Giro: Better Biking in Virtual Reality

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ABSTRACT

We present the prototype of a wireless tracker developed to improve functionality and experience of biking systems using virtual reality (VR) for augmentation.

VR has shown promise as an assistive technology to promote physical activity for older adult users. In previous studies, nursing home participants' intrinsic motivation to exercise has shown to increase when using VR to augment their biking exercise routine. The presented VR augmentation system previously used a wired Arduino UNO microcontroller, with magnets and Hall effect sensors to track the pedaling behavior of users. The prototype for a pedaling-tracking device that we present in this paper improves the real-time synchronization of proprioceptive and visual feedback to user actions along with an increased ease-of-use and flexibility, which can suggest future directions in VR technologies for various applications in both domestic and professional setups.

The new prototype presented is currently deployed for initial testing in two rehabilitation centers for older adults in Frederiksberg, Denmark.

Keywords: Virtual reality, domestic VR, immersion, user experience, wireless microcontrollers, gesture control, proprioceptive feedback, exercise, healthcare, rehabilitation, exergaming.

Index Terms: [Electronic design automation and methodology]: Virtual Reality; [Control systems]: Microcontrollers; [Engineering in medicine and biology]: Public Healthcare

1 INTRODUCTION

Augmenting the indoor stationary biking experience with virtual reality (VR) is not a new topic and it has been investigated by researchers through the past twenty years [1][2] on systems capable of higher and lower levels of immersion using visual, haptic and auditory feedback.

In recent studies [3][4][5], VR has shown promising indications that multimodal virtual environments (VEs) can increase exercise motivation for nursing home residents. The interaction design of the augmentation kept to the function of the original exercise routine, while providing the experience of an outdoor bike ride in nature. Nursing home residents enjoyed the augmentation and exploring the nature content. Some felt this allowed them to 'experience another place', which confirms results previously achieved in different contexts [5]. This is important, as nursing home residents need to uphold regular physical activity, to maintain their functional independence.

Following the notions of Slater [7], the sense of presence relates respectively to the place and plausibility of the illusion. This refers to the sensations of (respectively) being 'there' in the virtual world, and perceiving that events in the virtual world are actually happening. According to Slater [8], immersion refers to degree at which our senses are stimulated by a technological system and from the sensorimotor contingencies (SCs) it supports. SCs can be seen as contextually and perceptually meaningful actions in the VE. For an exercise-based VR system such as ours (Figure 1), the kinesthetic and proprioceptive cues from the exercise actions represent natural SCs, which are transferred to the VR exercise.

Figure 1: Using the VR system for bike exercise rehabilitation.

The better the mapping of the physical actions of the user onto the VE feedback and/or behavior, the more convincingly the proprioceptive stimuli can serve as a cue to defend the plausibility of the VE. And thereby the user's sense of presence inside the VE. This paper describes the construction and contextual function details of a system designed to improve such mapping from a cadence tracking system, to a real-time rotation controller.

2 BACKGROUND

To perform their exercise routine, users "bike" on a manuped: a biking device for simultaneous hand and feet pedaling, which can be used also seating on a chair, as shown in Figure 1.

When the session begins, users are offered the choice between four nature-based VEs: a mountain road, a city park, a snow-covered pine forest and a country side road around a small lake. An example image from the city park VE can be seen in Figure 2.

Our test systems, currently set up in a nursing home context, uses both a Samsung 8000 series 75" UHD flat screen TVs and Oculus Rift CV1 head mounted displays (HMD) as not all users are comfortable wearing a HMD. For the same reason, sound can be delivered through either headphones or loudspeakers, should certain users dislike some or all of the wearables.

When not running a VE, the flat screen TV displays images of the four VEs, for the user to choose between them, as can be seen from Figure 3. For more information on the VE designs, see [11].

A therapist guides the user about the display options, and helps the user activate the VE of choice, with the technology of choice. When the program starts, the user (VR camera) is positioned on a path inside the VE of choice. When the user pedals, the position inside the VE moves forward along the path. In most of the VEs

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there are several routes, which are chosen at random by the program. The users are not able to steer themselves, based on focus group results in a pilot study [3].

