2023-10-26

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Ciaran Nugent
TU Dublin, ciaran.nugent@tudublin.ie

Damon Berry
Technological University Dublin

Jonathan Turner
TU Dublin, jonathan.turner@tudublin.ie

See next page for additional authors

Recommended Citation

Ciarán Nugent, Damon Berry, Jonathan Turner, Michael Wilson, Ann Marron, Julie Doyle and Dympna O'Sullivan. Investigating the use of utility monitoring as a means of recognizing activities of daily living to enable independent living among People Living with Dementia. Proceedings of EAI HealthyIoT 2023, the 10th EAI International Conference on IoT Technologies for HealthCare, Bratislava, Slovakia, October 24-26, 2023.

Funder: Science Foundation Ireland

Authors

Ciaran Nugent, Damon Berry, Jonathan Turner, Micheal Wilson, Ann Marron, Julie Doyle, and Dympna O'Sullivan

Investigating the use of utility monitoring as a means of recognizing activities of daily living (ADLs) to enable independent living among People Living with Dementia

Ciarán Nugent[1], Damon Berry[1], Jonathan Turner[1], Michael Wilson[2], Ann Marron[2], Julie Doyle[2] and Dympna O'Sullivan[1],

[1] Department of Computer Science, Technological University Dublin, Dublin, Ireland
ciaran.nugent@tudublin.ie, jonathan.turner@tudublin.ie, damon.berry@tudublin.ie, dympna.osullivan@tudublin.ie

[2] NetwellCASALA, Dundalk Institute of Technology, Dundalk, Ireland
julie.doyle@dkit.ie, michael.wilson@dkit.ie, ann.marron@hse.ie

Abstract. Dementia can make it difficult for individuals to live independently, impacting their ability to carry out activities of daily living (ADLs). ADL data is frequently screened by clinicians using manual screening tools such as Katz' Index of Independence in Activities, Lawton Brody, and Barthel Index, to detect a degradation in the ability to complete ADLs. Identifying whether a person living with dementia (PLwD) can carry out an ADL can allow for early support to be provided.

This study explores the potential of utility monitoring to identify and monitor ADL achievement in PLwD. By leveraging Internet of Things (IoT) solutions and smart home sensors, including thermal sensors, door contacts, vibration sensors, wearable, motion sensors and smart plugs, utility monitoring is employed to capture ADL data. Through an open-source software framework, these sensors are integrated into a scalable and cost-effective architecture, enabling the real-time monitoring water and electricity usage. By analysing the data collected from these utilities, specific ADLs can be inferred, providing valuable insights into the daily routines and behaviours of PLwD.

This research contributes to the growing field of smart home sensor monitoring for ADL identification in dementia care. The results obtained from this study shed light on the feasibility and effectiveness of utility monitoring as a non-intrusive and scalable approach for supporting independent living in PLwD. The findings show potential areas for the development of innovative assistive technologies to enhance the quality of life for individuals with dementia and alleviate caregiver burden.

Keywords: Dementia, Activities of Daily Living, Utility Monitoring, Digital Toolkit, Independent Living

1 Introduction

Dementia is a term that is used for a range of conditions that cause damage to the brain. This damage can affect memory, other cognitive abilities, and behaviour that interferes significantly with a person's ability to maintain the ADLs. [1]. By 2050, it is expected that one new case of Alzheimer's Disease will develop every 33 seconds, resulting in almost 1 million new cases per year worldwide. People's ability to complete ADLs can decrease with Mild Cognitive Impairment and initial stages of Dementia. Research has indicated that the rate of decline in dementing illnesses can be slowed down by maintaining the ability to live independently.

The ability of older people to conduct ADLs, such as getting out of bed, toileting, bathing, dressing, grooming, and eating is frequently screened and assessed [2]. Measurement screenings and activities using psychometric instruments detect early-onset disabilities.

