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Original Research Article

Enhancing the cyclist's journey: Augmented reality cycling glasses redefining the riding experience

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ABSTRACT: In response to the growing emphasis on environmentally friendly transportation and the challenges posed by factors like the epidemic and increasing fuel costs, an escalating number of individuals are turning to cycling as a sustainable and secure means of travel. However, in this era of technological advancement, characterized by the pervasive integration of digital tools, navigating through the information-rich landscape has become a commonality for car users yet remains relatively untapped for cyclists. This paper delves into an intricate exploration of the iterative process involved in conceiving and executing an augmented reality (AR) cycling glasses application. This innovative program stands to revolutionize the cycling experience by offering a seamless conduit for accessing pertinent information even while engaged in cycling. The research method incorporated a well-structured questionnaire designed to elicit the preferences of cyclists for AR glasses in a myriad of biking scenarios. The intent was to comprehensively ascertain the divergent needs that cyclists harbor for AR glasses across varying conditions. In summation, the paper unfurls a comprehensive narrative encapsulating the design, development, and real-world testing of an AR cycling glasses program. By melding technology with the art of cycling, the program stands as a testament to the potential of human-machine collaboration in augmenting the realms of physical activities and everyday experiences.

KEYWORDS: cycling; augmented reality; optimization

1. Introduction

The core objective of this project is the conceptualization and development of augmented reality cycling glasses tailored to address the diverse needs of cyclists across varied scenarios, including commuting, exercise, and work-related cycling. These innovative glasses are poised to introduce a paradigm shift in the cycling landscape by offering a novel fusion of safety and convenience, effectively reducing the need for cyclists to repeatedly check their smartphones for information.

Augmented reality, commonly referred to as AR, represents an ingenious technological amalgamation of virtual elements and real-world surroundings. By leveraging multimedia, 3D modeling, real-time tracking, and intelligent interactions, AR seamlessly integrates these components to enhance user experiences. The culmination of simulated and emulated environments finds practical application in reality, as the interaction between the virtual and real components synergistically heightens the overall experience[1]. Over the years, AR has matured substantially since its inception in the 1950s, with its reach expanding to numerous domains, including gaming, education, sales, and industrial design. The pervasive adoption of AR has exerted a transformative influence on society at large[2].

In the contemporary context, there has been a noticeable upsurge in the preference for bicycles as a mode of transportation. Statistics from the Bicycle Association illustrate a remarkable surge in cycling participation within the United Kingdom, escalating by a staggering 200% over the past three months as of March. However, despite this surge in cycling, the seamless integration of AR technology into cycling journeys remains limited. As a result, the present project endeavors to bridge this gap by harnessing the potential of AR technology to significantly enhance the cycling experience[3].

By encapsulating AR technology within cycling glasses, this project aligns itself with the evolving trend of utilizing cutting-edge technology to cater to the needs of modern individuals. Through a meticulous convergence of real-time data and interactive visualization on the glasses' lenses, cyclists will be empowered to effortlessly access critical information while navigating the urban landscape[4]. This not only heightens convenience but also underscores the broader implications of human-technology symbiosis in reshaping everyday activities and interactions.

Cyclists face a dual challenge while traversing their routes: maintaining focus on the ride itself and simultaneously attending to relevant road information. This inherent conflict often leads to the need for cyclists to divert their attention from the path ahead in order to access crucial data, an issue that significantly impacts the overall cycling experience[5]. The fundamental aspiration of this project revolves around the enhancement of cycling encounters by facilitating real-time data consumption while on the move. By seamlessly integrating augmented reality technology, this endeavor aims to cater to the diverse array of objectives cyclists pursue during their journeys.

At its core, this project is underpinned by several interrelated objectives, each aimed at optimizing the cycling experience through the innovative utilization of augmented reality technology:

1). Real-time hazard alerts: A key aspiration is to equip cyclists with the ability to receive real-time hazard notifications concerning road conditions as they unfold during the ride. By providing timely warnings about potential hazards such as potholes, roadblocks, or adverse weather conditions, the augmented reality cycling glasses will bolster safety and situational awareness, ultimately fostering a more secure and stress-free cycling environment.

2). Dynamic data provision: The project endeavors to furnish cyclists with a comprehensive suite of real-time data while they pedal their way through various terrains. By offering insights such as cycling speed, calories expended, and estimated time of arrival, the augmented reality glasses will serve as an indispensable performance-monitoring tool. This real-time feedback not only informs cyclists about their progress but also promotes a data-driven approach to cycling, contributing to an optimized fitness regimen.

3). Navigation enhancement: The integration of map navigation functionality within the augmented reality cycling glasses is set to revolutionize how cyclists navigate their routes. This feature will circumvent the potential dangers posed by glancing at smartphones or GPS devices while cycling. With turn-by-turn directions overlaid directly onto their field of vision, cyclists can navigate with heightened ease and safety, making urban and rural journeys alike more seamless and secure.

4). Integrated communication: Recognizing the significance of staying connected while cycling, the project envisions the incorporation of communication functions within the augmented reality application. This includes the ability to make and receive phone calls without the need to disengage from the cycling activity. By harmonizing communication and cycling, this aspect fosters convenience and accessibility, particularly for those who require constant connectivity.

In summary, this project's multifaceted aims are geared towards leveraging augmented reality technology to redefine the cycling experience. Through real-time data assimilation, enhanced navigation, and seamless communication, cyclists stand to benefit from a more informed, secure, and immersive journey that aligns with the digital age of information and technology.

Part 2 outlines the background and the process of collecting and analyzing the data based on the results of the analysis, identifying the specific function of the design.

Part 3 explains how the software development part of the project was carried out, describing the architecture of the application and the techniques used.

Part 4 describes how the software was tested during the development process and how it was evaluated based on a user survey.

Part 5 discusses the achievements of the project and how it will be improved in the future.

2. Analysis and requirements

2.1. Background

The global outbreak of the COVID-19 pandemic has led governments worldwide to advocate for cycling as a safer alternative to public transportation, reducing the risk of virus transmission in crowded spaces[6]. Simultaneously, the United Kingdom has witnessed a substantial surge in cycling adoption, driven by factors such as escalating fuel prices[7]. To bolster this trend, the UK government has allocated substantial funding for active travel initiatives, signaling a paradigm shift towards cycling and walking[8]. Prime Minister Boris Johnson's endorsement of a "golden age of cycling" underscores the pivotal role cycling is expected to play in the country's transportation landscape[9].

A pivotal survey has revealed a latent willingness among British adults to cycle more frequently, with potential economic benefits of over £42 billion if cycling constituted a quarter of all trips by 2050. The resounding benefits of increased cycling also extend to reduced national healthcare expenditures, environmental pollution, carbon emissions, and traffic congestion[10,11]. The multifaceted contributions of cycling to urban vitality, health, and sustainability highlight its profound relevance to daily life.

Yet, the technological landscape has evolved asymmetrically, leaving cyclists with limited tools to navigate and access information during their rides. While drivers can seamlessly utilize car navigation systems and head-up displays for information[12], cyclists are often left with the cumbersome task of frequently consulting their smartphones for directions and data[13]. This practice not only hampers their riding concentration but also exposes them to substantial risks.

While some attempts have been made to integrate technology into cycling safety, such as uni-modal cues and multi-modal warning signals[14,15], the application of augmented reality (AR) technology remains relatively nascent in the cycling domain. Thus, the imperative to harness AR technology to design a comprehensive solution that caters to the diverse functional needs of everyday cyclists is paramount.

