Assistive IoT-centric Robotics for Senior Living

Zenon Chaczko[1] Christopher Chiu[2], Grzegorz Borowik[3] and Robin Braun[4]

***Abstract*— Senior citizens consider the most significant part of aging to be the changes that occur to their bodies. For this reason, they avoid doing body exercises and therefore often prone to heart diseases, muscle disorders and many other ailments. Although weakening of bones and muscles is inevitable as we grow old, we can still maintain our health by doing regular physical exercise. Encouraging elderly people to do physical exercise can be challenging, therefore the Robot-Trainer is introduced to make their exercising journey exciting accompanied by a friendly humanoid robot. The main goal of the system is to program an IoT-Assistive Robot to interact and conduct physical exercise training sessions with elderly people and maintain their physical fitness and mental health.**

Keywords—IoT, Robotics, Aged Care, Physical Health Training, Predictive Analytics, Health Care Infrastructure

I. Introduction

The aim of this project is to ensure and assist elderly people to maintain a healthy body, preventing diseases such as heart attacks, arthritis, and osteoporosis. The human body experiences such change as they grow old. These changes include weakening of bones and lowering of immunity to fight diseases which makes them feel lazy and avoid doing physical exercise. This project introduces a friendly, IoT enabled humanoid robot which will encourage elderly people to engage in doing physical exercise sessions for better physical and mental health maintenance.

The real scenario taken into consideration for this project is an old age home where several aged people live and therefore a robot training session can be conducted in real. It is a common thought that appears in the minds of individuals in this world that life becomes easier as we grow old. People anticipate retirement as relaxation period where there is less working stress [5, 9]. It is true that some elderly people find the golden years to be the best years of their life, but there are still challenges that are universal and others specific to this age group that are faced by elderly people.

In this system, attendees at the training facility will be able to register as new members and will be able to keep track of their weekly/monthly/yearly attendance through a client application. Collected data can be stored in the cloud real-time database for keeping track of attendees and future analytics purpose. Predictive Analytics conducted in the cloud database will be able to provide exercising statistics for each elderly person attending the training. It will also be tracking how many people attend the sessions on daily basis, so the system can be further improved.

II. Platform Objectives

A. Overview

The challenges faced by elderly people included: loneliness, lack of motivation to do physical exercise, age related memory loss, being prone to numerous diseases and physical aging and health care costs [1, 2, 8]. These challenges affect their physical and mental wellbeing therefore, it is important for us to come up with a solution that will assist elderly generation to overcome the most of these listed challenges and live their life in a much better way.

B. Objective

The main objective of this research project is to create a scalable android application system which enables communication between different IoT devices such as sensors, applications, and databases, and trialing its effectiveness on senior citizens. These objectives include the following components:

- Designing an Information Technology System solution for the identified problem,
- Research and select a suitable cloud database to manage system information,
- Research and select applicable Application Programming Interfaces (APIs) to be used in this system,
- Develop an application to be installed in the robot and used as required in this project, and
- Develop another Android mobile application solution (Robot-Identifier) to uniquely identify robots and their owners using Near-Field Communication (NFC) tags.

C. Purpose

The main purpose of this system is to interact with elderly people and enable exercise training sessions to be run between robot and elderly people. It also provides other interactive functionalities to be used by elderly people to make them socially active. The other mobile application, robot-identifier is specially made for medical administrators, installed in their mobile devices, which will help them uniquely identify robots.

D. Solution

The end-to-end solution of the research project consists of two applications developed with different purpose within the system.

- The first application is called Robot-Trainer-Application, installed on the robot to be utilized by users, and
- The second application is the Robot-Identifier installed on an android phone used by the administrator to uniquely identify robots and people the robot is assigned to.

