Activities of Daily Living as a Functional Assessment Predictor in Older Adults: A Systematic Review with Focus on Architecture in Connected Health

by

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ABSTRACT

Background: Functional Assessment (FA) in older adults is an important measure of their health status. FA using Activities of Daily Living (ADL) is a strong predictor of health outcomes, especially as we age. With the development of increasingly-connected health, we have a new opportunity for more robust and improved FA.

Objective: The objective of this thesis is to collate and discuss published evidence on FA predictors and how the FA predictors can be collected using the paradigm of Connected Health (CH) architectures through an industrial case study in CHAPTER 5: INDUSTRIAL CASE STUDY.

Methods: The method is to do two Systematic Literature Reviews (SLRs). The two SLRs were undertaken with Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA) and Parsifal, an online tool for SLR. This thesis catalogs various FA and state-of-the-art Software Engineering Architectural Tactics and Styles (SEATS) used within Connected Health (CH) that focus on ADL. The results of the cataloged information were used in the industrial case study where some of the FA predictors were automated.

Articles obtained from the data source during the SLRs were filtered based on the titles, abstracts, full-text provision, English language literature, including age, which must be sixty-five years and above. Another reviewer was also included in this study, while all the defined inclusion and exclusion criteria detailed in this thesis were applied. Information about FA via ADL were extracted from the articles with further extraction on the SEATS used for computer-supported FA during the industrial case study.

Data Source: During the SLRs processes, database searched included PubMed, EBSCOhost, Engineering Village, IEEE Xplore Digital Library, and ScienceDirect. The conducted search contains both controlled terms called Medical Subject Headings

(MeSH) such as activities of daily living and search strings such as functional assessment, older adults, geriatrics, seniors, elderly care, and aging.

Results: From four hundred and ninety-five initial abstracts and titles, nineteen full-text journal articles were included in the final review for the SLR on FA predictors. Six full-text journal articles were obtained from the SLR on CH architectures after reading its 449 titles and abstracts. In the SLR on FA predictors, predictor metrics for FA via ADL were extracted from each of the articles. Gait speed, sleep quality, and movement activities were assessed as ADL predictor metrics for FA in older adults. Other FA predictors published involved self-reported metric scale measurement using Barthel-20 scale and performance-based scale through Timed-UP and Go test. This thesis reviewed each metric for sleep quality and movement activities. In the SLR on CH architectures, quick response of ADL and resource efficiency such as sensors were some of the major tactics related to performance in Software Engineering (SE) quality in CH, while confidentiality and integrity of FA measures related to security in SE quality in CH was another major concern.

Conclusion: Having conducted the two SLRs, a wide range of measures were used for FA in older adults, including consideration on the SEATS used for computer-supported FA. Overall, these FA measures and SEATS provide inexpensive and easy-to-implement FA. The diversity of the FA measures and SEATS contributes towards the development of computer-supported FA. However, future work is needed to consider the result of this study as an open-source computer-supported FA tool, and such tool should also be evaluated and verified through direct examination with older adults.

Keywords: Functional Assessment, Activities of Daily Living, Geriatric, Older Adults, Aging, Connected Health, Architectural Style, Architectural Tactics, computer-supported FA.

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LIST OF ABBREVIATIONS

API: Application Programming Interface

AMPS: Amplified Musculoskeletal Pain Syndrome

ADL: Activities of Daily Living

FA: Functional Assessment

CH: Connected Health

TUG: Timed Up and Go test

SEATS: Software Engineering Architectural Tactics and Style

SE: Software Engineering

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DEDICATION

This research is dedicated to Almighty God, my late mother and two of my siblings, who went six feet under during this journey in graduate school. May their soul rest in peace.

CHAPTER 1: INTRODUCTION

1.0 GENERAL OVERVIEW

The importance of FA in older adults through ADL measurement is crucial in older adults health management especially in their everyday living[1], and its impairment is a strong predictor of their health outcomes especially in functional decline [2]. Improved Measurement of such daily activities and its metrics, including architectural designs for connected health using those metrics, forms an essential contribution to healthcare services via software engineering practice [3].

A significant increase in the aging population worldwide has been forecast by the World Health Organization (WHO), which predicted an increase within the aged population (people older than 60) to about 2 billion - 22% of the world population[4] in 2050. This age group is prone to health-related challenges, and such declined health status is detrimental to the group's quality of life, especially in developing nations [5]. Providing an improved FA measurement for this age group, such better support has an impact on their health and lowers the risk of poor quality of life, including the cost of providing healthcare services for this age group.

We know that FA is a crucial way to measure and intervene to maintain health, but we cannot do that for everyone without Information Technology (IT). IT can help both with better measurement and scaling-up of measurement. In order to provide a better measurement, it is necessary to know what to measure and the underlying SEATS to support any automated system that can be used for FA in older adults.

Also, ADL such as sleep quality and movement in terms of physical activities form a significant predictor of FA in older adult by affecting other physiological markers such as heart rate [6], mental stability, and active behavioral abilities [7].

1.1 KEY CONCEPTS DESCRIPTION

This section introduces and defines several key concepts that are core to this study: ADL, Quality of Life (QoL), and Functional Assessment (FA).

1.1.1 Activities of Daily Living (ADL)

ADL is a term used in healthcare to refer to people's daily activities for human regulatory functioning initiated or managed by themselves [8][9]. Such activities are personal hygiene, dressing, ambulating, and eating. They are mastered early in life by everybody, and they tend to degrade as people get older [10]. Measurement of such activities and the predictors of these activities in an older adult then becomes a critical concern.

1.1.2 Quality of Life (QoL)

According to the World Health Organization (WHO), QoL is a proper understanding of an individual state of life, especially in culture and value system context [11][12]. It is also related to a belief system, life intentions, standard, and focus.

QoL is a subjective term with various meanings. Sometimes, it might simply mean physical and mental wellbeing or feeling of social or behavioral wellness [13]. For this study, QoL is defined as a degree of wellbeing, comfort, and ability to partake in life events. Likewise, QoL could also mean the capabilities or skills to live a good life in terms of physical or emotional wellbeing. In this regard, this thesis focuses on the physical wellbeing of older adults[14], [15].

1.1.3 Sleep Quality (SQ)

Sleep plays a pivotal role in older adults' health, including their wellbeing, and having a good sleep especially at night time is essential [7], [16], [17]. SQ measures the degree of having an excellent sleep session, and the inability of quality sleep affects seniors during active participation in daily activities and even puts their health at risk[7]. In order to achieve quality sleep, sleep duration, and timing become essential metrics [17], [18], and we used such metrics to determine the sleeping pattern during the industrial case study.

1.1.4 Functional Assessment (FA)

FA is a multidimensional measurement of physical, cognitive, and social health in a patient for safety maintenance[10]. Although FA is a global term, it is focused on the physical function and meant to be carried out through comprehensive assessment, cognitive, and social functional behavior measures[19]. In this study, the focus is FA driven by physical functioning, and ADL in older adults is the principal concern.

In that regard, this thesis focuses on the FA of older adults using their ADL, and sufficient assessment of the ADL yields a good QoL for the age group, including the functional decline in this age group [2].

Notably, FA measurement is crucial to older adults to ensure timely recognition of the functional inabilities, which can lead to more effective interventions by clinicians [20]. In this regard, measuring ADL forms one of the critical tools used for functional assessment in older adults [20], [21] with several metric components mentioned in section 1.1.1[20] and the detailed list in Table 1. In order to evaluate the health conditions of the focus age group, each of the activity was assessed separately for functional performance [22].

Table 1: List of ADL for functional assessment

S/N	ADL Name	Inquired Questions for the FA of an ADL
1	Ambulating/Movement	Is there any walking aid (Frame or stick)?

2	Sleeping	When does the person go to bed and how often does the person wake up in-between sleep?
3	Eating/Feeding	Can you feed yourself without help?
4	Bathing	Can the person bath or shower without help?
5	Dressing	Dressing up without assistance.
7	Grooming	Can this person brush hair, shave or apply makeup?
8	Continence	During bowel movement, did you mess yourself?
9	Toileting	Do you require help during toilet usage?
10	Stairs	Can you climb stairs without help?
11	Gait	What is the gait speed of this person?

1.2 SEATS

This is a coined acronym from Software Engineering Architecture Tactics and Style. It is a collection of widely used architectural tactics and styles in SE. The style could be pipe and filter, push and subscribe or service-oriented while the tactics are the techniques used by the style based on the SE quality. An example is when performance becomes the key focus of a computer-supported system, such SE quality could use pipe and filter style with a focus on the quick response time of the computerized system as tactics.

1.3 PROBLEM STATEMENT

In order to plan appropriate treatment and management that will prevent adverse health outcomes, it is critical to identify the risk level of patients [23], [24]. The risk could be assessed by comprehensive functional assessment (FA) [25] through existing studies using various ADLs performed by the focus age group. Different studies have used various predictors to assess the FA of older adults using their ADL. Such predictors are Barthel Index [26], loneliness measurement [27], KATZ scale [28], but we were unable to find any studies that highlight the different FA measures via ADL for FA in older adults and also consider computer-supported FA for this age group. Also, the possibility of aggregating the functional measure such as ADL was explored by Lotte et al. [29] but it is unclear how to combine those FA measures.

1.4 RESEARCH OBJECTIVES

The major objective of this thesis is to find FA predictors and CH architectures proposed for FA via ADL. It also aims towards the use of some of the obtained FA and CH architecture in an industrial case study.

The specific objectives are:

i. To catalog the different FA measures through ADL used for older adults.

ii. To record the different SEATS that use ADL during their investigation of an older adult FA.

iii. To discuss the different observations from the cataloged information concerning the industrial case study conducted during this research.

1.5 RESEARCH QUESTIONS

The research is expected to answer this main question: "Which measures are being used for FA of older adults using computer-supported FA?

The main question will be further divided into four questions below:

Question 1: What FA measures through ADL have been defined for older adults?

Question 2: What FA measures via ADL have been used in CH?

Question 3: What types of SEATS have been used within CH to provide FA for older adults?

Question 4: How can we design a computer-supported FA using the FA measures and SEATS within CH?

1.6 RESEARCH DESIGN

This study has three parts:

Part 1: We conducted an SLR on ADL as FA predictors in older adults, reports the various ADL used to evaluate FA in this age group and presents an assessment of these ADL based on predictors' usage frequency by different researchers.

Part 2: We also conducted an SLR on CH architectures that considered ADL in their design, and cataloged some of the recurring SEATS used in designing a computer-supported FA system for older adults.

Part 3: This section involves discussion on the FA measures and SEATS that were considered during the industrial case study. The discussion also highlighted the benefits of the selected SEATS for the industrial case study[0] and future development of computer-supported FA.

1.7 RESEARCH CONTRIBUTION

Several types of research have been done on ADL for FA in geriatrics medicine as indicated in the literature review in chapter 2. Most of these studies only focused on describing the concept of the FA and sometimes mentioned the ADL used for FA evaluation. Various ADL for FA measurement have been used by different researchers, and such individual contributions cannot produce a catalog of various ADLs for FA measures that were used. Knowing the different ADLs used for FA widely reported by several researchers will be relevant. Understanding some of the befitting SEATS that consider these ADL in solution development will be an asset for further solution development of the health-monitoring system. Developers of such solution will benefit from the catalog, especially in building a useful, accurate, and sustainable automated FA solution for older adults.

In this regard, this research contributes to the body of knowledge by:

a. Systematic Literature Review on FA in older adults through their basic ADL, report and assessed different ADL used for FA from various researchers.
b. Systematic Literature Review on the SEATS used across different CH research that focuses on older adults.
c. The architectural design of a computer-supported FA done via an industrial case study[0].

1.8 THESIS OUTLINE

This thesis is broken down into the following chapters:

Chapter 1: discusses briefly the general overview of the study and provides key concepts needed by the reader.

Chapter 2: introduces the existing studies by describing the state-of-the-art predictors that have been used for FA in older adults through their ADL and the various architectural patterns in software engineering. Connected Health (CH) about geriatrics studies were also described including the processes used during data analysis of the industrial case study.

Chapter 3: presents the research methods used to perform the first SLR on FA predictors. We focus on the literature search and search strategy, inclusion and exclusion criteria, title, abstract, and full-text reading, including data extraction and the SLR on FA predictors results. In this chapter, the result of the extracted data from the SLR on FA predictors was cataloged.

Chapter 4: reports the research results detailing various FA predictors and the architectural patterns extracted from different articles during the second SLR on CH architectures. In this chapter, the research methods also involve literature search and search strategy, inclusion and exclusion criteria, title, abstract, and full-text reading, including data extraction. The literature obtained from this SLR was also cataloged, including the search procedure, inclusion, and exclusion criteria.

Chapter 5: This chapter presents the result of the industrial case study concerning the SEATS that combines the FA measures. In order to achieve the result, data provided by the industry partner was subjected to a cross-industry standard process for data mining (CRISP) methodology [30]. Also, the description of the SEATS used during the industrial case study[0] will be discussed.

Chapter 6: This brings together findings by rounding off the entire discussion in the study and proposes a prospective future in order to facilitate further studies within CH. Such improvement helps the health-monitoring solution service-providers in producing a robust support system for the automated older adults FA.

1.9 CHAPTER SUMMARY

This chapter provided an overview of the study, discussing the motivation for this study, objectives, the research questions, and a brief introduction of key concepts such as ADL, QoL, and FA about older adults' health. The study objectives and questions were described.