The manuped (partly visible in Figure 3) can be turned, so it either caters for exercise focusing either on feet pedaling only (with a handle bar) or combined hands/feet pedaling. When users choose the HMD option for visual display, the manuped setup allows only feet pedaling, for safety reasons. In a previous study [5], some participating nursing home residents showed a lack of proprioceptive awareness while using a HMD setup. Situations occurred where they would have hit themselves in the head with the hand-based pedals, had there not been an attending researcher present to hold their torso backwards. For this reason, combined hand/feet exercise has been prohibited in this setup.

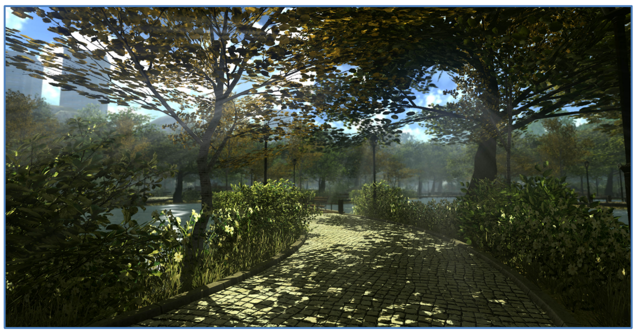

Figure 2: The city park VE

Figure 3: The TV displays the options for VE rides.

In our initial setup, the biking activity was tracked as cadence, by a mechanism where a small magnet attached to a pedal arm passes a Hall effect sensor placed on the manuped chassis (as shown in Figure 4). When the magnet passes, the sensor triggers and outputs a signal, which signifies a completed rotation cycle of the pedal arm. Similar tracking systems, where cadence is used to calculate speed, have been used in bike computers for decades. They remain the standard of many ANT+ based systems developed by e.g. Garmin, Motorola and Bontrager.

As we've come to realize, contemporary ANT+ systems are still relevant and applicable, because of the nature of the exercise and speed of the rotation cycle. Magnets are most often placed on very fast-spinning bike wheels. This means that the quantity of readings per second are large enough to detect speed changes quickly. And it also means that the cadence of the wheel is measured (and pivotal), not the user behavior on the pedals.

Being pedal based, our initial cadence tracking system generally had slow cycles completions, especially compared to bike wheel based solutions. This created imprecise pedaling feedback. For users biking at a slow pace, it could result in latency of several seconds. Certain professional training situations have been seen to take advantage of such slow setups. The small discrepancy between the real instantaneous biking speed and the VE cues, actually makes it possible to deceive the biker's perception of speed and distance, thus achieving higher speeds without the user even perceiving it or experiencing more fatigue [9].

At the nursing home, the slow system was neither an advantage nor a big disadvantage; as residents rarely changed pace once they pedaling began. The overall system was generally given praise, and latency issues were never mentioned by either nursing home residents or therapists. It is therefore likely that it was not a problematic feature of the system, and we can assume that the cadence tracking was able to output biking speed for the VE, to a satisfactory degree.

However, under different exercise conditions; with either the need for precise speed measurements or fast speed transitions (such as interval training), the latency of the magnet based system would become very noticeable in use. The mapping latency has been noticed regularly by many users during (later) internal testing, or when showcasing the nursing home version of the system at public demos and events. In most cases, it was suggested that it decreases the user experience of the augmented biking.

As the VR rehabilitation bike system is currently expanding its position to include hospital rehabilitation clinics, it brings a wider user spectrum and the need to account for different biking behavior, compared to the nursing home routines.

In addition to have the latency issue solved, the new hospital rehabilitation partners required other critical requirements to be implemented to the setup before instatement, such as flexibility, safety, and everyday ease of use.

Flexibility relates to the ability to change the tracking control from one exercise/rehabilitation device to another, quickly (e.g. one bike to another in the same room, something that so far is not easily achievable nor with our system or others [10]). Safety relates to anything that might endanger hospitalized users, such as the presence of wires, or protruding parts attached to the rehabilitation devices. Everyday ease of use relates to the device being simple to work with, and intuitive for non-experts.

To inform the changes made in the new tracker, we will quickly review the previous and new systems.