The robot-trainer-application is connected to a real time cloud database called Firebase which assists storing and retrieving data. It is also connected to different robotic sensors and motors including the camera for multiple functionalities. External APIs been integrated with the application for future extensibility and feature enhancements to improve the

[1]School of Electrical and Data Engineering, University of Technology Sydney, Australia. Zenon.Chaczko@uts.edu.au
[2]School of Electrical and Data Engineering, University of Technology Sydney, Australia. Christopher.C.Chiu@alumni.uts.edu.au
[3]Department of Computer Science, University of Social Sciences and Humanities, Warsaw, Poland; gborowik@swps.edu.pl
[4] School of Electrical and Data Engineering, University of Technology Sydney, Australia. robin.braun@uts.edu.au

usability of the IoT-enabled robot. On the other hand, the robot-identifier application scans an NFC tag and allows

Fig. 1. Main Features of iPal Humanoid Robot [3]

E. Existing Solutions

As part of the research project, an evaluation of current robotic technologies has been conducted to determine the strengths and weaknesses of existing solutions:

1) NAO the Humanoid Robot

NAO is used as an exercise trainer in senior living community called Golden Oaks in Oklahoma, USA. The reason behind introducing the robot was to study if humanoid robots were acceptable in the elderly peoples' community. NAO can interact and communicate with people and conduct exercise workshops with them. C++ and Python are the main programming languages used to develop on this robot. The main difficulty faced by researchers in this project was to predict the users' motivation to relate and engage with the robot [12]. They experienced that each time a workshop was conducted, they noticed changes in number of attendees which made it difficult for them to analyze the project's success. It is a small robot but has the capabilities to interact and conduct exercise sessions with elderly people. It is good at engaging and communicating as well [7].

2) The Hobbit Robot

To build motivation within elderly people to engage and participate in physical exercises, an application was programmed and installed into Hobbit robot with the aim of conducting physical exercise sessions. The authors have mentioned that one of the most crucial facts to be considered while dealing with elderly people is their physical and mental health. The reason to why they encourage people to engage in physical exercise activities is to avoid diseases such as dementia and depression. It is true that travelling is difficult for elderly people therefore, this robot is used to help them exercise at home in a comfortable environment. The application is installed on the hobbit robot and run to conduct exercise sessions with senior citizens. Hobbit robots perform simple exercise workshops, allowing elderly people to imitate them and follow as instructed [7].

3) Robotic Fitness Coach

This is another small humanoid robot created and developed to run physical exercise sessions with elderly people. It is introduced especially for homes to allow elderly people have healthier life in convenience of their homes. This robot can learn various exercising moves from human trainers and assist with explaining and conducting routines with people. It contains an advanced RGB depth camera vision that can monitor a person's moves and provide feedback on how well he or she does the exercise. It monitors movements that occur in the human's body in front of it [2].

4) Kengoro the Humanoid Robot

A team of researchers by University of Tokyo, Japan created a humanoid robot called Kengoro that can do push-ups, crunches and advanced stretches and conduct exercise sessions with humans. It can also play games like badminton and its body structure resembles completely like a human. Its features include 100 motors in its joints replicating the human skeletal and muscular form. Although, its capabilities are advance and able to perform hard exercise moves, it can still be used as a physical trainer for elderly people with simple exercises. Its best quality is that it is a humanoid robot with majority resemblance to a normal human being [10, 11].

III. PLATFORM DEVELOPMENT

The platform has been designed by identifying and determining relevant user requirements for the system. This system is considered to have the primary users: the elderly people and system administrators.

A. User Profiles

1) Elderly Person

Elderly person would simply be considered as a 'general user' of this system. A general user can access almost all features in the robot-trainer-application installed on robot. Besides using this application, they will not be able to access the cloud database or given access to use the robot-identifier application.

2) System Administrator

A system administrator would simply be considered as an 'administrator' user and would have full access to the system functionalities. He/she can use both robot-trainer-application and robot-identifier-application without being restricted. Furthermore, this user gets access to the cloud database, mail account and can edit details written on the NFC tag.

B. User Requirements

Requirements for this project is grouped in two categories, user requirements and system requirements [4].

1) System Context

The contextual diagram is depicted in Figure 2. It represents all major entities and their interaction with other entities including interaction with the cloud database, external cloud-centric APIs, and sensors. This system is further split into minor modules that have distinct requirements, development, and testing for each component.