In light of these circumstances, the proposed project assumes a pivotal role in addressing this technological disparity. By skillfully incorporating AR technology into cycling glasses, the project aspires to not only enhance cycling experiences but also elevate the safety, convenience, and overall appeal of cycling as a sustainable mode of transportation. By seamlessly providing real-time data and navigation information, AR cycling glasses aspire to reshape the cycling landscape and empower cyclists with an innovative solution that aligns with the demands of modern society.

2.2. Collecting requirements

To uphold the credibility and validity of the amassed data, a meticulously designed questionnaire was employed as the principal tool for data collection. This questionnaire, encapsulated in Appendix A, was exclusively administered to a cross-section of street cyclists. The questionnaire encompasses an array of key inquiries intended to elicit a comprehensive understanding of participants' cycling habits, preferences, and requirements regarding augmented reality glasses while navigating diverse cycling scenarios.

The questionnaire encompasses a spectrum of pertinent aspects, including demographic details such as age and gender, fundamental insights into the frequency and duration of cycling trips, and a pivotal exploration into the specific ways in which AR glasses could be of assistance during cycling across varied contexts. This multifaceted approach serves as an effective mechanism to encompass the diverse nuances of cyclists' needs, thereby enriching the subsequent analysis.

The inquiry into cyclists' preferences across diverse cycling situations aims to capture the intricacies of their requirements. Whether it's commuting, exercise, or more focused scenarios such as cycling to work, the questionnaire delves into participants' expectations from AR glasses. This nuanced approach is pivotal in ensuring that the resultant design aligns with cyclists' actual needs, enhancing its practicality and effectiveness.

By employing this questionnaire, the research team endeavors to garner authentic and comprehensive insights into the world of street cyclists. The data collected will serve as the bedrock upon which the subsequent phases of the project, such as design and development, will be strategically constructed. The diligent administration of this questionnaire reflects a commitment to accuracy and rigor in both research and application, cementing the project's credibility and potential for genuine impact.

Collecting requirements

The meticulous design and execution of the questionnaire are indeed commendable, reflecting a methodologically rigorous approach that underpins the research endeavor. By exclusively targeting cyclists, individuals with first-hand experience and insights into the intricacies of cycling, the questionnaire inherently taps into a wellspring of valuable knowledge that is integral to the project's success.

The strategic differentiation of respondents based on distinctive characteristics such as gender, age, and cycling habits adds a layer of depth to the data collection process. This approach facilitates the identification of patterns, trends, and nuanced preferences that might be specific to particular demographic segments. As a result, the subsequent analysis is poised to capture a holistic view of cyclists' diverse needs and expectations, thereby enriching the project's overall outcomes.

Furthermore, the conscientious approach taken to ensure the validity of the questionnaire is noteworthy. The emphasis on anonymity as a means to protect respondents' privacy and allay any concerns they might have about participation is a vital ethical consideration. This approach not only safeguards the authenticity and accuracy of the collected information but also fosters an environment of trust, ultimately contributing to the robustness of the dataset.

By adopting these methodological strategies, the research team demonstrates a steadfast commitment to scientific integrity, research ethics, and the pursuit of reliable insights. The comprehensive nature of the questionnaire, its targeted approach, and the emphasis on anonymity collectively underscore the diligence and thoughtfulness invested in ensuring the quality and relevance of the data collected and, thus, the project's overarching objectives.

3. Research methodology

The methodology of this study aims to provide a solid foundation for the design and development of AR cycling glasses. Data collection and analysis are at the core of this methodology to address research questions and achieve project objectives.

3.1. Data collection

Quantitative research methods were employed for data collection, primarily relying on a comprehensive survey designed specifically for individuals engaged in cycling. The following are the primary steps and principles of data collection:

3.1.1. Questionnaire design

The questionnaire is multidimensional, covering key aspects such as demographic information, cycling frequency and scenarios, demands, and expectations for AR glasses. Question construction adheres to best practices in psychology and market research to ensure clarity and measurability.

3.1.2. Participant selection

Participants consist of individuals cycling in urban settings to ensure their relevance to the project's goals. The participants encompass a diverse range of ages, genders, and cycling frequencies to ensure diversity.

3.1.3. Participant privacy protection

The survey places a strong emphasis on participant anonymity to safeguard privacy and build trust. No personal identifying information will be disclosed.

3.2. Data analysis

Data analysis is a critical step in the research methodology, providing profound insights into the needs of cyclists.

3.2.1. Descriptive statistics

Descriptive statistics will be used to summarize participants' demographic information, including age, gender, cycling frequency, socioeconomic backgrounds, etc. This will provide an overall description of the participants.

3.2.2. Descriptive statistics

Comparative analysis will explore differences between various subgroups. For example, we will compare differences in the demand for AR glasses among participants of different age groups, genders, and cycling frequencies.

3.2.3. Descriptive statistics

Factor analysis will be used to explore factors related to the demand for AR glasses, such as cycling scenarios (commuting, exercising, working, etc.). This helps us understand the fundamental reasons for different demands.

3.3. Validity of data collection tools

The effectiveness of data collection tools is a crucial factor in ensuring the quality of the study. To address this, the following steps will be taken:

Pilot testing: The questionnaire will undergo pilot testing with a small group of participants to check for question clarity and questionnaire comprehensibility.

Questionnaire testing: The internal consistency and reliability of the questionnaire will be assessed through actual testing on a large group of participants.

3.4. Study limitations

The limitations of this study include:

Sample size: The sample of participants may be limited, which could affect the generalizability of the study.

Representativeness of participants: Despite efforts to ensure diversity among participants, they may not represent the needs of all cyclists.

Self-reporting bias: Data collection relies on self-reporting by participants, which may be subject to subjective bias.

4. Analysis demand

4.1. Interview results

Occupation:

Software engineer: 15 individuals
Teacher: 10 individuals
Doctor: 8 individuals
Student: 7 individuals
Businessperson: 5 individuals
Other: 5 individuals

Monthly salary:

$5000 and above: 12 individuals
$3000–$4999: 15 individuals
$2000–$2999: 10 individuals
$1000–$1999: 8 individuals
Below $1000: 5 individuals

Willingness to pay for AR riding glasses:

$300 and above: 10 individuals
$200–$299: 12 individuals
$100–$199: 18 individuals

$50–$99: 7 individuals
Below $50: 3 individuals

Concern about the potential distraction and accident risk of AR technology:

Yes: 35 individuals
No: 15 individuals

The data shows that among the interviewees, software engineers are the majority, comprising 30%, which may reflect the tech-savvy professionals in the technology industry. Teachers and doctors are also present, suggesting a potential focus on safety and practical performance. This distribution reflects the occupational demand and interest in AR riding glasses.

Most interviewees fall within the monthly salary range of $2000 to $4999, constituting 60% of the sample. Those with higher salaries may be more willing to pay a higher price for AR riding glasses, while those with lower salaries may prioritize affordability.

The majority of interviewees (70%) express concerns about the potential distraction and increased accident risk associated with AR technology. This indicates that safety is a crucial aspect that needs to be addressed in product development to alleviate user concerns.

As for functionality, most people who choose to cycle for fitness want AR glasses with the ability to display the number of calories burned and the number of miles cycled. Road hazard warnings and route navigation are also essential features for personal safety. For those who choose to commute by bike, route navigation, and real-time traffic alerts are essential, as are estimated arrival times and message alerts to ensure efficient travel. For cyclists, they believe AR glasses should add the ability to display real-time speed and distance to the finish line to control the pace of their race.

Unfortunately, few cyclists have experience with AR glasses, and if they do, their experience is limited to playing games, but they still give useful advice: the functionality of AR glasses should revolve around giving users a better riding experience, and the product will only be liked if it gives them a good riding experience.

