A Framework Towards Ambient Assisted Living Enhanced by Service Robots

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ABSTRACT

Automated Human Activity Recognition (HAR) is a crucial technology for Ambient Assisted Living applications (AAL), which uses sensor data to detect and recognize human activities and behaviors. However, this technology faces several challenges, such as coping with the inherent variability of human motions, the presence of multiple people, nuisance factors such as partial occlusion, changes in lighting or viewpoint, etc. The proposed research work of ACTIVE aims to address these challenges by developing a digital assistant capable of accurately recognizing a wide range of human activities by introducing new methods and technologies for dynamic, adaptive multimodal data fusion and analysis. Additionally, the research work focuses on the incorporation of a mobile robotic platform to assist in the monitoring of human activities in dynamic environments. The ultimate goal is to provide a better understanding of human behavior, improve quality of life, and enable personalized services for individuals.

CCS CONCEPTS

• **Computing methodologies** → **Activity recognition and understanding**; *Vision for robotics*; • **Human-centered computing** → **Ambient intelligence**; • **Computer systems organization** → **Robotics**.

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KEYWORDS

Ambient Intelligence, Ambient Assisted Living Applications, Human Activity Recognition, Robotics

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1 INTRODUCTION

A key technology in Ambient Intelligence (AmI) and Ambient Assisted Living applications (AAL) is automated Human Activity Recognition (HAR). HAR systems utilize sensor data collected from wearable devices, smart homes, IoT devices, or robots to detect and recognise human activities and behaviours. The goal of HAR is to provide a better understanding of human behavior, improve quality of life, and enable personalized services for individuals. AmI is a paradigm that focuses on developing intelligent environments capable of sensing, processing, and reacting to human presence and behaviour, with the ultimate objective of achieving seamless and unobtrusive human-machine interaction. AAL systems, on the other hand, are designed to assist elderly persons or people with disabilities live independently and to improve their quality of life. HAR is a critical component of AAL systems, enabling automatic monitoring and detection of activities of daily living (ADLs) and laying the groundwork for proactive and personalised user assistance. As HAR technology advances, it has the potential to play a more vital role in healthcare, providing valuable insights to doctors and clinicians and aiding their work in illness diagnosis, treatment, and prevention. Mobile robots have been increasingly incorporated in the context of AmI and AAL applications, enhancing the capabilities and reach of the systems. These robots can serve as an extension of the environment, sensing, perceiving, and interacting with its surroundings and people. By incorporating human activity recognition into their functionalities, they can provide personalized assistance and support to individuals in carrying out daily activities as well as to assist the doctors or the clinicians in their screening tasks.

Despite significant advancements in human activity recognition in recent decades there are still limitations to overcome. Automated activity recognition presents a formidable challenge due to several factors. Firstly, human motions exhibit a high degree of inherent variability, as different motions can carry the same meaning (e.g., sleeping, resting, etc.). Furthermore, human activity recognition models often generalize poorly exhibiting over-fitting behaviours due to limited data. Secondly, activities are subject to numerous nuisance factors such as background clutter, partial occlusion, changes in scale, viewpoint, lighting, and appearance. While notable research results have been achieved in controlled environments, few attempts have been made to advance towards recognition "in the wild." Thirdly, the number of activity classes can be very large, and the manner in which an activity occurs can vary from one individual to another. Fourthly, the presence of multiple actors complicates both localization and recognition. Lastly, tackling sophisticated activities rather than simple actions, as in the smart home scenario, presents a serious challenge.

In this context, developing a digital assistant capable of accurately recognizing a wide range of human activities in an uncontrolled environment would be a significant achievement, but it requires overcoming the challenges mentioned above. To further enhance the capabilities of the digital assistant, we are also exploring the possibility of collaborating with a robotic platform that can assist in the monitoring of human activities. This collaboration enables the digital assistant to provide more personalized and context-aware assistance, as well as to extend its functionality to provide direct interaction with the humans via the robot. However, this also presents additional challenges in terms of integrating the two systems and ensuring their seamless coordination. We believe that this collaboration between a digital assistant and a robotic platform has great potential to improve the quality of life for individuals who need assistance in their daily activities, and has the potential to provide valuable assistance to doctors and clinicians in monitoring patients and supporting their work, ultimately leading to improved healthcare outcomes.

