UNIVERSITY OF TARTU
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Framework for Biofeedback

Master's Thesis (30 ECTS)

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Framework for Biofeedback

Abstract:

As technological innovations and digital transformations evolve, more enterprises are looking for digital strategies for workforce training, productivity, and data-driven business management while considering user engagement and experience. The study aims to bridge the gap between biofeedback, virtual reality, simulation training, and serious games and strategies to solve real-life training problems while considering the user's and facilitator's experience and how devices can be linked cost-effectively through the prototype. The proposed biofeedback prototype is modeled around a virtual environment (digital twin) that accurately captures and reflects bio-feedback data in virtual reality, simulation training, and serious games. The prototype displays real-time biofeedback data in both the Head-Up Display (HUD) and potentially in the facilitator's screen in the virtual environment (Meta quest two) during virtual reality simulation training as part of serious games strategies and methods. The paper also suggests that serious games mimicking real-life stressful conditions should be developed and integrate the vital systems captured after improvement. The areas in the prototype that need further improvement include data synchronization, user experience through the use of images and animations to display vital signs and adding audio feedback and incorporating vital signs captured to the game rewarding and scoring system and testing it using the target group who need occupationally related stress management.

Keywords:
Virtual reality, Biofeedback, Serious games, Open source, Digital twins, Simulation training, Real-life training problems, Stress management, User experience

CERCS:P170 Computer science, numerical analysis, systems, control

Biofeedbacki raamistik

Lühikokkuvõte:

Tehnoloogiliste uuenduste ja digitaalsete muutuste arenedes otsivad üha enam ettevõtteid digitaalseid strateegiaid tööjõu koolitamiseks, tootlikkuseks ja andmepõhiseks ärijuhtimiseks, võttes samal ajal arvesse kasutajate kaasamist ja kogemust. Uuringu eesmärk on ületada lõhe biofeedbacki, virtuaalreaalsuse, simulatsioonikoolituse ja tõsiste mängude ning strateegiate vahel, et lahendada reaalseid koolitusprobleeme, võttes samal ajal arvesse kasutaja ja juhendaja kogemust ning seda, kuidas seadmeid saab prototüübi kaudu kuluefektiivselt ühendada. Kavandatav biofeedbacki prototüüp on modelleeritud virtuaalkeskkonna (digitaalse kaksiku) ümber, mis salvestab ja peegeldab täpselt biofeedbacki andmeid virtuaalreaalsuses, simulatsioonikoolituses ja tõsistes mängudes. Prototüüp kuvab reaalajas biofeedbacki andmeid nii Head-Up Display's (HUD) kui ka potentsiaalselt fakultatiivse operaatori ekraanil virtuaalkeskkonnas (Meta quest two) virtuaalreaalsuse simulatsioonikoolituse ajal tõsiste mängude strateegiate ja meetodite osana. Artiklis tehakse ka ettepanek, et tuleks välja töötada tõsised mängud, mis jäljendavad reaalseid stressiolukordi, ja integreerida pärast parandamist kogutud elutähtsaid süsteeme. Prototüübi edasist täiustamist vajavad valdkonnad hõlmavad andmete sünkroniseerimist, kasutajakogemust piltide ja animatsioonide kasutamise kaudu elutähtsate näitajate kuvamiseks ja helitagasiside lisamiseks ning kogutud elutähtsate näitajate lisamist mängu premeerimise ja punktisüsteemi ning selle katsetamist, kasutades sihtrühma, kes vajavad tööga seotud stressijuhtimist.

Võtmesõnad:
Virtuaalreaalsus, Biofeedback, Tõsised mängud, Avatud lähtekood, Digitaalsed kaksikud, Simulatsioonikoolitus, Reaalsed koolitusprobleemid, Stressijuhtimine, Kasutajakogemused

CERCS:P170 Arvutiteadus, numbriline analüüs, süsteemid, juhtimine

Contents

1 Introduction

1.1 Problem statement and context

According to the Gallup State of the Global Workplace report, 2022 [1], workplace stress levels are rising, with the global percentage reaching an all-time high of forty-four percent. It has led business enterprises or organizations to be on the lookout for cost-effective solutions for stress management that also solve real-life training problems while improving employee well-being and productivity.

1.1.1 What is stress?

Stress is any challenge to the balance of the body (homeostasis) as perceived by the brain that can manifest as a concrete, life-threatening challenge or cause hidden stress to the body's physiological process [2]. Stress can be acute (short term), and an example includes doing a presentation or chronic(long term) that occurs more prolonged than a few days, as seen in people in the military, law enforcement, and those dealing with emergencies based services [3]. The primary stress triggers in the workplace include lack of clarity on the position allocated, lack of support, insufficient training or support to do the job, high demand on performance and productivity, salary, areas deployed to work, poor management, lack of communication and insufficient time given to complete a task, the work environment, job security, work-life balance and interpersonal issues[3,4].

Stress is manageable when one gains control over the stress response and reactions [2]. Awareness of the stress inducer during training may be beneficial in stress management. The solution aims to mainly monitor a stress-related response affecting the trainee's cardiovascular system, including a rise in heart rate and blood pressure through the biofeedback device linked to a virtual environment through a gateway. The monitoring is continuous, hence the need to store data during and after training to gauge whether stress effects are long-term or short-term.

The previous solution to monitor workplace-related stress included monitoring absenteeism, retention problems, level of employee productivity, employee exit interviews or grievances, or work-related surveys. The mentioned solutions have drawbacks since they are periodic or done when it is too late to help manage the stress levels and can be uncomfortable, for example, exit interviews, and not always helpful hence the advantage of the proposed solution in terms of early monitoring and continuous monitoring of trainee stress levels.

1.1.2 Real-life training problems as a stress monitoring opportunity

Real-life training favors learners executing learning tasks through hands-on experience fraught with training problems and is slow in terms of skills development compared to Simulation-based training, which shows more breadth of the problem, offers more training chances for tasks, and is risk-free [5]. Technological innovations, increased complexity in the learning process, limited resources, and the ever-shifting skills required by employers have created a need for a more flexible learning environment that mimics flexible real-life training scenarios that cater to the constant reskilling of the workforce and introduces the concept of data-driven business management. One must look at real-life training problems from each participant's perspective.

The main problems affecting trainees during real-life training include: how to manage the flow of tasks based on skills level, lack of interactive feedback and insights in real-time, support and guidance on each step of the training, controlling the pace involved in carrying out a task like speeding it up or slowing it down (learning pace), and lack of user engagement due to lack of focus and motivation during training [5].

Regarding the cost, the trainer and organization may not be able to create tasks in real-world scenarios due to limited resources and materials, the feasibility of replicating rare scenarios like natural calamities, and some training that needs to be constant, which may prove costly. Other problems affecting real-life training participants include a lack of guarantee of a risk-free and safe training environment, learning material or training venue availability, and human bias. Prejudiced feedback can be harmful or derogatory, affecting the trainee's mental well-being [11] and demotivating them during training. The real-life training problems based on the solution could be tackled through more motivation to learn through serious games and its reward system in scores, recording the training session and biofeedback data viewing and storage for further analysis, availability, and easy updating of learning resources digitally and unbiased feedback and flexibility in learning and training scenarios.

1.1.3 Cost of stress and training in the workplace

On average, employers spend 1308 US dollars (approximately 1250 Euros) per worker on learning and development, according to Statista [12]. Most organizations have limited training budgets and thus are looking for effective long-time solutions to counter training-related costs. The real-life training cost is affected by the geographically dispersed workforce, the cost of facilitation, renting training venues and obtaining learning materials needed, knowledge retention, learning habits, and lack of engagement. The proposed solution can curtail costs by using open source resources to cut development costs and time and also use readily available devices like smart bands to capture vital signs data. Trainees only have to install applications on their smartphones and use headsets, reducing costs for using real-life training venues and equipment.

1.2 Motivation and thesis overview

The thesis project motivation came from the recognition of the need to design and develop a biofeedback-based prototype as part of the vital signs capture system for use in virtual reality simulation training for stress management in the workplace [6] and after identifying a research gap whereby few academic papers on the integration of virtual reality, biofeedback, and serious games.

The technical outcome of this thesis is a prototype that integrates the link of virtual reality and biofeedback sensor data in real-time while incorporating biofeedback techniques with serious game methods and strategies. The design factors in a human-centric design, ways to address real-life training problems, data storage and analysis for improved training strategies, feedback and risk assessment on training scenarios, and finally, ways to cut virtual reality training costs through the use of readily available devices and use of open source resources.

This thesis organization is as follows, chapter one is an introduction to the project and discusses the problem statement, motivation, research purpose, and proposed solution application flow. Chapter two delves deeper into the background of the research and discusses related works. Chapter three discusses the research methodology used in the study. Chapter four discusses the steps taken to implement the study. Chapter five discusses the timeline taken to complete the study, and Chapter six discusses the data collected and how it was analyzed. Chapter six is the study's findings and suggested future research recommendations about the study.Chapter seven covers the Timeline taken to implement this thesis.

1.3 Research purpose

In this work, the thesis author develops a prototype that allows testing of the feasibility of using biofeedback, virtual reality, and serious games and strategies in applied game design for simulation training for stress management in the workplace while trying to solve real-life training problems and costs. Based on the defined solution goals and values, the following research questions are:

1. **RQ1:** To what extent can the solution bridge the gap between biofeedback, virtual reality, and serious games?
2. **RQ2:** Is it possible to show vital signs to the facilitator in real-time?
3. **RQ3:** How is the user experience in the virtual environment compared to the real-life training environment, and is it a viable solution to solve real-life training

problems?

4. **RQ4:** How effective are cost-cutting measures in developing the prototype using readily available resources and open source tools?

1.4 Application flow

The main focus of this prototyping solution is to seek ways for which to:

1. Minimize prototyping costs by using open-source resources in software development and bypassing vendor-locked software linked to the smart bands, which are the biofeedback devices.
2. Link biofeedback data from smart bands to the virtual reality environment.
3. Display biofeedback data to the facilitator on the laptop and the trainee in the HUD display.
4. Capture and store simulation training and all vital signs data for further analysis.
5. Help facilitators or trainers give interactive feedback to the trainee with a human-centric user experience included in the design.
6. Help organizations make data-driven business decisions through data stored and later used for analysis.

