Wearable technology as game input for active exergames

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***Abstract*—Wearable technology and exergames are topics with a growing interest since the wide adoption of the Internet of Things and other technological advancements around machine to machine communication. Our paper extends on existing work that combines heart-rate readings through body sensors as a means of playing a game or interacting with a game in real-time and proposes a development framework for exergames that use physiological signals through wearable technology as player input and combine with the Internet of Things. Our focus is on producing single experiences, that directly embed the wearable technology into the gaming experience, using heart-rate as the sole form of input in our methodology. We analyse the applicability of our proposed framework through the development of a proof-of-concept platformer game that where speed of character movement is produced through the player's heart rate. We highlight the empirical nature of our work and present the future directions of our research along with recommendations for researchers that wish to introduce their own solutions in the area.**

***Index Terms*—wearable technology, heart rate, affective games, exergames, serious games, games for health**

I. Introduction

Adaptive serious games describe a digital gaming experience that reacts to the player's capabilities and needs, personalising the experience during gameplay [1]. Serious Games and gamification are established fields of research dating back to the 1970s [2]. Serious Games describe the design and development of games that aim to engage an audience in an experience that is not for pure entertainment alone [3]. Serious Games are not confined to a digital form either. Gamification, describes systems or processes that embed game elements to improve the experience of the audience and engage them better [4]. Exergames describe games that focus on improving physical movement, balance and other activity related health improvements [5]. The latest advances and availability of sensor technology promotes new research into future developments on how we may improve the experiences we offer through serious games and gamification, when considering adaptive gaming through sensors.

The combination of serious games, gamification and the Internet of Things (IoT), termed as Smart Serious Games and Smart Gamification [6], has advanced to consider applications in smart cities [7], healthcare [8] and education [9]. With IoT devices becoming cheaper to obtain and more widely accepted in culture, an influx of sensor data has been observed [10], suggesting more research and innovation should be expected in the future for the field of Smart Serious Games.

Games for Health is a sub-category of serious games focused on improving health treatment or training around health using immersive experiences that follow the principles of games design and games development [11]. Considering the adoption rate of wearable sensors, such as smartwatches [12], new potential for developing gaming experiences for health that integrate sensor readings in real-time into the gaming experience has emerged.

While existing research in the field provide examples of optimising the heart rate of a person through a game [13], providing rewards for a game experience based on active heart rate [14], providing manual readings into a game experience [15] or optimising difficulty based on heart rate [16], no literature exists to our knowledge that examines how to integrate heart rate connectivity into a single solution, allowing people to control a game in real-time through their heart rate alone. We consider how is it possible to develop such and experience and why such an experience can help players reach a desirable level of exertion, where exertion describes "Rigorous physical activity" [17].

We present an affective games [18] development framework for the integration of smartwatch data in real-time, allowing gameplay to occur through pulse rate alone and explores how such a technology can transform research into games for health. We consider a case study of a 2D-platformer game and how it can be applied to improving physical health, based on our proposed development framework. We continue by considering the limitations of our case study and detailing how future work can expand on our method to advance their research in the field.

II. Background

The combination of Serious Games with sensors for adaptive experiences is an area of interest that is increasing in popularity and diversity. Smart Serious Games, includes applications for healthcare [8], student engagement [19], frameworks [20] and more. The principle behind Smart Serious Games relates closely to the theory of adaptivity [21]. Adaptivity enables computer solutions to react to the users, personalising the application, often in real-time. By connecting sensors to players, we are able to adapt and personalise gaming experiences, creating several benefits, such as higher engagement shown by Mitsis et. al. [22]. Adding adaptivity to serious games can create a more immersive and engaging experience and improve user acceptance of serious games [1], highlighting the necessity for further research in the field.

A. *Serious Games for Health*

Serious Games for Health is a growing topic that encompasses physical and mental health. The success of game-based interventions for promoting positive health outcomes depends on the motivation and engagement of players. Games must be both entertaining and functional to achieve serious outcomes and understanding the relationship between game elements and player motivation is crucial [23]. Games have the power to immerse and motivate players, making them effective tools for fostering cognitive gain, awareness, and behavioral change. This has led to an increase in the development of games for health in research and real-world contexts [24].

