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Design and Development of a Distance and Heart Rate Monitoring System for a Dynamic Bicycle

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Abstract

Air is a vital resource for human life and the ecosystem, playing a crucial role in sustaining living beings. Its quality directly impacts health and well-being, making it essential to preserve and monitor air for safe usage. Air pollution, which results from the degradation of air quality, poses significant health risks, prompting individuals to engage in physical activities such as jogging, marathons, futsal, and cycling. Among these, cycling is favored not only as a recreational activity but also as a sustainable mode of short-distance transportation, offering both physical health benefits and environmental advantages. In this study, we present the design and development of a dynamic bicycle system equipped with a distance and heart rate monitoring mechanism. The proposed system integrates cutting-edge sensor technology, including the MAX30102 optical heart rate sensor and the M8N GPS module, to provide real-time data on cyclist performance. This research aims to contribute to both engineering and health domains by addressing the dual objectives of enhancing physical fitness and supporting eco-friendly transportation. During the testing phase, the system demonstrated challenges in sensor noise and data accuracy. For instance, the MAX30102 sensor exhibited rapid fluctuations due to program-related noise and environmental factors, necessitating the implementation of advanced filtering techniques such as the Kalman filter to stabilize readings. Similarly, the M8N GPS sensor showed a 2-meter deviation in distance measurements, which, although acceptable for odometer functionality, requires optimization to improve precision during signal loss scenarios.
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Keywords: Treadmill Bike, GPS, Pulse Heart, Odometer

1. Introduction

Air plays a critical role in sustaining life for humans and other living organisms. It is an indispensable natural resource that must be preserved to maintain its optimal function. Air pollution is characterized by the deterioration of air quality, rendering it unsuitable for intended purposes due to the presence of harmful substances (Prasetyani et al., 2022).One of the leading contributors to air pollution is the emission of exhaust gases from motorized vehicles. These emissions include physical pollutants like particulate matter (dust) and chemical pollutants such as carbon monoxide (CO) and sulfur dioxide (SO_2). The detrimental effects of these emissions on air quality are profound, often leading to adverse health outcomes for those exposed to polluted environments.

In Indonesia, vehicle exhaust emissions represent the dominant source of air pollution, particularly in urban areas. According to data from the Statistics Center in 2017, motorcycles accounted for 86% of the total vehicle population, with passenger cars at 12% and buses at 2%. Combined, these vehicles contribute approximately 70-80% of the nation's air pollution, with urban residents bearing the brunt of its impact. To counteract the health risks posed by air pollution, many individuals are turning to physical activities that strengthen the immune system and improve overall well-being. Popular choices include jogging, futsal, marathons, and cycling. Among these, cycling has emerged as a favorite activity due to its dual benefits: promoting physical health and serving as an eco-friendly mode of transportation.

Transportation, especially in urban settings, plays a pivotal role in economic growth by facilitating production, consumption, and distribution activities (Nugraha et al., 2023). The increasing adoption of bicycles as a sustainable transportation option reflects a growing awareness of the environmental and health benefits of reducing reliance on fossil-fuel-powered vehicles. Morning cycling commutes, for instance, not only reduce air pollution but also contribute to improved cardiovascular health. Engaging in physical activities like cycling has been shown to enhance physical and mental well-being. Specifically, cardiac exercises improve the heart's

DOI xxxxxx

efficiency and promote oxygen circulation throughout the body (Azhar et al., 2020). These exercises aim to maintain cardiovascular health by ensuring that blood vessels and the heart work in harmony. Healthy blood vessels, in turn, support optimal heart function.

In light of these considerations, this study proposes the design and development of a dynamic bicycle system that functions both as a short-distance transportation medium and as a tool for cardiac exercise. By integrating innovative engineering solutions, the dynamic bicycle offers an alternative means of transportation that positively impacts physical and mental health, while also addressing environmental concerns.