CHAPTER 2: RELATED WORK AND FUNDAMENTALS

2.0 INTRODUCTION

In this chapter, the aim is to review existing studies on FA through ADL in older adults and discuss a framework used in achieving CH, including the architectural pattern utilized within CH for FA measurement in older adults. The reviews provide critical analysis in this research area in terms of the existing problem and solutions proposed by several researchers. Also, it helped in gap identification and filled the current void through the SLR and the industrial case study conducted in this thesis.

2.1 RELATED WORK

The FA in older adults in a real-life environment has been done through clinician expertise judgment [2] or via the wearable sensor-based approaches [31]. The clinical expert set up a questioner with various ADL questions to ask the seniors. The responses from the recruited participants in such studies were collated and quantified to determine the health scale of the person, otherwise known as the FA. The scale was used to determine the functioning status of the person [2]. This process involves a manual method of assessing FA, and it is laborious. Conversely, the wearable sensor is a technologically-driven approach, which aided near-real-time of achieving the FA. In such a technologically-driven method, most of the seniors do forget to wear those wearables [32], which makes it difficult during continuous FA through those wearables due to the inability of those wearable sensors making contact with the body.

Some of these FA techniques were used during the industrial case study. The industrial case study considered the use of both statistical approaches such as Ordinary Least Squares (OLS) [33] and Long Short Term Memory (LSTM) [34]. The non-wearable sensor provided a level of movement flexibility for the seniors and availed them the sense of not wearing any devices before they could be monitored.

2.1.1 Traditional FA

Several techniques like Bethel index [35] and the Katz scale [36] have been used to aid FA via ADL. These methods used by different researchers are laborious, manually intense, and lack scalability via automation and based on expert judgment. How could such lacuna be addressed by focusing on the weaknesses highlighted in Table 2 becomes a concern? In this regard, a computer-supported FA will help clinicians by supporting the current manual FA of older adults.

Table 2: Related Studies Strength and Weaknesses

Articles	**Considered ADL as FA predictors**	**Strength**	**Weakness**
Matzen et al. [37]	mobility, stair climbing, transfer,	Used Bethel Scale [35] to predict functional ability in terms of	How could those ADL contribute to computer-

	feeding, bathing, toilet use	survival and this was based on expert judgment	supported FA was not highlighted.
Anupama et al. [38]	Bathing, Dressing Toileting, Transferring, Continence	Identified the percentage of dependencies and non-dependencies of the ADL using the Katz scale [36] for early detection of functional decline among elderly	This lacks computational support to aid FA of the older adults
Lotte et al. [29]	Walking, House mobility, Toileting,	Considered functioning factors for each of the considered ADL	There is no design and description on how such ADL could be used in order to support

			the FA in older adults
Quinn et al. [10]	Used Bathing, Grooming, Continence, Toileting, Transfers, Mobility, Extended physical examination method to carry out the FA	Used Bethel scale for FA measurement	There is no computer-supported FA

2.2 FUNDAMENTALS

This section provided some of the basic fundamental terms used with the older adults FA and CH.

2.2.1 Activities of Daily Living (ADL)

In order to bolster the explanation of ADL described in section 1.1.1, ADL means activities carried out by a person daily[8], [21]. This term is more prevalent in geriatrics medicine to describe the daily activities of an older adult living independently. Such activities are sedentary, movement, and personal hygiene, among others. Shown in Figure 1 are some elements of typical ADL.

Figure 1: Typical ADL (Adapted from [10], [22] **)**

2.2.2 FA Measurement:

FA is defined as activities that objectively review individual mobility, transfer skill, and ADL [39]. FA is a continuous process [40], and its measurements within the geriatric context are complex because such measurement can either be a comprehensive FA which includes physical, emotional functioning, and cognitive including Instrumental Activities of Daily Living (IADL), economic resources and informal social supports [41] or measurement focusing on a specific assessment [42], [43]. Either of the two types of assessment tends to direct treatment that will invariably assist clinicians during FA activities for the older adults[44]. In order to effectively measure the FA in the focus study age group, clinicians need to ensure continuous monitoring of the patient and also provide a proper description of the functional challenges [20]. Assessing their functional abilities can direct treatment to improve physical function and reduce admission or readmission to the hospital[10]. The efficiencies of assessing such functional abilities can be either based on physical, social, cognitive, or emotional independence[43]. In this study, we focused on the measurement of physical independence, which allows for more ADL.

2.2.3 Functional Assessment Predictors (FAP)

FAP is defined as the metrics being measured during FA activities. Some of the metrics could be sleeping cycle, movement inactiveness, or when does a particular event occur most [45]. Even though FA involves the process of eliciting information and patient performance assessment, it has some critical metrics used to perform the measurement [46]. During the profiling phase, FAP can either focus on physical or cognitive activities. Considering the physical activities, such physical activities are either ADL or IADL[46]. These activities form a critical part of the person's daily routine, and usually, timing and frequencies of these activities were used to assess the functional performance in older adults[10], [46]. Since ADL provides useful information when assessing the functional status of adults [47], we focused on physical activity predictors in this study.

FA predictors such as sleeping and mobility are the predictors used during the industrial case study. Mobility involves the ability to move from one location to another. In this case, consideration was given to the frequency of the seniors going in and out of the toilet.

Sleeping predictor focuses on data that show how the adult was able to get in and out of bed and mobility predictor extracted data on how the adult was able to move within their various abodes. Continuously collecting the predictor's dataset, the study extracted the timing and frequencies of performing the activities. Also, the deviation of current activities from the pattern of previously collected data was also determined through OLS.

2.3 Connected Health Data Wrangling Approaches

The activities listed in this section present the various tasks performed during the industrial case study[0] using some of the CH approaches described in this section.

2.3.1 Extract Transform and Load (ETL)

ETL is a process applied during the preparation of the dataset provided by the industry partner during the industrial case study[0]; this dataset was transformed into its useful form before model analysis of the modified results. The Extract section involves the collection of the dataset from the source repository such as NoSQL database. The data also went through the transformation process in other to convert the data into the required format. A typical example was that the date and time captured in the data source system were transformed to the required date and time needed by the predictive model. This was done because the data collected from the source system was not in the correct format needed by the analytics engine[48]. Having transformed the source data; it then went to the load stage of the ETL process by storing the data into a data warehouse, as shown in Figure 2. The transformed data is loaded into the destination repository for further and easy analysis. At this stage, the feature set used for the analysis was extracted from the raw ADL data and transformed into the format required by the model. This transformation made the feature set readily available at every analytics iteration. Within the ETL process, data can be converted using either Structured or Terminology mapping[48].

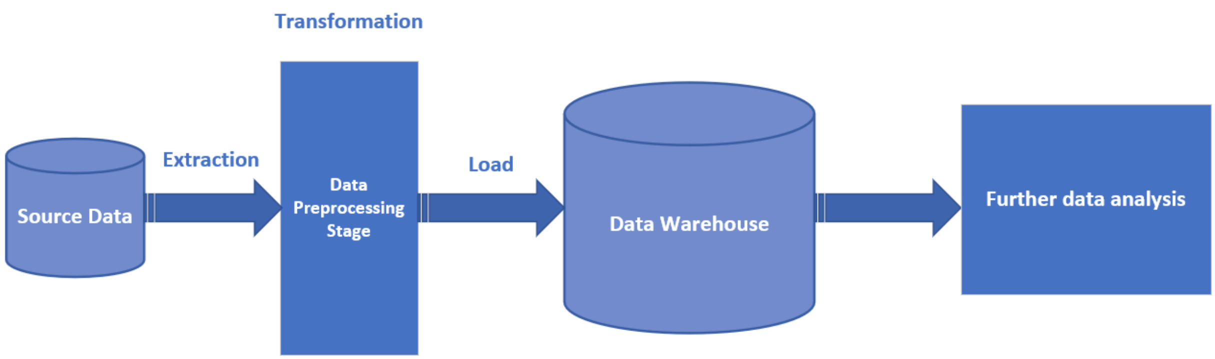

Figure 2: Typical ETL Process (Adapted from [49]**)**

2.3.2 Structural Mapping

Structural Mapping also called syntactic mapping and readily used in performing a different operation such as joins, data types conversion over a structured data set [48]. A typical example is the conversion of the relational tables into star schema containing fact and dimensions table.

2.3.3 Terminology Mapping

Conversion of data is based on data formats, value sets, or filling the missing values. The data format may involve changing date or number to a string, integer to float or numeric data format. Missing value could be transformed into null, using central tendencies tool such as mean or median of the data population or sometimes, using a specific string to represent the null data point [50].

In summary, the ETL process can be broken down into three different steps:

a. Data Profiling: It involves the comprehension of the dataset found in the source system and the value present in the source system. Shallow knowledge of the source data affects the results of the analytics.

b. Data Mapping: This entails the movement of the data from the source system to the target locations.

c. Terminology Mapping: During the data movement, it is necessary to convert the data from the current value to the needed value for analytics. This is done in this section.

2.4 Connected Health

Connected Health (CH) is a complex social-technical system that deals with the use of technology to provide remote healthcare services [51]. Sometimes, it can be referred to as Medical Cyber-Physical System (MCPS) [52], [53]. When a patient such as the aged population in our study focus, goes to the hospital for medical needs, health information about the patient will be recorded into the hospital Electronic Medical Record (EMR) using some digital devices like thermometer, Magnetic Resonance Imaging (MRI) scanner. The hospital might connect to the patient's health insurer for billing deductions and notify their primary care provider of the admission [54]. Through this connectivity of successful technology-driven healthcare, clinicians can effectively maximize various resources and effective management of care for the patients [55]. Such resources entail several telehealth programs, home care, disease, and effective lifestyles management. According to Lero [55], CH is an interconnection between processes, people, and technology within healthcare infrastructure. It can be inferred as a process-driven healthcare delivery, which tends to become one of the emerging and disruptive technologies in healthcare delivery [56]. In order to deliver productive care to the patients, considering all the ecosystem such as healthcare infrastructure, government policies, healthcare providers and insurance companies, there is need for smart solution that can reduce discomfort and minimize impact on patient wellbeing[51] including the suitability of a robust Software Architectural (SA) backbone for excellent healthcare components [57][54], [58]. This SA framework ensures a reduction in the latency challenges, minimizes data and information aggregation delay, and provides adequate interconnectivity systems within the CH ecosystem. Invariably, it fosters faster and more transparent healthcare delivery to patients. In this regard, this study highlights and enumerates the various SA patterns, tactics, and concerns used by the various solutions within the CH environment. Further expansion can also be done on the architectural concerns that inform several design decisions among socio-technical components of the CH ecosystem.

In order to make healthcare business a sustainable and competitive domain, it needs to provide accurate information based on connected data that are obtained efficiently. Additionally, there should neither be latency issues between these sources nor delays in aggregated information. The faster and more transparent the process, the better the service provided for the patients.

2.4.1 Architectural Challenges and Concerns in Connected Healthcare

Most of the solutions in the healthcare space focus on the challenges resolution, especially the e-health, without foundational consideration of the social part of the connected health [58]. This one-sided focus contributes to one of the critical challenges within the health sector. CH is meant to address these challenges with flexibility and ease of use by the entire stakeholders.

Within the CH architecture, the key focus was given to software performance of the CH solution, while a secure product that can enhance cost-saving for the stakeholder, availability, and accuracy of data handling within the health domain was another critical challenge. In brief, resiliency, availability, accuracy, privacy, access, and auditing of health data cannot be overlooked [58]. According to Microsoft [58], data can be classified based on volatility, context, and scope. In terms of data topology, data within connected health can be centralized, following a federated data model or a hybrid model which comprises both centralized and federated approaches [59]. Irrespective of the topological data approach, data should be able to conform to the qualities mentioned above, and different types of data requirement should be analyzed in order to choose the appropriate model for data communication within CH.

The highlighted qualities are critical to the stakeholders within the healthcare industry, and any architecture that will be accepted in this domain should be able to address these qualities. In this study, we cataloged the different architectural patterns and tactics used to address the key qualities of the stakeholders within CH.

Within the healthcare domain, agility, flexibility, scalability, service-oriented ability, interface, design, and service discovery, including federated security, are also some of the additional quality concerns for CH [58]

Several projects within the healthcare systems are driven by various features. These features become a major focus of the project stakeholders while the architectural concerns considered during CH development are [54], [60]:

1. CH Ecosystem Interoperability: Different devices and complex information technology systems exist within the healthcare domain with different functional abilities. Integrating these devices and systems is a significant concern across different healthcare organizations [54], [61]. However, how will the complex components connect for effective performance, which is one of the key considerations during an architectural design for a healthcare organization?