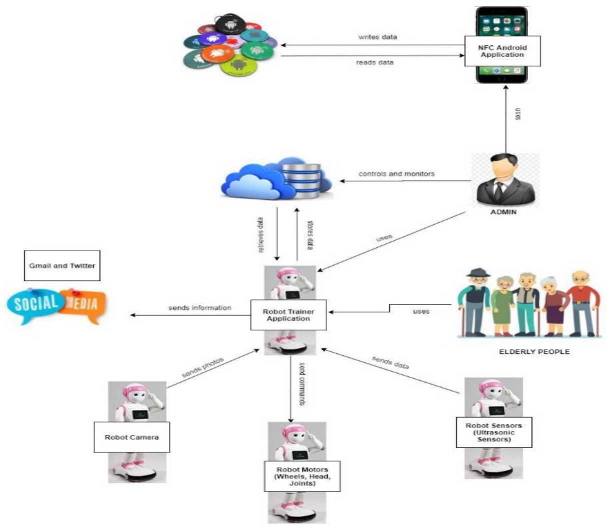

Fig. 2. Contextual Diagram of Senior Living IoT Platform

2) *Conceptual Design*

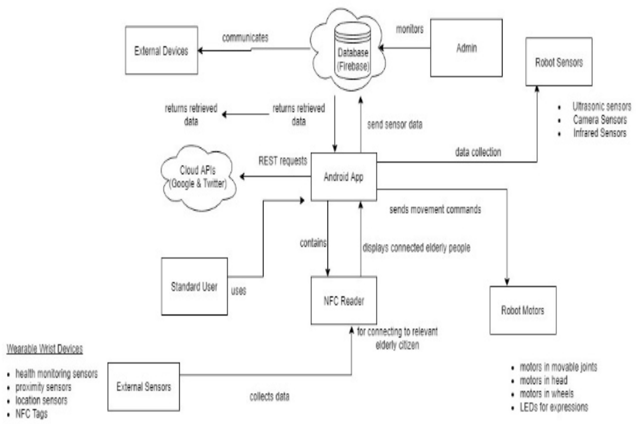

Fig. 3. Conceptual Architecture Diagram of Senior Living IoT Platform

The main concepts are categorized into two parts, which are the stakeholders and the objects. Stakeholders include the administrator, standard users (elderly people), and database administrators. The main object concepts include mobile scanning devices, NFC readers, assistive robot, and cloud database. The architecture also depicts the relationships between these main concepts and entities of the system. For example, both the administrator and the standard users can access the system through their own interfaces with different level of privileges. The administrator has access to the cloud database that shows historical data with various statistics.

The core application is the main component of this system, which is connected to all the robot sensors, robot motors, and the cloud services (APIs). Its main function is to facilitate communication between these entities. The cloud database team is the one that would be responsible for data storage and backup. It would also be responsible of running all the analysis on the data collected. After each session, administrators can generate reports on various statistics related to a specific training session from the cloud database interface.

All these conceptual architecture aspects are captured in Figure 3. As there are secondary stakeholders related to the client application such as the health experts who provide support and advice when required. The families of the elderly people who are concerned about their relative's health and the impact of the training sessions on their bodies and mind.

3) *System Implementation*

The aim of the implementation architecture is to identify the main processes of the system and the main information flows between the system. The architecture clearly depicts the processes which are independent of each other and processes that should be run together within the system [6]. This perspective captures the dynamics of the system and show how the system behaves, is controlled, and how its components move around the system working in conjunction. The architecture examines the output of each component and information flow between the main components. It utilizes all the narratives to present an expected outlook of the system.