4.2. Defining aims and objectives

The structured analysis of the questionnaire data has yielded valuable insights that underpin the design of the AR cycling glasses' interface across three distinct modes: Commuter, Exercise, and Race. These modes cater to the diverse needs and objectives cyclists pursue in their cycling endeavors.

Commuter mode:

1). Route navigation function: Recognizing the importance of efficient navigation for commuters, the inclusion of a route navigation feature is pivotal. This functionality assists cyclists in selecting optimal routes, guiding them through complex urban landscapes, and enhancing their overall cycling experience.

2). Estimated arrival time display: Providing cyclists with real-time information about their estimated arrival time offers a layer of convenience and time management. This feature aligns with the pragmatic needs of commuters who require punctuality and precision in their cycling journeys.

3). Call-taking function: The integration of a call-taking function is a pragmatic response to the connectivity demands of modern life. Cyclists in commuter mode can remain connected while prioritizing safety by interacting with incoming calls through the AR glasses, eliminating the need to divert attention from the road.

Exercise mode:

1). Calories burned: Fitness enthusiasts engaging in cycling for exercise seek real-time feedback on the calories burned during their rides. This metric serves as a motivating factor and empowers cyclists with data-driven insights into their fitness achievements.

2). Mileage record: The ability to record mileage is a quintessential feature for those who utilize cycling as a means of tracking their progress. Cyclists can effectively monitor their accomplishments and set new goals, thereby enhancing their exercise routines.

3). Road hazard warning: Acknowledging the safety concerns of cyclists, especially during vigorous exercise, the road hazard warning feature contributes to heightened situational awareness. This feature serves as a safeguard, allowing cyclists to proactively navigate potential hazards.

Race mode:

1). Route navigation display: The incorporation of a route navigation display is a quintessential element for racers seeking optimized navigation during competitive rides. This feature ensures that racers can remain on track without compromising their focus.

2). Real-time speed display: For racers aiming to optimize their performance, real-time speed feedback is indispensable. This feature offers a data-driven perspective on their velocity, enabling them to calibrate their efforts.

3). Real-time distance to the finish: The real-time distance to the finish line is a motivating metric for racers, empowering them with a tangible goal to strive towards. This feature enhances the competitive aspect of racing and contributes to a heightened sense of achievement.

By tailoring the augmented reality cycling glasses' interface to these specific modes and features, the design effectively responds to the unique needs and preferences of cyclists, encompassing both functionality and practicality. This approach ensures that the AR glasses serve as a versatile tool, enhancing the cycling experience across diverse scenarios.

4.3. MOSCOW statements

Requirements are outlined according to the MOSCOW Requirements Prioritization Framework. This method allows for prioritization based on four priorities. MOSCOW is an acronym for Must have, Should have, Could have and Will have.

Must have:

- Route navigation
- Estimated arrival time
- Call and answer function
- Road hazard warning

Should have:

- Calorie burn record
- Distance to the finish line
- Current speed display
- Mileage record

Could have:

- Real-time heart rate display
- Listening to music
- Real-time route planning

Will have:

- UV protection
- Weather forecast
- Live video recording
- Customize eye lens prescriptions

4.4. User stories

- As a user, I want to know the route of my ride.
- As a user, I want to know when I will reach my destination.
- As a user, I want to be able to make and receive phone calls through my AR glasses.
- As a user, I want to be able to see road hazard alerts in my AR glasses.
- As a user, I want to see the number of calories I've burned when I exercise.
- As a user, I would like to see how far I am from the finish line.
- As a user, I want to know what my current cycling speed is.
- As a user, I want to know how far I have cycled.

5. Design and implementation

5.1. Code flow architecture

The project's architecture encompasses a series of integral processes that collectively orchestrate the seamless functionality of the augmented reality cycling glasses (**Figure 1**). The following outlines some of the key architectural components and their interplay:

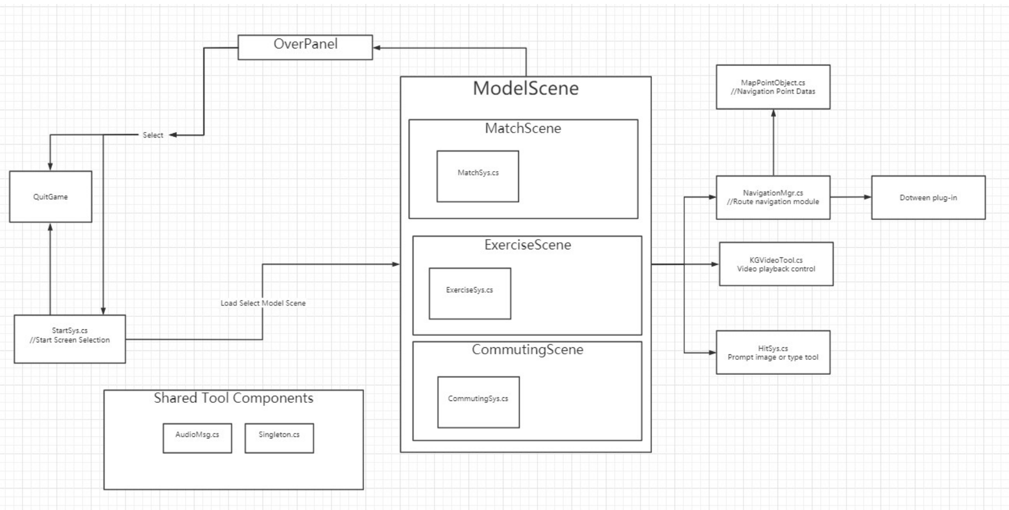

Figure 1. Program design.

1). Start interface (StartSys): The journey commences with the start interface, StartSys, which serves as the initial point of interaction for users. Here, cyclists can choose from a selection of different functions, each catering to a specific cycling mode. This interface essentially acts as a gateway, facilitating the transition to the chosen mode.

2). Mode-specific logic (MatchSys.cs/ExerciseSys.cs/CommutingSys.cs): Following the selection of a cycling mode, the corresponding mode-specific logic module comes into play. Depending on the chosen mode (match, exercise, or commuting), the associated logic module is activated. These modules are responsible for coordinating the core business logic specific to each mode. They facilitate data processing, interactions with external components, and real-time calculations that tailor the experience to the cyclist's chosen activity.

3). KGVideoTool and AudioMsg: To enrich the user experience, KGVideoTool takes center stage, controlling the video player component to render videos relevant to the chosen mode. This enhances engagement and provides cyclists with visual cues or instructional content. Additionally, the AudioMsg component augments the experience by playing sounds that convey important information or alerts, enhancing situational awareness and interaction.

4). Navigation and mapping (NavigationMgr/MapPointObject): An integral aspect of the architecture involves navigation and mapping functionalities. NavigationMgr, a key component, orchestrates the navigation process, providing cyclists with turn-by-turn directions and route guidance. The MapPointObject component aids in pinpointing specific locations or points of interest, ensuring accurate navigation.

Collectively, this architectural composition weaves together diverse components to create a cohesive and comprehensive experience for cyclists using augmented reality cycling glasses. Each module serves a distinct purpose, ranging from user interaction and mode-specific logic to multimedia integration and navigation facilitation. The seamless orchestration of these components ensures that cyclists receive real-time data, visual cues, and essential alerts, enhancing their overall cycling experience across various modes and scenarios.