2. Data Management (Data collection, Transformation, and Storage): According to WSO2, a healthcare interoperability organization, and a reference architecture that aids data collection, transformation, and storage from different healthcare stakeholders constitute another key concern [54], [61]. In this regard, data management activities within CH could be managed appropriately using big data technology [62].
3. Ease of Data Accessibility, Confidentiality, and Integrity: The importance of cyber-security of the data communication within the healthcare infrastructure cannot be underestimated [54]. Also, it is required to ensure the availability of patient information with a high sense of confidence and assurance that there is no leakage of such information to a third party. This is one of the major concerns of healthcare infrastructure users. Such data should be protected.
4. Event Generation and Processing: Actions generated within the CH infrastructure should be processed in real-time with zero latency [54]. In this regard, an architecture that aids streaming and real-time processing should be available within the connected health.
5. Effective Streaming of Data in CH is another major consideration. Collected data from different medical units involved streaming and requires to be analyzed in real-time to aid continuous monitoring [63]. Internet of Things (IoT) has been a form of data collector tools used within the CH framework, and whenever there

are numerous IoTs monitoring different sections of the CH, data collected from these sensors could be overwhelming. Processing these data sequentially becomes more tedious and time-consuming [64]. In this context, there is a need for an architecture that can scale-up processing of such IoT data within CH, and this can be achieved by subjecting the collected data through streaming. In addition, using an asynchronous means of managing the data during analytical phase is an excellent option that guards against failure and produces a right balance between scalability, maintainability, comprehensibility, availability, and reliability [65]. Such data streaming requires a suitable architecture for effective performance and to avoid delay in the analytical processes of the IoT data collected from the different sections of the CH framework. It also aids quick and easy message parsing within the healthcare system [66].

2.5 Architectural Patterns in Software Engineering

Software Engineering (SE) Architectural Patterns are fundamental building blocks for constructing a software system, describing the system components and its relationship [67]. Deciding on the use of any pattern during software projects becomes more tedious, and the decision needs to be in alignment with the business goals and defining the essential characteristics, including the behavior of an application [67], [68]. In this decision, it is vital to know the strength and weaknesses of most of the existing architectural patterns. This knowledge helps in using the right architecture for business goals requirements.

SE architectural patterns could be any of the following: Layered architecture, pipe and filter, service-oriented, publish and subscribe, and broker architectural pattern. Each of these patterns has its strengths and challenges in order to meet the business goals[69].

2.5.1 Layered Architecture

As the name implies, structures that form the building block of this architectural pattern are arranged in layers. Services located on the higher layer used by those services on the lower layer and some of the most common services layers are presentation, application, business, and data layers [70]. This pattern promotes maintainability and portability but comes with a high level of abstraction of the embedded components.

2.5.2 Pipe and Filter

This structure aimed to process the data stream and ensures its transformation into the data format needed by other processes or applications [67], [70]. Data that flows through a specific bucket size known as pipe can be processed through several filtering stages. Within each filtering step, the result of one filter becomes input into another filtering system until the final filtration goal is achieved [70]. This pattern promotes performance, reusability, and modifiability but brakes down in achieving interactivity and interoperability.

2.5.3 Service-Oriented Architecture (SOA)

This is the bedrock of microservice systems where each system component, performing a specific function, implements a service [69]. A different service can be combined at run time to provide more advanced functionalities. In a recent case, the use of Representational State Transfer (REST) has been the basis of communication for lightweight messaging over Hypertext Transfer Protocol (HTTP) built-in header compared to the Simple Object Access Protocol (SOAP) communication protocol that uses XML-based web service protocols widely known as Web Services Description Language (WSDL). The lightweight nature of REST was enhanced by requests and responses in JSON format. It also aided communication performance with reduced network traffic. However, either of the communication techniques uses Hypertext Transfer Protocol (HTTP) for communication over the transport layer protocol [71].

Based on Industry 4.0 standard, the SOA for application developments enhanced scalability, availability, modifiability, and agility[72]. The use of microservices reduces functional redundancies during implementation via the use of web service Application Programming Interface popularly called Restful API. This architectural pattern promotes interoperability, scalability, and reusability but comes with complexity, especially in distributed computations.

2.5.4 Client-Server

In this pattern, one or several clients can request services from just one server [70]. This architecture was prevalent in the early days of the web with ease of application deployment and accessibility but suffered availability, especially when the clients flooded the server with many requests that the server cannot handle. If the server is not well-protected, it can be subjected to Denial of Service (DoS) attack and render the application running on the server unavailable for the client's accessibility.

2.5.5 Publish-Subscribe

This pattern is also called Event-Bus pattern. It reflects a bus-driven system such that one system component provides the service and the other component that subscribes to the service uses the provided service [69], [70]. In order to use the provided services, all the existing components must subscribe to the event bus. Although the pattern provides scalability, extensibility, testability, and reusability, the performance of this pattern is a concern to users.

Having studied and used some of the architectural patterns described above in our industrial case study[0], the use of SOA architectural pattern, specifically RESTful service in conjunction with pipe and filter was embraced for the data analysis of the non-wearable Internet of things sensor data collected through seniors ADL. Using these hybrid patterns was underpinned by a decision to achieve the strength of both pipe and filter, including SOA. Although pipe and filter pattern was heavily used during the industrial case study[0], the use of SOA via the RESTful API was basically to fetch the sensor data from the repository. Pipe and Filter promoted performance as software quality, and SOA aided interoperability quality. The pipe and filter pattern was used for data collection, transformation, and prediction of the ADL activities while the RESTful service was used for data collection and provide the result of the analysis to the legacy decision support system. For a quick overview of the strengths and weaknesses of some of the described SE architectural patterns, Table 3 presents the differences concerning software quality.

Table 3: Architectural Pattern Strengths and Weaknesses (Adapted from[69]**)**

Architectural patterns	**Strengths**	**Weaknesses**
Layered[69]	Maintainability, portability, reusability, testability and design time modifiability.	It complexity affects performance
Pipe and Filter [69]	Performance, reusability, and modifiability.	Modification could be challenging.

Service-Oriented Architecture [71]	Interoperability, performance, reusability, and scalability.	Availability, reliability, and security are critical concerns in SOA.
Publish and Subscribe[69]	Extensibility, reusability, and testability.	Performance could be a challenge due to the asynchronous communication nature of the components.

2.6 Cohen Kappa Reliability

Cohen Kappa reliability scale is a measure that is used to determine the level of agreement between two reviewers. It is often used in SLRs [73]. The higher the kappa value, the closer and better the level of agreement between the reviewers. Cohen Kappa reliability method also considers agreement by chance during its calculation, and this makes it more robust and effective in its usage for classification agreement between reviewers [74]. Shown in Table 4 is a level of reliability scale for any form of the review conducted by two different raters[75].

Table 4: Cohen Kappa Scale and Meaning

Kappa Value on Scale (k)	Reviewer's Agreement
< 0	Less than Chance Agreements
0.01 –0.2	Slight Agreement
0.21 – 0.40	Fair Agreement
0.41 – 0.60	Moderate Agreement
0.61 – 0.80	Substantial Agreement
0.81 – 0.99	Almost Perfect Agreement

2.6.1 Kappa Calculation Description

For the purpose of knowing where the agreement between two reviewers lies on the scale, the calculation below shows the analysis presented by Kappa. In this thesis, an article with the same inclusion criteria, classified by both reviewers, were represented as agreed while disagreed classification was as a result of differences in the classification of both reviewers. In Table 5, "a" represents a situation where both reviewers agreed on the inclusion or exclusion criteria. "b" represents when reviewer 1 disagreed with the inclusion or exclusion criteria, but reviewer 2 coincided with the classification. "c" shows the reverse of the "b" classification and "d" depicts that both reviewers disagreed on the inclusion and exclusion criteria, which means they both agreed.

In summary, “a” or “d” means the total number of articles that were both agreed on as included or excluded respectively. While “c” or “d” means the total number of articles that both reviewers disagreed on by as shown in Table 5.

Table 5: Agreement Matrix

	Reviewer 1		
Reviewer 2		Agreed	Disagreed
	agreed	a	b
	disagreed	c	d

Using Kappa calculation described by Sim and Wright [76], Kappa formula can be rewritten as shown by equation 1

$$\text{Kappa (k)} = \frac{Total\ agreement - agreement\ expected\ by\ chance}{Total\ instances - agreement\ expected\ by\ chance} \qquad equation\ (1)$$

Where k: $0 < k < 1$ and

Total agreement is the sum of the value of “a” and “d”

Total instance is the sum of the entire article in consideration

Agreement expected by chance = $\sum \text{EFa} + \text{EFd}$ $\qquad equation\ (2)$

EF represents an expected frequency, EFa is the expected frequency of “a” and EFd is the expected frequency of “d”

$$Efa = \frac{(a+b)*(a+c)}{a+b+c+d} \qquad \text{equation (3)}$$

$$EFd = \frac{(b+d)*(d+c)}{a+b+c+d} \qquad \text{equation (4)}$$

After computing the kappa coefficient k, the value of k falls between 0 and 1, as shown in Table 4.

2.7 Chapter Summary

This chapter reviewed related work, its strengths, and weaknesses, including foundational concepts related to this study, the concept of ADL, and the different FA measures. The discussion also described relevant aspects of CH, including some of the software architectural concerns in the CH system. Description of some popularly-used SE architectural patterns was also presented. The strength and weaknesses of the described patterns were highlighted. Although the list of the presented architectural pattern was not holistic, those described in this study were tested during the industrial case study[0]. The chapter also emphasized the decision made during the FA through data analytics of the IoT sensor data meant for seniors ADL monitoring. The decision to use pipe and filter architecture with the service-oriented architectural pattern was to aid performance and interoperability of the analytical processes and results. The industrial case study was completed by extracting some of the ADL activities from the dataset captured by IoT sensors positioned at a different location within seniors' abode.

CHAPTER 3: SLR ON FA PREDICTORS RESEARCH METHOD AND RESULT

3.0. OBJECTIVE

The goal of this SLR on FA predictors was to provide an up-to-date catalog of published FA measures that would be relevant to measure in older adults in relation to their ADLs.

3.1 LITERATURE SEARCH METHODS

In this section, the methods used during the SLR on FA predictors are described. The methods include database search, search strategy, inclusion and exclusion criteria, title, abstract, and full-text reading, including the data extraction.

3.1.1 Databases Searched

In consultation with the subject librarian in the health and information science department at the University of Victoria, PubMed, EBSCOhost, and IEEE Xplore were queried for this SLR. The decision on these databases was based on the fact that PubMed has Medline as its index and EBSCOhost has several indexes such as CINAHL and AgeLine including IEEE Xplore that was indexed with Scopus, Web of Science, ProQuest, The Institution of Engineering and Technology (IET), USA National Library of Medicine (NLM) and CrossRef [77]. Another search source was Google Scholar search engine, used to search for similar articles that focus on the FA of older adults.

3.1.2. Search Strategy / Terms Used

In order to ensure robustness in the systematic literature review (SLR), the use of Medical Subject Headings (MeSH) such as "activities of daily living" was used on the selected databases in combination with other search keywords highlighted in Table 6. Using Mesh words and some of the crafted search keywords helps to tailor the searches towards the research questions in this thesis[78].

The search keywords were based on "AND" and "OR" including logical combinations of search strings such as "activities of daily living," "ADL," "comprehensive functional assessment," "older adult," "seniors," and "elderly "as shown in Table 6. In addition to the search string, our searches were limited by date of article publication between 2000 and 2019 and only peer-reviewed journal articles with full text in English language were included in our search filters. The search filters served as the initial screening and reduced the number of obtained articles from 495 to 110.

The search strategies used in this SLR were based on the use of Parsifal tool, a collaborative SLR tool [79]. The tool provided ease of use towards SLR activities.

Table 6: Search Keywords for Different Database

S/N	Database	Search with Mesh and Keywords
1	PUBMED	(Activities of daily living [MeSH Terms]) AND comprehensive functional assessment AND (older adults OR seniors).

2	EBSCOhost	Activities of daily living AND comprehensive functional assessment AND older adults or elderly or seniors or geriatrics or aging or age-related or older people.
3	IEEE Xplore	((("Mesh_Terms": activities of daily living) AND comprehensive functional assessment) AND older adults)

3.1.3 Inclusion / Exclusion for initial and final screening

The filtering techniques were applied before the screening phases of the relevant articles, as shown in the screening section in Figure 3. During the first screening, the results of the filtered articles were screened using the defined inclusion and exclusion criteria. The initial screening was based on title and abstract, while the final screening was based on the full-text of each of the articles. These screening activities were carried out after reading the title of the article, abstract and full-text using the criteria detailed in Table 7.

The inclusion criteria in the initial screening were based on articles that consider ADL or FA measures within the title or abstract while exclusion criteria focus on articles with chronic illness, cognitive impaired focused or articles that considered IADL or another type of assessment like nutritional or cultural assessment within the title or abstract.

In the final screening, the inclusion criteria include: articles with ADL and FA metrics in the full-text while the exclusion criteria for reducing the search results in the SLR on FA predictors were based on the following: "chronic illness patient", "cognitive impaired", “focus on other assessment like nutritional assessment”, “Instrumental Activities of Daily Living (IADL)” and “article with no functional metrics description within its full-text”.

Table 7: List of Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Availability of FA measures in the title, abstract or full-text.	a. Articles with no consideration on ADL b. Articles with only consideration on a single chronic illness, e.g. cancer c. Articles with consideration on cognitive impaired older adults e.g. dementia. d. Articles that focus on another type of assessment e.g. nutritional or cultural assessment

3.1.4 Title and Abstract Screening

The title and abstract for each of the filtered articles were read and screened using the inclusion and exclusion criteria defined in section 3.1.3. One hundred and ten (110) filtered articles were reduced to twenty-four (24) by the first reviewer. Randomly chosen sixteen(16) articles from the 24 articles included by the first reviewer including a randomly selected 15 articles from the excluded articles reviewed by the first reviewer were sent to the second reviewer in order to conduct his review. The two independent reviewers used the defined inclusion and exclusion criteria documented in Table 7. The reviewers, with no adjudicator, screened the title and abstract and decided whether to include or exclude the articles based on the defined criteria. After the review process, some articles were disagreed by the two independent reviewers, and those articles were not included in the results section 3.3.