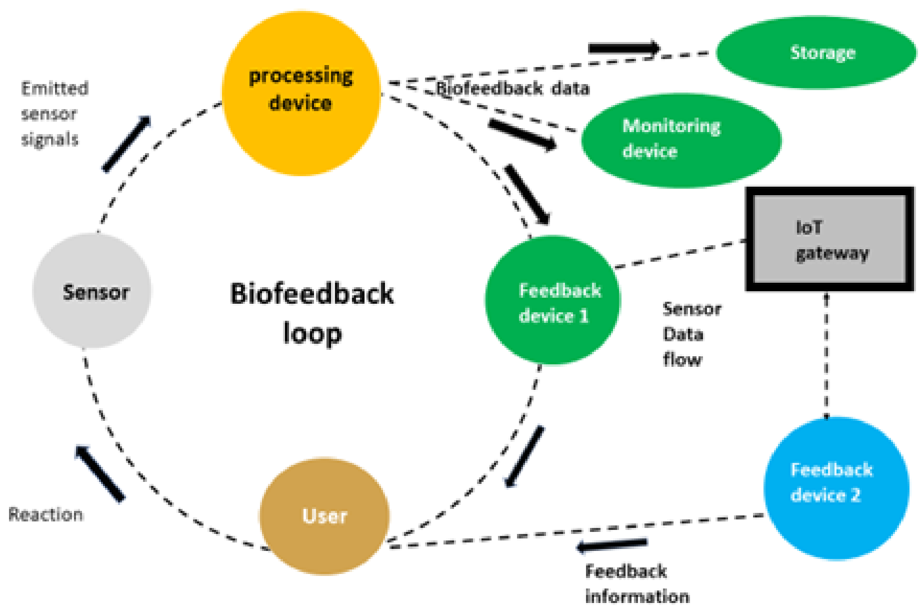

Figure 1. Overview of biofeedback loop

The Biofeedback loop in Figure 1. helps with the application flow below:

1. The trainee's smart band on the wrist collects, processes and stores biofeedback data.
2. The trainee's smart band then processes the sensor's signals which are then stored.
3. The trainee's smart band then sends the biofeedback data to the feedback device labeled one, the Bluetooth-paired android device belonging to the trainee.
4. The android phone has an open-source third-party application that bypasses the vendor-locked smart band to retrieve stored data and auto export it to a database.
5. The IoT(Internet of things) gateway represented by the trainer's laptop enables device-to-device communication between the android device and Meta quest two.
6. The trainer's laptop retrieves selected data from the android device database, which can be monitored, stored, and visible on the laptop browser.
7. The trainer's laptop sends the selected vital signs from the biofeedback data to the HUD display on the Meta quest two headset worn by the user.
8. The trainee views the vital signs captured from the biofeedback device on the HUD display in Meta quest two.
9. The trainee records the simulation training in the meta-quest for more detailed feedback.
10. The trainee views vital-signs data during and after training.
11. The trainer collects all the required vital-signs data from trainees' phones each time they connect the laptop to Android phones and can also view trainees' phones.

2 Background and Related work

2.1 Background

Biofeedback plays a crucial role in helping individuals understand their body's psycho-physical processes, positioning, movement, or augmented proprioception. In a virtual environment or digital twins, a bidirectional flow of data can occur in real-time, with biofeedback devices relaying processed data with digital copies and insights generated between the two devices to improve body processes and movement. Innovative use of virtual reality and biofeedback in the context of digital twins has also created immense opportunity for research and potential growth in various industries and sectors, with the International Data Corporation (IDC) spending guide 2020 predicting the five-year compound annual growth rate (CAGR) for Augmented Reality or Virtual Reality spending to be 54.0% [7]. The summary on the CAGR prediction is seen in Figure 2 below.

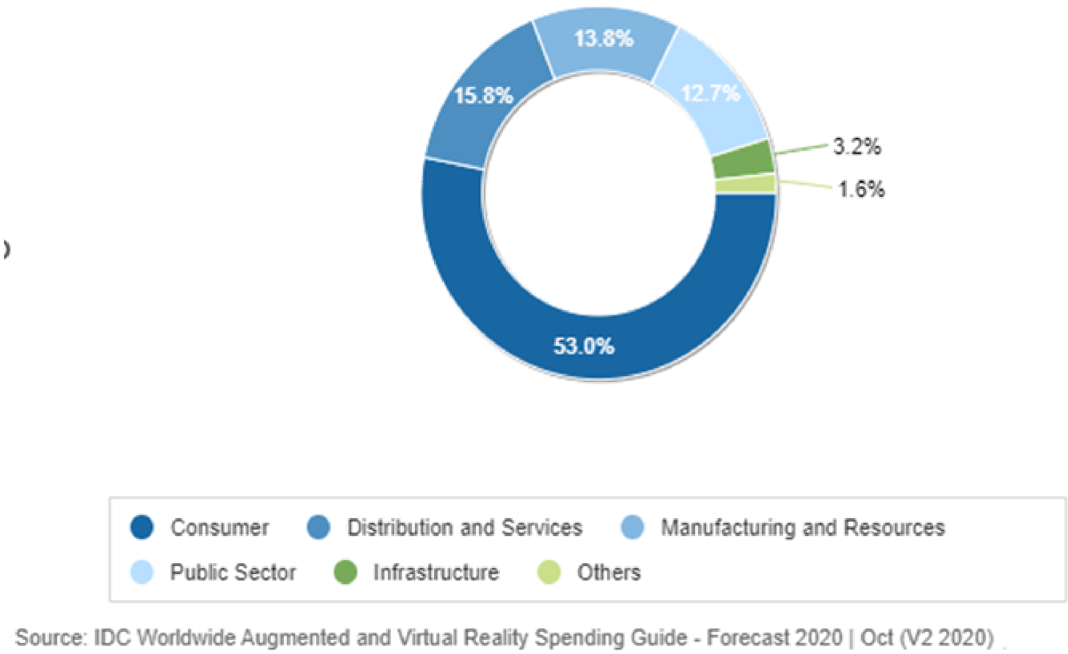

Figure 2. International Data Corporation (IDC) worldwide Augmented and virtual reality spending guide -forecast 2020

Digital transformation strategies in organizations and the recent popularity of having hybrid workplaces due to the pandemic have led many organizations to look for solutions that incorporate speed, maximize the limited resources for waste reduction, and leverage existing and use evolving technologies. The strategies also aim to improve internal communication, knowledge sharing, and overall employee well-being and engagement while improving productivity. The digital revolution has created disruptive threats that could impact an organization's value proposition. It has made organizations rethink business models and processes that permit continuous testing and experimentation with new technologies to develop new innovative technological applications [8]. According to the World Health Organization European framework for action on mental health(EFAMH), there is a need to explore and create new data platforms for mental health using current digital technologies [9]. Data-driven stress management applications could be helpful as a digital transformation strategy since most businesses lose an estimated $200-300 billion a year in productivity due to stress-related illness [10].

Cognitive behavioral therapy using immersive therapy has primarily been unexplored for psychoeducative purposes and is effective in addressing stress and anxiety in young children and adults when adopted in game design [11]. Gaming innovation like the use of serious games has created new and convenient ways of learning and combining digital technologies to mimic real-life scenarios. Serious games are non-entertainment designed games usually for military, government, corporate, political, religious, art, healthcare, and education institutions use. They usually shape a person's knowledge, skills, and behavior while giving insights. The advancement in applied game design has created an opportunity to explore biofeedback data, virtual reality, and serious games in simulation training as part of the active learning process while helping address mental-health-related work problems.

2.2 Analysis of related work and impact on thesis

2.2.1 Deep-Breathing Biofeedback Trainability in a VR Action Game

In this study, Michela et al. [12] aim to train physiological control skills in an arousing decision-making context to address the need for police to be aware and also be able to control physiological changes that could be useful in the field. The case study participants included nine police trainers in ten alternating sessions for four weeks with and without biofeedback. The study phases included the created game design validation without biofeedback and training validation with biofeedback in real-time to observe the evolution of heart rate variability and was part of single-case experimental design analysis. Eight of nine participants showed improved breathing in control in action as the training progressed, with full engagement observed in all participants. Three participants played the VR game during their free time. Devices used to measure breathing rate included a respiratory inductance plethysmography (RIP) belt from Plux S.A. and a BITalino (r)evolution board with heart rate measured in a Polar H10 chest strap[12].

The flaw was a lack of monitoring of the breathing-based skill learning transferred to subsequent sessions that lacked biofeedback. A future work suggestion was using the

VR game to investigate the interaction between physiological state and decision-making out of the lab settings, monitoring biofeedback regarding performance, in-action between physiology, and response inhibition, and further investigation with few participants reaching a plateau of biofeedback training.

The main things the solution implemented in this thesis is trying to avoid are the lack of continuous monitoring of breathing-based skills out of the lab and between sessions and using more than one biofeedback device restricted to the lab settings. The thesis prototype aims to monitor biofeedback data, especially the heart-rate variability, to analyze whether the training is practical for real-world scenarios and use a single cost-effective biofeedback device that is comfortable to wear at all times. The study by Michela et al. [12] enforces the aim of this thesis in solving real-life training problems like motivation to learn and better psychological control with participants where there was an introduction of online biofeedback.

2.2.2 Effect of virtual reality on stress reduction

Kim et al. [12] aimed to compare the stress-reduction effect on VR relaxation to that of individuals highly exposed to stress through psychological scale measurement and physiological parameters, including HRV indexes. Participants were eighty-three highly stressed individuals starting from eighteen years of age, with the study done within two years (2016-2018). The study also examined the change in stress after the relaxation session and excluded people with major psychiatric disorders, suicidal risk, neurological illnesses, including stroke or epilepsy, or severe medical illnesses [12]. The VR equipment included a Samsung Gear VR with a head-mounted display having separate screens for each eye, a head tracking feature, and stereo earphones. Biofeedback equipment was ProComp Infiniti by thought technology in Montreal with sensors attached to the participant's body: An electromyography (EMG) to evaluate the electrical activity of skeletal muscles, skin conductance, skin temperature, respiration, and heart rate/blood vessel pressure (HR/BVP) through sensors attached to the subject's body [12].