Screening tools that are used by clinicians and occupational therapists in the practice of identifying people's ability to complete ADLs include:

- Katz' Index of Independence in Activities of Daily Living (Basic ADLs (b-ADLs))
  - Bathing, dressing, toileting transferring, continence, and feeding. [3]
- Lawton Brody Instrumental Activities of Daily Living (Instrumental ADLs (I-ADLs)) [4]
  - Ability to Use Telephone, Shopping, Food Preparation, Housekeeping, Laundry, Mode of Transportation, Responsibility for Own Medication, Ability to Handle Finances.
- Barthel Index [5]
  - Bowels, Bladder, Grooming, Toilet Use, Feeding, Transfer, Mobility, Dressing, Stairs, Bathing.

Our research adopts a multidisciplinary approach to co-design innovative assistive technologies for PLwD. Our main focus lies in the creation of a comprehensive digital toolkit that facilitates the support and care of those with mild-to-moderate dementia, along with their informal caregivers.

This toolkit aims to enable the planning and monitoring of personalized care goals by incorporating targets derived from care plans, established models of daily activities, and activities that hold personal significance for both individuals with dementia and their caregivers. By integrating these elements, we strive to enhance the overall well-being and quality of life for PLwD, while also alleviating the burden on their caregivers. Recent research has shown that IoT solutions can be utilised to identify ADLs. Smart home sensors, such as thermal, door contacts, vibration, wearable, and motion sensors are extensively used to identify ADLs. Sensor operations are utilised to infer whether an ADL is occurring. Expanding upon prior research in the realm of dementia sensing, this study leverages utility monitoring as a novel approach to track ADLs. Additionally, exploring the advantages of this method reveals several promising aspects, including simplified setup and maintenance due to reduced device requirements.

The architecture of the proposed framework will be designed around the following principles to enable the utilisation of low-cost off-the-shelf sensors and maintain control of data. The architecture has the following characteristics.

1. Open-Source Software
2. Local Network
3. Low Cost

4. Scalable

The rest of the paper is organized as follows: Section 2 provides a comprehensive literature review of relevant studies and prior research in the field. Section 3 offers an overview of the methods employed in this study, detailing the proposed architecture and energy monitoring approaches utilized.

The results obtained from the conducted research are presented in Section 4, showcasing the findings and their implications. Finally, Section 5 concludes the paper with a discussion, analysis of the results, and offers perspectives on utility monitoring to identify ADLs.

2 Literature Review

There is a significant amount of ongoing research using sensors to passively monitor and infer ADLs. The ability to capture ADLs is being completed in the laboratory and field. Many contemporary researchers utilise smart home sensors, mobile and wearable devices. [6] [7] [8] [9] [10] [11].

Several studies have been completed to monitor ADL achievement for PLwD with a focus on smart home sensors. Rawtaer et al completed a cross-sectional study to establish the feasibility and acceptability of utilizing sensors in senior citizens' homes to detect changes in behaviours unobtrusively. Sensors such as smart plugs, a water usage sensor, passive infrared motion sensors, bed sensors, and a wearable activity band were deployed in the homes of community-dwelling senior citizens to monitor their behaviour patterns and detect potential signs of mild cognitive impairment. The water usage sensor was abandoned in this study as it was not deemed technically feasible [12]. Feng et al focus on leveraging mobile data for activity recognition to enhance human well-being, using the data from mobile phone sensors [13]. Park et al proposed the development of a self-organizing IoT device-based system for smart diagnosing assistance with ADLs. A pilot test was carried out in a hospital to recognise ADLs utilising smart home sensors such as acceleration, flame, temperature, and humidity. Appliance interaction was captured using General Purpose Input/Output (GPIO). Participants were instructed to complete ADLs via an electronic device [14]. Soma et al monitored ADLs using an IOT system consisting of magnetic, motion, current transformer (CT), and tilt sensors [15]

In addition to smart home sensor studies, other completed studies have utilised mobile phone and wearable sensors. Mighali et al presented an IOT system that can harness data from IOT sensors to capture positioning and motility data to detect behavioural deviations. Devices used in this studry included Bluetooth Low Energy (BLE) beacons and a wearable hand band equipped with a triaxial accelerometer, gyroscope, magnetometer, and BLE transceiver. The beacons were placed strategically to provide proximity to key regions and periodically send out Unique Identification Codes to receiving devices, either the hand band or the smartphone, which also receives Received Signal Strength (RSS) values. These values are then used to indicate the relative positioning of the person indoors [16].