In addition, few articles were disagreed due to the lack of clarity in the inclusion criteria. At this juncture, the two reviewers meet to discuss the coherent nature of the inclusion criteria, and it was resolved by adding the "full-text" word in the inclusion criteria. This decision made few articles to be included and was finally added to the list of articles screened for further full-text review.

3.1.5 Full-Text Review

Having screened the agreed articles title and abstract by the two independent reviewers described in section 3.1.4, the same inclusion and exclusion criteria described in section 3.1.3 were applied to the full-text for further eligibility selection. The full-texts of the resulted articles were read in order to extract various FA measures used in those articles. Prior to the result harmonization, the Cohen Kappa coefficient was computed in order to verify the degree of reviewed agreement. Notably, some articles were excluded after reading the full-text, as shown in Figure 3. The exclusion of five articles was obtained by the first reviewer after full-text reading of the 24 screened articles obtained from section 3.1.4. These five excluded articles were also among the prohibited articles from the second reviewer after conducting his full-text review. In this regards, the five excluded articles were discarded and not further studied for FA measures extraction but the collated results were based on the remaining Nineteen articles as detailed in section 3.3

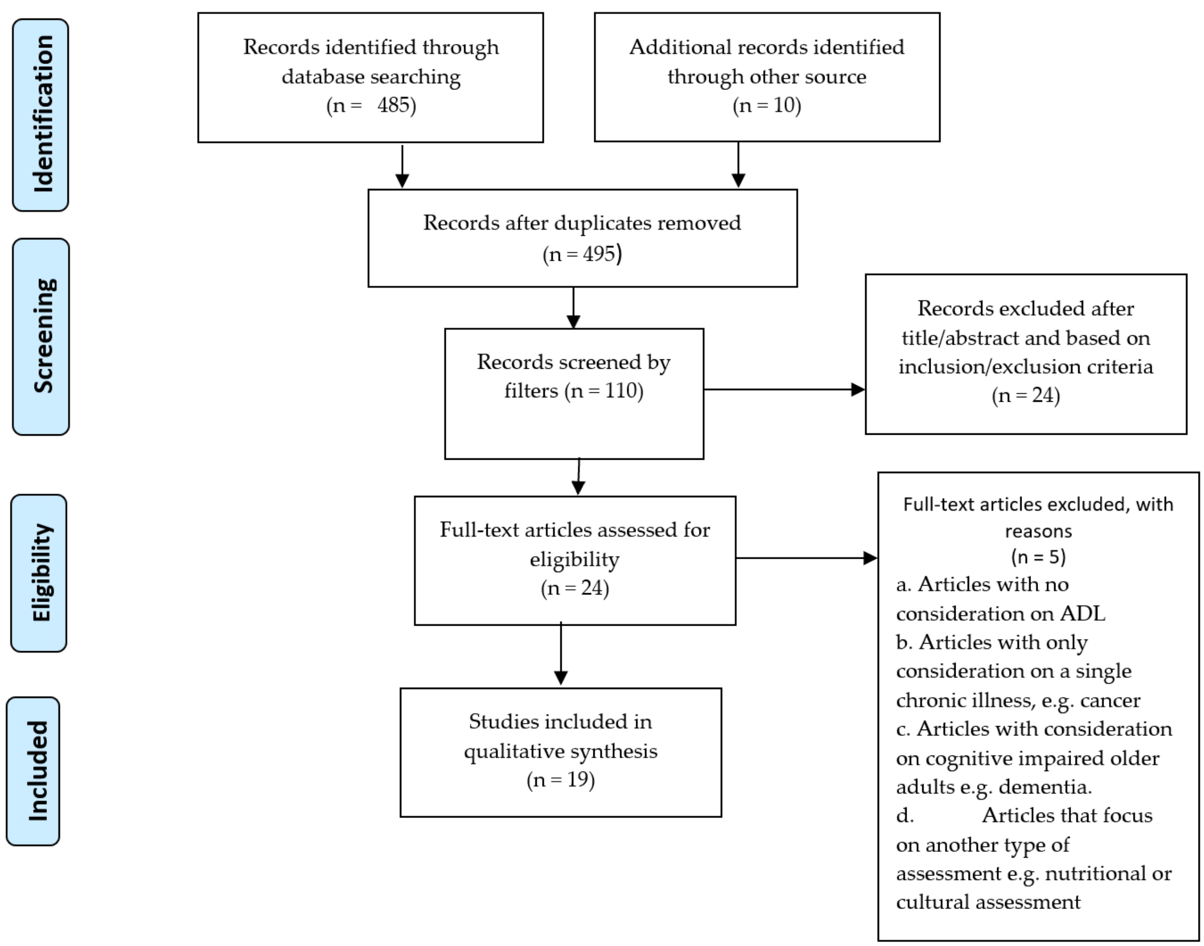

Figure 3: PRISMA Flow Diagram for SLR on FA Predictors

3.1.6 Data Extraction Process and Categories

This section focused on the presentation of data extracted from articles obtained from the database listed in Table 6. After applying the search techniques inclusion and exclusion criteria, discussed in section 3.1.2 and 3.13 respectively, the resulted articles were read to extract the FA measures that were used in the articles and cataloged in section 3.3.

3.1.7 SLR Reviewer's Agreement on Full-text screening

An agreement analysis was carried out to ensure the results of the SLR on FA predictors were reliable. The SLR on FA predictors was reviewed by two independent reviewers, applying the method, inclusion and exclusion criteria mentioned above on the 25% randomly selected articles. Majority of the articles were agreed by the two reviewers while the reviewers disagreed on some articles, but Kappa coefficient was used to calculate the level of agreement. Having completed the independent review on the SLR result discussed in section 3.4, we had an almost perfect agreement based on the Cohen kappa model [73] highlighted in section 2.6. Calculated below is the Cohen Kappa statistical justification that resulted in almost perfect justification. The reported Kappa coefficient (k) result was based on 25% random selection of all the included and excluded articles with 50% by 50% inclusion and exclusion criteria.

The second reviewer reviewed a random sample of sixteen (16) articles included by the first reviewer and fifteen (15) articles excluded by the first reviewer. These represent the “a” and “d” respectively from Table 4. Having completed the review by the second reviewer, the level of agreement was computed using the Cohen Kappa measurement described in section 2.6.

From Table 5, the variable a = 16 and variable d = 15. After the reviewed articles from the second reviewer, the value of “c” is 5 and “b” is 3. The total agreement is 27, and the total instance is 31

From equation (3.0), EFa = $\frac{(16+3)*(15+5)}{16+15+5+3} = 1$

From equation (4.0), EFd = $\frac{(15+3)*(15+5)}{16+15+5+3} = 0.974$

From equation (2.0), agreement expected by chance = EFa +EFd = 1+ 0.974 = 1.974

From equation (1.0), Kappa coefficient (k) = $\frac{(27)-1.974)}{31-1.974} = 0.8622$

Due to the result of the Kappa coefficient, which is 0.8622, we can conclude that there is almost perfect agreement between the two independent reviewers in the SLR on FA predictors. This conclusion was based on Cohen kappa analysis described in section 2.5.

3.3 Results

A total of four hundred and eighty-five (485) unique articles were collected from the selected database discussed in section 3.1.1 and an additional 10 articles were included from other sources. The 495 titles and abstracts were screened to 24 articles by applying the inclusion and exclusion criteria. Further screening by reading the full-text and also applying the inclusion and exclusion criteria reduced the articles to 19 as shown in Figure 3. Reading through the 19 pieces, the data shown in Table 8 were extracted and cataloged.

Table 8: Data Extraction for FA

Author/Year	Number of Participants/Age (Mean)	Study Period	ADL used for FA	Data Source/ Collection Method	Outcome Measured & Conclusion
Ishizaki et al. [80]	583/ 77	Three years	Basic ADL (walking, feeding, continence, bathing & dressing).	Longitudinal Interdisciplinary Study on Aging, from the Tokyo Metropolitan Institute of Gerontology / Questionnaires	-Inability to walk -Low hand-grip strength -History of hospitalization during the past year.
Idland et al. [81]	113 / 79.5	Mean of 9.3 years	-climbing steps -walking speed -functional reach.	Independent home living women / direct observation & follow-up study.	Walking Speed remains significant for the predictive model.
Schultz-Larsen et al. [82]	1021 / 79	Median of 8.3 years	-Physical activities such as walking.	Brønshøj-Husum study [83] / survey & interviews.	Walking & riding a bicycle for more than 30 minutes per day has a positive effect on human functional status.
Covinsky et al. [84]	1994/ 77	Three years	-Functional - Basic ADL -Cognitive measurement	Public study in USA / interviews and follow-up study.	Difficulty walking several blocks, problem completing ADLs, also

			-BMI measurement		difficulty bathing or dressing.
Nielsen et al. [85]	Not available(N/A) / 65	N/A	-Self-reported on Barthel-20 include bathing, feeding, getting on and off the toilet, ascending and descending stairs, getting dressed bladder continence, bowel continence, walking and transferring. -performance base using TUG, 30s chair stand, and AMPS.	Emergency Department at a university hospital/ face-to-face interview.	Self-reported measures and performance-based measures when assessing functional ability in elderly patients should complement each other.
Sharma et al. [86]	300 / > 60	N/A	Katz index was used to measure bathing, dressing, toileting, transferring, continence, and feeding.	A suburban colony of Chandigarh, Indian / interview.	Assessment of the functional disability in the older adult is crucial to prevent further morbidity.

Alexander et al. [87]	221 / 79.9	N/A	Walking, stance Maintenance and Chair Rise using Katz (ADL), Rosow-Breslau, and Nagi measurement.	University laboratory and community housing facilities / questionnaires.	Self-reported walking ability might be the excellent predictor of overall functional mobility.
Shinkai et al. [88]	736 / > 65	Six years	-handgrip -strength, -one-leg standing, -walking speeds	Tokyo Metropolitan Institute of Gerontology Longitudinal Interdisciplinary Study on Ageing / Interview & follow-up survey.	Walking speed was the best predictor for functional dependency in terms of physical performance.
Martin et al. [89]	245 / > 65	7 Days	Sleep-wake-sleep using PSQI score	Actigraphy during the rehabilitation period	More daytime sleep is associated with less functional recovery.
Isaia et al. [90]	280 / > 65	30 Days	-Basic ADL using the Katz scale was measured -bathing, -dressing, -mobility in bed, -toileting and eating	Acute geriatric unit of a University Teaching Hospital at Helsinki / Interview & Follow up.	Patients with a sleep disorder had a poor score on the cumulative index rating scale (CIRS).

			-Sleep disorder -pain availability		
Oh-Park et al. [91]	513 / > 70	1.8 years	-Stairs ascending time -Stairs descending time.	Einstein Aging Study, Albert Einstein College of Medicine, New York /Interview & Follow up.	Stair ascent and descent times are useful metrics for FA.
Matzen et al. [37]	5087 / > 65	Five years	Measure Barthel Index components	Existing patient records, patient administrative system, and personal civil registry of Denmark / Analysis of EMR dataset.	Assessment through ADL using Barthel Index is a strong predictor for functional assessment in geriatric.
Fong et al. [22]	/ > 50	Two years	ADL Count : dressing, walking, bathing or showering; eating, getting in and out of bed; and using the toilet, including getting up and down."	Health and Retirement Study (HRS) / Interview & follow up.	Bathing difficult is a strong predictor for nursing home placement.

Kingston et al. [92]	839 / 85+	2006–2007	Basic ADL and Mobility.	Recruited a cohort of 1040 from general practices in Newcastle and North Tyneside, UK and conducted interviewed on the health assessments.	Participants found it difficult in Climbing Steps, moving around the house, transfer from the toilet and walking 400 yards as a basic ADL and mobility.
Deschodt et al. [93]	442 / 75 years	Maximum of 3 months	Bathing, Dressing, Transfer, and Toileting.	A cohort study in a Belgian university hospital.	Providing proactive measurement will be a great benefit.
Tufan et al. [94]	136 / 75 Years	90- 100 minute	Sleep Quality.	Conducted interview based on some of the following questions a. difficulty falling asleep b. Sleep interrupted during the night etc.	Quality of sleep should be examined during the comprehensive geriatrics assessment.

Deckx et al. [95]	220 / 65+ Years	One year of follow up with patients	Bathing, dressing, toileting, transferring, continence and feeding were considered in the study.	An on-going observational cohort study of older adult.	Screening tools that measure the functional assessment metrics show that older adults tend to have functional decline with functional assessment declination.
Vergara et al.[96]	577 / 65+ Year	Six months	Movement from wheelchair to bed and vice versa, transferring to and from the toilet, walking and stair movements.	An ongoing observational and follow-up process.	Patient health deteriorated once the scores for basic ADL for functional assessment increased to 90%.
Huisingh-Scheetz et al. [97]	2261 samples / 65+ years	5 Years	Movement and physical activities	Conducted survey and bio measure data collected from community-dwelling older adults.	Timed up and go, 3 minutes timed walk, repeated chair stands, self-reported physical activity via accelerometer. The highlighted functional assessment is critical to understanding FA in older adults.