Stress was induced in the game using VR videos mimicking dizziness and discomfort through a high degree of movement and cognitive load to create motion sickness for three minutes and thirty seconds with a break in between two sessions. A relaxation session closely followed this. Both the stress-induced sessions and relaxation sessions were random. The study found VR more effective with a slight variation in biofeedback regarding subjective stress reduction. The study showed the possibility of using VR as a tool for stress management. The downside was that induced stress sessions' adverse effects could interfere with the relaxation process in some participants hence the need to select non-pharmacological relaxation methods. The primary limitations included: exposed stressors delivered in the lab environment depending on the individual, insufficient time allocated for stress induction, study investigation only investigating the short-term effect of stress, and study limitation to adults. The study concluded that VR's effectiveness reduces subjective stress in highly stressed individuals.

Kim et al. [12] study's lab-based stress-induced strategy contrast with the thesis prototype in that it had a time limit with side effects on some participants, yet real-world stress inducers are varied, different, and have different periods. They are other ways to replicate stress-inducing parameters, like the use of adrenaline. Adrenaline raises some of the body's physiological functions like blood pressure and heart rate.

The prototype aims to use an adrenaline-based open source VR game-Beep, Saber, where stress simulation is more realistic with no side effects and time limit. Stress inducers should not be limited to training or created inducers. It can be other factors outside training and can vary based on individuals.

The current thesis solution aims not to limit the period stress is monitored in an individual but to have a continuous monitoring strategy that could help organizations develop customized solutions for each individual by giving unbiased feedback. It also aims to overcome the limitation of age groups, as seen in [12] , where the study deals only with Adults. Mental-related illness brought by stress also affects children, and the prototype design in this paper aims to target all age groups if reused in other biofeedback-based VR games.

2.2.3 Serious Game for Obsessive-Compulsive Disorders Therapy

The virtual reality game used serious games and strategies to expose patients to OCD trigger-based stimulants like cleaning, checking, and tidying [13, pp. 1-8]. The game used an Oculus rift headset with its two wireless controllers and Unity engine for serious game development, with psychologists participating in the game design process. Participants testing the game were seven psychologists and three psychiatrists, with the central part of the game involving the player grabbing something but only gaining points when one avoids grabbing an item and leaves it. Covid-19 limited the testing of OCD patients with a vital-signs capture system using a smart band to capture the ECG, heart rate, blood pressure, and oxygen. The health professionals that formed the study participants were optimistic about its use as a therapeutic tool, and the study hoped to introduce a vital signs capture system with the game, incorporating levels based on the patient's pathology. The downside was that the elderly could not participate due to a lack of technology experience. This study's [13] impact on this thesis prototype design is the use of a vital signs capture system in serious games and the fact that health professionals used in the study were optimistic about its therapeutic role. It helps reinforce the need for future improvements in the prototype for training to be done anywhere and anytime with remote training.

3 Methodology

3.1 Design

The biofeedback prototype design process considered the following steps:

1. Requirements gathering and analysis
2. Hardware and open source software selection

3.1.1 Persona

A human-centered design focuses on the user's wants, needs, and pain points, hence the need to use personas. In user-focused design, personas help with the interaction and navigation during product development [14]. The personas' needs, challenges, and frustration helped identify the opportunities that the solution would help address realistically. Figure 3. captures a trainer's persona, while Figure 4. the trainee's persona.

Figure 3. Trainer persona

Figure 4. Trainee persona

3.1.2 User stories

Based on the defined application flow, user stories were derived as a guideline to give a general idea of the prototype setup with defined components and leave room for further architecture refinement based on user feedback or limitations experienced when working on the prototype. The user stories are as follows:

1. Jane (trainee), employed in a local police unit, selects Friday afternoon when free for an hour to schedule it for her virtual reality training with her trainer Eric in the office training room.

2. All employees or trainees have smart bands and android phones preinstalled with open-source software as part of the previous month's stress management program initiative approved by all stakeholders.

3. Eric, the trainer, before each session, checks the android phone to see if Bluetooth and location are on, and the SSH(secure shell-based) session and wake lock in the chosen android application is activated to ensure continuous data flow.

4. Eric also ensures that the meta quest two training device has the simulation training game for Jane ready for the session with the guardian boundary set to ensure that Jane carries out the training in a secure environment free of risk with enough space around.

5. Eric installs Android APK to the Meta quest two headset in case it is missing or modified using an air link or data link cable.

6. Training begins with Jane hitting the start button using one of the meta-quest two controllers on her right and left hand.

7. Jane's Smart band continuously captures the body's physiological data or vital signs, which are then processed and transmitted to the Bluetooth-paired android device for data collection and visualization through an open-source Android-based application that replaces the vendor-locked application linked to the Smart band. It enables generated data to be manageable and easily accessible.

8. SQLite data saved in the android application is auto exported to Eric's (trainer or facilitators) laptop through a selected SSH-based android application that allows a network communication protocol for connection within the organization's local network and can run the selected framework for data visualization, retrieval and further exporting.

9. The node-red flows on Eric the trainer's laptop are accessed via the browser using the phone's IP address and the port number generated at the start of ssh in Termux.

10. The flows also enable the vital signs captured to be transmitted to the HUD display

in the virtual environment using a web socket linked to the Godot engine that allows the bidirectional flow of the data.

3.1.3 Architecture overview

The section gives an architectural overview of the prototype as visualized in Figure 5. The proposed prototype consists of a smart band that collects and processes the sensor of the body's physiological data linked to the trainee. The data is then transferred to a Bluetooth-paired android phone and accessed by the GadgetBridge application connected to the smart band. The smart band should be initially paired to the GadgetBridge, as seen in Figure 5, using the tokens retrieved using the Huafetcher android application. Once data synchronization completes, one can find the SQLite database in the following path /storage/emulated/0/Android/data/nodomain.freeyourgadget.gadgetbridge/files and is regularly auto exported based on the time interval chosen.

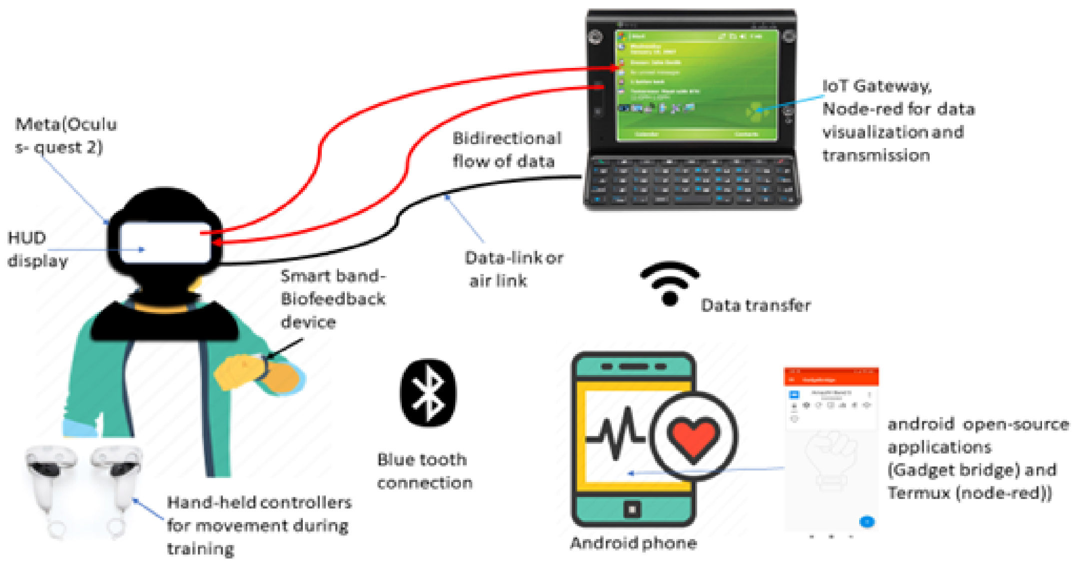

Figure 5. Architecture overview of biofeedback prototype

For connection and to view node-red flows on the trainer's laptop, the IP address, port number, user id, and ssh password(created during android device setup) of the android phone are required if using putty in windows. Once connected, node-red is run and should be able to access the flows in the browser based on the IP address of the phone and port number indicated by node-red. The node-red flows should be able to retrieve the required SQLite vital signs data, send them to Godot engine-based game Beep Saber, and display the data on the HUD display in meta quest two headsets. The link cable or air link (wire-less) enables the installation of the modified APK in the Godot engine in the meta quest two headset.

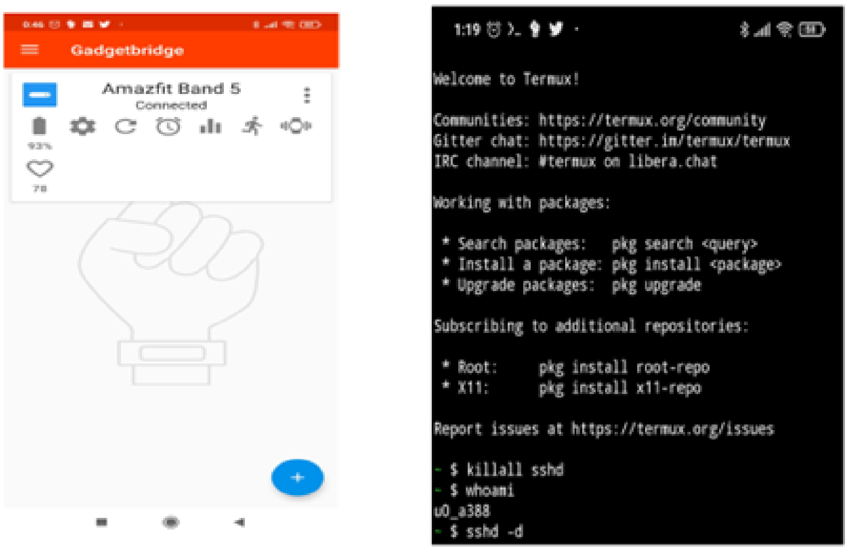

Figure 6. Screenshot of GadgetBridge and Termux android application setup

3.1.4 Requirements

The scenarios created in the personas helped prioritize the product requirements and put problems into perspective on how they would be solved for the prototype to be considered a success.

Functional requirements The functional requirements derived from the user stories are defined as follows, as seen in Tables 1-4.