There are three main types of components identified which include active components, service components and user-initiated components. User initiated components depend on an input from the user for an action to take place. These mainly relate to concurrent processes. On the other hand, active components are the ones that continuously loop and monitor a process before an event is triggered. These work in real time

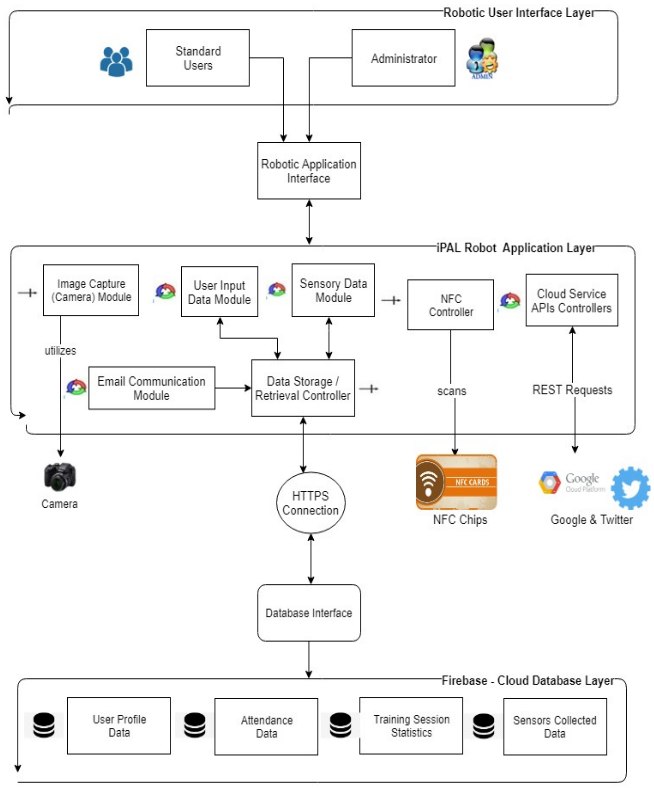

Fig. 4. Implementation Diagram of Senior Living IoT Platform

and initiate other concurrent processes which proves that the architecture is reliable.

The architecture keeps the interface for the administrator and standard users separate as different stakeholders related to the system will have their own interests and certain approach towards the system. For example, requirements from the secondary stakeholders such as the health experts and the relatives of the elderly people where neglected. These could be added later within the system but at the current state the architecture should be as simple as possible and not very ambitious, as shown in Figure 4:

a) Core Platform Components

The core platform components need to consider the main concerns of performance, security, and reliability, and these could be achieved when the main components are kept as separate as possible to have more control over the system.

Thus, the implementation architecture above is well defined and well depicted as supported with the following core components.

- **Robot Trainer Application** – This application is installed on the robot to be applicable for the main purpose of this project. It allows new member registration, existing member confirmation, various exercise sessions to be conducted on the robot, sharing user experience and moment on social media websites, providing diet suggestions to users, and allowing the users to interact and play with different robotic features such as motors, wheels, head, and emoji,
- **Robot Identifier Application** – This application is installed on mobile devices specially developed for administrator purposes. It allows writing data to NFC tag and reading data from it. This will help them to uniquely identify robots and their owners by scanning the NFC tag on the robot with the Robot Identifier Application,
- **Firebase Cloud Database** – Firebase is a real time database hosted in the cloud that allows storing and retrieving data to the client application. In this system, user registration information is stored on firebase cloud database and data is retrieved when confirming if the user is already registered or not,
- **Social Media Connection** – The robot trainer application interacts with Gmail and Twitter public APIs on the internet. Gmail API is used to allow immediate communication between elderly person and administrator through the robotic interface and Twitter API is used to connect and allow elderly people to be socially active by sharing photos and moments on Twitter from the robotic interface,
- **Robotic Sensors** – The robot has infrared and ultrasonic sensors used for object detection. These sensors help the robot to not collide over object. In other words, it detects objects and avoids collision with them. In addition, they have five touch sensors on their skin. These sensors notify them of being touched and react responsively to allow a human feel and interaction with the end-user,
- **Robotic Motors** – The robot has motors on their neck, arms (shoulder, elbow, wrist, and fingers), wheels and head. Motors are used for body movements considering angle or distance in which the part should move accordingly,
- **Robotic Camera** – The robot has 1.3 Megapixel camera in their eyes. The camera can be accessed normally as other android devices and used for various functionalities in the project, and
- **NFC Tags** – NFC means Near Field Communication. NFC allows wireless communication and exchange of data between different devices over a short range of about 10cm distance. In this project, Robot-Identifier application is developed to read and write data on the NFC tagDevelop solution (Robot-Identifier) to identify devices and their respective owners using NFC tags.

