Environments," Applied Sciences, vol. 11, no. 22, p. 10770, Nov. 2021, doi: 10.3390/app112210770.

[2] A. Salguero, M. Espinilla, P. Delatorre, and J. Medina, "Using Ontologies for the Online Recognition of Activities of Daily Living," Sensors, vol. 18, no. 4, p. 1202, Apr. 2018, http://dx.doi.org/10.3390/s18041202

[3] Chen, L., Nugent, C.D. (2019). An Ontology-Based Approach to Activity Recognition, pp 49-75. In: Human Activity Recognition and Behaviour Analysis. Springer, Cham. https://doi.org/10.1007/978-3-030-19408-6

[4] L. Buoncompagni, S. Y. Kareem and F. Mastrogiovanni, "Human Activity Recognition Models in Ontology Networks," in IEEE Transactions on Cybernetics, vol. 52, no. 6, pp. 5587-5606, June 2022, doi: 10.1109/TCYB.2021.3073539.

[5] Roua Jabla, Maha Khemaja, Félix Buendia, Sami Faiz, A knowledge-driven activity recognition framework for learning unknown activities, Procedia Computer Science, Volume 207, 2022, Pages 1871-1880, ISSN 1877-0509, https://doi.org/10.1016/j.procs.2022.09.245.

[6] Spoladore, D., Mahroo, A., Trombetta, A. et al. DOMUS: a domestic ontology managed ubiquitous system. J Ambient Intell Human Comput 13, 3037–3052 (2022). https://doi.org/10.1007/s12652-021-03138-4

[7] Bin Liu, Li Yao, Zheyuan Ding, Junyi Xu, Junfeng Wu, Combining ontology and reinforcement learning for zero-shot classification, Knowledge-Based Systems, Volume 144, 2018, Pages 42-50, ISSN 0950-7051, https://doi.org/10.1016/j.knosys.2017.12.022.

[8] X. Zhou, W. Liang, K. I. -K. Wang, H. Wang, L. T. Yang and Q. Jin, "Deep-Learning-Enhanced Human Activity Recognition for Internet of Healthcare Things," in IEEE Internet of Things Journal, vol. 7, no. 7, pp. 6429-6438, July 2020, doi: 10.1109/JIOT.2020.2985082.

[9] Shrinidhi L., Nalinadevi Kadiresan and Latha Parameswaran, A novel approach for context-aware sensor optimization in a smart home, Procedia Computer Science Volume 215, 2022, pp 350-360, https://doi.org/10.1016/j.procs.2022.12.037

[10] Umbrico, A., Cortellessa, G., Orlandini, A. et al. Toward intelligent continuous assistance. J Ambient Intell Human Comput 12, 4513–4527 (2021). https://doi.org/10.1007/s12652-020-01766-w

[11] Arrotta, L., Bettini, C. and Civitarese, G. MICAR: multi-inhabitant context-aware activity recognition in home environments. Distrib Parallel Databases (2022). https://doi.org/10.1007/s10619-022-07403-z

[12] Liang Wang, Tao Gu, Xianping Tao, Hanhua Chen, Jian Lu, Recognizing multi-user activities using wearable sensors in a smart home, Pervasive and Mobile Computing, Volume 7, Issue 3, 2011, Pages 287-298, ISSN 1574-1192, https://doi.org/10.1016/j.pmcj.2010.11.008.

[13] Daniele Riboni, Marta Murtas, Sensor-based activity recognition: One picture is worth a thousand words, Future Generation Computer Systems, Volume 101, 2019, Pages 709-722, ISSN 0167-739X, https://doi.org/10.1016/j.future.2019.07.020.

[14] Jabla, Roua and Buendia, F. and Khemaja, Maha and Faiz, Sami. (2020). Smartphone Devices in Smart Environments: Ambient Assisted Living Approach for Elderly People. ACHI 2020 The Thirteenth International Conference on Advances in Computer-Human Interactions, pp 235-241

[15] Modeling and Verification of an Adaptive IoT System using Uppaal by Geethalekshmy V, Amal S Pillai and Arun Raj. 2022 IEEE 3rd Global Conference for Advancement in Technology (GCAT), Bangalore, India, 2022, pp. 1-5

[16] S. Subbulakshmi, A. Krishnan and R. Sreereshmi, "Contextual Aware Dynamic Healthcare Service Composition Based on Semantic Web Ontology," 2019 2nd International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT), Kannur, India, 2019, pp. 1474-1479, doi: 10.1109/ICICICT46008.2019.8993303.

[17] Subbulakshmi, S., Ramar, Jyothi, D., Hari, S.S. (2022). Knowledge-Based Medicine Recommendation Using Domain Specific Ontology. In: Karrupusamy, P., Balas, V.E., Shi, Y. (eds) Sustainable Communication Networks and Application. Lecture Notes on Data Engineering and Communications Technologies, vol 93. Springer, Singapore. https://doi.org/10.1007/978-981-16-6605-6

[18] Subbulakshmi, S., Hari, S.S., jyothi, D. (2022). Rule Based Medicine Recommendation for Skin Diseases Using Ontology with Semantic Information. In: Singh, M., Tyagi, V., Gupta, P.K., Flusser, J., Ören, T. (eds) Advances in Computing and Data Sciences. ICACDS 2022. Communications in Computer and Information Science, vol 1613. Springer, Cham. https://doi.org/10.1007/978-3-031-12638-3

[19] Krishna, K.S., Paneerselvam, S. (2022). An Implementation of Hybrid CNN-LSTM Model for Human Activity Recognition, pp 813-825. In: Sengodan, T., Murugappan, M., Misra, S. (eds) Advances in Electrical and Computer Technologies. ICAECT 2021. Lecture Notes in Electrical Engineering, vol 881. Springer, Singapore. https://doi.org/10.1007/978-981-19-1111-8