Table 1. Functional requirement for viewing biofeedback data by trainee

Use Case ID	**PUC-01**
Use Case name	View biofeedback or vital signs
Primary Actor	Trainee
Description	Monitor vital signs displayed on HUD in a VR environment during training
Priority	High
Triggers	Simulation training when started in the virtual environment.
Pre-conditions	The trainer should set the simulation training environment with the smart band, android phone, trainer's laptop, and meta quest two and have them well linked.
Actions	1. The trainee selects play and should see the latest timestamp and heart rate displayed next to the score. 2. The HUD screen should continuously display updated biofeedback during training as the game progresses.
Post-Conditions	The vital signs should be visible in simulation training video recording, and trainees should be able to monitor their vital signs.
Alternative Scenario	3. Video recording should be able to capture trainees' vital signs
Quality in use – ISO / IEC 25010 [15]	Satisfaction(Usefulness), Context coverage(Flexibility), Efficiency, Freedom from risk

Table 2. Functional requirement for viewing biofeedback data by trainer

Use Case ID	**PUC-02**
Use Case name	View biofeedback or vital signs
Primary Actor	Trainer
Description	Monitor vital signs on his laptop browser.
Priority	High
Triggers	when the android device and laptop are linked and setup for the flow of data
Pre-conditions	The trainer should set the simulation training environment with the smart band, android phone, trainer's laptop, and meta quest two well linked.
Actions	1. The trainer setups environment and deploys the node-red flows that retrieves SQL data and creates Web-socket connection. 2. The browser UI setup should continuously display live biofeedback data when connection between devices is set.
Post-Conditions	The vital signs should be visible in the trainer's browser
Alternative Scenario	3. The trainer's laptop should be able to save the biofeedback data in a database or CSV file for further analysis.
Quality in use – ISO / IEC 25010	Satisfaction(Usefulness), Context coverage(Flexibility), Efficiency, Freedom from risk

Table 3. Functional requirement for viewing saved biofeedback data by trainer

Use Case ID	**PUC-03**
Use Case name	View saved biofeedback data
Primary Actor	Trainer
Description	View saved trainee's data
Priority	High
Triggers	Simulation training environment on setup on android phone and laptop
Pre-conditions	The trainer should set the simulation training environment with the smart band, android phone, trainer's laptop, and meta quest two and have them well linked.
Actions	1. The trainer setups environment and and is able to view live biofeedback data and have started the Web-socket connection between the laptop and Meta quest two. 2. The browser UI setup should continuously display live biofeedback data
Post-Conditions	The vital signs should have been saved
Alternative Scenario	3. The trainee should be able to record the training session in the Meta quest two
Quality in use	Satisfaction,Context coverage, Efficiency

Table 4. Functional requirement for viewing saved biofeedback data by trainee

Use Case ID	**PUC-04**
Use Case name	View saved biofeedback data
Primary Actor	Trainee
Description	View biofeedback data anytime and anywhere
Priority	Medium
Triggers	Have an Android application on the phone with location and Bluetooth enabled and linked to a smart band.
Pre-conditions	The trainee should have a charged phone and smart band that are linked in an android application through Bluetooth
Actions	1. The trainer opens the android application and makes sure that the data is synchronized. 2. The trainee should be able to monitor vital signs on the installed android applications while out and about.
Post-Conditions	The trainee should be able to monitor all vital signs captured 24/7 if wears the smart band.
Alternative Scenario	3. The trainer should be able to share stored data or videos from the simulation training
Quality in use	Satisfaction,Context-coverage, Efficiency

Non-Functional requirement The tables 5-8 cover the non-functional requirements

Table 5. Non functional requirement for capacity

Use Case ID	PNFR-01
Use case name	Storage capacity
Primary Actor	Trainer
Description	The prototype should have enough storage space and backup options
Priority	Medium
Pre-conditions	The training environment is well set and devices linked. The laptop should have enough storage space and be efficient.
Post-Conditions	The environment setup should have been able to sync biofeedback data when the android phone and the smart band are still linked
Success criteria	The Android phone and laptop should have enough adequate storage options and capacity
Quality ISO / IEC 25010 Sub characteristics [15]	Capacity

Table 6. Non functional requirement for user guide documentation

Use Case ID	PNFR-02
Use case name	User guide documentation
Primary Actor	Trainer
Description	The prototype should have an essential setup guide.
Priority	Medium
Pre-conditions	The guide should be easy to use and replicate.
Post-Conditions	The trainer should be to set up the training environment
Success criteria	The User documentation guide should be available and easy to follow
Quality ISO / IEC 25010 Sub characteristics [15]	Documentation

Table 7. Non functional requirement for real-time data perfomance

Use Case ID	**PNFR-03**
Use case name	Real-time data performance
Primary Actor	Trainer, Trainee
Description	The trainee or trainer should be able to see biofeedback data updates every minute.
Priority	High
Pre-conditions	The training environment is ready, and devices are well linked and devices charged.
Post-Conditions	The primary actors should view updated real-time data 80% of the time
Success criteria	The trainee sees updated real-time biofeedback data every minute in the HUD display and trainer in the laptop browser 80% of the time.
Quality ISO / IEC 25010 Sub characteristics	Performance

Table 8. Non functional requirement for User interface design

Use Case ID	**PNFR-04**
Use case name	User interface design
Primary Actor	Trainer, Trainee
Description	The prototype should have a good overall user experience
Priority	High
Pre-conditions	The training environment is ready, and devices are well linked and properly charged
Post-Conditions	The users are motivated to use the prototype based on the overall user experience.
Success criteria	The main actors approve of the prototype's basic User interface and are motivated to learn and should have an overall good user experience
Quality ISO / IEC 25010 Sub characteristics	Usability

3.1.5 Sequence diagram

The sequence diagram is a behavioural diagram that is used to visualize the interaction of components presenting the dynamic view of the prototype.

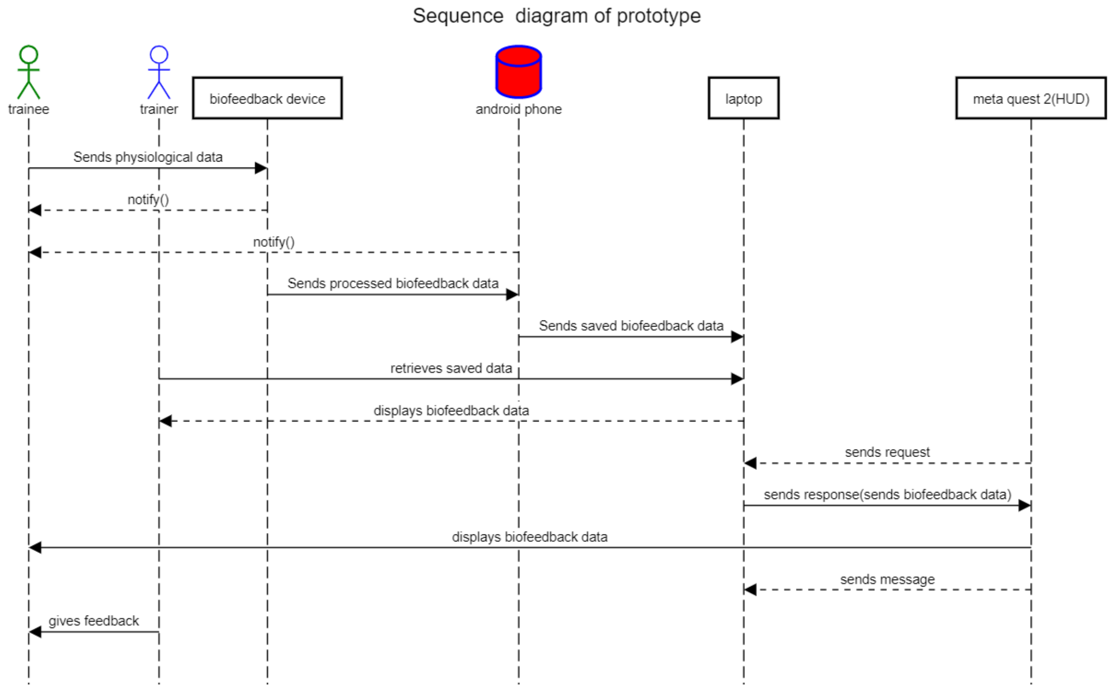

Figure 7. Sequence diagram

3.2 Component analysis and selection

Initial research of the hardware and software components helped to determine what to use in the prototype design as part of the requirement analysis.

3.2.1 Biofeedback device selection

The biofeedback device used was determined to be a smart band with its selection criteria involving looking at its sensors, health monitoring features, cost, third-party integration, and pros and cons [16]. The finally selected hardware devices were Amazfit band 5, Mi-band five, and Mi-band two. Detailed biosensing capabilities of all three devices overview seen in earlier work by the author of the thesis [16] and steps for device hacking that enables one to connect the smart bands to GadgetBridge, an Android-based application also listed. GadgetBridge [17] supports all three selected Huami-based smart bands, so using the same open-source resources was more manageable and made the collection of stored data the same for all devices.

The bypassing of the vendor-locked software in the smart band was made possible by the Huafetcher android application since it worked well for all three smart bands enabling the retrieval of all three Huami tokens necessary to pair the smart bands with GadgetBirdge it was selected. The other bypassing options proved to be problematic and time-consuming. The token retrieval steps can be found in previous research by this paper's author [18] undertaken or on the GadgetBridge site. The application only paired up with one device at a time, contrary to the extra pairing feature had some issues, so testing all three devices was done in phases, with data stored in the application's SQLite database. The auto exported database [19] contains 39 tables and three indexes, as seen in Figure 7. below, with the main tables of interest of the three smart bands highlighted in green. The main interest table is the MI_BAND_ACTIVITY_SAMPLE table, where the following data is derived heart rate, timestamp, and steps.

Figure 8. Overview of GadgetBridge database tables

The MI_BAND_ACTIVITY_SAMPLE table columns represent the following:

1. TIMESTAMP representing a point in time data got added to a specific row in the table.
2. DEVICE_ID is the ID code of a device and is helpful for multiple pairing devices to GadgetBridge.
3. USER_ID represents an ID code identifying the user's information.
4. RAW_INTENSITY represents the activity intensity.