A review into games for physical health discovered potential through mostly empirical studies that examined the concept [25]. A recent review of the research evidenced further positive results from empirical studies [26]. Games for health extend to Virtual Reality (VR) and cardiac rehabilitation, helping players reduce pain and improve movement, though again these studies are empirical and lack longitudinal studies at large [27]. The results of a systematic review on games for behavioral change [24], particularly for the health studies samples, showed the priority of involving the contextualised challenge element and several ways of rewarding either through scores/points, or incentive feedback. A meaningful feedback loop is considered important, be it through sensor input or not.

VR games for rehabilitation or Virtual Reality Exposure Therapy (VRET) empirical research identified the potential for integrating sensors in personalising the therapy elements within the virtual environment [28]. The automated approach aligns with our work conceptually, though their research did not present any developed games experience at this stage and the sensors they describe are stated as a hypothetical solution. We present the early stages of our research into using heart rate to control and adapt an exercise game with a working solution towards adaptivity in games.

B. *Exergames*

Commercial sports games, or exergames, such as the Nintendo Switch Sports [1] demonstrate public acceptance around sensor integration for sports games. Nintendo's 3rd Quarter results disclosed 8.61 million copies of Nintendo Switch Sports were sold from release to December 2022 [2] further evidences the popularity of sensor driven exergames. Nintendo use Bluetooth controllers with an array of embedded sensors that is designed and developed bespoke for their console system. Within their controllers, they include an accelerometer and gyro-sensors and an infrared (IR) camera that all combine to enhance the real-time interaction with games [3]. Our research presents a single sensor input in its case study, though our development framework accounts for several sensors.

Exergames have also been used to help with mental well-being treatment [29] and used to support children with developmental disorders [30]–[32] evidencing notable applications for exergames for physical and mental wellbeing.

The field of exergames seen research embed sensors to either add another dimension to player experience and immerse players better, to innovate in how players control games to balance gameplay better or to monitor engagement [22].

Research into the impact of heart rate informed adaptivity in exergames investigated the validity of existing heart rate measures that consider optimal heart rate based on age and other parameters against pre-assessed heart rate measures [13]. Their study monitored heart-rate during a playthrough of a sports game and noted the significance on immersion through the inclusion of physiological signals such as heart rate.

Research into how heart rate can integrate with gameplay investigated how power-ups in exergames can improve exertion. The results noted that heart rate related mechanics can improve engagement with the gaming experience [14]. Their presented research did use wrist wearable sensor that monitored heart rate and provided power ups based on higher heart rate, promoting exertion. The game was controlled by a pedaling using other exercise specific equipment. Their research demonstrates an effective application for combining heart-rate into a gaming experience to promote exertion. Our case study follows the same principles and extends by reducing the hardware required to a single wearable and controlling the game experience solely by the use of a heart rate.

Other research in the field focused on using heart rate to control exercise in a game. Early work used manual readings of heart rate fed into a game to allow the experience to react and progress simultaneously to heart rate [15]. Recent advances in wearable technology allow for real-time, direct connectivity embedded alongside IoT. More recent work in the field used exercise equipment alongside a heart rate monitoring device to balance the gameplay and scale game performance [16]. Their work noted that scaling gameplay through heart rate was able to produce satisfaction in the gaming experience alone.

Our research uses the findings from the field and couples the latest technological advancements and public acceptance in wearables to propose a new development framework along with a case study. We hypothesise that a single, widely available, wearable device coupled with appropriate game mechanics can produce Active Exergames (AEG) without

[1]https://www.nintendo.co.uk/Games/Nintendo-Switch-games/Nintendo-Switch-Sports-2168292.html, Accessed 21/03/2023

[2]https://www.nintendo.co.jp/ir/pdf/2023/230207_4e.pdf#page=18, Accessed21/30/2023

[3]https://venturebeat.com/games/nintendo-switch-has-high-tech-joy-con-controllers-with-motion-detection/, Accessed 12/06/2023

the need for exercise specific equipment or other high-end laboratory equipment.