Suijker et al. [98]	1025 / 75+ Years	1-2 years	Dressing, Toileting, and Movement.	Self-rated questions on the dependence of ADL.	Walking speed is a crucial FA measure. ADL measurement is among the multifactorial interventions needed for functional assessment.
Buurman et al. [99]	/ 65+ Years	48 hours	Movement and Sleeping.	Observational cohort study with a questionnaire.	Critical FA measures are mobility difficulties and sleeping disorder.

3.4 Outcome Variable Extracted from the SLR on FA Predictors

Having presented the extracted data from the SLR on FA predictors in Table 8, shown in Figure 3 is the number of articles that reported FA measures via ADL for the older adults in the researchers' investigation. As shown in Figure 4, measuring movement activity via walking was the most reported measure, with more than 25% of included studies using this metric. Other common measures were: toileting, bathing, dressing, and sleep quality. The frequency of these major activities contributes up to 75% of the entire reported activities. Such activities become unavoidable metrics towards the functional ability of older adults.

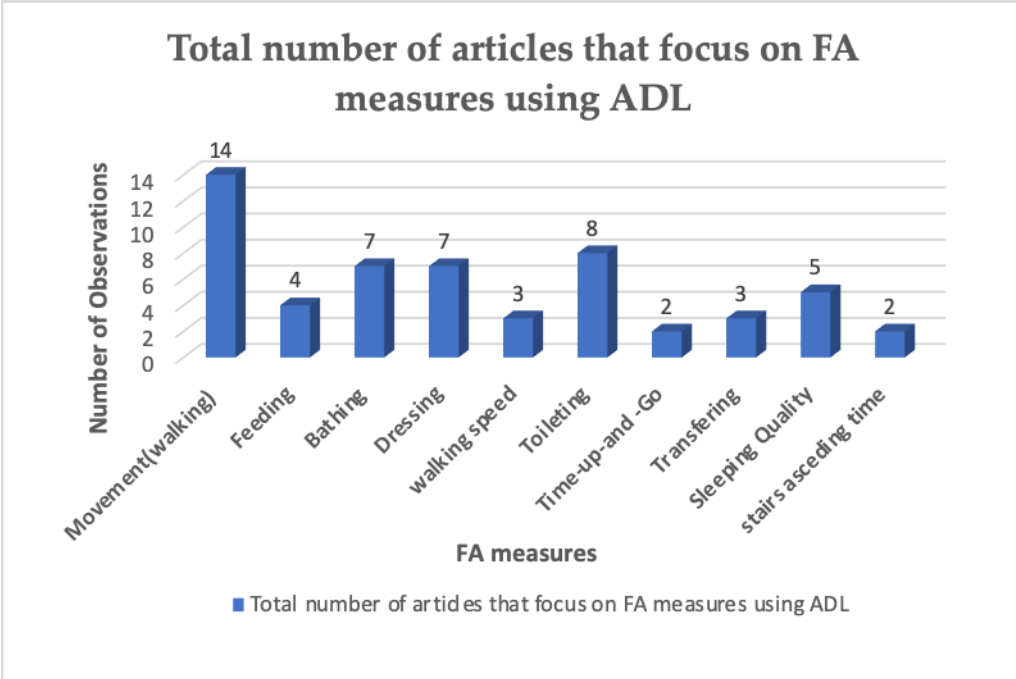

Figure 4: Total number of articles that focus on FA measures using ADL

3.5 Chapter Summary

This chapter described the research method used to perform the SLR on FA predictors. The SLR involved search strategies for extracting literature from the list of databases detailed in Table 6. Figure 3 presented a summarized overview of information extracted from various stages of our search using a PRISMA diagram. Table 7 provided the list of inclusion and exclusion criteria used to reduce the articles during the SLR process. The SLR on FA predictors cataloged the different FA measures based on ADL, and it addressed the first objective of this thesis stated in chapter one. Movement in terms of walking, toileting, bathing, dressing, and sleeping forms the major ADL used for FA in older adults. The most common measure in the included studies for FA assessing walking followed by bathing, toileting, and sleep quality, as summarized in Figure 4.

The FA measures, together with supporting information, were extracted and cataloged in Table 8. In conclusion, summarized frequency analysis on the cataloged FA measures in Table 8 were presented in Figure 4. This frequency data gave a quick view to addressing the first research question in this thesis, and the description was detailed in section 3.5.

CHAPTER 4: SLR ON CH ARCHITECTURES RESEARCH METHOD AND RESULTS

4.0. OBJECTIVE

An SLR on CH architectures was conducted based on the results of the SLR on FA predictors. The strategy behind such SLR activity was because we needed to extract those CH architectures articles that use some of the FA measures obtained from the SLR on FA predictors within their system design. The SLR on CH architectures considered different SEATS that used ADL in their investigation relating to automated FA. Such a computer-supported FA system can be used to support older adult FA.

The objective of this SLR was to provide up-to-date results from the published journal articles on various SEATS used for FA through ADL for older adults. Having read each of the article's title, abstract and full text, the SEATS used for the selected articles were extracted and cataloged.

4.1 LITERATURE SEARCH METHOD AND STRATEGY

4.1 Methods

In this section, the methods used during the SLR on CH architectures were described. The methods include database search, search strategy, inclusion and exclusion criteria, title, abstract, and full-text reading, including the data extraction.

4.1.1 Databases Searched

In consultation with the subject librarian in the health and information science department at the University of Victoria, the queried databases for the SLR on CH architecture were IEEE Xplore, Science Direct and Engineering Village.

The decision on these databases was driven by the fact that the databases focus on automated systems related to health management and other engineering-related researches. Engineering Village index breath of databases that were not indexed by IEEE Xplore [100] and vice versa [77]. Engineering Village and Science Direct were provided by Elsevier and Science Direct provided articles geared towards core science disciplines. Using these databases gave the SLR on CH architectures a robust search in several engineering literature.

The use of activities of daily living as a Medical Subject Headings (Mesh) was applied on IEEE Xplore and as a controlled term on the Engineering Village database in combination with other search keywords highlighted in Table 9. Using Mesh word, controlled term and some of the crafted search keywords helps to tailored the searches towards the research questions defined in this thesis [78].

4.1.2. Search Strategy / Terms Used

The search keywords were based on "AND" and "OR" including logical combinations of search strings such as "activities of daily living," "ADL," "comprehensive functional assessment," software architecture tactics", "software architecture styles" and 'connected health' as shown in Table 9. In addition to the search string, our searches were limited by date of article publication between 2000 and 2019 and only peer-reviewed journal articles with full text in English language were included in our search filters. These filtering techniques were applied during the screening of the relevant articles as shown in the screening section in Figure 5.

Table 9: Search Keywords for different Databases

S/N	Database	Search with Mesh and keywords
1	IEEE	("Mesh Terms": activities of daily living) AND comprehensive functional assessment) AND older adults) and ((((software architecture tactics) OR software architecture styles) AND connected health) AND comprehensive functional assessment) Filter by Journal.
2	Science Direct	"connected health" AND "functional assessment".
3	Engineering Village	(((((((Telehealth) WN CV)) OR ((connected health) WN All fields)) OR ((Medical Cyber-Physical System) WN All fields)) AND ((activities of daily living) WN All fields)) AND ((software architecture) WN All fields)).

4.1.3 Inclusion / Exclusion for initial and final screening

The filtering techniques were applied before the screening phases of the relevant articles as shown in the screening section in Figure 5. During the first screening, the results of the filtered articles were screened using the defined inclusion and exclusion criteria. The inclusion and the exclusion criteria were used to select appropriate articles from the numerous articles returned after the filtering activities. The initial screening was based on title and abstract while the final screening was based on the full-text of each of the articles. These screening activities were carried out after reading the title of the article, abstract and full-text using the criteria detailed in Table 10.

The inclusion criteria in the initial screening were based on articles that consider SEATS within the title or abstract while exclusion criteria focus on articles with chronic illness, cognitive impaired focused, general description of a technology in healthcare or articles that considered IADL or another type of assessment like nutritional, cultural or questionnaire-based assessment within the title or abstract.

In the final screening, the inclusion criteria include: articles with SEATS in the full text while the exclusion criteria for reducing the search results in the SLR on CH architectures were based on the following: “chronic illness patient”, “cognitive impaired”, “focus on other assessment like nutritional assessment”, “No FA measure being used” and “article with no SEATS description within its full text”.

Table 10: List of Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Availability of SEATS in the title, abstract or full-text.	a. Articles with no consideration on ADL or FA measure. b. Articles with consideration on chronic illness e.g. dementia, cancer c. Articles with consideration on cognitive impaired older adults. d. The articles that focus on another type of assessment e.g. nutritional or cultural or questionnaire-based assessment. e. General description of technology in healthcare. f. No discussion on software engineering patterns or tactics.

4.1.4 Title and Abstract Screening

The title and abstract for each of the obtained articles were read and screened using the inclusion and exclusion criteria defined in section 4.1.3 by a single reviewer. Besides, Parsifal tool provides ease of use functionality for the screening activities.

4.1.5 Full-Text Review

Having screened the titles and abstracts by two reviewers, the same inclusion and exclusion criteria described in section 4.1.3 were applied to the full-text for further eligibility selection. The full-texts of the resulted articles were read in order to extract various SEATS used in those articles. Notably, some articles were excluded after reading the full-text as shown in Figure 5.

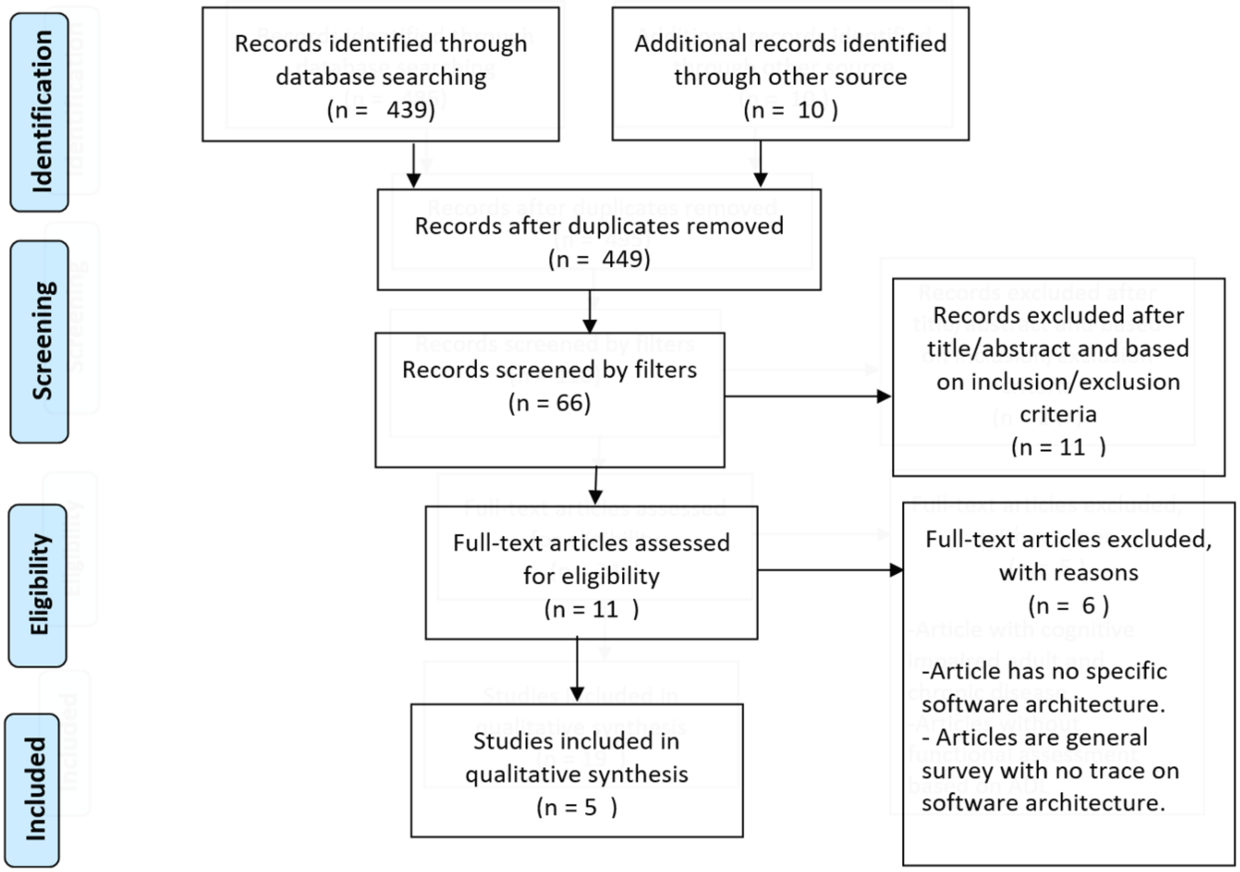

Figure 5: PRISMA Flow Diagram for SEATS in CH

4.1.6 Data Extraction Process and Quality

This section focused on the presentation of data extracted from articles obtained from the database listed in Table 9. After applying the search techniques inclusion and exclusion criteria, discussed in section 4.1.2 and 4.13 respectively, the resulted articles were read to extract the SEATS that were used in the articles and cataloged in section 4.3. Before the results elicitation, a quality assessment checklist on each of the obtained article was conducted as detailed in section 4.1.6.1.