The proposed research work of ACTIVE aims to address the need for more precise and robust automatic human activity recognition in smart homes as shown in Figure 1. This can be achieved by introducing new methods and technologies for dynamic, adaptive multi-modal data fusion and analysis as well as the incorporation of mobile service robots. Our research focuses on overcoming some of the main challenges of existing HAR techniques when applied in realistic domestic AAL environments, such as the difficulties in coping with changes in the sensing infrastructure (e.g. sensor failures, additional sensing parameters) that are common in dynamic environments by utilizing a mobile robotic platform alongside the rest of the sensing infrastructure. Additionally, the recognition system must be able to tackle complex activities that involve a hierarchy of actions executed in parallel, overlap, and interleave, rather than simple actions in typical domestic scenarios. The presence of multiple users in domestic environments adds further complexity to the activity recognition process. Finally, the diversity and complexity of human behavior make it challenging to recognize even the simplest activities, as they can be performed differently not only between people but also between execution instances of a single person.

Mobile robots can add significant value to the proposed system by providing a physical and dynamic platform for data collection and analysis. With the integration of mobile robots, the system can track activities across different locations in the smart home and gather a more comprehensive data for analysis. However, incorporating robots into the system also introduces extra challenges, such as the need for robust localization and mapping capabilities, and the need to handle the additional sources of noise and variability that come with robot sensors. These challenges can be addressed through the development of advanced robot perception and localization algorithms, as well as the use of machine learning and artificial intelligence techniques to enhance the system's robustness and adaptability.

The goal of ACTIVE is to develop novel methods to reliably recognize and understand complex activities in smart homes, even upon violations of static assumptions about sensor availability and characteristics of the environment utilizing the additional sensing data coming from the mobile robotic platform. ACTIVE aims to achieve this through the fusion of static and dynamic sensors, including unobtrusive IoT sensors, wearables, and sensors on a mobile service robot. The project thus addresses a series of core research questions related to the development of a goal-oriented cooperative sensing framework, the definition of dynamic adaptation principles to cope with short-term changes and long-term trends in the smart home sensor infrastructure, and the introduction of an effective context-specific human activity recognition and behavior monitoring framework, coupled with advanced fusion. In particular, the mobile service robot plays a key role in the project, providing intrusive sensing capabilities (such as cameras) and facilitating dynamic data collection and fusion. The main contributions of the proposed system is as follows:

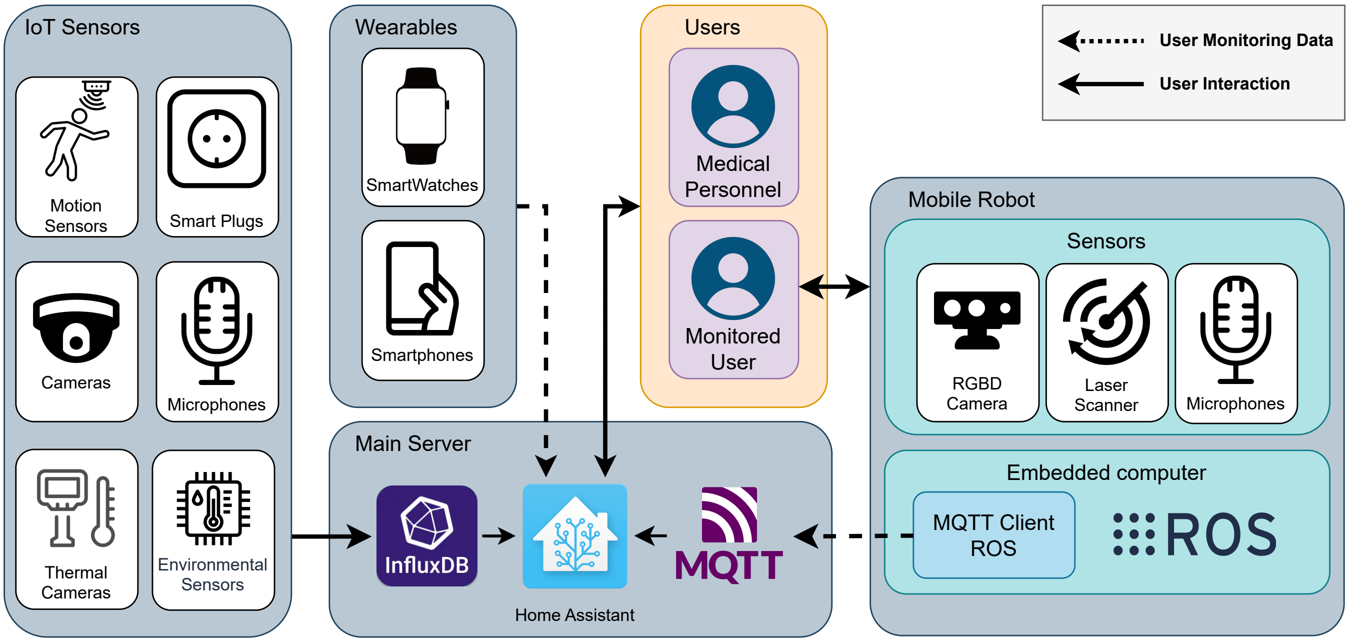


Figure 1: High-level architecture of the proposed framework

- Development of a novel, multi-level adaptive framework for automatic activity recognition through multiple data modalities. The framework is capable of advancing the level of detail and robustness of state-of-the-art HAR approaches on a variety of real domestic scenarios.
- Investigation and development of a novel approach for fusing wearables and static IoT sensors with a mobile-robot based dynamic sensing modality within the smart home.
- Investigation and development of a novel robot decision-making mechanism that utilizes sensing data from all modalities to assist the robot navigation and positioning at a place that allows effective robot vision-based monitoring.

2 RELATED WORK

AAL is a rapidly growing field that is focused on using digital technologies to improve the quality of life for older adults [12–14]. The use of sensors, smart devices, and other digital tools can provide important insights into the health and wellbeing of elderly individuals, allowing healthcare professionals and caregivers to monitor their conditions more closely.

To achieve this, a plethora of technologies can be employed. Various smart home sensors, such as temperature, pressure, humidity, motion sensors, microphones, cameras, etc. can be used to collect data related to the activities of the patients [10, 11]. Mobile and wearable devices that continuously monitor the user's position, steps, distances traveled along with their vital signs (heart rate, respiratory rate, ECG, HRV, VO2 max, etc.) can also be utilized in order to obtain a comprehensive view on the health of the user [2, 3, 7].

For more active monitoring and assisting the users in these AAL scenarios, mobile service robots can also be deployed, due to their ability to traverse a home environment and reach the person needed. This facilitates a direct engagement with the subjects and enables access to alternative perspectives, thereby enhancing the efficacy of data gathering [1, 9]. In [4] an intelligent robotic walker is presented that integrates data from visual and laser sensors for human activity recognition and fall detection. A robotic assistant for patients with Mild Cognitive Impairments (MCI) is described in [6], that can monitor its user and the home environment and aid them by providing multi-modal human-robot communication interfaces and safe manipulation of objects. In [8] a robot was integrated into an AAL system along with environmental sensors and sensorised daily-use objects; this system allows for monitoring and providing social, cognitive, and physical stimulation to the users.

By leveraging the data obtained from sensors and devices, it is possible to develop accurate and reliable systems for human activity recognition (HAR). A variety of techniques and approaches for HAR have been explored and documented in the review works [5, 15].

3 FRAMEWORK ARCHITECTURE

The proposed framework architecture illustrated in Figure 1 is focusing on three main sensor categories consisting of wearables, IoT, and robot sensors that are all connected though the main server to the Home Assistant[1] platform providing the system with the needed user monitoring data. For the first category, the main source of information is acquired mainly from smartwatches and smartphones which can provide physical activity and bio-signals related data in real time. More specifically, the signals of interest relate to the person's physical activity, such as accelerometer-based signals and bio-signals like heart rate, temperature, galvanic skin response, etc. These sensors are connected to the Home Assistant platform through InfluxDB[2] where the data is stored. InfluxDB is an open-source database designed to store large volumes of time series data and quickly perform real-time analysis. A more detailed view of the system sensors can be seen in Figure 2.