2. Material and methods

2.1. Research Flowchart

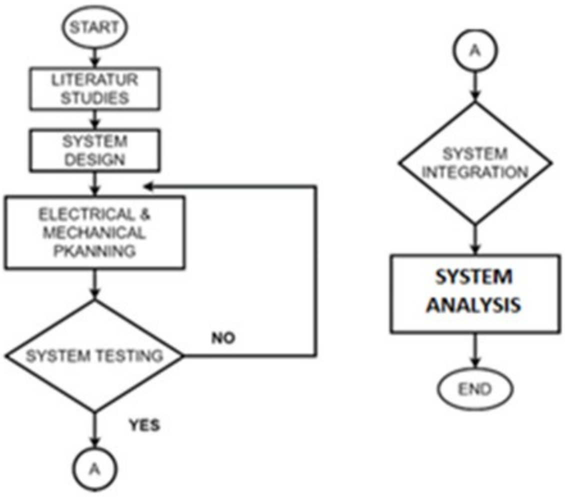

Figure 1. Research Flowchart

This research begins with a literature review to gain a deeper understanding of the problem and identify suitable solutions. Based on the findings from the literature review, a prototype design is developed, including assembling the electronic components for a heartbeat monitoring circuit. Subsequently, hardware is designed for a dynamic bicycle, intended as an alternative medium for cardiac exercise. After preparing the necessary tools and materials for testing, the next phase involves integrating the mechanical and electrical components to assess whether the bicycle functions as intended and whether the heart rate monitoring system operates effectively. The final stage involves analyzing the performance of the designed system.

A. Heart rate

Heart rate can be considered normal when measured at rest or during physical activity. It is determined by calculating the sudden pressure changes that travel as waves through the blood vessel walls (Natsir et al., 2019). To manually calculate heart rate, a stethoscope can be used as a tool to measure the pulse.

Heart rate is also an indicator of an individual's health, with changes in heart rate at rest offering insights into physical condition. Measuring heart rate is valuable for assessing one's current physical state in relation to factors like age and gender. When measuring heart rate, it is helpful to consider your body's condition based on age and gender, as referenced in the table below.

Table 1. Male resting condition heart rate

Condition	Ages					
	18-25	26-35	36-45	46-55	56-65	65+
	Heart Rate (BPM)					
Very-Very Good	49-55	49-54	50-56	50-57	51-56	50-55
Very Good	56-61	55-61	57-62	58-63	57-61	56-61
Good	62-65	62-65	63-66	64-67	62-67	62-65
More Than Enough	66-69	66-70	67-70	68-71	68-71	66-69

Condition	Ages					
	18-25	26-35	36-45	46-55	56-65	65+
	Heart Rate (BPM)					
Enough	70-73	71-74	71-75	72-76	72-75	70-73
Not Enough	74-81	75-81	76-82	77-83	76-81	74-79
Bad	82+	82+	83+	84+	82+	80+

Table 2. Female resting condition heart rate

Condition	Ages					
	18-25	26-35	36-45	46-55	56-65	65+
	Heart Rate (BPM)					
Very-Very Good	54-60	54-59	54-59	54-60	54-59	54-59
Very Good	61-65	60-64	60-64	61-65	60-64	60-64
Good	66-69	66-68	65-69	66-69	65-68	65-68
More Than Enough	70-73	69-72	70-73	70-73	69-73	69-72
Enough	74-78	73-76	74-78	74-77	74-77	73-76
Not Enough	79-84	77-82	79-84	78-83	78-83	77-84
Bad	85+	83+	85+	84+	84+	84+

2.2. Material

A. Treadmill Bike Design

This study faces several challenges related to hardware design for dynamic bicycles, where precise calculations are required to determine the appropriate size to avoid critical errors, such as having a bicycle that is too small, positioning the bicycle too low, or, even worse, wasting materials (such as iron) that are inefficient for creating the dynamic bicycle design. The following is a design of the dynamic bicycle created using AutoCAD software (Ravi et al., 2021).