5. STEPS represents the number of steps a user takes.
6. RAW_KIND represents the activity type.
7. HEART_RATE represents the number of times the heart beats per minute.

3.2.2 Gaming engine selection

To determine which gaming engine to use due to time constraints feature comparison seen in Table 9 led to the selection of which gaming engine would be the easiest to use for prototyping. Godot engine was selected because it was a free, open-source 2D and 3D game engine that is easy to use with a less learning curve, saving on cost and development time compared to unity and unreal.The table below gives an overview based on the three gaming engines: Godot ,Unity and Unreal.

Table 9. Game engine comparison table

Features	**Godot engine**	**Unity game engine**	**Unreal engine**
Release date	January 14, 2014	June 2005	May 22, 1998
License	MIT license Open-source or Expat license	Unity terms of service and Open source for UltimateXR	End User License Agreement
Cost	Free	-Free with no conditions only for UltimateXR,Free to use but with conditions when one starts earning revenue from the game one develops,Cost for using the unity pro-toolset increases with the team size-1800 euros per year for each individual.	Free to use, but with conditions when one starts earning revenue from the game, one develops in the form of royalty fees.

Features	Godot engine	Unity game engine	Unreal engine
Ease of Use for beginners	Easiest due to its modular design	Easy to learn due to its intuitive design	Complex
Learning curve	Easiest to learn	Second easiest to learn since it uses C sharp	-Hardest due to C++, which is trickier than C sharp,which is more manageable than the two and uses a finite state machine to manipulate actor states through animation that is also complex to learn. -Has more features to learn
XR, AR and VR support for cross-platform development	Yes	Yes, with XR features in Universal Render Pipeline (URP) varies by URP package version.	Yes
Cross-platform integration	Native libraries for iOS or Android, Linux, Mac OS, and windows	iOS, Android, Windows Phone 8, Tizen, Android TV, Samsung SMART TV, Xbox One and 360, Windows PC, Mac OS X, Linux, Web Player, WebGL, HoloLens, SteamOS, PS4, PlayStation Vita, and Wii U	iOS, Android, VR, Linux, Windows PC, Mac OS X, SteamOS, HTML5, Xbox One, and PS4
Editor and User experience	-Built-in editor(syntax highlighting, real-time parser, and code completion) -Best user experience with easy-to-navigate GUI	-More robust feature sets with the smaller code-base, so the next most straightforward to use after Godot in terms of user experience.	-Complex, so user -experience only improves with time as learning.

Features	Godot engine	Unity game engine	Unreal engine
debugger	Built-in debugger	Unity supports debugging C sharp code using the following code editors: Visual Studio (with the Visual Studio Tools for Unity plug-in) and Visual Studio for Mac.Jetbrains Rider. Visual Studio Code	-Blueprint debugging, -game-play debugging that enables one to analyze real-time game-play data in real-time. -AI debugging with AI debugging tools
Installation size	-Standard-37.333 Mb per install-Mono-63.5 Mb per install Small engine	It depends on modules one adds when installing the unity hub but can be more than 1.5 GB per install	8-32 GB Ram is required depending on the Os
Resources, tools, and tutorials	Low but the quality is better than for unity	High	Medium
Key contributors and technical risks	Contributors are a small team, so there is a high risk if any individual in the core team leaves.	Contributors are a large team therefore minimal risk with an individual leaving team	Contributors are more of a medium team as compared to unity, so the risk is medium

Features	Godot engine	Unity game engine	Unreal engine
Performance	-Rendering lags in 3D -Best support for 2D games -fast to run	-3D engine with a 2D engine built on top of it, resulting in dependency-based problems. - Optimized 3D rendering with features for real-time 3D simulations that are ideal for digital twins, -2D games support is medium -slow to run	Has the best 3D rendering -2D games support least with less frequent updates -Unity takes a significantly more streamlined approach to its interface design, making it quicker and more responsive than Unreal.
Mobile development support	Kotlin	iOS and Android	Cross-platform support for both Android and iOS plat-forms simultaneously
Language flexibility	GDScript, C sharpwhen using mono, Full C++ support, Visual scripting using blocks and connections, Gdnative, D, Kotlin, Nim, Python, and Rust	C++ (runtime) and C sharp (Unity Scripting API)	Blueprint Visual Scripting or C++
Community-based support	Low	High	Medium
Integrated documentation	Yes	Yes	Yes
Professional or job opportunities	Low	High	Medium

3.2.3 Node-red

Node-red [20], an open-source visualization tool built on Node.js for low-code programming for event-driven applications, was selected for the device-to-device communication between the android phone and Meta quest two. It has a browser-based editor with flows for easy deployment and configuration and also helps save software development costs, thus making it ideal for iterative designing and rapid prototyping. Initial tests of node-red to see if stored SQLite data from GadgetBridge could be retrieved proved to be working as expected.

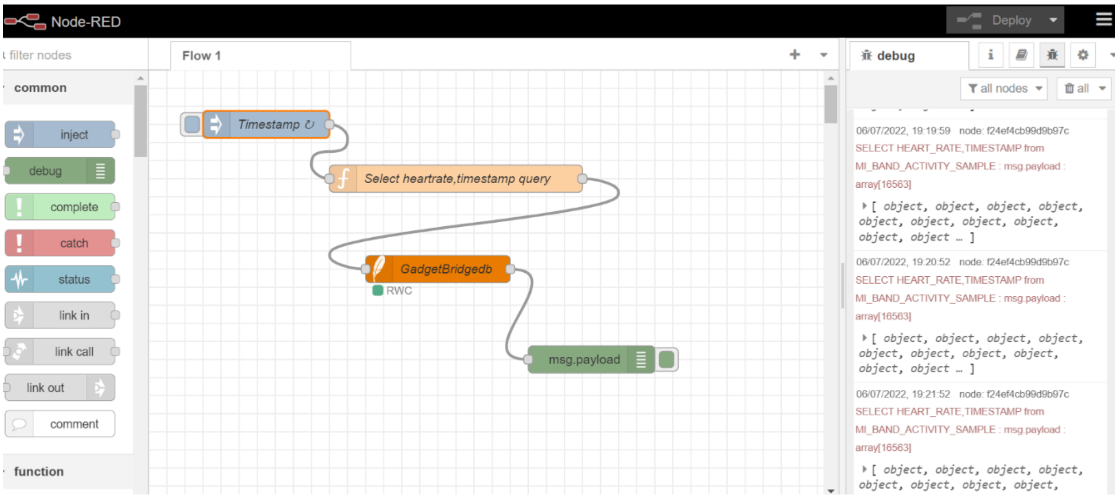

Figure 9. The node-red flow setup for data retrieval from SQLite database

3.2.4 Termux

To set up the SSH connection within the local network, the android application Termux was selected. Termux [21] is an Android terminal emulator and Linux environment application that is a minimal base system that allows for SSH and node-red setup within the android phone. The setup of SSH and node-red is essential for device-to-device communication in the IoT gateway.

3.2.5 BeepSaber

Beep Saber [22], a basic open-source VR game developed from the Godot game engine and Godot Oculus Quest Tool Kit, was a logical option for integrating with the biofeedback prototype to test the prototype. The game involves slashing of red and blue objects matching the swords created by the right and left controllers of the Meta quest two to the rhythm of the beat of the music selected. Music is adrenaline pumped with the slashing movement of the arms giving an upper body workout. Psychologist Archibald Halt theorized that heart attack and stress-induced illnesses were a byproduct of too much adrenaline [23]. Using an adrenaline-based game thus made sense to be used to test the prototype.

The initial source code had to be tweaked initially for the game to play in Meta quest two. There was a problem downloading the music required for the game to start. The correction in the BeepSaberMainMenu.gd file by commenting out a line of code highlighted in the Figure 9.that enabled the game to start. The problem solution is in the issue section in the Beep Saber repository. It finally enabled the chosen song to be downloaded to be used to start the game by playing it.

```
    #copy sample songs to main playlist folder on first run
    var file = File.new()
    var config_path = "user://config.dat"
    if not file.file_exists(config_path):
        var dir = Directory.new()
        var copy = Directory.new()
        dir.make_dir_recursive(bspath+"Songs/")
        # dir.open(path+"Songs/")
        dir.list_dir_begin(true,true)
```

Figure 10. Overview of BeepSaberMainMenu.gd highlighted code

4 Implementation

The following chapter covers the prototype implementation after all the device setup.The Github link for the prototype implementation can be found in the appendix of this thesis.

4.1 Node-red flows

4.1.1 SQLite data retrieval

On further scrutiny of the data retrieved from the SQLite database, one thing observed was that retrieval of data per second meant heart-rate could only be retrieved per minute, so there was a need to filter out unnecessary rows. HEART_RATE of 255, which meant inaccurate wrong value measurement. Any value of -1 in HEART_RATE AND RAW_INTENSITY also means unknown values. Incoming data filtering involves omitting rows with HEART_RATE OF 255 and -1 and RAW_INTENSITY of -1 in the MI_BAND_ACTIVITY_SAMPLE table one. The resulting flow gets incoming biofeedback data based on the time interval set and is as follows:


```
[{"id":"4f52a1df9967643a","type":"tab","label":"Flow 1","disabled":
    false,"info":"","env":[]},{"id":"367d597980312aa7","type":"sqlite"
    ,"z":"4f52a1df9967643a","mydb":"7fa3cc2dfbc0ccef","sqlquery":"msg.
    topic","sql":"USE Gadgetbridge","name":"GadgetBridgedb","x":480,"y
    ":120,"wires":[["f24ef4cb99d9b97c"]]},{"id":"f24ef4cb99d9b97c","
    type":"debug","z":"4f52a1df9967643a","name":"","active":true,"
    tosidebar":true,"console":false,"tostatus":false,"complete":"
    payload","targetType":"msg","statusVal":"","statusType":"auto","x"
    :650,"y":160,"wires":[]},{"id":"a90a8a65fd127769","type":"function
    ","z":"4f52a1df9967643a","name":"Select heartrate,timestamp,steps
     query","func":"msg.topic = \"SELECT HEART_RATE,STEPS,TIMESTAMP
    from MI_BAND_ACTIVITY_SAMPLE where HEART_RATE != 255 and
    HEART_RATE != -1  and RAW_INTENSITY !=-1  ORDER BY TIMESTAMP DESC
    LIMIT 1\"\n\nreturn msg;\n","outputs":1,"noerr":0,"initialize":"",
    "finalize":"","libs":[],"x":340,"y":220,"wires":[["367
    d597980312aa7"]]},{"id":"97442a28ed7e4433","type":"inject","z":"4
    f52a1df9967643a","name":"Timestamp","props":[{"p":"topic","vt":"
    str"}],"repeat":"60","crontab":"","once":true,"onceDelay":"1","
    topic":"","x":130,"y":160,"wires":[["a90a8a65fd127769"]]},{"id":"7
    fa3cc2dfbc0ccef","type":"sqlitedb","db":"/storage/emulated/0/
    Android/data/nodomain.freeyourgadget.gadgetbridge/files/
    Gadgetbridge","mode":"RWC"}]
```


The nodes used for the flow were an inject node, a function node, an SQLite storage node, and a debug node. The retrieved data in msg.payload is an array object, as seen in Figure 10.

