Buying vs. Building: Can Money Fix Everything When Prototyping in CyclingHCI for Sports?

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ABSTRACT

This position paper explores the dichotomy of building versus buying in the domain of Cycling Human-Computer Interaction (CyclingHCI) for sports applications. Our research focuses on indoor cycling to enhance physical activity through sports motivation. Recognizing that the social component is crucial for many users to sustain regular sports engagement, we investigate the integration of social elements within indoor cycling topics. We outline two approaches: First, we utilize Virtual Reality (VR) Exergames using a bike-based controller as input and actuator aiming for immersive experiences and, therefore, buying a commercial smartbike, the Wahoo KickR Bike. Second, we enhance traditional spinning classes with interactive technology to foster social components during courses, building self-made sensors for attachment to mechanical indoor bikes. Finally, we discuss the challenges and benefits of constructing custom sensors versus purchasing commercial bike trainers. Our lessons learned contribute to informed decision-making in CyclingHCI prototyping, balancing innovation with practicality.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; *Haptic devices*; *Virtual reality*; • **Applied computing** → *Consumer health.*

KEYWORDS

indoor cycling, spinning, bike, sports, prototyping

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1 INTRODUCTION

The escalating prevalence of obesity and overweight conditions among global populations presents a critical challenge to contemporary society. According to the World Health Organization [20], obesity rates have almost tripled worldwide in the past 45 years. Alarmingly, this trend extends to younger demographics; while only 2.9% of children and adolescents aged 5 to 19 were obese in 2000, this figure rose to 6.8% by 2016 [21]. Particularly in Europe and North America, unhealthy lifestyles contribute significantly to these statistics [5]. This worrying trajectory is set to have profound implications on societal health, with obesity linked to an increased risk of severe conditions such as cardiovascular diseases and diabetes [4, 11, 16]. In this context, maintaining a healthy lifestyle, particularly through regular physical activity, emerges as a pivotal solution. Engaging in sports is universally recognized as a vital approach to mitigate the risks associated with high blood sugar and elevated blood pressure, thus fostering overall health [18].

Indoor cycling emerges as a viable and accessible form of cardiovascular training. However, consistent engagement in physical activity often lessens due to a lack of motivation. Exergames try to address this issue by integrating game elements to improve sports motivation. But still, for many individuals, the social component of exercise is pivotal to maintaining regular sporting habits. As indoor cycling is suitable to accommodate varied fitness levels at once, it allows all participants to engage collectively. This can be done either through collocated indoor biking sessions or through technology-mediated communication (e.g., in VR). Researching how these different approaches influence users is a core research challenge in CyclingHCI research. It requires sensor-enabled bikes that can create realistic riding experiences. Thereby, researchers face a critical decision: whether to invest in an off-the-shelf fully-equipped indoor bicycle with integrated sensors or to construct and attach custom sensors to an existing regular bicycle. We started working on projects addressing both scenarios. Firstly, we acquired the Wahoo KickR Bike, integrating it into VR exergames to serve as a high-fidelity, bike-based game controller with haptic feedback. Secondly, we developed and attached custom sensors to traditional, mechanical indoor bikes. Our objective with the latter was to maintain affordability and scalability, while ensuring ease of attachment and removal from existing bikes. In this work, we discuss the challenges we faced when implementing both approaches.

2 THE BUILD-VERSUS-BUY SPECTRUM

In the existing literature, researchers have navigated similar crossroads, making strategic decisions based on diverse considerations. These choices range from renting to buying, building, or utilizing user-owned devices, each motivated by varying project needs and constraints. Some opted for an intermediate approach, acquiring bike trainers and supplementing them with custom-built sensors,

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inputs, or feedback mechanisms. This spectrum of approaches reflects the multifaceted nature of technology integration in cycling research and highlights the adaptability required in the field.

2.1 Leveraging User-Owned Devices for HCI Cycling Research

The first approach involves leveraging user-owned devices. Bentvelzen et al.'s research on the at-home cycling system Zwift involved interviews with users primarily using direct-drive and on-wheel bicycle trainers at their homes [3]. Similarly, Franz and Reilly explore the dynamics of group road cycling outdoors, focusing on user experiences with their own outdoor bikes to design systems supporting team maneuvers [6]. But utilizing user-owned equipment will not be suitable for all studies for comparability reasons. Additionally, this approach may not effectively capture the experiences of novices to cycling technology or those less committed, as individuals who invest in their own bikes often require less external motivation compared to occasional spinning class attendees.