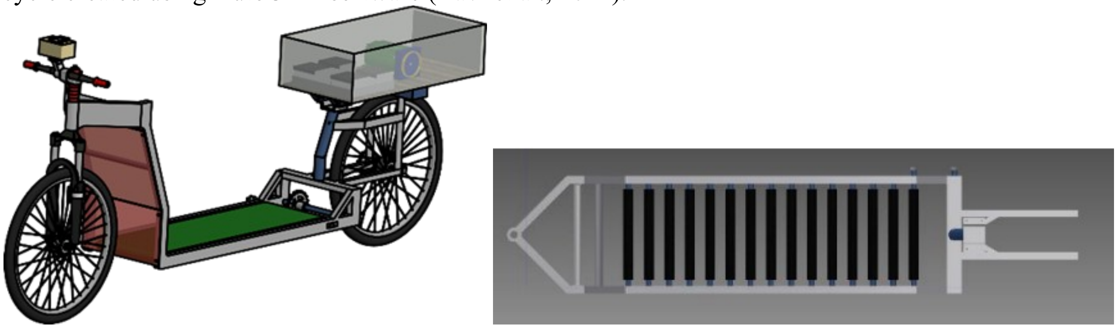

Figure 2. Design of Treadmill Bike Using AutoCAD Software

In this case, the material used for the dynamic bicycle is mild steel, with varying sizes chosen to match the applied designs. For the treadmill, the authors utilize a used treadmill from health equipment. The design is adjusted to fit the dimensions of the treadmill. One issue that arises is the adjustment of the treadmill itself. The treadmill used in this design is a mechanical one, which operates without the use of a motor to move it. Next discussion is related to the materials used in treadmill bicycles. In this discussion, the material used as a bicycle frame is to use mild steel boxes that have different sizes. The following is a trim of the mild steel used to build this dynamic bike.

Table 3. Materials Used In The Preparation Od The Framework

No	Item Name	Size	Quantity
1	Hollow Iron	25 x 25 mm, long 1,5 meters	2
2	Hollow Iron	15 x 15 mm, long 1,5 meters	2
3	Hollow Iron	35 x 20 mm, long 1,5 meters	2
4	Iron Plate	40 x 40 cm, Thick 30 mm	2

5	Iron Pape	Diameter 15mm, Thick 1mm, Long 1,5 meters	2
6	Iron Pape	Diameter 32mm, Thick 1mm, Long 1,5 meters	2

B. GPS Ublox M8N Sensor

The Ublox M8N is a Global Navigation Satellite System (GNSS) device, commonly referred to as a GPS. It is an advanced version of the earlier Ublox M6N and M7N GPS devices. The Ublox M8N can receive signals from GPS, GLONASS, and GALILEO systems, offering high precision with an accuracy range between 2 meters and 1 meter (Safitri et al., 2021). It supports various communication interfaces including UART, SPI, USB, and DDC. Additionally, the Ublox M8N can operate at temperatures up to 80℃ and is capable of receiving signals from more than 20 satellites. This wide satellite coverage allows for extensive testing of the system to assess the precision of the GPS in navigation applications (Firdaus & Jatmiko, 2020).

Figure 3. Ublox M8N

C. MAX30102 Sensor

The MAX30102 sensor module is a device that can detect human heart rate and body temperature. It uses infrared and red LEDs, along with a side-mounted optical sensor, and operates with a low noise level, effectively eliminating ambient light interference. This sensor is commonly used in fitness equipment to monitor the body's condition during exercise and is integrated with smartphones, tablets, or other compatible devices (Wiryadinata & Palega, 2014).

The sensor operates on a single 1.8V supply, with a separate 3.3V supply powering the internal LEDs (Realdo et al., 2021). It is equipped with I2C, a standard compatible interface, enabling communication between the mobile device and the microcontroller. Additionally, the module can be turned off through software, ensuring zero standby current, while allowing the system to remain powered on when necessary.

(A) (B)

Figure 4. A) Back Side on Sensor MAX30102, B) Front Side on Sensor MAX0102.

Table 4. Specification

Spesifikasi Sensor MAX30102	
Operation Voltage	1,8V ~ 5V
Current Consumption	20mA
Output Signa Interface	I2C
LED supply voltage	3,3V ~ 5V
Detection Signal Type	Light Reflection Signal
Communication Interface Voltage	18~3,3V~5V

D. Arduino Nano

The Arduino Nano is a microcontroller board based on the ATmega328 chip (Tiwana et al., 2021). It features 14 digital input/output pins, 6 of which can be used as PWM outputs, and 6 analog inputs (Ivannuri et al., 2022). The board also includes a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button (Ramadhan et al., 2021) (Nugraha, 2022). The Arduino Nano is designed to provide all the necessary components to support the microcontroller, making it easy to connect to a computer via a USB cable, power it using an AC to DC adapter, or use a battery to get started (Edilla et al., 2020).