The next step was to convert the timestamp to human-readable format and format the data

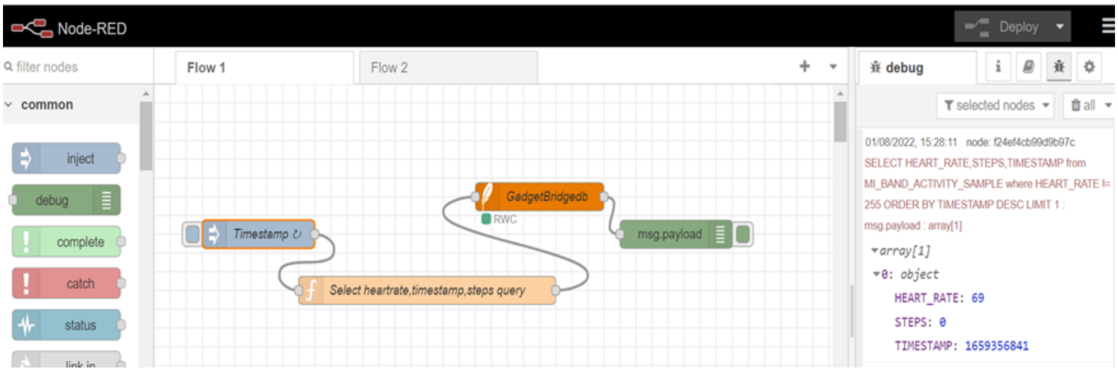

Figure 11. The node-red flow of SQLite filtered data retrieval

for sending to Godot through the WebSocket connection. The conversion implementation is in the change node where the msg. payload[0].TIMESTAMP is set to

```
$moment($now()).tz("Europe/Tallinn").format('YYYY-MM-DD HH:mm:ss.SSS'
    )
```

with the Object data from the query converted to JSON string for use in the WebSocket.The resulting JSON string is as follows:

```
[{"HEART_RATE":69,"STEPS":2,"TIMESTAMP":"2022-06-01 20:44:18.929"}]
```

The respective flow created is seen in Figure 11.

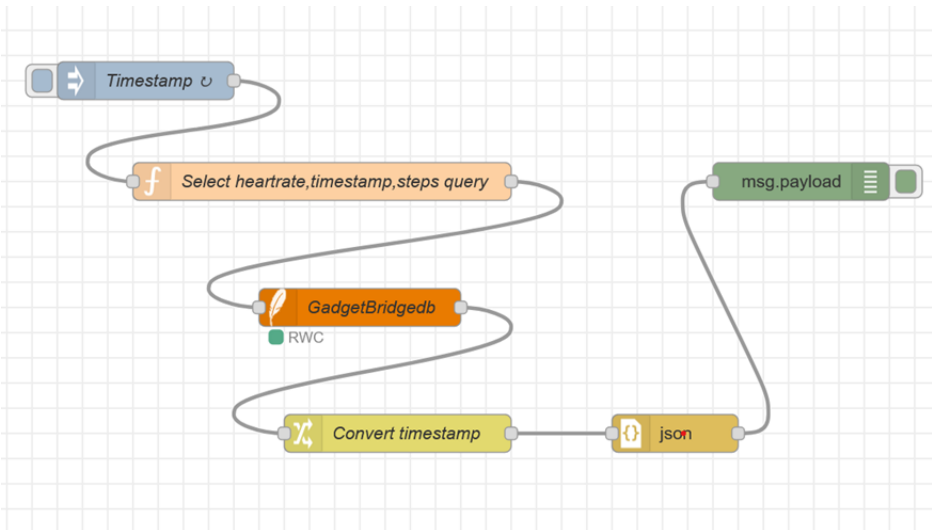

Figure 12. The node-red flow with timestamp conversion and object data conversion to json string.

4.1.2 Node-red WebSocket Server

The WebSocket full implementation flow diagram involves adding the Websocket out node to the end of the function node. It is a WebSocket server that sends biofeedback data to the Godot-based game, Beep saber. Figure 12. shows the server configuration used to publish and receive messages.

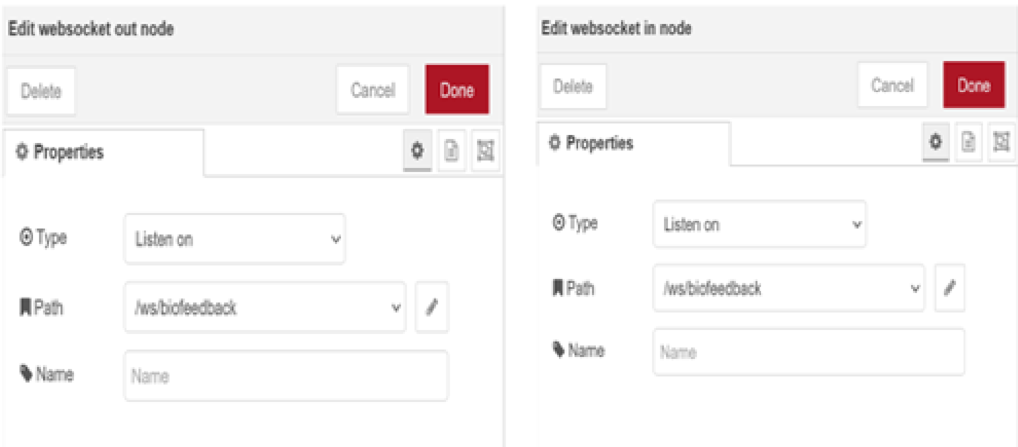

Figure 13. Websocket socket out and in nodes the configuration server configuration in node-red

The WebSocket out node for publishing messages and WebSocket in nodes, if properly configured, should show a green light with a connected one, as seen in the Figure 13.

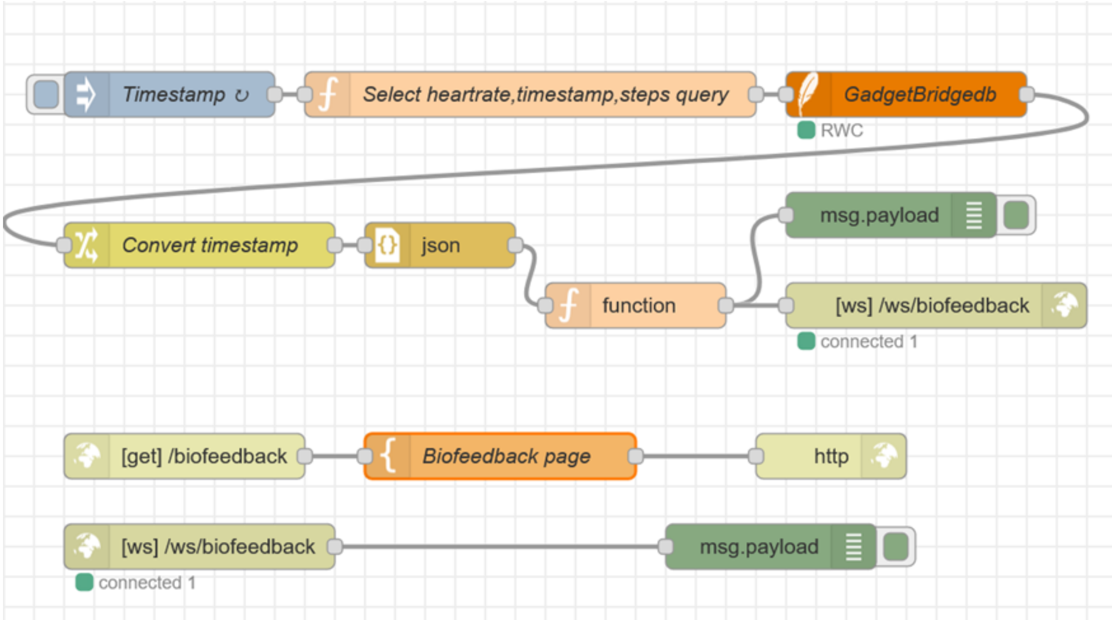

Figure 14. Websocket socket server and live biofeedback display flow

To test the live display of data, one uses the following URL.

`http://androidphone-ipaddress:1880/biofeedback`

The url should display to the trainer in the browser live biofeedback data as seen in Figure 14 below.

Figure 15. Websocket socket connection testing of live data and trainer browser display

The final flow implementation summary all the node-red flows can be found in the github link shared in the appendix and its listed as the main node-red flow. This flow helped the trainer view biofeedback data per functional requirement PUC-02 and help analyze the real-time biofeedback data performance per non-functional requirement PNFR-02 using the live biofeedback display. The live biofeedback data dis-play also helped check if the devices were connected and the WebSocket was working as expected to publish and receive messages from the Meta Quest two, ensuring the bidirectional flow of data.

4.1.3 Data visualization and analysis

The data visualization section formed the alternative scenario of functional requirement PUC-02 (view biofeedback data-trainer) and the flow can be found in Github repository indicated in the glossary.