4.1.6.1 Analysis Process for Quality

The quality of systematic literature review that was carried out in this thesis was assessed based on the Database of Abstracts of Reviews of Effects (DARE) [101]. The quality criteria were based on the following questions which include a "Yes", "No", "Maybe" or "Don't Know" answers. The criteria are:

- Is the research question clearly stated, including the objectives of the SLRs?
- Is there a clear description of the search method used to identify relevant studies?
- Is a comprehensive literature search conducted using more than one database?
- Is selection bias avoided within the study by explicitly defined the inclusion and exclusion criteria?
- Was there a duplicate study selection and data extraction by using multiple reviewers for study verification?
- Was the scientific quality of the included studies documented by showing the level of agreements among reviewers?
- Does the presented data support the mentioned conclusions?
- Is the conflict of interest stated by highlighting support received to aid the success of the systematic literature review?
- Is there any appropriate conclusion based on the extracted data from the included articles?

4.1.7 SLR Reviewer's Agreement on Full-text screening

Following Kappa Cohen description in section 2.6, including agreement and disagreement variables in Table 5, the required variables were obtained.

The variable "a" = 5 and variable "d" = 15. After the reviewed articles from the second reviewer, the value of "c" is 1 and "b" is 1. The total agreement is 18, and the total instance is 20

From equation (3.0), EFa = $\frac{(5+1)*(1+5)}{5+1+1+15} = 1.6363$

From equation (4.0), EFd =$\frac{(15+1)*(1+15)}{5+1+1+15} = 11.6363.$

From equation (2.0), agreement expected by chance = EFa +EFd = 1.6363 + 11.6363 = 13.2727.

From equation (1.0), Kappa coefficient (k) = $\frac{(18)-(13.2727)}{20-13.2727} = 0.7027$

Due to the result of the Kappa coefficient, which is 0.7027, we can conclude that there is a substantial agreement between the two independent reviewers in the SLR on CH architectures. This conclusion was based on Cohen Kappa analysis described in section 2.6.

Although, minimal articles were disagreed by the two reviewers, and the value of k was lower compared to the result of k obtained from section 3.1.7. This was due to the uneven distribution of included and excluded articles used during the review process. In the SLR on FA predictors, there are almost 50 by 50 percent for included and excluded articles used by the second reviewer but, in SLR on CH architectures, there are more excluded articles than the included articles used by the second reviewer. The justification for several excluded articles in this section was to support that several articles were excluded during the SLR process due to limited research on CH architectures that uses FA measures in their design or solution.

4.3 Results

Shown in Table 11 are the SEATS extracted from the SLR on CH architectures. This table shows the outcome of the SLR carried out using the methodology and strategy discussed in section 4.1. A total of four hundred and thirty-nine (439) articles were collected from the selected databases addressed in section 4.1.1 using the search strategy described in section 4.1.2 and the criteria discussed in section 4.1.3 including 10 articles from other sources. A total of 449 items were gathered. The final total number of articles was reduced to five (5) after the systematic application of the methods discussed in section 4.1. This vast reduction was due to the lack of articles in interdisciplinary research combining FA measures and SEATS. Reading through the 5 articles, the data were extracted and cataloged (shown in Table 11).

Table 11: Data Extraction for SEATS in CH

Author(s)	**FA Measures**	**Architectural Pattern (Style)**	**Architectural Qualities (Tactics)**
Helbostad et al. [102]	Physical activities such as exercise, walking, climbing stairs, and Timed up-and-Go	Deployment pattern	Usability: a. Provide user-friendliness interface for users. Availability: a. Exception prevention during data transfer within the cloud. Performance: a. Provide quick responses for the FA measures. Security: a. Confidentiality and Integrity of the data over communication infrastructure.
Zhang et al. [103]	a. Timed-up-and-go (TUG) b. Groningen activity restriction scale (GARS)	Pipe and Filter for data collection and analysis.	Performance: a. Resource efficiency of the sensor-based chair. b. Time-bound execution of the sensor-based chair for TUG during peak usage. c. Instant response time during GARS.
Alwan M. [104]	a. Movement Activity monitoring b. Sleep monitor	Publish-subscribe pattern.	Performance: a. Stable sensor measurement and distribution.

	c. Gait and Balance monitoring		
Arcelus et al. [105]	Aduration of a sit-to-stand (SiSt)	Deployment, pipe-and-filter.	Performance a. Provision of stable measurements during standing position and forward trunk lean position. b. Prioritize event responses with time synchronization.
Lowe et al. [106]	a. Energy expenditure b. Ascending and descending stairs and hills. c. Stepping d. Time active and sedentary	Deployment and used pattern.	Security a. Verified integrity of predictive results and measurements from the sensors. Availability a. Timely sensor measurement availability Performance a. Improved resource efficiency via low computational requirements.

4.4 Outcome Variable Extracted the SLR on CH Architectures

In Figure 6, performance, security, and availability shows a key concern in terms of Software Engineering Qualities needed for developing automated FA. These qualities have their corresponding tactics cataloged in Table 11. In the included articles for the SLR on CH architectures, each of those software qualities presented diverse SEATS in their research. These SEATS show things to be considered during the process of developing an FA automated system which can support effective FA of the older adults.

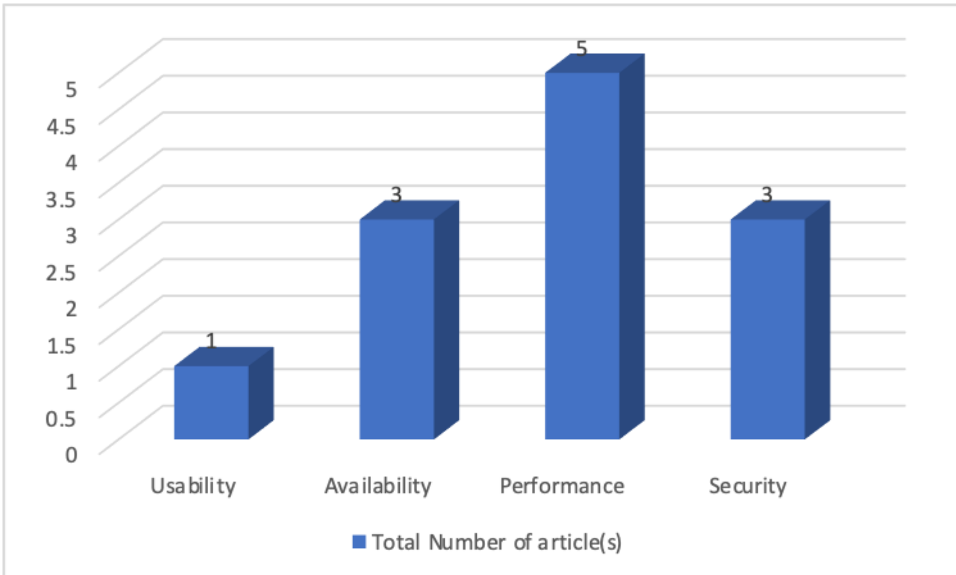

Figure 6: Total number of articles that focus on FA measures with consideration on Software Engineering Qualities

4.5 SLR on CH architectures Results Correlation with CH

As discussed in section 2.4, the CH architecture, the key focus for this architecture is the performance of the CH. Different investigator reports, collated in section 4.3 as the SLR on CH architectures results, show that performance is also an unavoidable Software Engineering quality in CH [58]. In this regard, there is a positive correlation between CH architecture and the results of the SLR on CH architectures. This performance software quality becomes the major focus in the industrial case study[0] discussed in Chapter 5. In addition, other qualities such as security and availability are other qualities to be considered within CH. The additional qualities are correlated with the reports of the SLR in section 4.3. Although security and availability are not considered in this thesis, they can be researched further in future study considering FA within CH.

4.6 Chapter Summary

In this chapter, the discussions were based on the results of the SLR on CH architectures. In this SLR, the catalog was based on the various SEATS used for FA of older adults, as shown in Table 11. The tactics were grouped based on software qualities such as performance, security, availability, and usability. Performance quality with instant response time and efficient resource management was the important tactics in the SLR on CH architectures. Figure 6 also shows the frequencies of references to these qualities by different investigators. The performance of an automated system to support FA within CH proves to be a key concern, and it should be considered during any automation of FA for the older adult.

CHAPTER 5: INDUSTRIAL CASE STUDY

5.0 Introduction

This section of this thesis benchmarks the evidence results obtained from the two SLRs. In the first review, FA measures through ADL were cataloged, as shown in Table 8, while Table 11 presented various FA SEATS focused articles. Focusing on the information extracted from both SLR, we conducted an industrial case study using two major FA measures: movement (walking) and sleeping quality activities. During the industrial case study with Tochtech Inc, the movement and sleeping activities were collected from Internet of Things (IoT) sensors installed at different locations of the old adult home. Based on the previously–discussed software quality, the performance was a key concern in the SLR on CH architectures. This software quality focuses on tactics such as resource efficiency and quick response time with low computational overhead highlighted in Table 11. Considering these tactics, we applied an architectural style that can support such tactics. We used a pipe-and-filter software engineering architectural style that enhanced performance by providing parallel processing of collected data and cached such data locally for future manipulation and processing.

During the industrial case study, the frequency of the activities was the major features and it was extracted from movement and sleeping ADL. These features include frequency of movement activities, frequency of going in and out of the toilet, including night time on and off the bed. These features were aggregated to form a pattern for the monitored old adult. A deviation from the regular pattern means the monitored person is not performing his or her ADL efficiently. The regular pattern was formed by collecting the ADL of the monitored person and it was used to train the anomaly-detection model. Although deviation from the normal ADL pattern does not correlate to the nonfunctional ability of the old adult, it raised concern for the service provider while conducting the industrial case study. If the deviation becomes repetitive beyond a certain threshold defined by the service provider, the service provider becomes more proactive and qualified for further investigation.

A Pipe-and-Filter software engineering architectural style was used during the data analysis of the extracted features from the selected ADL. The performance ability of Pipe-and-Filter architectural style [69] contributes to the data pre-processing of the extracted features efficiently. During the ADL data preprocessing phase, the features mentioned above were extracted for further processing by the models, as shown in Figure 7.

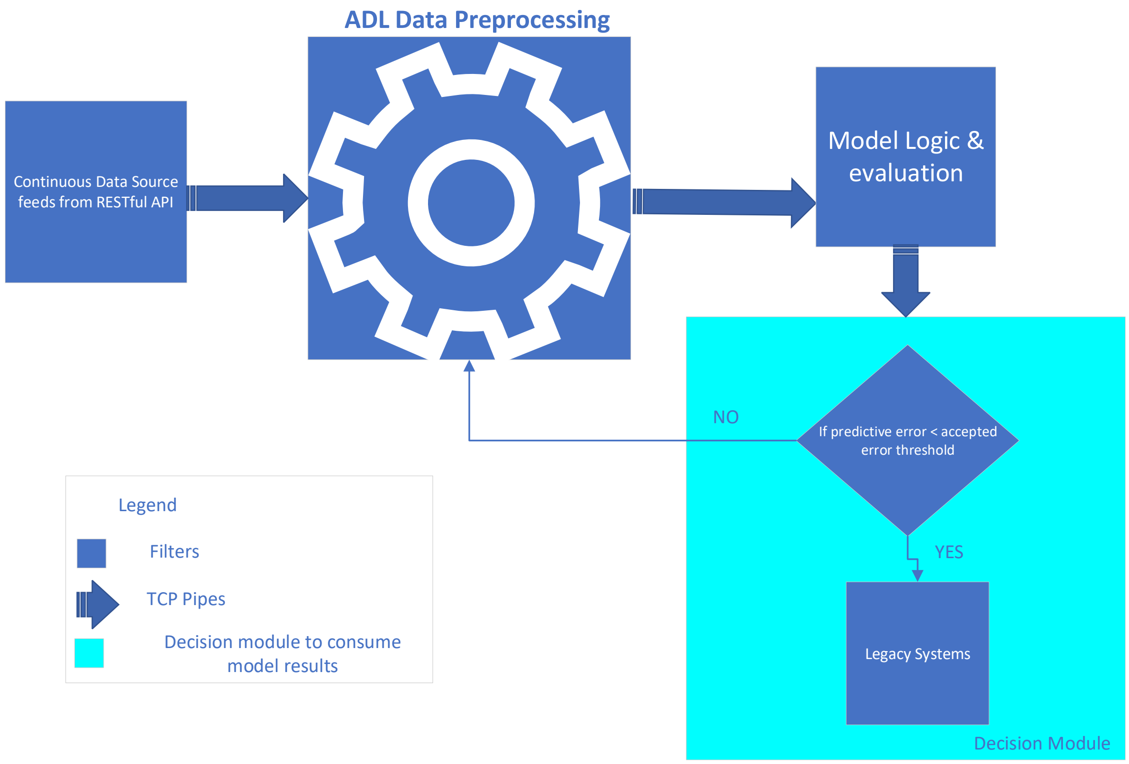

Figure 7: Pipe and Filter Software Engineering style for ADL

5.1 Continuous Data Source feeds

The data that was used for analysis resides in a remote repository, and the analysis was done in a controlled and secured environment. Due to the data residence on different systems, there is a need for continuous fetching of data from the source to the destination where it was processed. In Figure 7, the filter fetched the ADL dataset from the source repository through an implemented RESTful API, passed through the TCP pipe for further processing. The collected data entail movement activities, including the places where the movement activities occurred. The activities time stamp was also appended with the collected information. Data collected was saved locally to reduce the pre-processing and fetching waiting time. The parallelism properties of the pipe-and-filter software architecture style enhanced the continuous and parallel collection and processing of the ADL data from the source. This technique aided the performance of the pipe-and-filter architectural style used for the data preprocessing in the industrial case study. During the data processing phase, sleeping activity was the major focus. Although other activities such as movements were also considered, it was just on the frequencies of performing movement activity.