2.1 Previous setup

The initial system overview can be seen in Figure 5. The magnet is attached to the pedal arm and the Hall effect sensor is attached to the manuped frame. The Hall effect sensor is connected to an Arduino UNO[1] microcontroller and triggers the signal every time the pedal passes in front of the sensor position on the manuped chassis (as shown in Figure 4). The Arduino is connected to a PC running the VE. The VE is audiovisual, and is displayed through 2.1 speakers and either an Oculus Rift HMD or a flat screen TV. The sensor applied to the bike streams data to a desktop PC, where it's routed to a Unity3D script that controls the forward movement in the VE, along the fixed path. The Arduino code streams the value being read by the Hall effect sensor via USB, sending a continuous sequence of 0s and 1s. These binary values are received in the PC by a small MaxMSP[2] code which reads the Arduino serial port, clean incoming sensor readings, and route them via a netsend object over an internal loopback TCP/IP connection to Unity3D. In Unity, a single value of "1" is received at every complete pedal cycle.

[1] https://www.arduino.cc
[2] https://cycling74.com/products/max

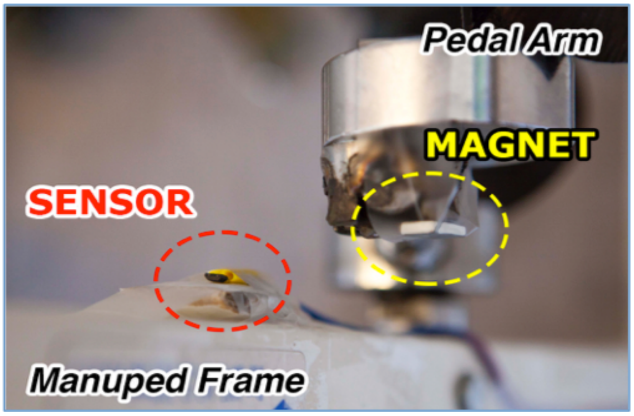

Figure 4: Hall Effect sensor and magnet on manuped chassis

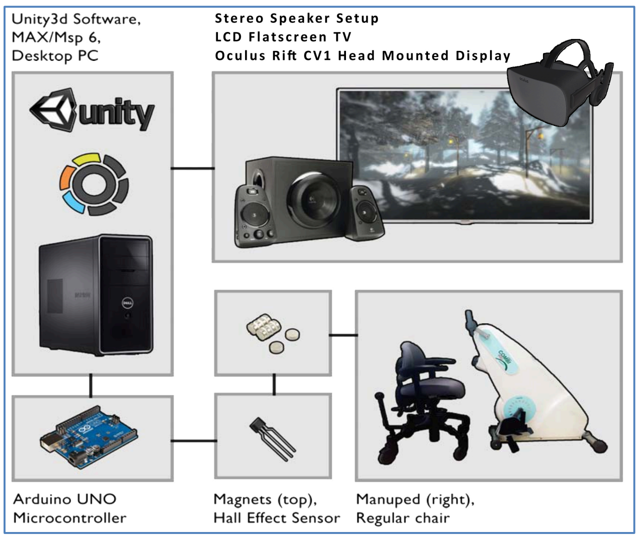

Figure 5: System overview for initial VR bike exercising.

Inside Unity3D, three custom-made scripts would interpret the 1s values into forward momentum in the VE: 1) a 'pedaling' script checks for the Arduino input and sends data to 2) an 'interpreter' script, which detects input triggers every 'FixedUpdate' recording the timing between sequential triggers and estimating the revolutions per second. Finally, 3) an 'acceleration' script would check for the time between successive trigger events from the interpreter script, to estimate whether to keep the camera speed constant, accelerate or decelerate.

2.2 New Setup

The previous setup lacks requirements in all areas previously mentioned: functionality, flexibility, safety, and everyday ease of use. Functionally, the feedback latency was too high for interval training to be feasible. Due to the wired nature of the Arduino and sensors, quick flexibility to reposition the tracking device is difficult. Wires also affect safety, in a space with lots of user traffic, transport aids and ill-balancing users.

Meanwhile, the previous system required that not only the Unity3D program should be opened, but also the person operating the system had to open a MaxMSP window and correctly select several check boxes before starting the training session. A therapist in previous studies learned this procedure, but it should be simpler.

Requirements for the new design were:

- Functionality: very little latency is key to make a 1:1 mapping of user action and system reaction also at slow pace pedaling.
- Flexibility: the tracker has to be inherently easy and fast to attach on similar bicycles/devices.
- Safety: The device needs to be as compact as possible, and wireless.
- Easy operation procedure: need for a self-configuring device that requires no setup and eliminates the precedent multiple-software chain in place. As soon as the tracking system and the computer are turned ON, they should just work without the need to setup anything. (Ideally, the tracking device should almost "be forgotten" by the users who would need only to start the VR software.)
- Easy battery recharging procedure for the tracker.