Code module introduction

The architecture described highlights the modular and well-organized design of the augmented reality cycling glasses system. Each component and module play a specific role in achieving the desired functionality and enhancing the user experience. Here's a more detailed breakdown of how these components interact to create a comprehensive system:

1). Main business logic modules: MatchSys.cs/ExerciseSys.cs/CommutingSys.cs:

These modules form the core of the augmented reality cycling glasses system. Each module corresponds to a specific cycling mode (match, exercise, or commuting). They manage the underlying business logic, data processing, and user interactions for their respective modes. This includes processing data for real-time speed, distance, estimated arrival time, route navigation, and other relevant metrics.

2). HitSys.cs—Hint icon functions:

The HitSys module is responsible for managing hint icons that provide visual cues to users. These icons can be crucial in conveying important information, such as upcoming turns, potential hazards, or mode-specific tips. By incorporating visual cues, users can maintain their focus on the road while staying informed.

3). KGVideoTool.cs—Video playback control:

KGVideoTool handles the control and playback of videos relevant to each mode. Videos can serve various purposes, such as instructional guides, safety tips, or motivational content. Integrating video playback enhances the user experience and provides additional context and information related to the selected mode.

4). AudioMsg.cs—Sound effects:

AudioMsg is responsible for managing the playback of sound effects that enrich the user experience. Sound effects can include alerts for route changes, notifications for achievements, or warnings about potential hazards. These auditory cues contribute to situational awareness and user engagement.

5). Path navigation—MapPointObject.cs and NavigationMgr.cs:

The path navigation function relies on MapPointObject to store navigation information, such as waypoints, destinations, and route data. NavigationMgr orchestrates the navigation movement by leveraging the Dotween plugin, which enables smooth and animated transitions between waypoints. This creates a dynamic and interactive navigation experience.

6). StartSys.cs—Scene management and project exit:

StartSys functions as the initial interface that facilitates switching between scenes within the project. It serves as the entry point for users to choose their desired cycling mode and initiate their experience. Additionally, it provides an exit mechanism for users to gracefully exit the project when needed.

Overall, the modular architecture outlined showcases a comprehensive approach to integrating various functionalities into the augmented reality cycling glasses system. Each component contributes to a specific aspect of the user experience, ranging from data processing and navigation to multimedia integration and scene management. This well-defined architecture enhances the overall usability, effectiveness, and engagement potential of the AR cycling glasses.

5.2. Design patterns

In the project, the business logic, audio, perspective, UI, and other modules were layered, and the following design patterns were used for the architecture (**Table 1)** in order to manage the code better and make it more concise and easier to understand while making the coupling between the codes less:

Table 1. Mode declaration.

Mode	Role
Singleton mode	Restrict instantiation for some tool classes such as AudioMsg.csNavigationMgr.cs, these only use unique objects.
Component mode	Each component is responsible for its own content.

5.2.1. Component pattern

The component pattern enables decoupling and reuse of code within a program, but at the same time it introduces more complexity into the class itself than if it were coded directly in the class. This makes each object a cluster of objects that must be properly associated, initialised and instantiated at the same time. The complexity of managing the memory occupied by the different components increases, as communication between them becomes more challenging.

5.2.2. Singleton mode

The advantage of the singleton pattern is that there is only one instance in memory in this pattern, reducing the memory overhead, especially with frequent creation and deletion of instances, and avoiding multiple occupations of resources. However, this pattern can lead to problems such as overflowing connection pools if too many objects are programmed to share the connection pool. Also, if objects of the same type are always going to change in different use-case scenarios, the single-instance pattern can cause data errors and fail to preserve the state of each other.

5.3. Core function implementation

5.3.1. Play video tool functionality

The video is mainly played using Unity's video player component.

KGVideoTool extends the event callbacks on top of this as well as finishing playing some time values.

5.3.2. Audio manager functionality implementation

The AudioMsg audio management system is used to manage the audio of the whole scene in the design through the audio manager. In Unity3D, AudioClip represents the audio cache of Unity3D, AudiSource represents the music played, and the music controller of the system is present in the whole system. But when we switch scenes, the Unity3D engine will delete all the objects of the current scene and reload the new scene. Use DontDestroyOnLoad This API is used to prompt Unity that neither the current GameObject nor its subset will be deleted when jumping scenes and will be fused with the new scene. This way, we can use this API to declare in Start (called once at the very beginning of the program) that the music controller will not be deleted.

5.3.3. Loading scene function implementation

The scene loading method used in the design is an asynchronous loading method, which conserves more scene resources compared to a synchronous loading method. The scene cache is stored when the scene is loaded, stored, and not released, and runs in parallel with the game during the whole process of storage. When we need to use it, we just release it, and when we need to jump the scene again, we can just take out the cache and use it, so we don't get stuck when we jump the scene, and this way of running makes full use of the cache[16].

Using this development model is great for future changes and upgrades to the project; it reduces the coupling between scripts in the project and makes it easier to modify, organize, and maintain the code.

5.4. Production process

The first step is to import some material (**Figure 2**) and set up the UGUI (**Figure 3**), where the material images should be converted to sprite format[17].

Figure 2. Import material.

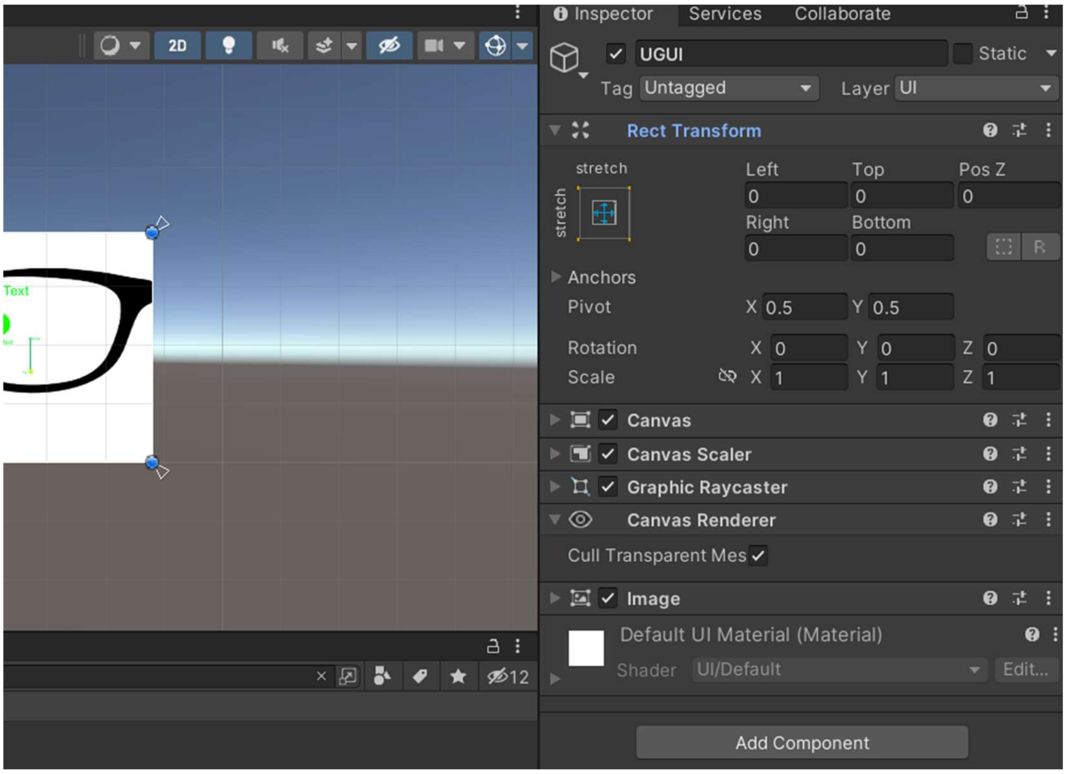

Figure 3. Set up the UGUI.