5.1.1 Sleep Analysis in Relation to Health

Sufficient sleeping has become an essential aspect of human health [7], and its detailed analysis in the industrial case study has helped to determine the sleeping activity metrics for the monitored person and the effect of inadequate sleep on the health status.

Measuring sleep health with a self-report scale is denoted by the acronym SATED having five dimensions. These dimensions are Satisfaction with sleep; Alertness during waking hours; Timing of sleep; Sleep Efficiency; and Sleep Duration [107]. In the industrial case study, a self-report scale for measuring sleep health via sleep dimensions was used. Shown in Table 12, all the sleep dimensions but Timing, efficiency, and duration of sleep were considered for the industrial case study computation analysis of sleeping activities using SATED[107]. The scale highlights the sleep dimensions with the corresponding measurement yardstick that was used for health deterioration computation. This scale uses a manual process of computing the sleeping health score. In order to use this scale, the healthcare assistance asked patient the questions highlighted in the measurement yardstick, and the obtained response determines whether measured results would be classified as seldom, occasional or always as shown in Table 12.

After conducting these questions, the entire sleep-scale value would be added together to determine the overall sleep-scale value. A low scale value corresponds to poor health, while high scale simply means that the patient health score in terms of sleeping is good. However, this value forms the key factor in the decision-making on the health deterioration of the patient in terms of sleeping activity.

Computationally, some of these dimensions can be addressed using the automation process implemented during the industrial case study. The considered dimensions were extracted from the cached dataset collected from the non-wearable sensors. These sensors were placed at different locations within the old adult house and they collected their ADL data. Collected data were manipulated to extract sleep timing, sleep efficiency and sleep duration before the sleep score was calculated. Based on the individual score value assigned to each sleep dimension, the cumulative sleep health score which can either increase or decrease after computation, depending on the sleeping behavior, of the monitored person.

Table 12: SATED Scale Sleep Dimensions

Sleep Dimensions	Measurement Yardsticks	Scale Values		
		Seldom	Occasional	Always
Satisfactory	Are you satisfied with your sleep?	0	1	2
Alertness	Do you stay awake all day without dozing?	0	1	2
Timing*	Are you asleep or trying to sleep at night?	0	1	2
Efficiency*	Do you spend less than 30 minutes awake at night?	0	1	2
Duration*	Did you sleep between 6 and 8 hours per day?	0	1	2

Computationally, during the industrial case study, sleep timing and duration were considered for the data extraction of daily sleeping activity. Considering these types of sleep dimensions, the question based on how many minutes does the monitored person sleep at night was asked. This question is a combination of sleep timing and duration from SATED scale and was addressed in section 5.2c.

Based on the current state of non-intrusive sensors used during the industrial case study, we can only compute the sleep timing, sleep efficiency, and durations based on the assumption that the monitored person is sleeping while in bed. Though this was an assumption during computational development, it is not always the same in real life where we usually have differences between the time in bed and the actual sleep time.

Nevertheless, we can afford to work on this assumption since we have more than one metric that will determine the possible health risk.

To the best of the researchers' knowledge from different references [7], [17], [107], sleep duration was very critical to be considered in the industrial case study. This decision was based on the different sleep duration classifications research carried out by the National Sleep Foundation (NSF) research with contributions from more than fifteen (15) medical doctors and faculties in the United States of America [17]. The data shown in Table 13 was adapted from NSF research report on sleep duration for different age groups.

Table 13: Sleep Duration for Elders

Adult Age	**Recommended (Hrs)**	**Also Appropriate (Hrs)**	**Not Recommended (Hrs)**
26– 64	7 – 9	6 – 10	<6 &> 10
≥ 65	7 – 8	5 – 6, 9	< 5 &> 9

Following the values shown in Table 13, the industrial case study considered the recommended number of sleeping hours for the old adult of sixty-five (65) years and above during the computational analysis to extract the sleep timing and sleep duration.

5.2 ADL Data Pre-processing

The activities in this section involve extracting timed movement activities within the home, toileting visitation activities as well as on and off bed activities. The time used on each of these activities was extracted and reshaped into a time-series format. The time-series pre-processed data were fed into the Model Logic and evaluation filter for activity pattern discovery, including future activity prediction.

5.2a Computational Analysis of Daily Movement Activity

Extracting movement activities require the ADL pre-processing module to extract the movement carried out by the old adult within a day, and we also fetched the data that show different places the person had visited. The number of places visited by the monitored person within the house was extracted at different time intervals. Over time, the movement activities form a pattern, and any deviation from such patterns was flagged and reported to the monitoring unit. The logic that manages the interaction between the movement activities and the pattern deviation was built in the model logic.

5.2b Computational Analysis of Daily Toileting Activity

Concerning the toileting activity, we consider the frequency of going to the toilet within a day. This toileting frequency activity extracted from the entire dataset forms a pattern for the monitored person over time. The toileting activity was flagged once the current activity deviated from the previous known pattern.

5.2c Computational Analysis of Daily Sleeping Activity

Extracting the night sleeping duration was the primary focus in the industrial case study. We developed an algorithm that extracted the night time sleeping duration and collated the different times in and out of bed that was done in the night sleeping session. Shown in Figure 8 is the daily sleeping scale evaluation scale that was developed during the industrial case study. This depicts the sleeping period that was considered. From left to right in Figure 8, it indicates hour zero of the current day and hour 10 for the next day. Since we are considering a nighttime sleep, we can decide to start at hour 20, which is 8:00 p.m. to 10:00 a.m. the next day. The sleeping session is a variable and can be adjusted by the developed algorithm. Within the night sleep session, the various sections on the timeline scale correspond to the activity that can be performed. A typical activity is the "off bed" but the real sleeping session was represented with x1, x2, and x3. The monitored person might wake up in-between night sleep session and this was denoted as "No sleep session". For the daily nighttime sleep, the sleep duration of x1, x2, and x3 were added to form the total nighttime sleeping time for that day. This computational process continues until the daily sleeping activity of the entire dataset for the given period was extracted. The result of this extraction forms a time series for daily nighttime sleep. These times series results were passed into a Long Short Term Memory (LSTM) predictive model to predict the future sleeping duration.

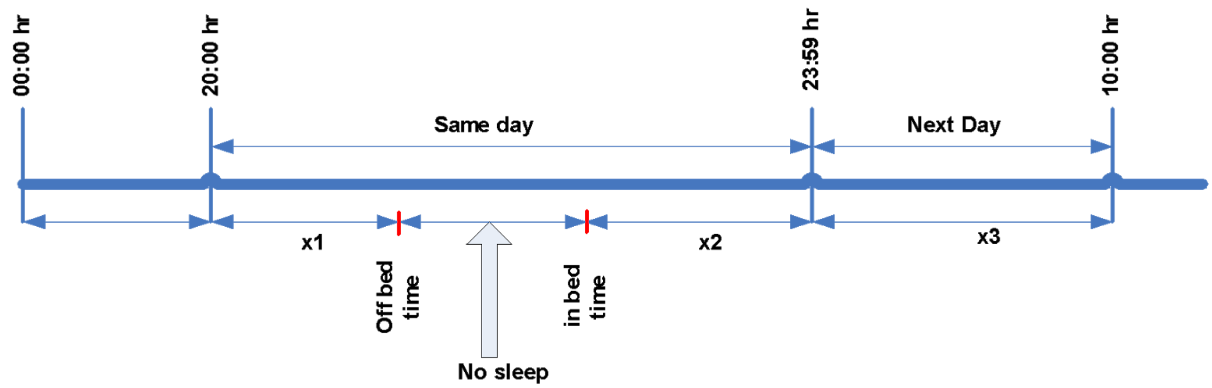

Figure 8: Daily Sleeping Extraction Scale

5.3 Model Logic and Evaluation

The model logic used a Long-Term Short Memory (LSTM), a variant of deep-learning algorithm, to predict the future activity and an Ordinary Least Square(OLS) model was used for anomaly-detection model [33]. Each of the activity pre-processed, discussed in section 5.5.2 A and B were fed into the LSTM model for future activity prediction. Concerning the anomaly detection, OLS manages any deviation from the known in-house movement, toilet movement, and sleep time activities. The future and deviation activity were reported to the system custodian through the Model decision module.

It is noteworthy however, that the detailed description of LSTM for future activity prediction and OLS for anomaly detection is beyond the scope of this thesis.

5.4 Proposed Overview Framework for Computational Analysis

The framework overview shows the high-level operations starting from the data collected from the sensors to the prediction phase. Sensors data were collected through the developed RESTful API shown in Figure 9. This API enhanced continuous data collection into the data wrangling and splitting section. The data wrangling and splitting section perform the ADL data preprocessing by reproducing a time series data for the collected sensors dataset. The wrangled data was fed into the predictive model for prediction and anomaly detection. Whenever there was a deviation from the usual ADL partner, the anomaly detection model sent a notification to the decision module for further analysis. A typical anomaly detection signal for a month dataset was presented in Figure 10 and Figure 11. In these figures, a typical question on the frequency of waking up in-between sleep within the month of June 2017 was considered and sleep activity detail analysis was explained in section 5.2C.