The majority of studies mentioned in the literature review are cross-sectional or feasibility studies. There is a need for more longitudinal studies that examine the long-term effectiveness and benefits of utility monitoring and smart home sensors in supporting independent living and tracking changes in ADL performance over time.

The accuracy and reliability of smart home sensors in inferring specific ADLs needs further validation. While these technologies hold promise, it is essential to evaluate their performance against established assessment tools and clinical observations to ensure their effectiveness in capturing ADLs accurately. One area which could augment the accuracy and reliability of monitoring ADL activity is utility monitoring such as work completed by Bilodeu et al [17]. Sensors could be attached to the main incoming electrical cable to a home and also the main incoming water pipe. As electricity and water are used while completing many of the ADLs outlined in the screening tools mentioned before. The data gathered from these sensors could be used to increase accuracy when inferring ADL activity.

As the use of smart home sensors involves collecting personal data in private spaces, there is a need to address privacy concerns and ensure appropriate ethical practices. Research should focus on exploring strategies to safeguard sensitive data, obtain informed consent, and address any potential intrusiveness perceived by PLwD and other cohabitants.

The reviewed studies have predominantly focused on specific populations or settings, which may limit the generalizability of findings. Further research should involve diverse populations and consider cultural, social, and environmental factors that can influence ADLs and the acceptability of monitoring technologies across different contexts.

To ensure the successful adoption and long-term use of utility monitoring and smart home sensors, studies should prioritize user-centred design approaches. Engagement with PLwD, caregivers, and healthcare professionals in the development and evaluation of these technologies should enhance their acceptability, usability, and overall user satisfaction.

3 Proposed Methodology

This paper proposes monitoring energy usage to infer whether ADLs are being completed. Energy usage can identify a wide variety of ADLs including Food Preparation, Housekeeping, Laundry, and Bathing. Monitoring the electricity consumed on kitchen appliances can infer food preparation, the electricity consumed by a vacuum cleaner or dishwasher indicates housekeeping. A washing machine, tumble dryer or iron can indicate laundry. While the use of electrical devices: water heaters, power showers or immersion heaters can be used to infer bathing activity although monitoring water usage may be more appropriate.

Building on ADLs identified in previous papers [17] and from gaps identified in the literature review an architecture must be created to allow all types of in-home sensors from different manufacturers to be easily integrated. Initially, the architecture will be designed to capture electricity usage but it is envisaged that further smart home sensors will be required to demonstrate the accuracy of inferring ADL activity with and without utility monitoring. As data to be captured is personal in nature, data should be stored securely. From this, the architecture is built upon principles of Open-Source Software, Local Network, Low Cost, and Scalability, there rests a significant emphasis on ensuring a blend of versatility and security in deploying this system across diverse settings. Due the sensitive nature of collecting data in people's homes, particularly PLwD. Additional emphasis is given to ethical considerations.

3.1 Open-Source Software

Open-Source Software will be utilised as it allows for the use of sensors from different manufacturers and communication protocols to be managed with one system. This principle aligns with the study's objective by enabling a diverse array of sensors from various manufacturers to be integrated into the system, thereby enhancing the system's ability to monitor numerous ADL facets.

3.2 Local Network

All data will be stored within a local database on a local network with appropriate levels of security. As the data is very personal, the bulk of all data shall be stored within a local network with access limited to approved persons. Restricting data to a local network reduces the risk of personal data being exploited by third-party software platforms. This underscores a commitment to privacy and data security, vital given the sensitive nature of monitoring ADLs in vulnerable populations. This aligns with ethical considerations, ensuring that PLwD's daily activities are securely monitored and stored, protecting their dignity and privacy

3.3 Low Cost

A low-cost approach not only ensures scalability but also aligns with an objective of inclusivity, ensuring that the benefits of ADL monitoring through smart technologies are accessible to a wide demographic. It addresses the financial challenges of implementing smart home solutions on a wider scale, thereby potentially democratizing access to supportive dementia care solutions and contributing to reducing disparities in care quality and availability.