b) Training Platform Enhancements

The training module focuses on individual and groups trainings of all sorts that include aerobics, yoga, Zumba, and robot specific training sessions. The 24 /7 support module will focus on communicating with our health experts' team and allowing information and data exchange to be facilitated between the robot and experts. Robotic sensors module will be hardware specific as it will control all the main sensors and motors linked to the system.

The Cloud API module will focus in communicating to the cloud through securely encrypted API requests. The robot would be able to exchange information and data with Google and Twitter APIs to meet usability requirements for the system. The NFC module will be used occasionally but would focus on reading NFC cards that help determine the identity of an individual robot.

In summary, the architecture was reviewed to capture all the non-functional requirements of the system which include security, performance, modifiability, and scalability. The architecture also shows the major constraints related to the system and the future enhancements that need to be done for deployment-ready experimentation.

IV. Preliminary Results

The client interfaces were designed with senior citizens in mind but is easily extendible for a wide variety of users for future usability. An initial sample set of five people in a home dwelling was qualitatively surveyed for initial feedback and evaluation, to improve upon the initial software prototype. Their initial feedback has been incorporated in the following results discussed in this section of the research work.

A. Humanoid Robot Interface

The humanoid robot interface includes the use of large icons, along with visual representations or iconography whenever possible, that helps to assist the end user to navigate through the robot's functionality with minimal external guidance. Bright colors are used throughout the menu bars to distinguish different functions of the robot, while giving a standardized look and feel that is similar when using a mobile tablet-based application as shown in Figure 5.

The initial feedback from the robot's interface was positive overall, with some curiosity and intrigue over the operation of the robot. The added inclusion of health-based training, including dietary and exercise tips, was well received by the citizens to consider incorporating in their lifestyles.

The element of 'surprising and delighting' the end user was also carefully considered as part of the initial trial. Much of the health and dietary presentations were from readily available sources, but it was the novel displaying of this information on a humanoid robot that brought a new perspective when it was first introduced to the senior citizens. These usability concerns were beyond the scope of this initial research but could be further examined in a quantitative level for further research work.

B. Mobile Client Interface

The mobile client provides a secure and safe layer to ensure ownership of the robot to the end user. This provides a level of comfort and assurance that a physical token, by means of an NFC tag, can be readily used to demonstrate ownership and control of the robot when required, as shown in Figure 6 below.

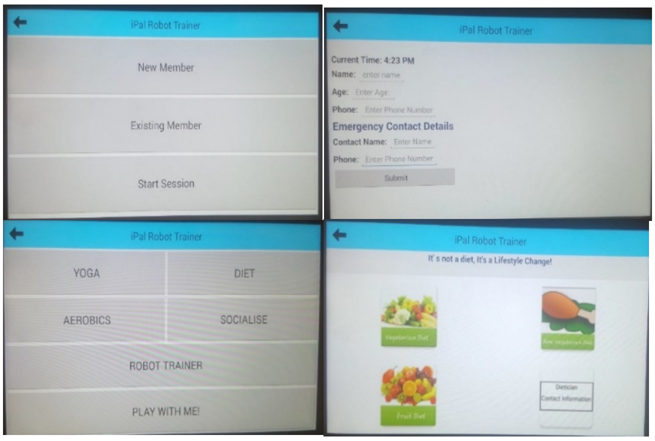

Fig. 5. Screen captures of Humanoid Robot interface

Fig. 6. Screen captures of NFC Client Mobile Application

The NFC client tag association process requires the user's name to be associated with the presented NFC tag, and optionally a photograph can be associated with the user. The NFC tag is an inconspicuous device measuring the size and thickness of a postage stamp, and easily affixed to a keychain or similar item possessed by the senior citizen.