III. A DEVELOPMENT FRAMEWORK FOR WEARABLE TECHNOLOGY AS PLAYER INPUT

We propose the following development framework for the development of AEG that use physiological signals as the primary form of player input, illustrated in Figure 1. We note the benefits of low-cost widely available devices in our proposed framework and highlight the modularity of the framework, allowing future research to adapt towards their specific needs. We describe low-cost as a single wearable device under £200. It is important to note that a smartphone and a laptop or computer is required to run the game, though there are no specific needs around this, allowing participants to use their own existing devices. The framework considers IoT integration from sensors and actuators, be it intrinsic or extrinsic [20]. Intrinsic sensors describe sensor data activity that occurs from direct input from a user or player. Extrinsic sensors describe sensor data obtained from the players wider environment where the data considers the location rather than the single person. We divide our framework into five conceptual layers: user, hardware, connectivity, data and software. We also highlight three key areas of consideration when using the proposed framework: connectivity requirements, hardware limitations and applications.

A. User

Users in this context describe the players of the exergame. There are no restrictions to the number of players placed by the development framework or the location of the players. Players may be in the same room or in different countries around the world. Players may take part in synchronous experiences or be part of asynchronous challenges. When considering the development of exergames focused on exertion, researchers must ensure appropriate inclusion criteria are met for the safety of players. We propose the collaboration with experts in sport sciences for future researchers that wish to design and develop their own solutions.

B. Hardware

Hardware in our propsed development framework considers wearable technology along with sensors and actuators that may be in the same room or in the wider environment. Information on the hardware in our case study is presented in section IV-A. Consider an exergame where the player is in a virtual space that simulates locations worldwide with real-time weather and time of day changes depending on the player selection. Such wider sensor integration can promote immersion and allow people to feel better connected when exercising. We highlight the bi-directional flow between all layers as we consider actuators and sensors in scope. Where a single sensor, such us our case study, is the sole game input, it is crucial the sensor is tested for the effectiveness for the task it will perform and for the reliability of communication, considering different physical locations of play.

C. Connectivity

The connectivity layer describes the internet protocols, topologies and networks required to combine wearable technology along with other sensors and actuators into an exergame experience. We focus on two conceptual components within the connectivity layer: local and world wide. Local solutions would operate in a single space where the user or users are present. Consider an exergame used within a classroom where a local server within the school is handling all communication. The connectivity layer also considers machine to machine communication such as Bluetooth, Bluetooth Low Energy (BLE), Zigbee and others. Section IV-A describes the connectivity used for our case study.

D. Data

The data layer focuses on what data is sent from our sensors and actuators towards the gaming experience, how will the data need to be transformed from a raw reading to a meaningful value in the game and what filtering is required to ensure the correct quality of data is reaching our game. It is possible researchers will choose to embed the data processing either within the sensors themselves prior to data being broadcast over a network to minimise network traffic. We recommend researchers attempt to minimise the amount of data being broadcast to and from the hardware layer to improve their security and reliability. We also suggest data filtering occurs either at middleware or within game development solution, remembering that we describe real-time communication with the wearable.

E. Software

The software layer consists of the digital game produced as part of an exergame experience. Note that we separate the game from the game mechanics conceptually. Game mechanics describe the software packages used to handle game input [33]. Though the game mechanics will be part of the gaming solution we separate the concepts to amplify the distinct nature game mechanics have with the hardware layers. Future research should aim to produce experiences where the user does not disengage from the gaming experience due to sensor set up or the intensity of the sensor requirements on the player. Consider an exergame where the player is not allowed to rotate their body to ensure the sensor readings perform to the required standard. Such an exergame would be limited in effectiveness as the experience becomes disconnected from the technology. Researchers should carefully design mechanics that align with the strengths of the hardware used. This change to the game mechanics requires careful design processes, such as the use of accelerometers to capture and punish the player for not following the rules.