For the second category, IoT sensors include sensors that are positioned statically in the smart home environment. These sensors are mainly used for monitoring environment parameters such as temperature, lighting conditions and humidity as well as the state of domestic elements such as cupboards and electric appliances. Other sensors, such as cameras, can allow human tracking to an extent, depending mainly on the user position and the field of view of the camera. An additional modality of great importance to our method is audio sensors, which may give auditory information on user activities by collecting environmental noises associated with those activities.

Finally, the last category is comprised by sensors that are integrated into the mobile robot (Figure 3). These sensors consist of an RGBD camera, microphone arrays and a 2D laser scanner. Measurements from these sensors are all fused together in order to monitor the user activities. Since the sensors of the robot are integrated into the Robot Operating System (ROS)[3] an MQTT[4] bridge is utilized in order to communicate with the smart home server infrastructure. Finally, users including the medical personnel as well as the individual monitored can access these information through the Home Assistant interface.

The setup of the proposed framework has been implemented in the ITI Smart House (Figure 3) which is a rapid prototyping and novel technologies demonstration infrastructure at CERTH premises. Regarding the sensor modalities we are utilizing an OZZIE robot as our robotic agent that features an Orbbec Astra 3D camera, a ReSpeaker V2.0 microphone array and an RPLIDAR-A1 laser range scanner. The sensors modalities that are installed in the smart home

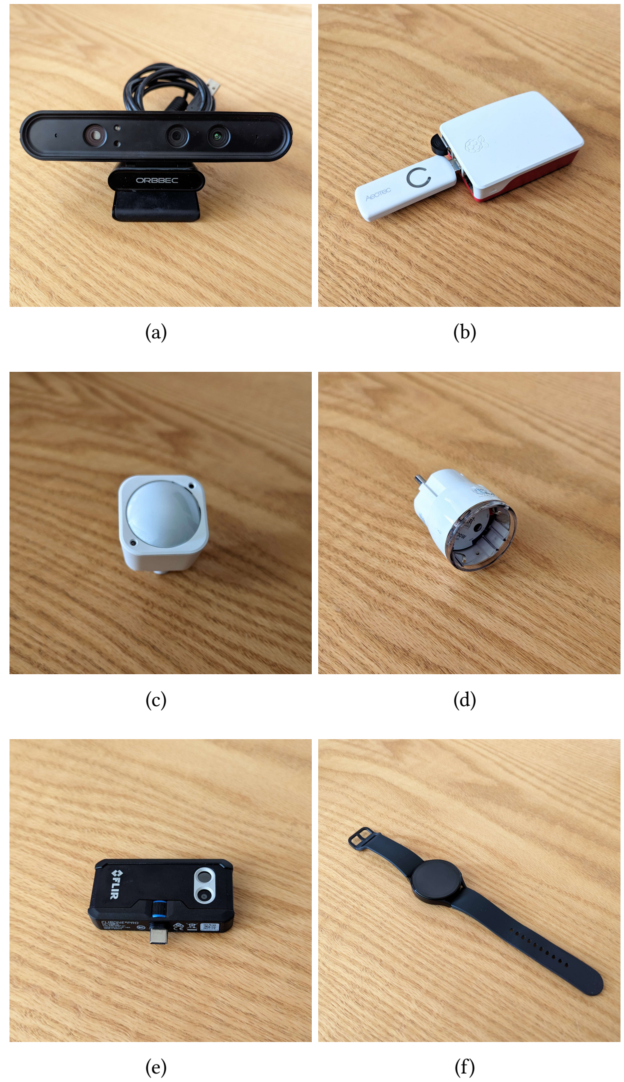
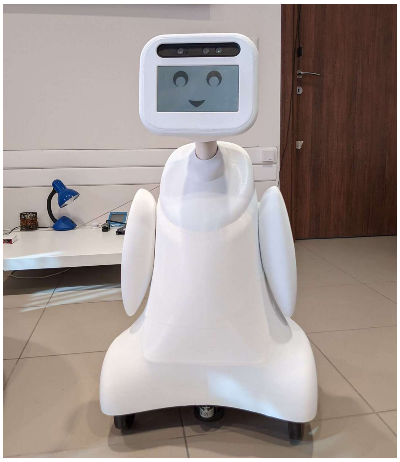


Figure 2: Sensing Modalities of the proposed system: (a) RGBD camera, (b) Microphone, (c) Motion and Environmental sensor, (d) Smart plug, (e) Thermal camera, (f) Wearable device

environment as seen in Figure 2 are an Orbbec Astra 3D camera, an Adafruit USB mini microphone mounted on a Raspberry Pi 3, a Aeotec MultiSensor 6 enviromental and motion sensor, a FIBARO wall smart plug, a Flir One Pro thermal imaging camera and a Samsung Galaxy Watch 5.