4.2 Godot engine

The building blocks of Godot are called Nodes, which usually form a tree-like structure with parent and child nodes forming a scene which is crucial in-game architecture and modeling [24]. Godot editor has three types of root nodes used in game creation 2D scene, 3D scene, and User Interface. We are mainly interested in the User interface node used in modifications in the HUD display part in the Beep Saber game that only gives two options a label or a rich text label. Rich text labels allow for adding images; therefore are selected for use and show the retrieved biofeedback data in the design. The HUD dis-play in the Beep Saber game has three main panels interested in modifying, which are the settings panel (settings_Panel.gd) that forms a part of the Beep Saber game main menu (BeepSaberMainGameMenu.gd) seen at the game start like in figure 15, the main points section displayed during gameplay and End score panel at the end of the game.

4.2.1 Game HUD display mockups

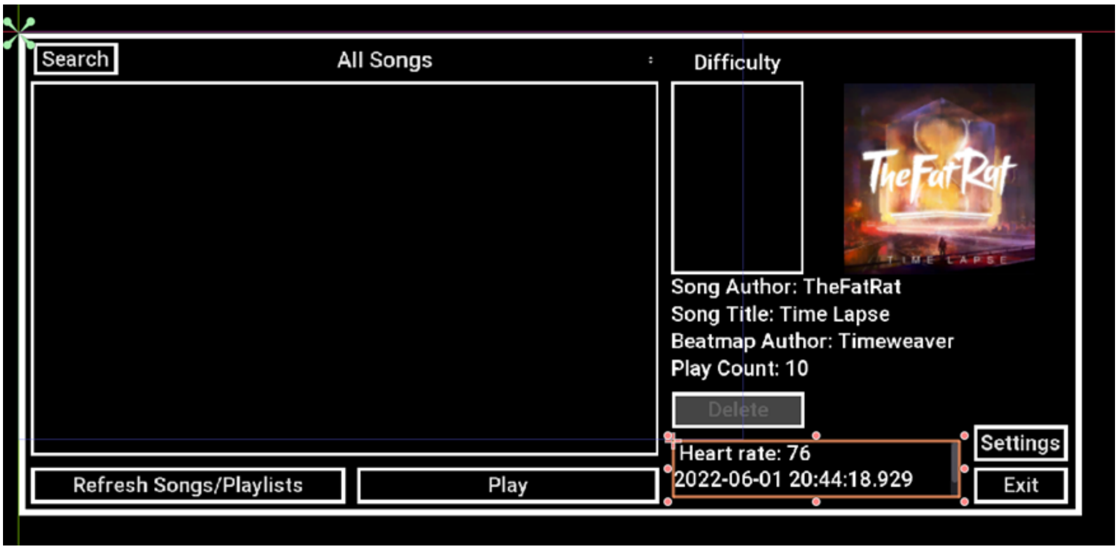

Figure 16. The design perspective of the beep saber main menu HUD display

Figure 16 shows the overall game perspective on start in 3D in the virtual simulation environment.

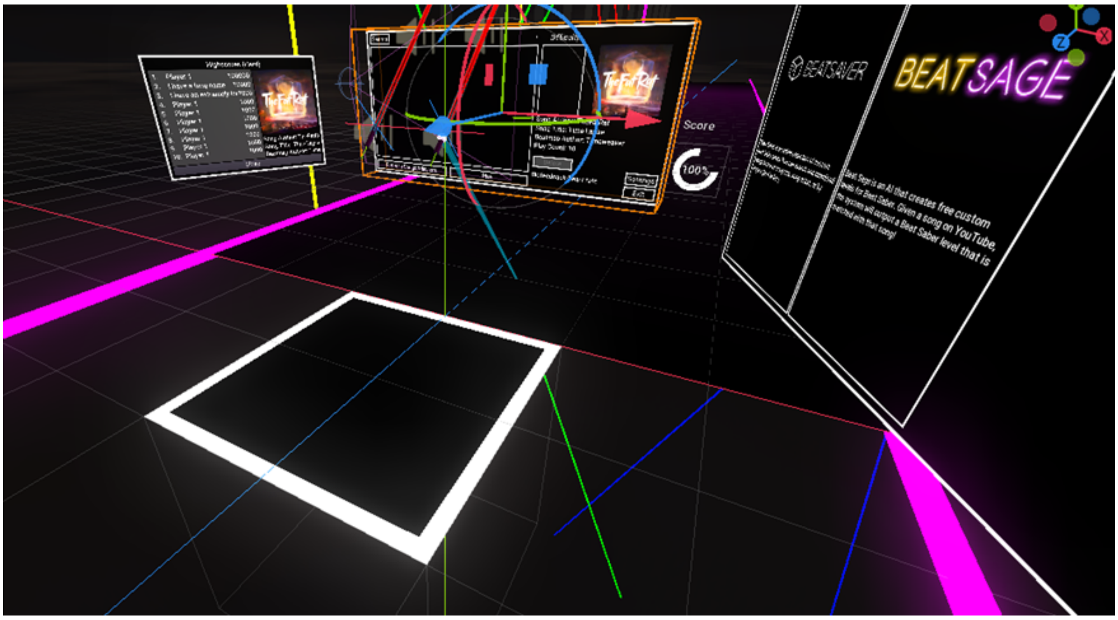

Figure 17. The design perspective of the game start HUD display in 3D

The Figure 17 shows captured vital signs data which are STEPS,HEART_RATE AND TIMESTAMP in the form of date time on the HUD display during the simulation training.

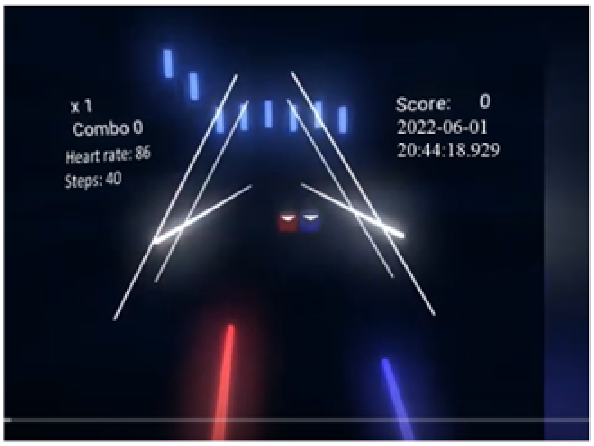

Figure 18. The design perspective of HUD display in the main game during simulation training

At the end of the game Figure 18 shows the central display in the 3D environment.

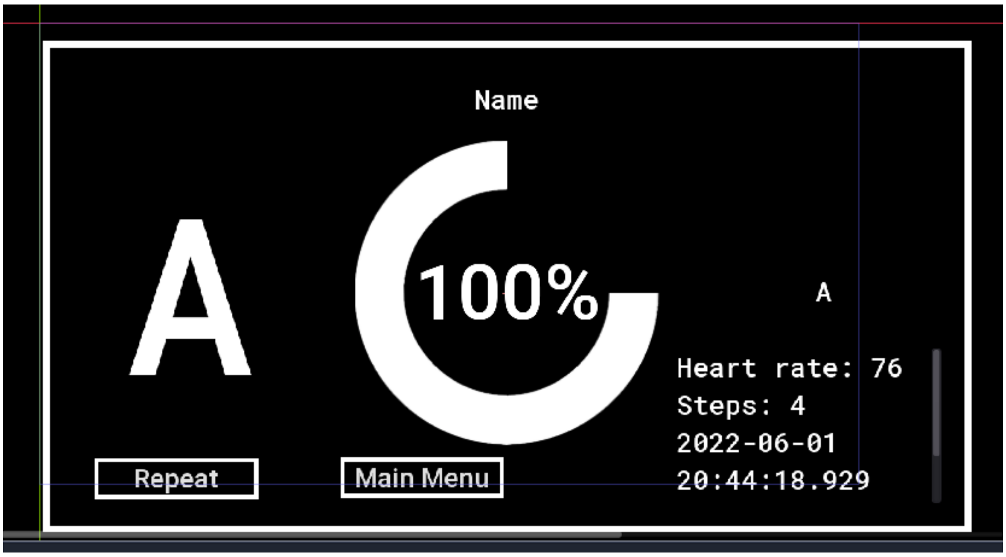

Figure 19. The design perspective of the end score display scene

4.2.2 Godot WebSocket client connection

The Godot WebSocket connection involved adding a network script(Network. gd) for the WebSocket client and connecting it to the Websocket Server created in node-red to re-trieve data for the selected HUD displays. The network file used to retrieve data, as seen in Figure 19.

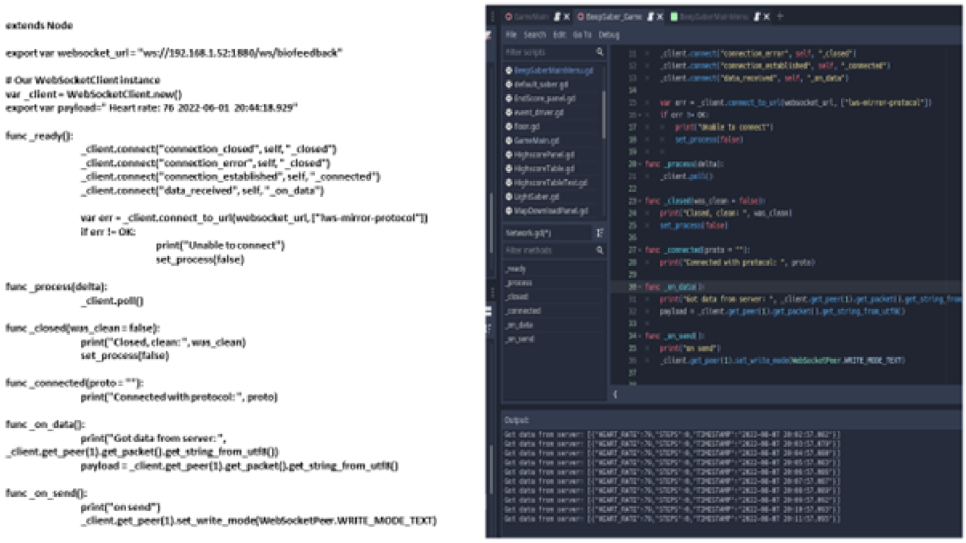

Figure 20. Godot client network setup and testing

The only section in the game that is modified to display the data in Godot is the User In-terface rich text labels for which the incoming data from the node-red server is displayed.

5 Data collection and analysis

This section covers the data collection methodology used and data analysis strategies.