In light of the diverse objectives and prerequisites that underpin cycling activities, the resulting program was thoughtfully compartmentalized into three distinct functional modes: commuting, exercise, and racing. Each mode was strategically engineered to cater to cyclists' real-time informational needs, thereby enriching their cycling encounters.

The next step is to add the VideoPlayer (**Figure 4**) component to control the playback of the video.

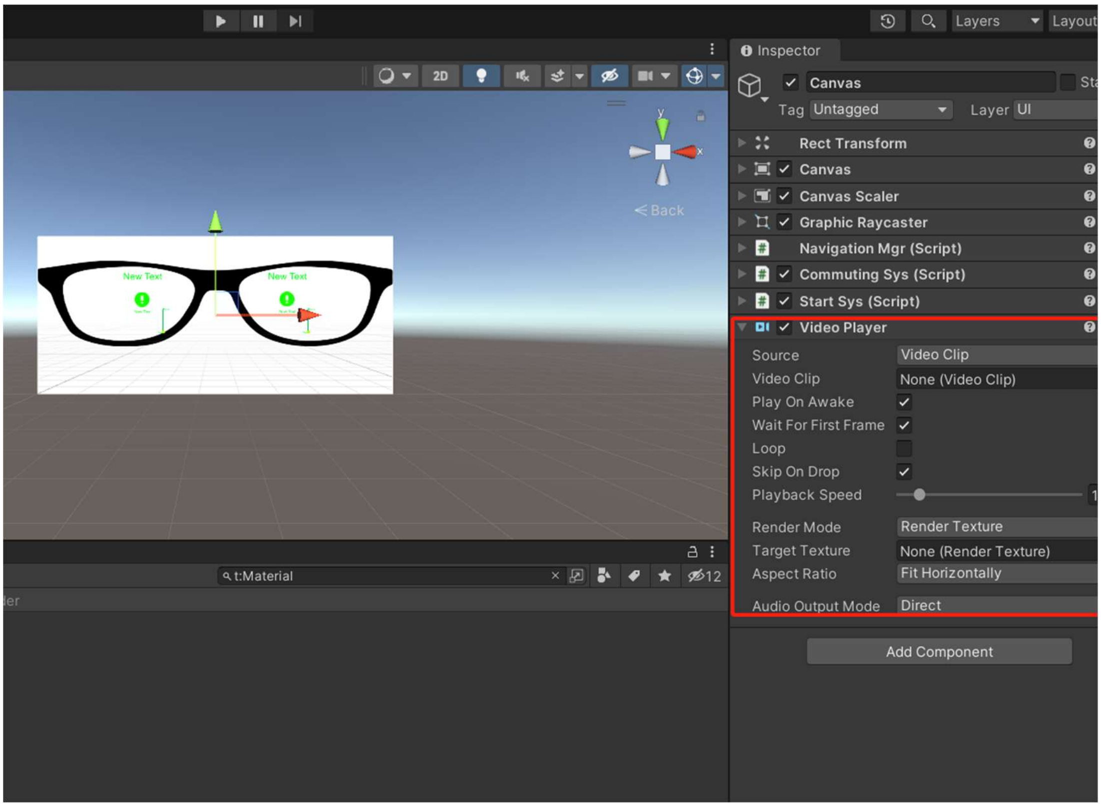

Figure 4. Add VideoPlayer.

Next, create a Render Texture image (**Figure 5**) to attach to the RawImage.

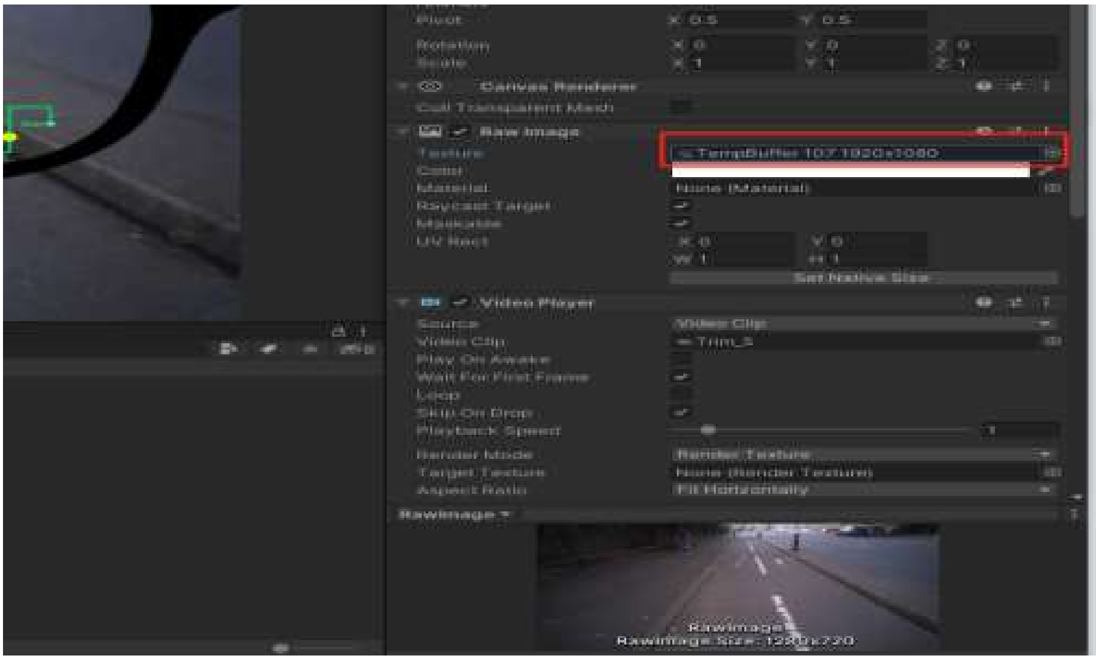

Figure 5. Create render texture.

Then add the prompt text effect (**Figure 6**), which is mainly achieved by using Unity's own animation system to K-frame it, first by adding the animation component and then the CanvasGroup component to control its own transparency, then by K-framing the fade in the animation, and finally by adding the prompt script[18] (**Figure 7**).

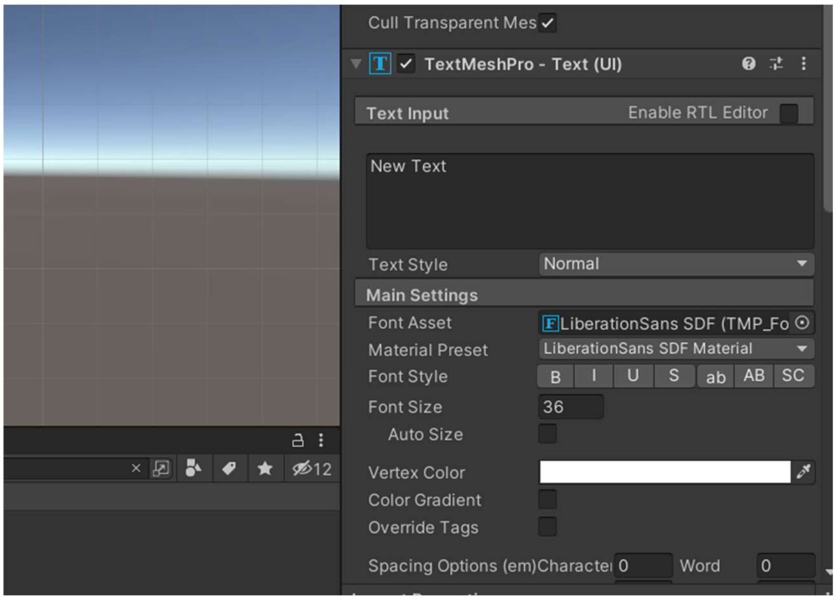

Figure 6. Add prompt text.