Figure 5. Arduino Nano

E. Liquid Crystal Display (LCD)

An LCD (Liquid Crystal Display) is an electronic display type that uses CMOS logic technology (Shiddiq et al., 2021) (As'ad & Nugraha, 2022). Unlike traditional displays, it does not produce light but reflects surrounding light forward or transmits light from a backlight. LCD screens are used to display data such as characters, letters, numbers, or graphics. The screen consists of an organic composite layer sandwiched between transparent glass layers, with transparent indium oxide electrodes in the form of a seven-segment display (Zakariz et al., 2021). A layer of electrodes is placed on the back of the glass. When the electrodes are activated, the electric field affects the long cylindrical organic molecules, aligning them with the electrode segments (Putra & Nugraha, 2021).

Figure 7. LCD

F. Modul 12C Backpack LCD

The I2C/TWI LCD module is designed to reduce the number of pins required for connecting an LCD screen (Febrianto & Nugraha, 2021). This module uses only 4 pins to connect to the Arduino. The Arduino Uno already supports I2C communication with the I2C LCD module, allowing it to drive 16x2 and 20x4 character LCDs using just two pins: analog input pin 4 (SDA) for data and analog input pin 5 (SCL) for the clock signal (Zaibah & Nugraha, 2021).

Figure 8. I2C Modul

G. System Diagram

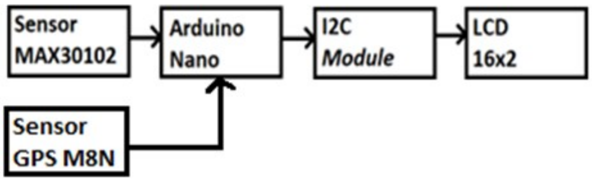

Figure 9. Diagram system

A system diagram that serves as a reference for circuit design is used. The system diagram is divided into three main parts, namely sensors, controllers and actuators. Sensors are used as input to the microcontroller, Arduino is used as a controller to execute instructions according to the designed program, while actuators are outputs that are used to follow instructions from the control (process).

3. Results and discussion

3.1. Heartbeat Test Using MAX30102

The following are the test results of the MAX30102 sensor using a validator comparison. The test results and the calculation of the average percentage error are as follows. Testing the BPM (Beats Per Minute) value was carried out at night by the author himself with the age criteria of 22 years without doing strenuous activities before doing the test.

Table 5. MAX30102 Sensor test

No	Oximeter (BPM)	Sensor MAX30102 (Average BPM)	Error
1	85	82	3,529
2	84	90	7,142
3	84	85	1,190
4	84	80	4,761
5	84	88	4,761
6	85	86	1,176
7	85	90	5,882
8	88	88	0
9	90	80	1,111
10	90	87	3,333
11	90	85	5,555
12	88	87	1,136
13	88	81	7,954
14	87	87	0
15	87	81	6,896
		Average Error	4,29%

The results of the MAX30102 sensor calibration test carried out 15 times with readings as shown in the table, it can be calculated the average value of the error percentage on the validator readings, which is 4.2955%.

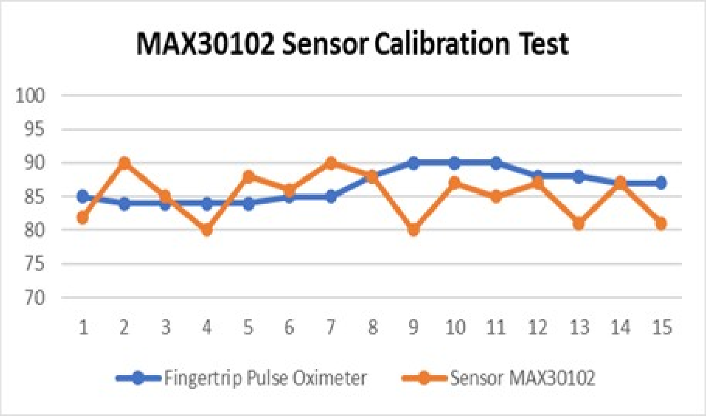

Figure 10. MAX30102 Sensor Test

3.2. Heartbeat Test Using MAX30102 After Doing Leisurely Walking Activities

In this study, the authors conducted a heart rate test after doing a leisurely walk for about 5 minutes. The results obtained when carrying out these activities are as follows.