In terms of conceptual architecture the framework is divided into 3 main levels. The first level concerns the unimodal HAR level, where the basic data collection and signal processing for each sensing modality is happening, that eventually leads to extracting the low level features that are fed into machine-learning based classification schemes. In the

[1] https://www.home-assistant.io/ [2] https://www.influxdata.com/
[3] https://www.ros.org/ [4] https://mqtt.org/



(a)

(b)

Figure 3: (a) The mobile robotic platform of the proposed system, (b) View of the robotic platform while observing its user in a home environment

second level, the wearables and IoT data fusion takes place in order to provide more effective inference enabling us to detect not only whether the activity happens but also how it is performed by the monitored user. This is performed by hierarchical and multi-modal feature abstraction, coupling both low-level features and inference from the previous level, under probabilistic weight fusion schemes and utilizing deep-learning based systems that are used for the classification of diverse input data streams. Finally, in the third level the fusion of the last two levels takes place along with the dynamic sensing of a mobile robot. In this level the coordination framework takes decisions on whether and how further monitoring information, derived from the mobile robot vision and audio modality, should augment the HAR inference outcomes obtained so far. This approach includes initially determining whether the activity of interest has started based on the observations, then estimating whether the robot should further enhance the sensing modalities utilized so far and finally considering whether social norms and user preferences would allow the robot to navigate to a position that enables more effective, detailed HAR.

The proposed framework involves the development of a set of algorithms designed to facilitate the perception of a mobile robotic platform. The algorithms are specifically geared towards the detection, tracking, and recognition of human behaviors. By leveraging this pipeline of algorithms, the mobile robotic platform is equipped with the ability to systematically and accurately detect, track, and recognize various types of human behaviors. The system is designed to work in real-time and employs lightweight and efficient algorithms to operate on edge devices with limited processing resources and capabilities. To perform the HAR task, our suggested system incorporates a pipeline of algorithms that work together to analyse sensor data and detect particular human activities. The pipeline includes three core processes: human detection, tracking, and activity recognition. Each of these tasks is divided into sub-modules in order to increase the overall accuracy and efficiency of the system.

Human Activity Recognition (HAR) can face difficulties when it comes to recognizing activities performed by multiple people simultaneously, as they can suffer from performance degradation due to the confusion between different activities performed in the same scene. To address this challenge, an approach is being developed to isolate each user during the HAR process, which enables the system to perform multi-person HAR. However, special attention is given towards attaining the real-time characteristics of the system even in multi human environments.

4 CONCLUSION AND FUTURE WORK

The proposed research work of ACTIVE aims to address the challenges of automated Human Activity Recognition (HAR) technology in Ambient Assisted Living applications (AAL), with the ultimate goad of developing a digital assistant capable of accurately recognizing a wide range of human activities. This can be achieved through the introduction of new methods and technologies for dynamic, adaptive multimodal data fusion and analysis. Furthermore, the research work incorporates a mobile robotic platform to assist in monitoring human activities in dynamic environments. The incorporation of a mobile robotic platform in the proposed framework allows for a more comprehensive understanding of human behavior, which can improve the quality of life for individuals and enable personalized services. ACTIVE framework has the potential to revolutionize assisted living applications by providing a digital assistant capable of accurately recognizing a wide range of human activities and a mobile robotic platform to assist in monitoring these activities. By addressing the challenges faced by HAR, this framework aims to improve the quality of life for individuals and enable personalized services. Future work for the ACTIVE framework could involve expanding the range of activities that the digital assistant is capable of recognizing. This could be achieved through the incorporation of additional sensors or the refinement of existing methods and technologies. Additionally, the framework could be applied to other domains beyond assisted living applications, such as industrial automation, healthcare, and public safety. This would require customization of the framework to meet the specific requirements of each domain.

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