2.2 Lab Setups: Economical Considerations vs. Rental Collaborations

Lab setups range from highly affordable to prohibitively expensive, contingent upon the availability of rental agreements with cooperation partners. On the one hand, researchers employ bicycle ergometers for their prototypes, which are generally cost-effective. For instance, Michael and Lutteroth utilized these for studying self-competition in VR exergames [15], while Høeg et al. applied both upright and recumbent bicycle ergometers for collaborative VR exergames aimed at rehabilitating elderly users through a virtual tandem bike experience [8]. On the other hand, researchers engage in collaborations to utilize more advanced systems to create realistic environments in the lab. Haliburton et al., for example, investigated the impacts of VR walking on positive emotions and mindfulness using the h/p/cosmos Saturn 300/100 r treadmill [7]. This versatile equipment, capable of adjusting its incline, supports various activities, including walking, cycling, wheelchair movement, roller skating, and skiing, thus facilitating a wide range of scenarios.

2.3 Enhancing Lab Equipment: Turning Bike Trainers into Cycling Simulators

The subsequent approach involves setting up a bike trainer in the lab (either direct-drive or on-wheel) and augmenting it with additional sensors or actuators for enhanced input and feedback mechanisms. This setup has been adopted by researchers like Wintersberger et al. and Matviienko et al. in their studies to address various research questions within CyclingHCI [13, 14, 19]. They have employed these enhanced setups to investigate appropriate steering methods and the use of airflow to alleviate VR sickness caused by discrepancies between visual and physical movements. Furthermore, to assess cyclists' perceived safety, they utilized a VR bicycle simulator equipped with an on-wheel bike trainer, integrating additional components like potentiometers and Arduino boards. Their research extends to evaluating the essential elements required for a convincing VR cycling experience and its impact on user experience. This includes comparisons between different setups: a pedal trainer with a speed sensor, a stationary platform-mounted bicycle with speed sensors and a turntable, and a real outdoor bike equipped with a speed sensor [12]. Finally, they employed a direct-drive bike trainer complemented by a motion-capable platform. This setup, enhanced with various sensors and actuators for steering and braking, evolves into a comprehensive bicycle simulator. This simulator aims to find an optimal balance between user immersion and minimizing simulator sickness by fine-tuning the motion-based tilting function [19].

Figure 1: Left: The Wahoo KickR Smart Bike enables a real-time inclination change of -15% to +20% and high precision measurements of power, speed, distance, and cadence. Right: programmable buttons, gear shift, and brakes of the bike.

2.4 Custom Solutions: Developing and Attaching Self-made Sensors to Bicycles

The final approach explores building sensors from scratch and attaching these custom sensors to existing (indoor) bicycles. Andres et al. utilized this by adding sensors to an eBike to monitor exertion and to actuate movement, enabling cooperation between the user and the bike [1, 2]. Hsu et al. applied IoT technology for tracking public fitness equipment, utilizing reed switches for data collection and storing the data in a database via a web service [9, 10]. Ruengjittaveekul and Phadoongsidhi provided a cost-effective method to retrofit traditional treadmills, enhancing indoor training experiences [17]. These instances highlight the practicality and impact of self-made sensors in fitness technology.

3 PROTOTYPING TWO APPROACHES

The goal of our research is to implement social components for indoor cycling. In the following, we describe the prototypes that we are implementing to address these two scenarios and challenges that we faced so far during developing these new cycling systems.

3.1 Utilizing the Wahoo KickR Smart Bike

To achieve high immersion, particularly in VR exergaming, we aimed for a realistic indoor bike simulator. We need an interface for our prototype to collect data like cadence, speed, power, and heart rate, and to adjust the bike's resistance. This will allow external software on a computer or VR headset to interact seamlessly with the bike.