Table 6. MAX30102 sensor test after walking

No	Oximeter (BPM)	Sensor MAX30102 (Average BPM)	Error
1	101	108	6,93
2	105	110	4,76
3	105	112	2,85
4	105	112	2,85
5	102	96	5,88
6	102	93	8,82
7	102	100	1,96
8	102	105	2,94
9	98	93	5,10
10	98	96	2,04
		Average Error	4,415%

After testing 10 times, the average error value was obtained with an average number of 4.415 %.

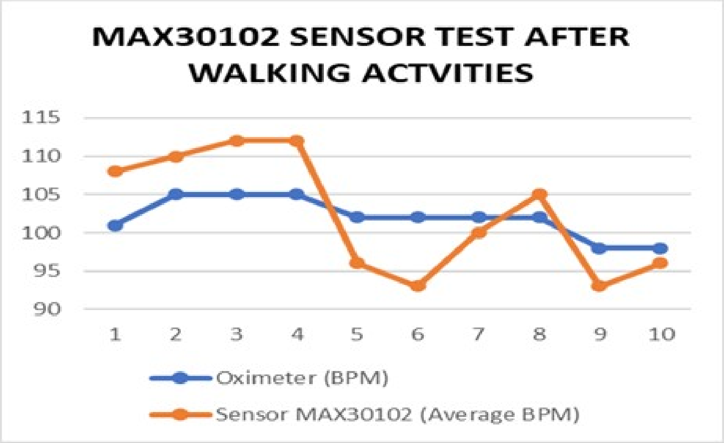

Figure 11. MAX30102 Sensor Test after walking

3.3. Testing the Odometer Using the M8N GPS Sensor

Testing the odometer using the GPS is performed to determine the distance traveled based on the GPS sensor readings, which can then be displayed for the user. This test is conducted using an LCD as a medium to display the data received from the GPS sensor.

The test is carried out 15 times, and the values obtained are compared with a validator, such as the Google Maps Android application, to assess the accuracy of the distance readings from the M8N GPS sensor. The average distance traveled is calculated for each reading, and the resulting values are used to determine the percentage error. The unit of measurement for this test is kilometers (Km). The test results, along with the calculation of the average percentage error, are presented below.

Table 7. M8N Gps Sensor Test (Odometer)

No	Google Maps (KM)	Sensor GPS M8N (KM)	Error
1	1	0,99	1
2	1	1,04	4
3	1	0,95	5
4	1,1	1,08	1,8181
5	1,2	1,22	1,6666
6	1,4	1,38	1,4285
7	1,5	1,56	4
8	1,8	1,82	1,1111
9	2	2,07	3,5
10	2,2	2,18	0,9090
11	2,4	2,41	0,4166
12	2,6	2,57	1,1538
13	3	3,1	4
14	3	3,1	3,3333
15	3,3	3,32	0,6060

No	Google Maps (KM)	Sensor GPS M8N (KM)	Error
	Average Error		2,262%

Based on the calculation of the average percentage error in the table above, the average value of the percentage error between the odometer calculation and the distance on Google Maps is 2.262%.

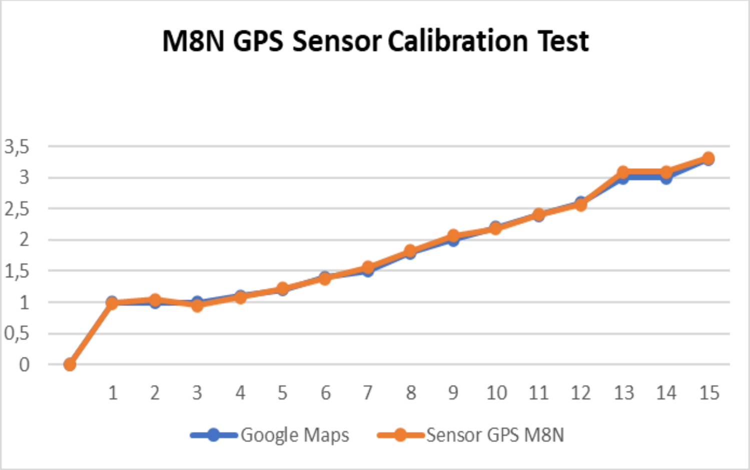

Figure 12. M8N GPS Sensor Calibration Test For Odometer

3.4. GPS Sensor Accuracy

GPS accuracy testing serves to determine the accuracy of position readings by the U-Blox M8N GPS sensor module. The test is done by comparing the output on the GPS sensor and the actual position as a validator. The coordinates of the location of the actual position are determined by selecting a point on Google Maps, so the value of the coordinates of the actual location does not change. In this test, 15 experiments were carried out, so that the value of the difference in distance was obtained, then the difference in distance from each experiment would be calculated to determine the average value of the difference in distance. In the results of the average difference in the distance is then considered as an error value. The actual location is at D'bamboo which is located in white with coordinates -7.293150, 112.801566 (latitude, longitude).