3.4 Scalable

By prioritizing scalability, the architecture ensures that it can be adapted and expanded to accommodate advancements in sensor technology and emerging research on dementia and ADLs. Scalability implies the methodology can evolve to encapsulate more nuanced or additional ADLs in future, or to integrate with other smart home technologies, thereby ensuring the study remains relevant and adaptable to the dynamic needs and challenges of dementia care.

3.5 Ethical Considerations

Navigating the ethical landscape necessitates a blend of technological and humane strategies, particularly in managing sensitive data from PLwD. Initiating with informed consent, clear and accessible informational materials should be presented to PLwD and caregivers, followed by interactive sessions to assess understanding and acquire agreement. Stringent data security measures, involving robust encryption and access restrictions, safeguard participant privacy, while transparent documentation underscores data usage protocols. Upholding dignity involves respecting PLwD's physical and emotional boundaries and autonomy, facilitated through user-friendly interfaces. A continuous cycle of ethical evaluations and feedback mechanisms, coupled with defined withdrawal protocols, ensures sustained adherence to ethical practices throughout the study, weaving a framework that respects, protects, and empowers PLwD amidst technological interfacing and data management.

4 Sensor Framework

4.1 Architecture

Utilising the principles in the previous section, the architecture in Fig. 1 has been created. This paper is focused on using one type of sensor electricity monitoring, but the framework designed allows for many wireless sensors to be utilised to infer ADL activity such as thermal, door contacts, vibration, wearable, and motion sensors. From left to right, sensors communicate to a central device through various communication protocols. The packets of data pass through an MQTT broker. The data is homogenised and then populates a time-series database, InfluxDB. The data in the time-series database is analysed using rules set out to identify which ADL has been completed. An example of this could be seen using a toaster to prepare food: if the toaster has been switched on and consuming electricity (1,700 W - 2,200 W) for a period (2 min – 3 min). Then the basic and instrumental ADL activity of preparing food can be inferred. The information is then communicated to end-users via data visualisation tools.