	Wind Speed	Grade	Crr (Coefficient of Rolling Resistance)	Cw (Wind Resistance Coefficient)
Byte Order	LSO...MSO	LSO...MSO	LSO...MSO	LSO...MSO
Data type	SINT16	SINT16	UINT8	UINT8
Size	2 octet	2 octets	1 octets	1 octets
Units	Meters Per Second (mps)	Percentage	Unitless	Kilogram per Meter (Kg/m)
Resolution	0.001	0.01	0.0001	0.01

Figure 2: Simulation parameter array format for set indoor bike simulation parameters procedure - Table 4.20 in the FTMS Bluetooth Protocol.

The Wahoo Fitness[1] KickR Smart Bike (see Figure 1) offers a wide variety of sensors and actuators. This bike accommodates users ranging from 152 to 192 cm in height and up to 115 kg in weight, featuring adjustable standover height, saddle height, setback, reach, stack, and crank for optimal fit. It boasts a power measurement capacity of up to 2200 Watts with an accuracy of ±1%. The bike also incorporates an electrical motor to simulate inclines up to +20% and declines down to -15%, providing realistic feedback for uphill and downhill cycling experiences. Additionally, it is equipped with programmable buttons, gear shifts, and brakes. The bike can transmit measurements of power, speed, distance, and cadence via Bluetooth, ANT+, and WiFi connections. Specifically for Bluetooth, it employs the standardized FiTness Machine Service (FTMS) Bluetooth Protocol[2], enabling two-way communication to gather data and send commands.

Despite the capabilities provided by the FTMS protocol, we encountered challenges in accessing specific values due to the protocol's design for energy-efficient devices, which utilizes flags and bits for commands and data fields. Implementing changes in resistance, inclination, and wind speed within the exergame required obtaining control permission, as outlined in Section 4.16.2.1 of the FTMS documentation. Successfully sending the "Set Indoor Bike Simulation Parameter Op Code" and receiving a "Success Result Code" allows for the application of new simulation parameters. The crucial 16-byte data format for these parameters, essential for accurately translating into the game environment, ensures the realism of the bike's simulation in the VR experience. This format's structure is shown in Figure 2.

3.2 Enhancing Mechanical Spinning Bikes

We have also embarked on developing and attaching custom sensors to traditional, mechanical indoor bikes typically used during in-person spinning classes. We aim to create a system capable of measuring and displaying key parameters such as heart rate, cadence, and resistance to athletes during sessions. For scalability reasons, these additional sensors must be both cost-effective and straightforward to attach and remove.

For this project, we have constructed our own sensing devices. We utilize two reed switches, attaching magnets to the pedals of the spinning bikes to track the pedal positions and thereby calculate the users' cadence. Additionally, we plan to measure the mechanical braking force using an analog pressure sensor placed between the adjustment knob and the brake pad, as direct power measurement is not feasible. Instead, by combining data on set resistance and cycling cadence, we can formulate an indirect estimate of the power exerted during cycling.

[1]Wahoo Fitness. https://www.wahoofitness.com/, last retrieved February 29, 2024.
[2]FTMS Bluetooth Protocol. https://www.bluetooth.com/specifications/specs/fitness-machine-service-1-0/, last retrieved February 29, 2024.

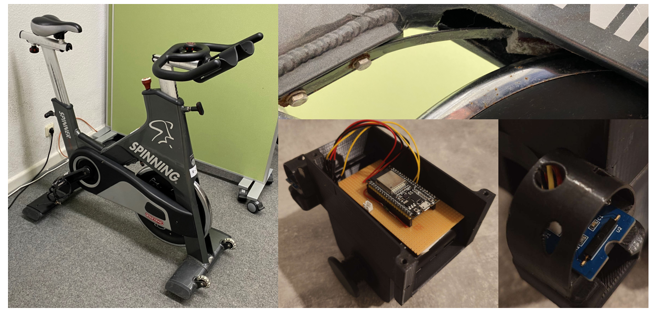

Figure 3: Left: A mechanical spinning bike with a flywheel and mechanical brakes in the top right. Right: ESP32 with reed switches and connection for the force sensor.