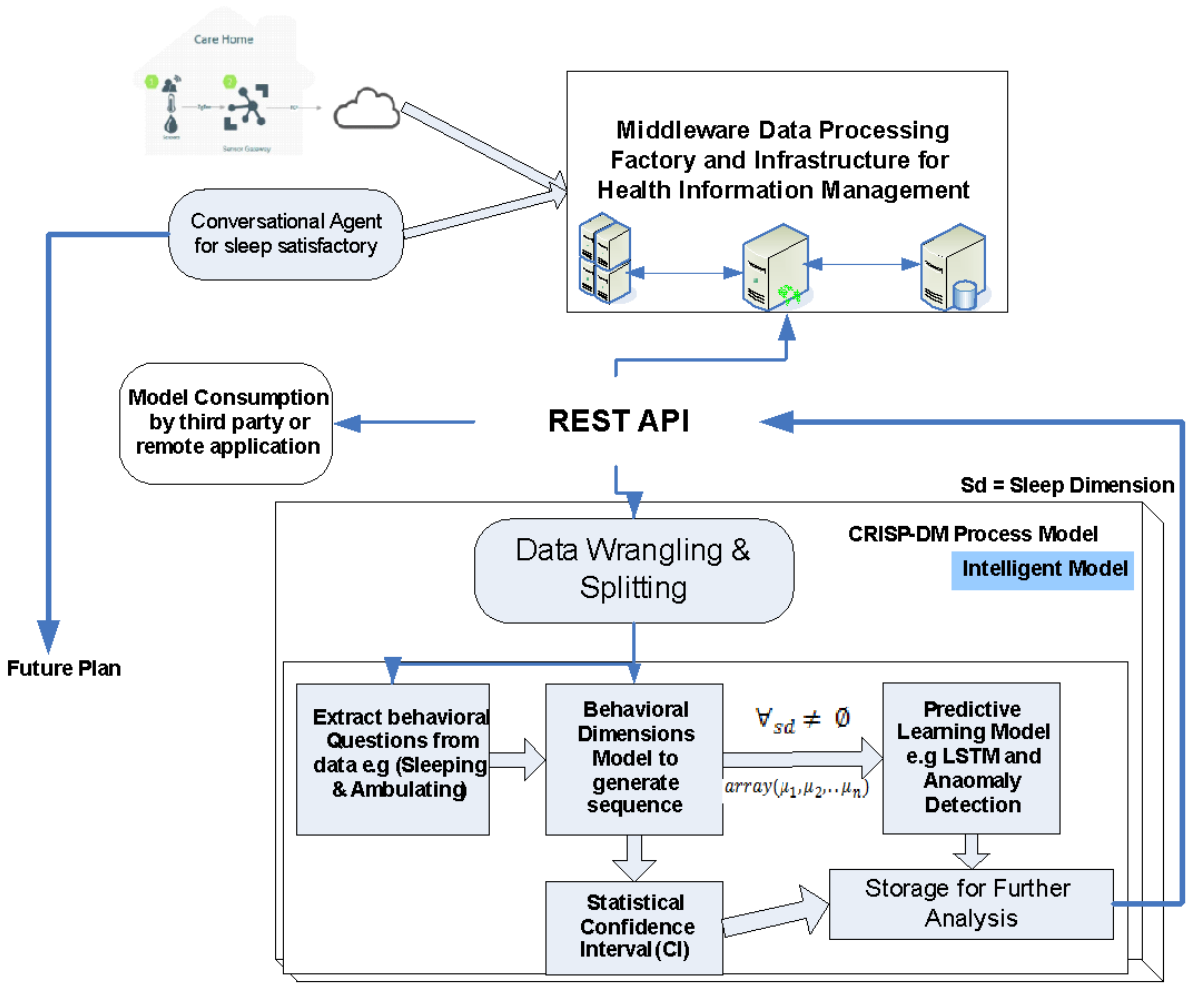

Figure 9: ADL Predictive Framework Overview

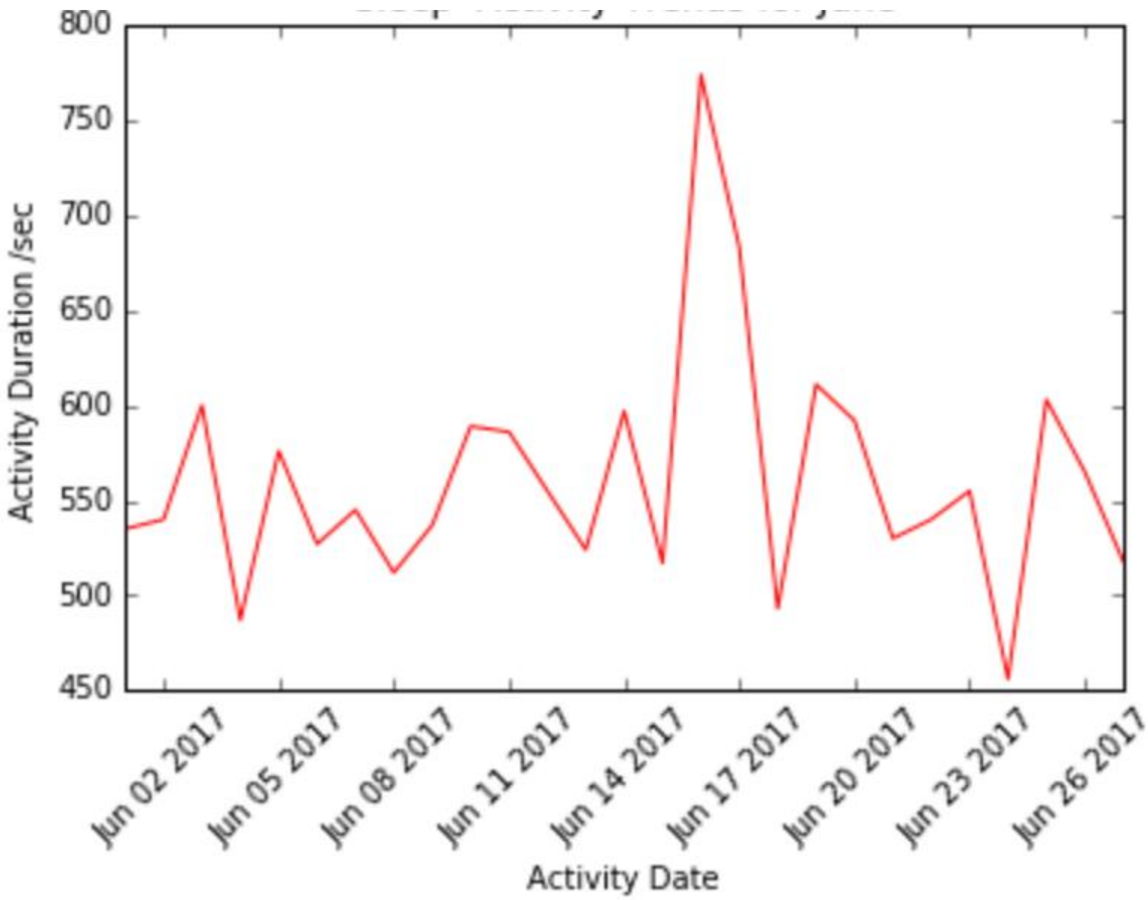

Figure 10: Sleep Activity Trend for One Month

It was deduced that the sleeping activity time between 2nd of June, 2017 and 14th of June 2017 revolved around an average of 540 seconds which is nine hours. Suddenly, around June 17th of the same year, the sleeping activity duration increased to 770 seconds. This was a deviation from the usual sleeping pattern of the monitored person. The anomaly detection model picked this abnormality and notified the decision model to take action. The deviation from the usual pattern became more remarkable whenever consideration was given to the frequency of waking up at night time for the same month that was considered in the analysis as shown in Figures 10 and 11.

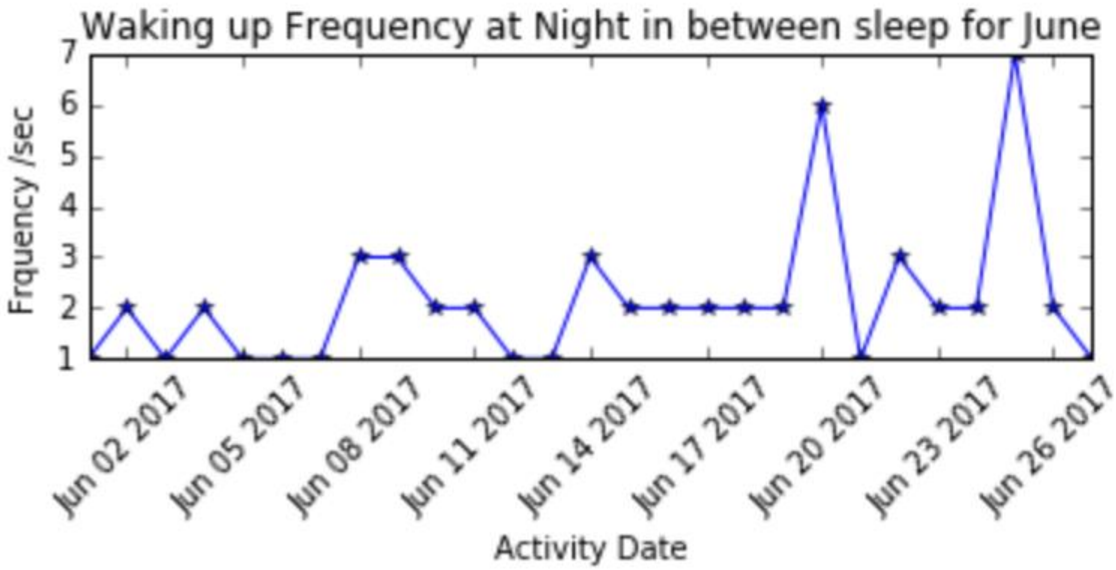

Figure 11: Waking up Frequency at Night in-between Sleep for One Month

Between June 17th and June 20th in Figure 11, there was a noticeable increase in the frequency of waking up in-between sleep in the nighttime for the month. During the industrial case study, it was realized that, during the period the monitored person had a distinct increase in the frequency of waking up at night within sleep time, they tended to have unstable health during the day. When such visible activity frequency continues, as we can see between June 17th and June 20th, including June 23rd and June 26th, the health of the monitored person in terms of sleeping activities became more challenging. Such apparent changes were detected and notified early before the situation got worse, and the supervised person had to be taken to emergency care in the hospital.

5.5 SLRs and Industrial Case Study Interaction

Having conducted a CH-driven SLR that extracted the SEATS used for CH component design, the SLR based on CH architectures considered the FA measures during the article inclusion process. The included articles in such CH-driven SLR used the FA measures displayed in Figure 4 during the article selection, which made the two SLRs dependent on each other. The CH-based SLR highlighted performance as a critical software quality that focuses on resource efficiency and quick response time with low computational overhead as tactics. The SLR on CH architectures also presented a pipe and filtered architectural style that can aid the performance tactics concern within the CH. The resource efficiency was due to the separation of computational processes during the pipe and filter activities on the data collected from the sensors. Due to the separation of activities, each activity can process its task quickly before passing its result to the next task for further processing. In this regard, we have used pipe and filter architectural style described in section 2.5.2 and 5.0 to aid performance tactics in the industrial case study described in this chapter.

5.6 Chapter Summary

In this chapter, the discussion was based on the tasks and results of the industrial case study. The industrial case study benchmarked on the results of two SLRs documented in chapters 3 and 4. The current chapter explained the processes involved in the computational analysis of the ADL dataset provided by the industry partner for the industrial case study. The data set went through the process of data transformation to extract the essential features needed for prediction and anomaly detection. The computational engine applied the pipe-and-filter architecture style detailed in chapter 2, and such an architectural style aided the performance of the computational analysis. In conclusion, this chapter provided an analytical view of patient activities via ADL. The visualization of the monitored person activity provided an instant view of ongoing features that were extracted for the computational analysis and enhanced quick decision making.

CHAPTER 6: CONCLUSION

6.1 RESEARCH SUMMARY

This research was conducted principally to examine the FA measures via ADL and the SEATS that use some of the ADL in designing a computer-supported FA system. The research went further to investigate some of the extracted FA measures using one of the SEATS. The methods and results of two SLRs were described in chapters 3 and 4. In chapter 5, the description of the industrial case study was done. The case study project was based on the design of a predictive and anomaly-detection model that combines the extracted FA measures with the SEATS used by CH. When the SLRs were conducted, the aim was to extract evidence from different existing studies on the FA and SEATS through ADL of older adults. The obtained evidence was considered during feature extraction in the industrial case study. The aim of the industrial case study was to ensure that there is an early prediction of the older adults' activity based on their historical activities, and this was evident by the product produced by Tochtech Inc. [108]. Conducting the two SLRs and the industrial case study that provides an avenue to utilize the information extracted from the two SLRs, the obtained results will support the development of computer-supported FA for older adults. The computer-supported FA will be used to support the clinicians during FA for the focused age group. Such computer-based FA will also promote a proactive measure towards older adult FA management.

The SLR on FA predictors was based on extracting FA measures through ADL carried out by the older adults, and the strategies for conducting the SLR was detailed in chapter 3. In the SLR on CH architectures, the focus of this thesis was on the various types of SEATS used by similar studies but referenced the use of older adults ADL in their study. The result of the two studies was combined and formed a basis for the design and implementation carried out during the industrial case study.

Overall, the extracted FA measures in the SLR on FA predictors and the SEATS in the SLR on CH architectures which were used during the industrial case study for computer-supported FA gave practical evidence that the extracted features such as frequency of movement and sleeping time measure contributed to active FA in older adults. This implies that these measures will enhance a predictive FA within a computer-supported FA and such a tool can be used to support the clinician during FA of older adults. One could see from the distribution statistics of the extracted FA measures and the SEAT in Figure 4 and Figure 6 respectively, the key concern of the previous studies from the literature obtained during the SLRs.

Notably, despite the focus of the industrial case study in this thesis which is on movement (walking) and sleeping quality FA measures, FA is also affected by other measures such as walking speed, time-up-and-go, and staircase ascending time highlighted in Figure 4. These measures also contribute to the FA of older adults. Conducting an additional industrial case study that uses some of the other FA measures highlighted in chapter 3, will contribute towards future research.

Also, an evaluation of the FA measure considered in this thesis can be a step further to future research on FA measure for older adults. Moreover, other software qualities such as security or availability are of critical concern in CH and developing a computer-supported FA that will eventually expand CH. As well, consideration should be given to some of the SEATS mentioned above in terms of security and availability.

6.2 RESOLUTION TO RESEARCH QUESTIONS

In this chapter, various questions asked in section 1.4 were addressed by conducting two SLRs discussed in Chapter 3 and 4 with supportive evidence via the industrial case study explained in chapter 5. The first question was addressed with the SLR on FA predictors, while the second and the third questions were addressed by conducting the SLR on CH architectures. The fourth question was addressed by describing some of the FA measures and SEATS used in the industrial case study discussed in chapter 5.

In conclusion, conducting an industrial case study gave a good insight into the extracted FA measures discussed in Chapter 3, and the SEAT on CH performed in chapter 4. The analysis and design using the movement and sleep quality activities aided a computer-supported FA assessment and could be used to reinforce the state-of-the-art manual FA currently used by clinicians for older adults FA.

6.3 RECOMMENDATION

The main goal of this thesis is to collate different FA measures that have been used by various researchers and analyze some of the collated FA measures for the computer-supported FA to strengthen state-of-the-art FA of older adults. While working on this thesis, the observation was based on FA measures that were frequently used and studied by other researchers. Those FA measures provided an evidence source that supported the industrial case study on the selection of effective FA measures for the computational analysis. Describing the computer-supported FA design that used two (2) of the most frequently-used FA measures with time slot extraction of the activities described in section 5.2c was an immense contribution.

The industrial case study has some practical implications for older adult FA by supporting the state-of-the-art FA through the predictive ability of the future FA measures and deviation from the known ADL patterns.

6.4 LIMITATIONS AND FUTURE WORK

This study focused on published literature. There is likely considerable additional knowledge in this area that is in the grey literature. Further, as a new area with rapidly changing connected devices, new data types and data sets are likely being collected and are either not yet published or held within company datasets. Further, this study did not go into the analysis of which measures were best suited for connected health measurement or which are most predictive, only which have been more frequently used.

In summary, future research might focus on analyzing additional FA measures besides the one described in this thesis and providing an open-source algorithm based on the description in this thesis. Such consideration will bring further openness to the research community, especially towards computer-supported FA, to buttress state-of-the-art FA for older adults.

It will be valuable to consider security and availability software quality, including some of the SEATS discussed in this thesis.

In addition, using the FA measures in a non-independent senior home will be a step towards further study in CH. The researcher could collect the images of the occupants living in the shared custody and provide a useful classification through image recognition analysis. Such contribution can identify each person activities when combined with the result of this thesis but individual privacy as a security tactic for the people within the senior home becomes a key concern and this quality will provide a more robust computer-supported FA for older adults.

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