F. Connectivity Requirements

In this context, connectivity considers not only the internet protocols, quality of service and network architectures, but also the physical space where an exergame may be played in. It is possible to combine several mini-games into one

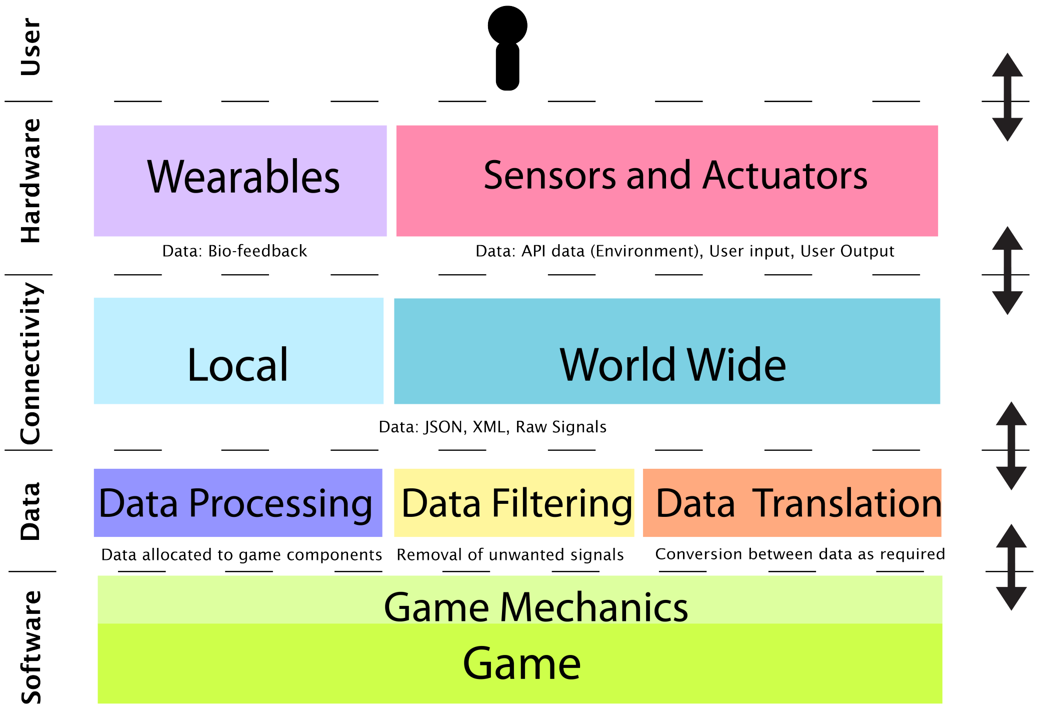

Fig. 1. Development framework for wearable driven games that combine with IoT.

large exergame experience that would see several connectivity requirements driven by each mini-game be used for one overall active exergame. Similarly, we acknowledge that the sensors and game mechanics are driving factors when specifying the connectivity requirements of an active game that uses physiological sensors as input. Our case study details a standard example with low connectivity requirements. We advise researchers to scale up the connectivity requirements accordingly.

G. Hardware Limitations

We highlight hardware limitations as a design requirement as the combination of physiological signals for game input can introduce barriers to experience. Consider a game experience that requires a low latency skin conductance readings to adjust the level of stress induced on the player in real-time. Such a mechanic would need to consider the connectivity requirements along with the maximum possible sample rate from the sensors. No specific measure of latency can be defined as minimum acceptable as the game experience should set the requirements around connectivity. We highlight game mechanics in our development framework as it drives the innovation around the field. Our case study implements game mechanics by reducing the hardware requirements and only sampling heart rate once per five seconds, while building on the research identified in the background section. Efficient use of physiological sensors must be considered at the conception phase.

H. Applications

A wide range of applications is encouraged as future works from our proposed research framework. The application area will drive connectivity requirements and the hardware involved in the field. We recommend applications that extend beyond laboratory settings and allow players to easily play the game at a location of their choosing. We highlight the low-cost and low-technological barrier of our case study as key benefits to our interpretation of the proposed framework. We further recommend the minimisation of computer literacy around future applications of our proposed framework to allow a range of ages and social-economic backgrounds to benefit.