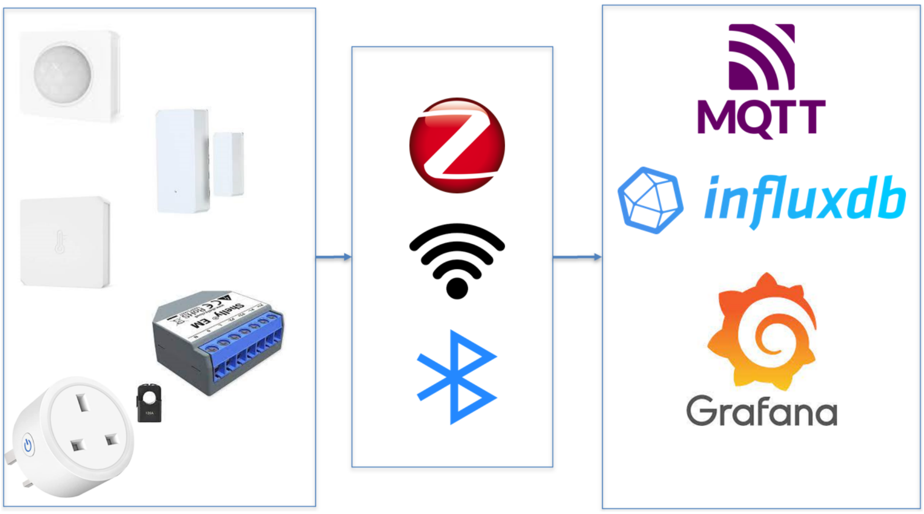

Fig. 1. Proposed SDC Architecture

4.2 Energy Monitoring

Energy usage can identify a wide variety of ADLs including Food Preparation, Housekeeping, Laundry, and Bathing. Monitoring the electricity consumed on kitchen appliances can infer food preparation, while the electricity consumed by a vacuum cleaner or dishwasher indicates housekeeping. Use of a washing machine, tumble dryer or iron can indicate laundry. In a similar way, the use of electrical devices: water heaters, power showers or immersion heaters can be used to infer bathing activity although monitoring water usage may be more appropriate.
The monitoring and testing took place in a household comprising four individuals; however, it should be noted that this home did not include a person with dementia. The electricity usage was monitored at the distribution board by installing a current transformer around the main incoming cable (refer to Fig. 2). Additionally, the monitoring encompassed the cooker circuit, as it is considered a fixed-wired appliance. To broaden the scope of monitoring, smart plugs were employed to track the electricity usage of specific devices, including a television, kettle, microwave, and toaster (as depicted in Fig. 3).

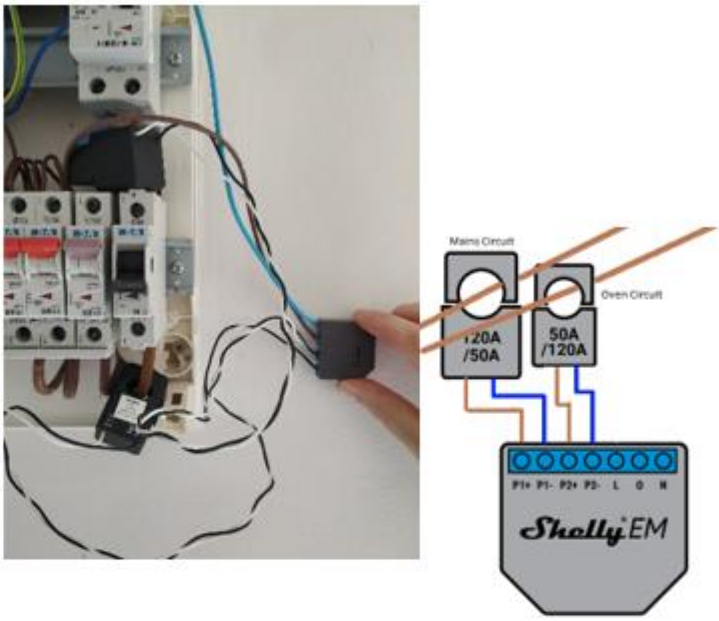

Fig. 2. Mains Power Monitoring

Fig. 3. Appliance Monitoring

Figure 4 4 shows data recorded over a 24hr period in a home. The top graph shows the total electricity consumed. Devices such as a kettle, oven, microwave, and TV were captured using Wi-Fi CTs and smart plugs. The red box shows a kettle being used in the orange graph (spike of 2,500 W for 2 min) and an oven being used in the green graph (spike of 2200 W for 10 min). These two time series signals can be seen in the total electricity consumed by the house, blue graph as a spike which reaches circa 6,000 W but reduces to 3,000 W after a period of 2 minutes and further reduces to baseload 8 minutes later. The green box shows a 10,000 W signal for 5 minutes. This was an electric shower being used. The benefit of capturing data and main incoming data is that it

is possible to capture all the electrical device/appliance usage like the electric show which would not be possible to connect to a smart plug due to the high load.
Appliance power consumption can be broken down into the following variables power used, real and reactive, and duration. All electrical current consumed in a home flows through the main incoming electrical power cable. Therefore, the powerline signature of every electrical appliance in a home can be monitored from the mains monitoring current transformer. The data will be analysed to identify which electrical appliance is being used. When the appliance usage is identified this can be used to infer what ADL is occurring at that time.