The initial feedback of the NFC operation has been positive, with the users commenting on its ease of use and simplicity in its association process. The app provided a 'physicality' in the ownership of the assistive robot, and that it was not just a virtual association between the user and the robot.

Whilst being cognizant of the client mobile applications limited feature set, the end users recommended further integration work could be done with the mobile application, including remote surveillance and enhanced reminders. These concerns are elaborated in detail in the next section.

V. Further Work

There were notable points of concern during the project development process that would require further research, to improve and optimize the platform for a larger userbase and broader experimental deployment. These concerns, along with the greater need for experimenting the platform with a larger user group with quantitative feedback, will help to assist the research and development team in providing a stable base for further investigation work.

A. Software Platform Optimizations

This project has great scope in future if further developed and implemented with innovative and interactive ideas. More important modules can be added to the system and current modules can be upgraded to improve performance, usability, scalability, security of the system. This will also gain more attractions of elderly people towards using this system:

1) Remote Monitoring System

Assistive-living robots can be utilized to remotely monitor an elderly person at home. The robot has camera in its eyes which can detect danger and record videos to be monitored by family members. Whilst developing this feature, one can also program a live chat functionality which allows elderly people to talk to the family members in detected dangerous situation which will be automated, and an immediate automated call will be done to close family members.

2) Proactive Reminder and Scheduling System

One of the main problems faced by elderly people is short term memory. They forget things very easily. The software application can be extended to have a feature that could act as a reminder to them. They will be able to input the to-do list and set reminders to remind them of tasks to do. In addition, a family member can also set reminder on the robot to remind elderly person take medicines and monitor them. After some minutes, call the family member who will then talk to the elderly person and confirm if medicine was taken or not.

3) Interactive Companion Enhancements

The system can further be developed and upgraded to allow adding more features that are interactive and fun to be used by elderly people. For example, people of this generation prefer watching news. Therefore, we can add a feature which will play latest news videos and keep them busy for some hours. This will also prevent them from feeling lonely. This is one such example, but there is more that can be done to keep elderly people busy and away from loneliness.

4) Unobtrusive Security and Surveillance

It is true that elderly people lack security in their old ages. Assistive robots can be used to provide security to elderly citizens at homes. Remote monitoring will go hand in hand with the security application. Implementing the facial recognition functionality, the robot will be able to recognize family members and non-family members.

Therefore, once the elderly person is alone at home, it will be responsible to authorize a family member and let him or her enter the house if recognized or else will take a photo of the stranger and immediately send it to a close family member as an alert. The robot can also be used to stand outside the property and be integrated with a door lock system, such that door is unlocked only if the human face is recognized, or else the door remains locked and family members are notified immediately.

B. *Humanoid Robot Enhancements*

1) *Technical Support for Robotic Hardware*

The robotic platform requires detailed resources online and development efforts to effectively utilize the robot APIs and sensors to its full potential. As well, the updates need to accommodate current and future technical risks and security patches. Therefore, the research platform has been designed with extensibility in mind to accommodate robotics beyond the robot employed in this experimental prototype.

This is important not only from a design standpoint, but a practical perspective as well. The stakeholders of the health software platform depend on the reliability and consistency of its operation, and the architecture must be developed in a manner so that the data persistence is not inherently linked with the hardware without significant abstraction of critical information points of concern.

The design of the software platform should not be designed with one single robotic system in mind; hence it is an important design philosophy to build a flexible architecture that can be modular enough to accommodate current and future robotic systems for daily living.

2) *Robotic Operating System Limitations*

The robotic platform runs on Android 4.4, which is a significant impediment to development. The operating system is limited compared to the latest operating systems currently available, from a security, functionality, system feature-set and technology standpoint.

To ensure that the software platform is not impacted by such limitations, an API centric approach has been employed to ensure critical dependencies between the software and hardware is kept to a minimum. This also serves the additional benefit of modular architectural flexibility from an abstractive point of view.