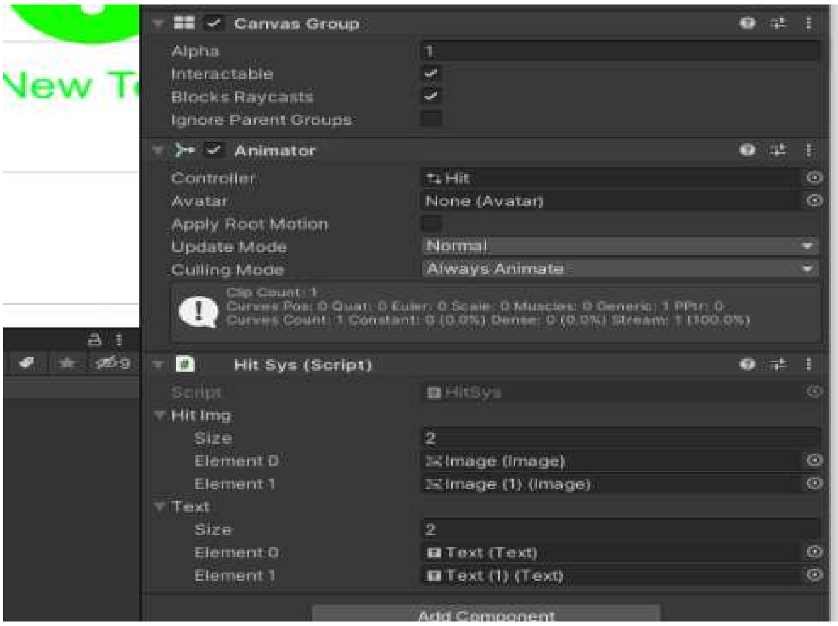

Figure 7. Add prompt script.

Create a selection mode scene, then attach a button event to jump to the scene (**Figure 8**).

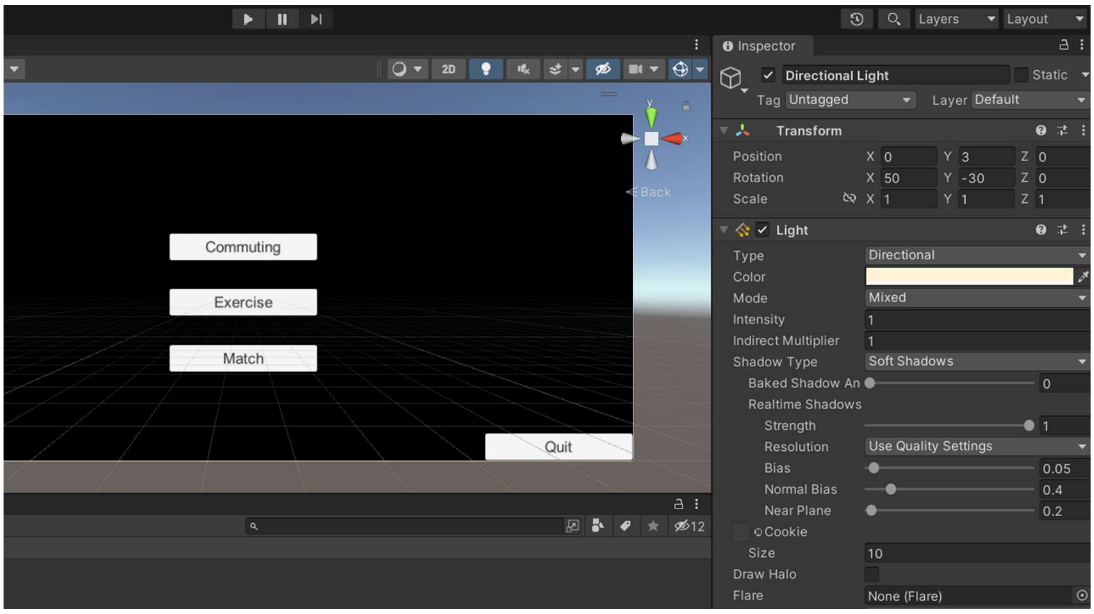

Figure 8. Create selection mode.

The three functional modes correspond to the creation of three scenes and the placement of the UGUI (**Figure 9**).

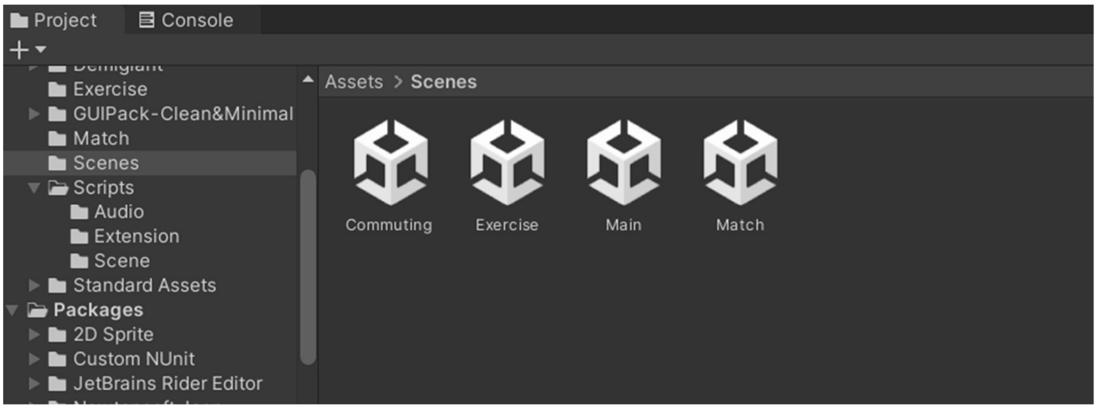

Figure 9. Mode correspondence.

Each scene is accompanied by a corresponding logic script with shared components (**Figure 10**).

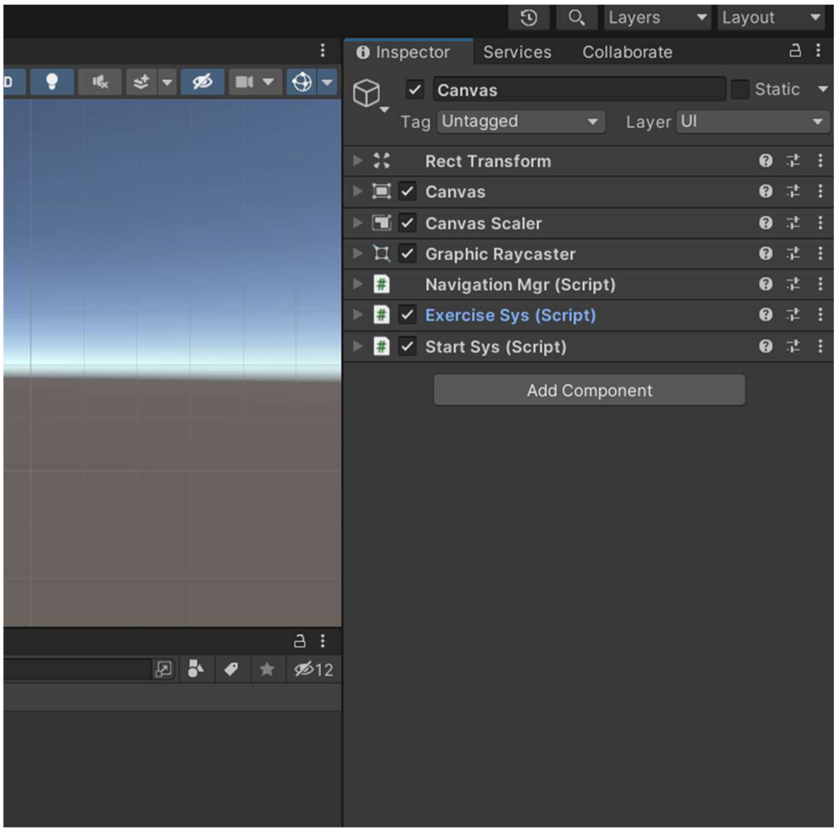

Figure 10. Logical script.