IV. Case Study

We present our exergame named Cardia as a demonstration of our proposed development framework. Cardia converts real-time heart rate obtained through a smartwatch to player speed in a 2D platformer runner. We utilise one reading per five seconds to minimise data traffic and optimise reliability. We note that there is a one to one relationship between player, smartwatch and exergame in our solution. Our case study features a one-directional input data flow, which influences the visual and audio feedback through the game provided to the player. Figure 2 illustrates Cardia's system architecture. The system contains two applications, and a game, connected through Bluetooth, Internet connection and Cloud Websocket.

A. System Design

Before exploring the relationship of Cardia and our development framework, we detail the physical set up of the game

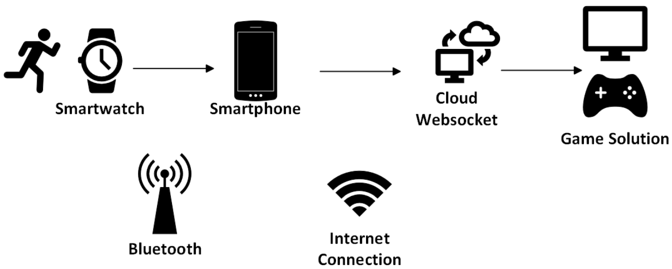

Fig. 2. System architecture for a game controlled by real-time heart rate named Cardia

and how it is played in 3. The player runs or performs other exercise on the spot, in an attempt to raise their heart rate, allowing the game to run in smaller rooms. The player sees the game projected on a monitor or TV from a laptop or computer that runs the digital game. The feedback from the heart rate to the game is in near real-time, helping the gaming experience meet its adaptivity aim.

The hardware layer consists of a FitBit Versa 2 for our wearable. We consider the smartphone within the context of our wearable as it did not offer any extra sensor readings nor did it act as an actuator for the experience. The smartphone receives the heart rate from the FitBit and then sends that information to a cloud websocket provider. We used PieSocket as our websocket provider. Two software applications are required, one on the smartwatch and one on the phone, to enable the communication of heart rate from the watch to the Internet. We have made the code for these two applications available on GitHub [4] to help accelerate future research in the area. We have not released the game solution on GitHub.

Our game solution was developed using the Unity game engine. We programmed the websocket communication directly into the game solution. In line with our recommendations discussed in Section III, we designed two game mechanics that focused on the abilities of our hardware and connectivity, the ability to run and jump in-game. Running used the heart rate data and translated the value to a float 5% the original value. For example, a heart rate *Hr* of 100 beats per minute would result to a float speed *S* of 5, as shown in Equation 1. We strained the game using various percentages before deciding on the speed that matched the desired experience the best.

$$S = Hr * 0.05 \quad (1)$$

We introduce two types of jumping, jump *J* and super jump *SJ*. Jump requires the player to exert themselves for 15 seconds in attempt to raise their heart rate. We calculate the average heart rate *AHr* of the three samples we receive over the 15 seconds and translate the value to a float that is 12.5% the original value, as show in Equation 2. Again, we used empirical tests to determine a value for jump and super jump that matched our expectations for the game experience.