5.1 Data collection methodology

Interviews are a qualitative research method and can be online-based, face-to-face, or by phone. Face-to-face interviews as a research methodology seemed ideal for getting a more in-depth user experience based on open-ended questions. It was done immediately after the simulation training session.

5.1.1 Questionnaire design

The questionnaire for evaluating the prototype's design took a more user-centric approach in terms of questions and was as follows:

1. How was the user experience?
2. What did you like about the training simulation?
3. What did you dislike about the training simulation?
4. How likely or unlikely would you recommend the finished product to a friend?
5. What, if anything, would make users want to use this product frequently?
6. What could be done better?

5.1.2 Study participants

The study involved four participants: three trainees and one trainer who was the author of the thesis.

5.1.3 Research limitations

The main research limitations included project risk factors like:

1. Time constraints, the time available to test the viability of constant monitoring of participants, and the analysis of the data collected over time between sessions was not enough.
2. Technological constraints regarding introducing new, improved biofeedback devices in the market with better measuring capabilities and features after smart band device selection was complete and devices already bought.

3. Technological constraints in terms of how vital data signs are read in the smart bands with the movement of the arm during simulation training sometimes the band can give wrong measurements, unknown values, or no values at all, especial-ly for heart rate and raw intensity. For vital signs like oxygen saturation (Sp02), one must sit still for the readings, which is impossible during simulation training.
4. Data management and synchronization from the GadgetBridge application had their own issues.

5.2 Initial user evaluation

A user experience research and usability testing enabled the understanding of the user perception of being able to monitor vital signs in the virtual environment and to check if the quality in use- ISO / IEC 25010 criteria defined in functional requirements were acceptable. The data collection method used was face-to-face interviews immediately after the simulation training. The study participants got prepped on the game, its purpose, and questions would like to answer after the training. The participants were also informed to look for the following quality in use characteristics when answering the questions: comfort, usefulness, context coverage(flexibility), and efficiency. Based on that, the overall user feedback was as follows:

5.2.1 How was the user experience?

The overall user experience was good, with the ease of use improving after familiarizing themselves with the game and controllers. Most participants found the simulation training therapeutic, said it felt good when exercising, and believed it could be an excellent way of learning while relieving stress. Only one participant experienced discomfort with the Meta quest two headset due to its size and weight being too heavy for the head and straps fitting being a bit loose, resulting in the use of a clip. Two participants noted that their heart rate slightly varied once they understood the game. One participant noted irregularities with heart-rate.

5.2.2 What did you like about the training simulation?

One user liked that the smart band alert on wrist watch gave a vibrating alert when the heart rate got too high and mentioned that it was handy also since in case concentrated on the game, could get an alert in another way. All participants liked that they could monitor their vital signs in real-time and enjoyed using the simulation training since they felt the game was motivating.

5.2.3 What did you dislike about the simulation training?

Most participants mentioned that the HUD display was wordy in the main game-play, so between playing the game and keeping track of scores, they had to choose what to follow keenly and gave suggestions for improving vital signs data displayed through the Use of images and animation to improve the look and feel and make the date-time display with less font than the scores. One participant did not like that vital signs were missing game sounds.

5.2.4 How likely or unlikely would you recommend the finished product to a friend?

All participants were in favor of recommending the finished product to friends.

5.2.5 What, if anything, would make users want to use this product frequently?

The participants suggested customizing what to display in the main HUD while playing the game in the beginning in the settings panel before the game start. Some felt that if given the option to remove time or steps would remove steps due to the game using fewer steps or displaying only steps taken within the game. Two participants suggested allowing users to choose what vital signs to display from the settings panel in all the HUD displays with vitals signs.

5.2.6 what could be done better

The leading suggestions were the improvement of the HUD display through images and animation and adding game-based alert sounds when heart rate went up or down as a form of audio feedback. Most participants mentioned that the game should link vital signs control and improvement with the game's scoring system by adding or deducting points based on whether scores are good or bad. One participant mentioned that the heart-rate change in some game-play seemed constant for a short period and found it distracting and that should look into the accuracy of dis-played data and how the data was syncing. One participant also mentioned that images like a heart with animations through enlarging or decreasing the image based on the heart rate. Other suggestions include showing the incremental steps at the end of the game. To save and show vital signs summary at the end of the game, like showing the highest and lowest heart rate achieved in the game end HUD display.

5.3 Observations

The observations made as a trainer included constantly monitoring incoming vital-signs data from GadgetBridge to laptop browser live-feed display and checking if gadget bridge was synchronizing the data as expected. The following problems occurred with data syncing:

1. The failure to start background service in Gadgetbridge alert saw it once though it was not recurrent but solved it using autostart. It was solved based on possible fix-es listed on the GagdgetBridge wiki [25] that included: using autostart, disabling battery optimization, starting on boot for the Xiaomi phone used in this study, or enabling companion device pairing.

2. The auto sync in Gadget bridge and data export while testing sometimes would get a synchronize notification on the android device. So during the training had to monitor both the phone and the trainer's browser. For the wake lock in the Termux application, one has to activate it to prevent the ssh connection between the phone and laptop from disconnecting during the simulation train-ing. The keep awake lock drains the battery, so one has to ensure the phone charge is enough for the simulation training. Trainees, when given the game to play for the first time, initially struggled with using the controllers for a few minutes but became familiar with it and enjoyed playing it. Most participants played the game at least twice.

5.4 Improvements

The summary of improvements to the prototype that can be done in the future included:

1. Use of images and animations on the HUD vital signs data displays.

2. Use audio feedback to monitor how trainees attempt to implement or control their physiological changes. It could benefit the trainer and trainee, who are both alert-ed.

3. Addition of customization on what vital signs is displayed in the HUD display at the beginning in the settings panel.

5.5 Discussion

RQ1: To what extent can the solution bridge the gap between biofeedback, virtual reality, and serious games?

The solution showed the possibilities of incorporating vital-signs capture and ways cost-effective biofeedback devices could be used.

RQ2: Is it possible to show vital signs to the facilitator in real-time?

Based on the results, it is possible to capture real-time data and display the vital signs in the trainer and trainees' HUD monitor display. The performance, though, felt it needed further improvement regarding data syncing and auto exporting from the GadgetBridge application. The trainer must be vigilant to see if the devices are connected and if data flows as expected. Termux had an awake lock option that helped the device stay awake and allowed back-ground services to run, ensuring the connection had no disruption when the phone was idle.

RQ3: How is the user experience in the virtual environment compared to the real-life training environment, and is it a viable solution to solve real-life training problems?

The participants were optimistic about using a vital-capture system in a real-life training scenario and felt the tool would be therapeutic in stress management.

RQ4: How effective are cost-cutting measures in developing the prototype using readily available resources and open source tools?

Using node-red for rapid prototyping and GadgetBridge to bypass vendor-locked software made it possible to cut costs and save time in terms of development costs. Node-red when generating flows, one only needs Javascript, HTML, and CSS for coding. Once one knows how to install missing palettes that use as nodes and how to combine and deploy, the learning curve for beginners with time decreases.

6 Conclusion

The developed biofeedback prototype can be a valuable tool if incorporated and tested with Serious games designed to simulate the real-life training scenarios experienced by people working in a stressful environment as a vital signs capture tool.

The solution showed the possibility of linking Virtual reality and biofeedback techniques with serious games methods and strategies using open-source materials for rapid prototyping and cost-effective devices to create the prototype.

The prototype testing during development, data capture, storage, and processing enabled identifying the areas that could be further improved in future works since the prototype had the minimum viable features.

Future work included testing newer wearable, cost-effective smart bands that can use third-party applications to see if sensor readings had improved with time and if the filtered data is less than the device used in the study.

Other future recommendations included:

1. Improving UI design through images, animation, and audio feedback to alert users on the variability of the vital signs when linking it to the serious game
2. Testing the bidirectional flow of data from Godot engine game to node-red WebSocket for display in trainers browser,
3. Improve the data synchronization in GadgetBridge to be more efficient since one sometimes had to manually sync and export during the simulation training as the trainer.
4. Enabling one to carry out training remotely with a less complicated prototype setup during simulation training
5. Incorporate data analysis and report generation in the prototype.
6. Make the vital systems capture remote so that the trainer and trainee do not have to be in the same room.

7 Timeline

This chapter summarizes the timeline taken to do the research and develop the prototype.The Figure below gives an overview of work done and study taken to learn Godot and improve on my node-red knowledge.It should be noted more work was done to familiarize myself with components used, develop the prototype and test both the prototype and user for feedback.

Date or period	Task and description	Hours
Early march 2021	Topic selection and discussion with the supervisor	4h
Sep- Nov 2021	Open source tools and components research, analysis, and smart band token retrieval and comparison of retrieved data from gadget bridge and vendor-based application	90 h
Nov 2021	Thesis initial action plan report	4h
Sep 2021	Smartband device testing	15h
Oct 2021	Smartband device testing and third-party android integration	15h
Oct 2021	Biofeedback data analysis	10h
Jan 2022	SSH and Node-red environment setup in Android and laptop and testing	10h
March 2022	Meta account creation and quest two development environment setup.	10h
March 2022	Node-red refresher course	30h
March 2022	Node-red implementation and testing	80h
April to July 2022	Godot engine environment setup for serious game System Integration -Youtube video tutorials on Godot, Android, and oculus setup. -Godot beginners course-Udemy- Godot editor, Nodes and scenes, Instancing, scripting, signals, Pong game and star shooter and practice - Reading Gdscript basics in Godot documentation-getting started	80 hrs 4 hrs 20 hrs 20 hrs

Figure 21. An overview of time taken to develop prototype

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Appendix

I. Glossary

Terms and Notations

APK Android Package

BVP Blood Vessel Pressure

$CGAR$ Compound Annual Growth Rate

CSV Comma Separated Values

$EFAMH$ European Framework for Action on Mental Health

EMG Electromyography

HRV Heart-Rate Variability

HR Heart Rate

HUD Heads Up Display

IDC International Data Corporation

IP Internet Protocol

IoT Internet of things

LAN Local Area Network

OCD Obsessive-Compulsive Disorder

PC Personal Computer

RIP Respiratory Inductance Plethysmography

SSH Secure Shell Protocol

UI User Interface

VR Virtual reality

XR Extended Reality

https://github.com/Onunda/Biofeedback_Prototype

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