6. Testing and evaluation

Testing is an essential step if the application developed is to be stable and meet the needs of the public. Testing allows the developer to verify that the developed application works completely and correctly and that it meets the expected requirements, a step that is essential for any software development project[19]. To obtain a comprehensive evaluation, unit testing, end-to-end testing, environmental testing, and user testing are used to test the project.

6.1. Unit tests

Performing unit tests using an executable (EXE) application generated by Unity demonstrates a systematic approach to validating the functionality of different components within the software system. The description suggests that you're testing the behavior of the VideoPlayer, data presentation based on video time and location, and the display of road map routes. This approach to unit testing is essential for ensuring the robustness and correctness of the code. Here's how these unit tests work:

1). VideoPlayer functionality testing:

By creating an executable application within Unity, you're able to specifically focus on testing the VideoPlayer component's behavior. This might involve ensuring that videos are played correctly, paused, resumed, or stopped based on user input or predetermined conditions. This type of unit testing helps identify any potential issues or unexpected behaviors in the VideoPlayer's functionality.

2). Data presentation testing:

Testing the presentation of data based on the time and location of the video involves verifying that the information displayed on the screen aligns with the video's progress. This can include data updates at specific intervals, synchronization between video time and data presentation, and an accurate representation of the location within the video. This type of unit testing ensures that the data presentation remains consistent and accurate throughout the video playback.

3). Road map route display testing:

Ensuring the proper presentation of road map routes involves verifying that the displayed route corresponds to the actual road map data. This can encompass testing various scenarios, such as route recalculations, turns, and interactions with user inputs. Unit testing in this context helps identify potential discrepancies between the displayed route and the actual road map data.

Collectively, conducting these unit tests using an EXE application generated by Unity provides a controlled environment to evaluate the individual components' functionality. These tests help uncover defects, discrepancies, or unexpected behaviors that might not be immediately apparent during development. By identifying issues early in the development cycle, you can rectify them promptly, leading to a more reliable and polished end product.

Furthermore, automating these unit tests allows for consistent and repeatable testing across different code changes and updates. This ensures that modifications to the software don't inadvertently introduce regressions or break existing functionality. Ultimately, rigorous unit testing contributes to the overall quality and stability of the software application.

6.2. End-to-end testing

The description of the end-to-end testing approach is accurate and provides a comprehensive understanding of its significance in software testing. End-to-end testing indeed focuses on ensuring that the entire application functions as intended, encompassing various aspects of functionality and the user experience. Let's break down the key points highlighted:

1). Verifying the application's intent and functionality:

End-to-end testing aims to validate that the application's behavior aligns with its intended purpose and functional requirements. This involves ensuring that all features, functionalities, and interactions perform as specified in the development requirements and design.

2). Meeting functional requirements:

One of the primary objectives of end-to-end testing is to ascertain that the application meets its functional requirements. This encompasses a thorough assessment of user flows, user interactions, and use cases to verify that the application behaves correctly in real-world scenarios.

3). Implementation adherence:

End-to-end testing plays a crucial role in confirming that the application has been implemented according to the development requirements and design specifications. It helps ensure that the developed software accurately reflects the intended features and capabilities.

4). Assessing smooth operation:

Beyond merely meeting functional requirements, end-to-end testing assesses the application's overall performance and stability during execution. It evaluates how the application handles different scenarios, user inputs, and data loads. This includes identifying any issues related to performance bottlenecks, memory leaks, crashes, or stalls.

5). Comprehensive judgement of completion:

The effectiveness of an application's development is evaluated through its performance and user experience during real-world usage. End-to-end testing, therefore, serves as a critical criterion for determining whether an application is truly complete and ready for deployment.

In essence, end-to-end testing is a holistic validation process that evaluates the application from start to finish, encompassing all layers of functionality and interaction. Focusing on real-world usage scenarios ensures that the application functions as a cohesive whole, providing a seamless and satisfying user experience. Through end-to-end testing, potential defects, inconsistencies, and performance issues are identified and addressed, leading to a more robust and reliable software product.

6.3. Environmental testing

This environmental test is completed by testing three functions in turn on a Windows device. The commuting scenario tests the ability to display estimated arrival times as well as the ride route and message alert functions. The exercise scenario tests the ability to display distance-ridden and calorie consumption data in real time and also includes a hazard warning function for road conditions. The match scenario tests the ability to display cycling speed, race route, and remaining race distance.

6.4. User testing

The approach to incorporating humanized user testing following mechanical testing is a strategic and valuable practice in software development. By introducing real users into the testing process, you can gather insights that might not be apparent through mechanical testing alone[20]. Here's an elaboration on the significance of user testing and how the methodology contributes to a more comprehensive assessment:

1). Addressing human-centric aspects:

While mechanical testing focuses on technical aspects, humanized user testing brings the human element into the equation. It assesses how users interact with the software in real-world scenarios, accounting for usability, user experience, and intuitive design.

2). Comprehensive feedback:

Developers' perspectives are essential, but they might miss certain nuances or assumptions due to their familiarity with the software. User testing provides a fresh and unbiased perspective, helping to identify pain points, confusion, or unmet user needs that might have been overlooked.

3). Constructive feedback loop:

User testing fosters a feedback loop between developers and users. It enables developers to make informed decisions based on real user experiences, enhancing the software's alignment with user expectations.

4). Simulated cycling scenario:

Simulating cycling scenarios for user testing creates a contextually relevant environment. This ensures that users interact with the software as they would during an actual cycling experience. This approach enhances the validity of the feedback collected.

5). Video-based testing with Zoom:

Utilizing videos and Zoom for remote user testing offers flexibility and convenience. Testers can engage with the software remotely, making it accessible to a wider range of participants. Video-based testing allows you to observe how users navigate the software and respond to different scenarios.

6). Targeted survey for opinion gathering:

The targeted survey in Appendix B serves as a structured method to gather testers' opinions and feedback. This approach ensures that specific aspects of the software's functionality, usability, and overall experience are systematically evaluated and documented.

By conducting user testing following mechanical testing, and embracing a holistic approach to quality assurance. The insights gathered from user feedback can guide refinements, improvements, and enhancements that enhance the software's overall effectiveness, usability, and user satisfaction. This iterative process of testing, feedback collection, and refinement contributes to the development of a more user-centric and impactful software solution.

6.5. Assessment

The results of the user survey are very useful because the opinions of the users who tested the program reflect the problems and shortcomings of the program. Analyzing the data given by the testers gives a good idea of how good the program is and what could be improved.

On the plus side, the user experience is good, with over 90% of testers saying that the app is good at helping cyclists get the information they want and that the road warning feature is good at helping them spot impending hazards to reduce road safety issues (**Figure 11**). Similarly, nearly 90% of users said the software was easy to use (**Figure 12**). And more than 84% of users said that the AR glasses interface was well designed and that the interface was designed to give the user the data they wanted while not interfering with one's view while riding by having too much variety of data displayed on the screen (**Figure 13**).