Based on these requirements, "Giro", the new tracker, became a small and compact wireless device with an embedded gyroscope, which can be attached to the bike or manuped pedal with a Velcro strap, without exceeding in measures the pedal thickness.

2.2.1 Giro's Hardware

A gyroscope, a microcontroller, and a battery are embedded together into a self-contained laser cut chassis. The electronics for the current prototype consist of an Adafruit Feather HUZZAH board[5] with ESP8266 WiFi chip, and an ITG-3200 gyroscope (Figure 4). Both the gyroscope and the HUZZAH board feature low levels of energy consumption resulting in the total demand of ~90mA of current in operation, and ~8mA in standby.

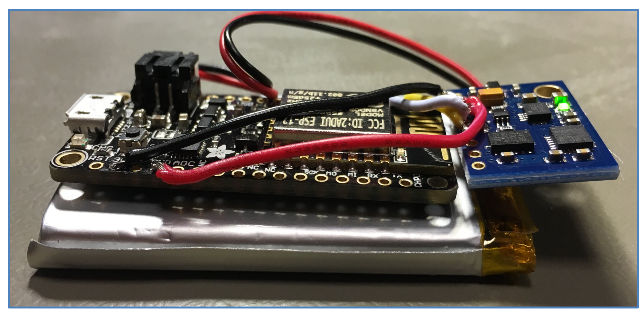

Figure 6: The wireless system.

The tracking system runs on a 3.7V, 1200mA LiPo battery for enough hours (more than eight) to cover an entire day of training exercise, which makes it easy for hospital and clinic operators to establish a daily routine for recharging the battery overnight. The microcontroller features an onboard recharging unit, and it can be simply recharged connecting the device to a standard 5V microUSB smartphone-like power adapter.

To attach the device to the pedal in the easiest way a design was developed so that all the hardware components fit into a small box, that is easily attached with a strap of Velcro around the pedal on its side (see Figure 7). This way the tracking device do not interfere with the design of the bike or with the bikers' movements, and can be easily attached, removed, or moved to another bike without complex operations. Finally, a top transparent layer makes it possible for users to get basic feedback from the board such as seeing a green light indicator when operations are functioning normal. A flashing red indicator triggers in case hardware problems occur, and a yellow indicator which blinks as long as the battery is in recharging status.

[5] https://www.adafruit.com/products/2821

Figure 7: The tracking device with Velcro straps; here while charging the battery.

Figure 8: The mount method is on the side of the pedal arm (here without the Velcro for clearer visualization).

By implementing this new hardware, the latency issue could be fixed for all users, and particularly for those users who can only pedal at a very slow pace. The pedaling gesture is now sampled 20 times per second, regardless to the pedaling pace. From initial user feedback on the two setups currently deployed, this resolution is found to be good enough for all kind of users to perceive a consistent real-time synchronization between their pedaling gesture and the advancement of the VE visualization without demanding higher sampling, which would in turn decrease the battery life.

2.2.2 Software

On the software side, the MaxMSP bridge is eliminated, resulting in an additional reduction of the overall latency and in the simplification of the system: users now only need to start the Unity3D program; the microcontroller streams directly the rotational speed of the bike pedal (radians-per-second) over a WiFi UDP connection to Unity3D.

In Unity, a single script receives the rotational speed and translates it into the forward speed of the virtual camera. An "inertial system" script is implemented on the camera, to prevent it from suddenly stop in case the biker stops to pedal, and to let instead the virtual bike lose its kinetic energy over distance.

The tracker does not need any setup, as it automatically logs into the local network and starts to stream the gyroscope data to the computer as soon as a WiFi connection is established. This also helps the system to be used by non-experts such as doctors, nurses, healthcare patients, but also just by people at home on their stationary training bikes.

The new overall setup can be seen in Figure 9. It has simplified the number of elements and increased the system performance: it was immediately possible to deploy a test system into two different rehabilitation centers for older adults, without the need for a trained person or tech-specialist to be present and assist users in starting up the system.