[4]https://github.com/doctorhenry/FitBitGame, Accessed: 22/03/2023

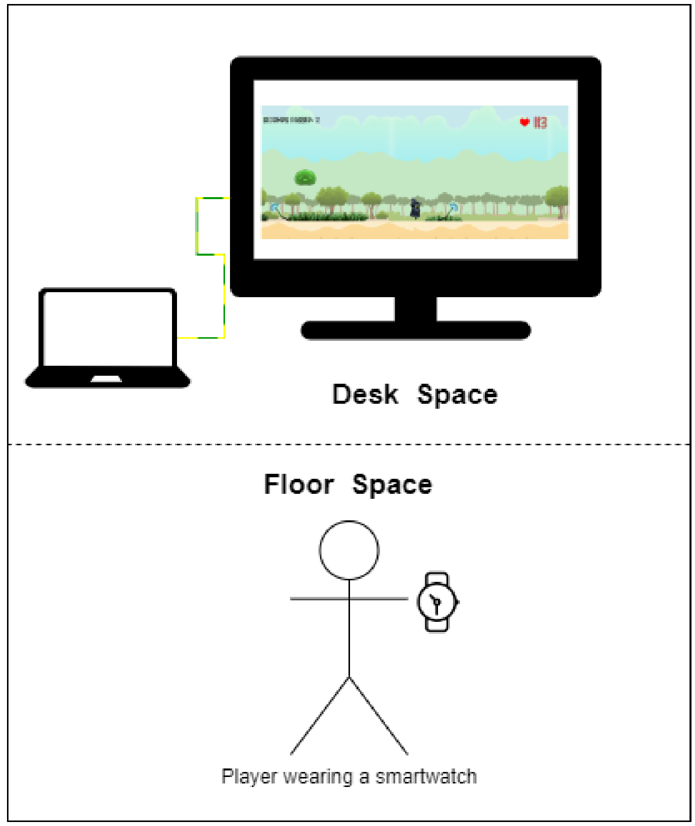

Fig. 3. An illustration of the physical set up of the game detailing how the game is played

$$J = AHr * 0.125 \quad (2)$$

Super jump still uses the last three sampled heart rates to determine an average but does not require the player to exert themselves for 15 seconds as it is placed in the gaming experience after a period of sustained stress. We increase the multiplier as shown in Equation 3.

$$SJ = AHr * 0.275 \quad (3)$$

B. Game Design

The art style of the game used creative commons art available from itch.io [5] as the art was not a significant component of our case study. We focused our design efforts on replayability, positive sense of stress and healthy competition. The running mechanic described above was implemented to avoid being caught by a slime monster that chases the player, as seen in Figure 4. As the character would always move while a heart rate signal was present, the game allowed the player to feel a positive levels of stress to avoid being caught by the monster.

We integrated the jump mechanic as an element of strategy as well as replayability. Players with low heart rate and low exertion can reach the jump pad but would be caught by the monster as a consequence because the player's avatar remains

[5]https://maaot.itch.io/mossy-cavern, Accessed: 22/03/2023

Fig. 4. Player running away from a slime monster in game using their heart rate

still while generating the samples that are in turn translated into a jump. After several iterations we separated the jump pads in the distance pictured in Figure 5.

Fig. 5. Player exerting themselves for 15 seconds with countdown to jump onto platforms

We introduced a second slime monster that moved at a higher rate while instantiating further enemies before the player is able to use the super jump mechanic, seen in Figure 6. Players would have to exert themselves motivated by the positive stress induced from the faster enemy. The super jump helps the player's avatar escape from an underground tunnel they fall into, back onto ground level, where after a short distance they are greeted with the finish flag.

If any of the slime monsters in our case study collide with our player's avatar, the game ends and the player is presented with how long they lasted in the game along with the option to try again. Early trials at public showcase events indicated that players will perform better in their second attempt at the game, as they heart rate is already faster than their resting rate. To win the game, players must cross the finish line on ground level. Once a player wins the game, they are presented with the three fastest times for completing the game and are placed on the leaderboard if their attempt is within the range, as seen in Figure 7. The use of the leaderboard fosters healthy competition against self and other players that may be participating before or after.

We used an animated heart icon that responds to the heart rate readings and displayed the current heart rate reading to provide positive feedback to the player with an aim to further motivate the player to engage with the experience. Early trials shown players relied on the visual feedback to ensure the

Fig. 6. Player approaching a super jump pad after a period of sustained exertion

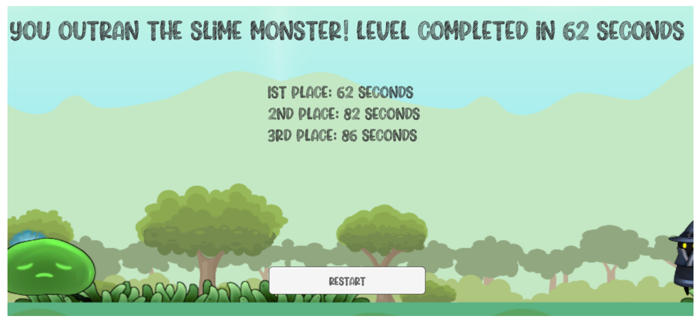

Fig. 7. Player win state including a leaderboard of the three fastest times for completing the game

system was working as expected and as a metric to the current level of exertion they need to perform in the game. Likewise, the games audio pitch has weighting based on the players heart rate. Thus, players with a low heart rate will have a low pitched audio and as the heart rate increases the pitch will become higher.