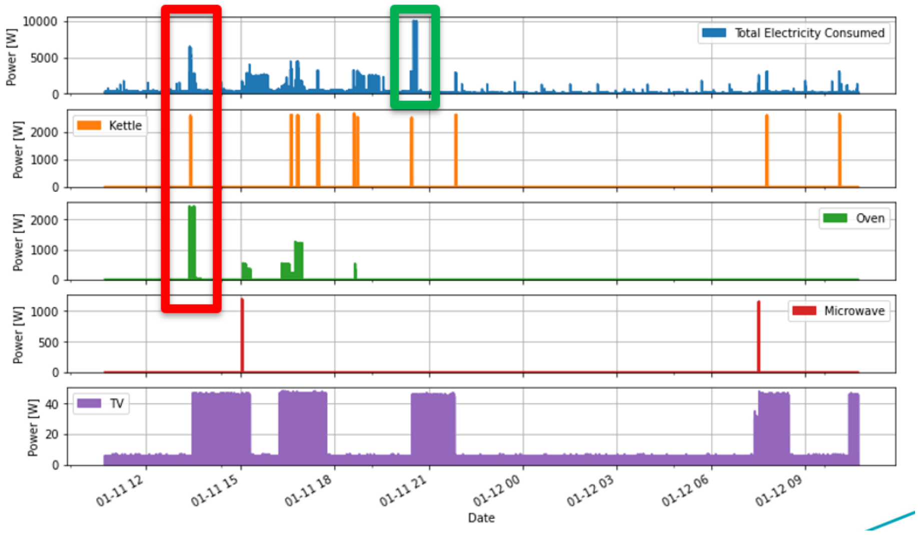

Fig. 4. Electrical Power Usage Main Incoming and Appliances

To enhance the accuracy of our system that correlates ADL activity with energy usage, we propose the following multi-stage validation process. First, we have established an ADL Register by creating a comprehensive list of ADLs that can be inferred from energy consumption patterns. Next, we will subject the identified ADLs to controlled experiments in a laboratory setting. In this phase, each activity will be systematically performed and logged with precise timestamps to capture its unique energy signature. The testing will then transition to a real-world domestic environment, where participants will log their ADL activities using a dedicated smartphone application. This ensures we have an accurate record (the ground truth) against which energy consumption inferences can be compared. Lastly, we will extend the system's testing to homes of PLwD to assess its practicality, accuracy, and usability in real-world scenarios tailored to this demographic.

5 Conclusion

By observing the activities of ADLs for PLwD, we can empower them to maintain an independent lifestyle within the familiar comforts of their own home. This paper proposes the implementation of a sensor framework that incorporates smart home in-home sensors to identify ADLs and facilitate subsequent analysis. The framework combines the information from inexpensive off-the-shelf smart home devices with utility energy monitoring as a potential application to identify ADL activities for PLwD. This paper introduces a proposed implementation of a sensor framework that incorporates smart home in-home sensors to identify ADLs and facilitate subsequent analysis. As part of our research, we will actively engage dementia specialists, groups, and PLwD to gather valuable insights into the suitability of using sensors for ADL monitoring. We acknowledge that living with smart home sensors in a home may raise concerns about intrusion, and we will actively seek feedback from both PLwD and other cohabitants to address any concerns. Living with smart home sensors in a home can feel intrusive to the people living in the residence. Feedback on concerns will be sought from both the person living with Dementia/MCI and any other cohabitants.

To begin, we will identify commercially available sensors, taking into consideration factors such as communication protocol, power usage, range, and cost. This critical information will guide us in selecting appropriate sensors for our framework. We will then create a robust communication system capable of efficiently collecting data from sensors that use different communication protocols. As data packets from different manufacturers may have varying formats, we will homogenize the data and pass it into a structured time series database.

Next, we will determine which ADLs can be effectively monitored using utility sensors. We will create a comprehensive register of ADLs and utilize sensors to track these specific activities. The collected data will be carefully analysed to identify when a selected ADL has occurred. To ensure usability for end users, the data will be appropriately aggregated to facilitate interpretation. A register of ADLs will be created, and sensors can be used to monitor these ADLs. The data will be analysed to identify a selected ADL has occurred. The data should be aggregated to allow for interpretation of end users.

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