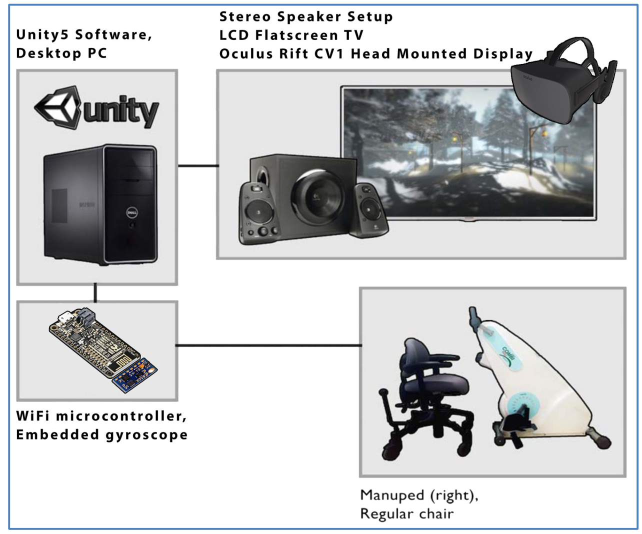

Figure 9: System overview for the new VR bike exercising.

3 Discussion

The new tracker design and functionality meets the requirements of the hospital rehabilitation clinics, while representing a noticeable performance improvement to the previous setup. The performance relates to not only the low latency, but also the very precise relationship between a user's proprioceptive cues and the feedback given from the virtual world. In future VR installations, the system will output more reliably, on minute speed differences or abrupt changes in the input from the user. This affects the possibilities for the VR rehabilitation designs, both for hospital rehabilitation centers and for nursing homes.

There are several commercial virtual bike devices available from companies such as Taex or Zwift. However, these products are built for regular road bike mount, with software that targets able and capable exercise practitioners (and relate to competitive and performance oriented aspects of the user experience). The Ebove bike experience is more immersive and custom built to the formerly mentioned, but also targets a very balance-capable user audience. The scene of VR rehabilitation (e.g. for older adults) needs to focus on the therapeutic practices first, and place the virtual augmentation on top of it. For that, our controller is likely to be useful, as long as it is able to deliver on the fundamental attributes described earlier; flexibility, safety, and everyday ease of use, found in collaboration with hospital personnel.

The benefits of the new design, and users' perceived differences to the old design are yet to be empirically validated, which is planned for a near future. Also interesting to investigate is whether or not the exercise behavior of the nursing home residents will actually be affected by the increased performance of the new tracker. Do they feel differently about pedaling through the VEs, if they suddenly have increased speed control at their disposal?

While we have support for the previous system working in nursing homes, we are starting to see early results from the test demos currently set up at the hospital. Therapists report that patients are starting to bike longer, with one patient highlighted to ride previously unseen 9 km on the exercise bike. Such feedback provides belief that the VR technology could become valuable to both patients and clinic in the future.

In the near future, we also plan to improve the design of the tracking device, making it more robust, and more energy-efficient. 3D printing should encapsulate the electronics, and the incentive to save battery life is reducing the need for battery recharge, which again helps the ease of use.

Logging the more detailed data is also now an option, due to the higher resolution of the measuring tool. User profiles could prove useful for the benefit of users who like to track their progression and reach exercise goals. Therapists can also to a higher degree be able to track and log user performance and developers/researchers can gain insights to user behavior inside the VE, preferences and responses to different aspects of the VEs. This, of course, depends on the surrounding software, but the new tracker is a step in that direction.

Also, different uses of the tracking solution should and will be investigated in future implementations. The easiness and accessibility of its setup and reconfiguration makes it possible to use a single tracker on different training devices. For example; it can easily be applied to other rehabilitation devices where users have to perform circular movements, and the VR experience can be designed accordingly to match different scenarios.

4 CONCLUSION

The new tracker upholds the everyday needs and requirements set by the hospital partners, and is likely to be a very useful tool going forward with VR rehabilitation in physical therapy. The need for new control devices such as the one introduced in this paper, has come from discovering how VR rehabilitation can promote execise motivation. In this case, for nursing home residents or hospitalised individuals, who are forced to perform repetitive exercise in order to regain function or uphold independence. From our experiences, the upgrades that the new tracker provides, could very well improve the user experience for both users and the caretaking therapists. However, studies on both usage and user experience are needed to concretely show and further discuss these advantages. We do expect that the tracker will prove a good foundation to further study flexibility, safety, and everyday ease of use of such setups, under conditions such as hospitals, rehabilitation clinics and nursing homes.

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