V. Discussions

Our paper introduced a framework for developing a AEG using physiological signals, in the form of player heart rate. The development framework demonstrates how wearable technology and IoT can combine to create a single, real-time AEG. We extend on the existing research where physiological data is used as part of a gameplay mechanic or combined with other forms of input and developed a case study where real-time heart rate is the only form of input, as highlighted in Table I. Furthermore, the proposed framework enables more flexibility in the physical setting of the experience, allowing exergames to be implemented in natural environments, schools and more.

Our developed game evidences the use of our proposed framework. Due to the empirical nature of our work, no experiments with participants have been conducted, though the game has been presented to the public in three separate occasions. Firstly, the game was presented to a community

TABLE I
COMPARISON OF EXISTING HEART RATE GAMES

Author	Natural environment	Sensor only	Ubiquitous technology
[14]	X	X	✓
[15]	X	X	X
[16]	X	X	X
Ours	✓	✓	✓

panel on AI transparency as part of a project that *"aims to build public trust in artificial intelligence (AI) and repair negative perceptions created by the media"* [6]. The developed game was also used as an outreach activity in two occasions. The game was played by the general public at the Manchester Museum as part of the British Science Week [7]. Data collection was prohibited at the event due to underage participants but we have been permitted to disclose that the overall reception was positive by those that experience the game. The game was also presented to the public at the *Get Curious* [8] event hosted by the Science and Industry Museum in Manchester. The data obtained from this event will be made available at a later date as it has not been released by the Museum yet.

A. Future Work

The case study will be developed into a full exergame with the help of an expert from sport sciences. Our vision is to use the game to help promote exercise to children and adolescents in schools. We envisage the low cost and pervasive nature of our game to be key drivers in adoption. We will also perform further research on adaptivity, tailoring the experience based on the goals set by an instructor and the real-time physiological response rate of the player. Once the full game is developed we will run a longitudinal study to test the effectiveness on our game against level of fitness and uptake of exercise compared to a control group with the standard physical exercise practise.

B. Limitations

We note system and practise based limitations with our case study. First, FitBit permit one wearable per smartphone companion of the same time. This causes scalability issues, requiring multiple phones to be purchased to accommodate for more than one player at a given time. Future work could consider adopting a different wearable to overcome this technical challenge. We envisage installing the application on peoples own devices promote adoption. We highlight that Fitbit have sold 37.4 million units of since the release of the FitBit Versa 2 in 2019 [9], evidencing a significant adoption of the technology.

We also consider the use of heart rate as a limitation for players that may have a heart condition. Aside of the health risks that may be associated, certain conditions where a player would be safe to take part could either boost or reduce the player's ability in the game experience, disassociating from the player's level of exertion. We recommend future research embeds expertise from sport sciences to determine how these user cases can be resolved.

[6] https://www.mmu.ac.uk/research/research-centres/cfacs/projects/gm-people-panel-ai, Accessed: 23/03/2023

[7] https://events.manchester.ac.uk/event/event:ms0-lcszuk9z-kaogkc/british-science-week-at-the-manchester-musuem, Accessed: 23/03/2023

[8] https://www.scienceandindustrymuseum.org.uk/whats-on/get-curious, Accessed: 23/03/2023

[9] https://www.statista.com/statistics/472591/fitbit-devices-sold/, Accessed: 23/03/2023

VI. CONCLUSION

Our paper introduced a development framework for AEGs that use wearables for player input and combine with IoT. We demonstrate the applicability of the proposed framework via a heart rate driven game, using the FitBit Versa 2, named Cardia. We have presented the game to the public at three separate events but have not been able to gather or analyse data either due to the nature of the event or due to the time the event took place and the time of writing this paper. We highlight that the lack of statistical conclusion does not deter from the scope of our paper, presenting a new development framework and a working case study based on our proposed framework. Though we have not been able to present a statistical conclusion we are able to share that the public adopted and engaged with the game in all events. In future, we will carry out a longitudinal study on an expanded version of Cardia used for engaging children and adolescents with exercise.

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