3) *Natural Language Understanding (NLU) Work*

NLU technologies are rapidly evolving to the point that they can be deployed on modern embedded technologies. The current NLU solution can only recognize a limited vocabulary for the current experimental trial and was raised as a significant barrier for broader adoption.

In future, the NLU needs to accommodate the lingual differences of culturally diverse environments, other than the English language. This means that the robot could be deployed for more experimental studies in aged care centers worldwide where languages other than English is natively spoken.

VI. Conclusion

The application allows the assistive robot to interact with the attendees, encourage them to exercise and look after their wellbeing. The exercise training module will include Simple Yoga and Aerobics sessions where group of elderly people can train whilst interacting with a robot-trainer. The client application includes a diet module which can provide information on different diets to the users (elderly people) and encourage them to follow a healthier eating practice. The system utilizes the ultrasonic sensors and NFC tags to develop an intelligent IoT identification, localization, and tracking.

The initial application supports several functionalities that include data collection and presentation, notifications, and communication functionalities. The robot has an Android Operating System, and the client application follows Android design principles and takes advantage of external services such as Firebase Real Time Database, Authentication Services, Cloud Storage, Gmail Integration API and several other media processing API's and libraries.

To conclude, this research shows the potential for further developing the platform, as the preliminary results show promise. Although the target audience of this system are elderly people, but it can also be used by people of any age including youths and young children. Health fitness is important for every human being; therefore, this application is helpful to every individual. In addition, robot trainer can be used in fitness centers, aged care homes and even private homes.

References

[1] Adami, I., et al. 2006. '*A robotic based application for physical exercise training*', Foundation of Research & Technology, pp. 45-52

[2] Akim, L., et al. 2013. '*A Robotic Fitness Coach for Elderly People*', Conference Paper, pp. 125 – 139

[3] Avatarmind 2018. '*Robot for children's education, elder care and hospital/retail environments*' first viewed at 25/10/2020.
https://www.iPalrobot.com/

[4] Beal, V., 2021. '*Seniors embrace computer skills training in Stewiacke*' first viewed at 16/07/2021.
https://www.saltwire.com/atlantic-canada/communities/seniors-embrace-computer-skills-training-in-stewiacke-100612031/

[5] Better Health Channel, 2021. '*Physical activity for seniors*', first viewed at 13/04/2021
https://www.betterhealth.vic.gov.au/health/healthyliving/physical-activity-for-seniors

[6] Chang, Y.J., et al. 2011. '*A Kinect-based system for physical rehabilitation: a pilot study for young adults with motor disabilities*', 13th ACM SIGACCESS conference

[7] Cook, L., et al. 2016. '*Evaluating Humanoid Robot Interaction Using a Robot Exercise Instructor at a Senior Living Community*', Computer Technology, Southern New Hemisphere University, pp.16-24

[8] Fasola, J., et al. 2012. '*Using Socially Assistive Human–Robot Interaction to Motivate Physical Exercise for Older Adults*', Computer Science Proceedings of the IEEE

[9] Hsieh, W.-M., et al. 2013. '*Combination of the Kinect with Virtual Reality in Balance Training for the Elderly*', Engineering, 5, 171-175

[10] Otake, T. 2017. '*University of Tokyo robots mimic human exercise',* Japan Times, first viewed at 15/04/2020.
https://www.japantimes.co.jp/news/2017/12/21/national/science-health/university- tokyo-teams-robots-mimic-human-exercise-even-working-sweat/#.WtbTtOhuaUk

[11] Tangermann, V. 2017. '*Six Life-Like Robots That Prove The Future of Human Evolution is Synthetic*', viewed 21/10/2020.
https://futurism.com/the-most-life-life-robots-ever-created.

[12] Unnikrishnan, R. et al. 2013. '*A physiotherapy toolkit using video games and motion tracking technologies*', IEEE Global Humanitarian Technology Conference: South Asia Satellite