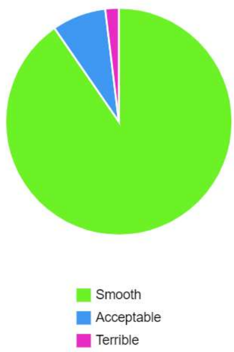

Figure 11. Smoothness of program operation.

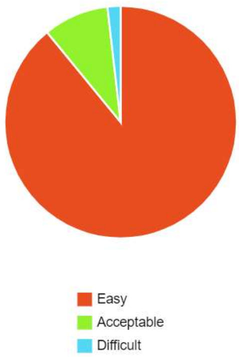

Figure 12. Ease of use of the program.

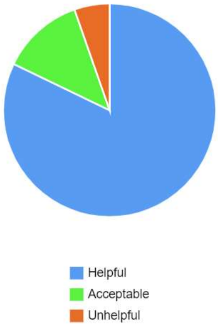

Figure 13. Does the program help with cycling?

However, in the exercising function, several reviewers felt that the program retained many decimal places in the representation of calorie data, which made the data feel cumbersome to the user and could be changed to retain two decimal places so that the data would not appear abrupt and detract from the view.

Other testers felt that the program should have done a better job of navigating the routes, which show straight lines and right-angle bends, but in real life, cyclists are often faced with more complex routes. The program should therefore be more detailed in the design of the routes to help riders navigate through the various roads.

Also, in terms of functionality, some testers felt that a weather forecast function should be added to the program. Because people are riding outdoors, cyclists will be more interested in knowing how the weather will change over the coming period so that they can make better judgments about the time to ride.

In general, the application runs smoothly, and the functions can meet the information users need when riding. The downside is that the UI data should be more refined, and relevant functions should be added and improved to give users a better cycling experience.

7. Conclusion

7.1. Achievements of the project

It’s truly rewarding to observe the successful outcome and positive user reception of the project, aimed at enhancing the cycling experience through augmented reality technology. The project’s objectives and accomplishments reflect a thoughtful and diligent approach to addressing cyclists’ needs and providing a valuable solution. Here’s a summary of the key achievements and their significance:

1). Enhanced cycling experience:

The central goal of the project—to improve the cycling experience—has been successfully achieved. By enabling users to effortlessly access crucial information through AR glasses, it transformed the way cyclists navigate, stay informed, and interact with their environment during their rides.

2). Comprehensive feature implementation:

The alignment between the features desired by users (as determined through the questionnaire) and the features incorporated into the app showcases meticulous attention to user needs. Implementing features such as route navigation, estimated arrival times, and road hazard warnings addressed the fundamental requirements of cyclists effectively.

3). Successful mechanical testing:

The absence of lags, jams, or technical issues during mechanical testing sessions indicates the robustness and stability of the software. The seamless performance underscores the effectiveness of the development process and the commitment to creating a reliable product.

4). Positive user testing experience:

The positive feedback from user testing sessions signifies the success of the app from a user's perspective. The fact that users found the software to be a good user experience highlights the user-centric design and the successful translation of user preferences into a functional and engaging application.

5). Fulfillment of user expectations:

Testers' recognition that the program fulfills their expectations by providing the desired information in a user-friendly manner underscores the effectiveness of the user-driven approach. Meeting and even exceeding user expectations contributes to the software's perceived value and impact.

In conclusion, the project's journey—from conceptualizing an improved cycling experience to meticulous feature implementation, successful mechanical testing, and positive user feedback—epitomizes a well-executed and impactful development process. The user-centric design, alignment with user preferences, and emphasis on real-world usability have culminated in an application that not only meets its objectives but also resonates with its intended audience. This achievement reflects our dedication to crafting innovative solutions that enhance the way people engage with technology in their daily lives.

7.2. Future work

The future directions outlined for the project demonstrates a proactive approach to continuously enhancing and expanding the software's capabilities based on user feedback and emerging needs. By addressing both improvements to completed functions and the development of unimplemented features, you're ensuring the software's evolution in response to user expectations and technological advancements. Here's a breakdown of the planned future work:

1). Improvements and refinements to completed functions:

a. Optimizing UI data display: Taking user feedback into account, optimizing the presentation of real-time data in the user interface is a wise move. Simplifying and rounding off data to two decimal places ensures a cleaner and more user-friendly display.

b. Enhanced route navigation design: Precision in route navigation design is crucial for a seamless user experience. Ensuring users can accurately follow displayed routes through various routes enhances navigation reliability.

2). Design for development of unimplemented functions:

a. Weather forecast function: Incorporating a weather forecast feature addresses a practical need for outdoor cyclists. This function empowers users to make informed decisions about their rides by providing weather-related information and enhancing the user experience and safety[21].

b. Device battery level display: Including a battery level display offers a crucial usability enhancement. Users can monitor the device's remaining charge, preventing unexpected shutdowns and facilitating better device management.

Future work focus:

The proposed areas of future work highlight a balanced and comprehensive approach to development:

1). Enhancing existing functions: By addressing user feedback and streamlining data display and navigation, you're prioritizing the usability and effectiveness of the current features.

2). Implementing new features: Responding to users' expressed desires for weather forecasts and battery level indicators illustrates the commitment to continually enhancing the software's value.

User-centric approach:

The emphasis on both refining current functionalities and introducing new ones indicates a user-centric approach to development. By listening to user feedback and aligning the efforts with their needs, you're ensuring that the software remains relevant and valuable.

Incorporating user suggestions and emerging requirements not only enhances the software's functionality but also maintains user engagement and satisfaction. The commitment to ongoing improvement and feature expansion positions the project has a successful and impactful future, ultimately contributing to a better user experience for cyclists.

Author contributions

Conceptualization, BM; methodology, BM; software, BM; validation, BM; formal analysis, BM; investigation, BM; resources, BM; data curation, BM; writing—original draft preparation, XT; writing—review and editing, XT; visualization, BM; supervision, XT; project administration, BM; funding acquisition, BM. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare no conflict of interest.

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Appendix A

Cycling questionnaire

Q1: What is your occupation?
Q2: What is your monthly salary?
Q3: How much are you willing to pay for AR cycling glasses?
Q4: Are you worried that using AR technology in riding may distract your attention and increase the risk of accidents?
Q5: If you choose to ride for exercise, what do you hope AR glasses can provide for you?
Q6: If you choose to ride for commuting, what do you hope AR glasses can provide for you?
Q7: If you could use AR glasses while riding a race, what do you hope it could provide for you?
Q8: If you encounter traffic problems while riding, what do you hope AR glasses can provide for you?
Q9: Are you nearsighted? Do you have any concerns about the practicality and safety of AR glasses?
Q10: Have you ever worn AR glasses? Under what circumstances have you used AR glasses? How has it been convenient for you?

Appendix B

User test questionnaire

1). Does this program run smoothly?

Smooth

Acceptable

Terrible

2). How easy or difficult did you find using this program?

Easy

Acceptable

Difficult

3). How helpful or unhelpful did you find the program for cycling?

Helpful

Acceptable

Unhelpful

4). Do you think that the data information displayed on the lenses affects the view when riding?

Affect

Acceptable

No effects

5). What's your experience with the commuting function?

Convenient

Acceptable

Doesn't work

6). What's your experience with the exercise function

Convenient

Acceptable

Doesn't work

7). What's your experience with the match function?

Convenient

Acceptable

Doesn't work

8). Will you be using this program to help you ride in your future life?

Will

Won't

9). Is there anything about this program that you are not satisfied with?

10). What other features would you like to see added to this program?