The collected data from these sensors are captured and processed by an ESP32 microcontroller and transmitted in real-time to a NodeJS server via WiFi. This server not only acts as a data repository but also provides an API for data access and persistence. To facilitate the data transfer, the ESP32 is programmed to convert the sensor readings into a JSON format, which is then sent to the NodeJS server using the UDP protocol for efficient, real-time communication.

The primary aim of this project is to balance cost-effectiveness and scalability, permitting the extension to multiple units. Simultaneously, we focus on creating a system that allows for straightforward attachment and detachment to and from the bikes to enable large-scale studies on social components during spinning courses using gamification approaches.

4 LESSONS LEARNED

In the following, we will discuss lessons learned for prototyping in CyclingHCI for sports applications. We start by looking at the possibility of buying bike trainers as simulators and conclude this position paper with the advantages and disadvantages of building sensors for HCI applications from scratch.

4.1 Buying in CyclingHCI for Sports

Purchasing commercial bike trainers for CyclingHCI prototyping presents several advantages. They offer high precision in measuring critical metrics such as power, speed, and cadence, which can be vital for accurate research outcomes depending on the use case. These trainers provide an integrated technology framework, featuring built-in sensors and various connectivity options, thus facilitating a seamless setup and integration with VR and other applications. However, it is essential to verify the compatibility with various protocols such as ANT+, ANT+ FE-C (Fitness Equipment Control, which enables manipulation of the fitness equipment), Bluetooth

Low Energy (BLE), potentially the FTMS protocol for Bluetooth-enabled fitness machines, or WiFi. The realism and immersive features, combined with durability and standardization, make them ideal for sophisticated CyclingHCI studies.

However, there are notable drawbacks to using commercial bike trainers. The high cost can be a significant barrier, especially for projects requiring multiple units. There is a limitation in terms of customization and flexibility compared to building a completely new system. Dependency on manufacturer-specific technology might restrict research flexibility and innovation. Additionally, relying on manufacturers' software may break custom solutions after firmware updates, especially if they cannot be turned off. In our case, this led to several weeks of debugging since our bike stopped responding to resistance, inclination, and wind speed adjustments. Therefore, we needed to implement several workarounds with changing from C# to web requests via Python and finally to C++ and custom-built Dynamic-Link Libraries (DLLs) that could still communicate with the bike. Lastly, compatibility with existing equipment and the physical space they occupy can be challenging in constrained environments.

4.2 Building in CyclingHCI for Sports

Building custom sensors for CyclingHCI prototyping offers significant advantages, primarily through customization and cost-efficiency. Tailor-made sensors can be designed to meet specific research needs, allowing for precise data collection tailored to unique project requirements. This approach can also be more budget-friendly compared to purchasing commercial units, especially for large-scale implementations. Additionally, the process of developing custom sensors fosters innovation, pushing the boundaries of current CyclingHCI capabilities. Flexibility is another key benefit, as custom sensors can be modified or upgraded as research evolves, unlike more rigid commercial systems.

However, the development of custom sensors also presents challenges and drawbacks. Custom sensors may not provide the same level of measurement accuracy as commercial devices, particularly concerning power metrics, making them less suitable for studies requiring exact measurements. The complexity of dealing with hardware aspects like sensor properties and detection speeds, introduces significant entrance hurdles. Issues such as signal interference can compromise data accuracy while ensuring low latency and stable connectivity for real-time data transmission presents additional technical challenges. At this point, scalability becomes an issue when attempting to replicate handmade sensors for larger studies, contrasting with the ease of acquiring multiple commercial units. Without adequate expertise, constructing effective and reliable sensors can be difficult, potentially compromising data accuracy. This process of prototyping is often time-consuming, which can divert resources and attention from other research areas.

4.3 Vision for Prototypes in CyclingHCI

Overall, when approaching research questions within CyclingHCI, it is essential to carefully weigh the advantages and disadvantages of various prototyping approaches. It is advisable to leverage existing building blocks, whether they are commercially available products or proven systems from the community, and adapt them specifically to the intended research objectives. In the field of Human-Computer Interaction, there is a growing focus on reproducibility and open-source efforts, which could also enhance the efficiency of evaluating cycling-related subjects, relying on the community's willingness to share resources with fellow researchers.

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