Table 8. Latitude, Longitude Using M8n Gps Sensor And Google Maps Application

No	Sensor GPS M8N		Google Maps Application	
	Latitude	Longitude	Latitude	Longitude
1	-7,293158	112,801544	-7,293150	112.801566
2	-7,293145	112,801556	-7,293150	112.801566
3	-7,293157	112,801544	-7,293150	112.801566
4	-7,293158	112,801567	-7,293150	112.801566
5	-7,293157	112,801592	-7,293150	112.801566
6	-7,29315	112,801581	-7,293150	112.801566
7	-7,293157	112,801541	-7,293150	112.801566
8	-7,293158	112,801536	-7,293150	112.801566
9	-7,293158	112,801540	-7,293150	112.801566
10	-7,293155	112,801558	-7,293150	112.801566
11	-7,293159	112,801587	-7,293150	112.801566
12	-7,293143	112,801590	-7,293150	112.801566
13	-7,293153	112,801591	-7,293150	112.801566
14	-7,293148	112,801588	-7,293150	112.801566

No	Sensor GPS M8N		Google Maps Application	
	Latitude	Longitude	Latitude	Longitude
15	-7,293149	112,801591	-7,293150	112.801566

From the M8N GPS sensor readings when placed on flat media and not being moved anywhere, it can be concluded that the sensor reads changes in location, this is because the program designed has a reading r depending on the time that has been set. In the programming used, the application of the time value using “millis” to speed up the reading of the location.

3.5. Discussion

Based on the results of the tests, several points can be discussed to improve the sensor readings. For example, when comparing the MAX30102 sensor readings before and after intense activities like running or a 5-minute walk, we observe a blood pressure response in the body. This leads to errors in the sensor readings. Table 6 shows that the sensor plot is unstable and does not align with the expected certification readings. This instability is likely due to noise from either the sensor readings or the program itself. To mitigate this, an algorithm could be implemented to reduce or eliminate the excessive noise generated by the program or the wiring setup. Notably, the difference in heart rate graphs before and after intense activity became more pronounced, even after moderate exercise.

As for the M8N GPS sensor readings, it can be concluded that the sensor accurately measures the distance traveled by the bike, with an error rate of approximately 2.2%. This error is due to the GPS sensor’s sensitivity, which records small "millimeter" level changes in position. As a result, when using the distance formula, the GPS continues to register changes even when the bike is stationary.

4. Conclusion

- Sensor Reading Noise: The rapid changes in sensor readings are caused by noise from the program, not just the circuit. For example, in the MAX30102 sensor, the response is too fast, leading to quick value changes. To address this issue, a filter should be implemented in the program. Filters such as the Kalman filter or other filtering methods can be applied to smooth out the sensor readings and reduce the noise, improving the accuracy of the MAX30102 sensor.
- M8N GPS Sensor Precision: The M8N GPS sensor has a relatively small level of precision, with the difference between the actual distance and the sensor's reading being approximately 2 meters. When used as an odometer in this study, the sensor's readings were fairly accurate. However, occasional errors occurred due to the loss of GPS signal during data collection on the road. Overall, the readings were reliable. In the future, the accuracy could be further enhanced by adding multiple filters to improve the precision of the sensor readings.
- Mechanical Design of the Dynamic Bicycle: The results of the mechanical design of the dynamic bicycle show that it can be used for long-distance transportation. Below are the results of the 3D design of the treadmill bicycle, which demonstrates the feasibility of the dynamic bicycle for such purposes.

Credit authorship contribution statement
Author Name: Conceptualization, Writing – review & editing. **Author Name**: Supervision, Writing – review & editing. **Author Name**: Conceptualization, Supervision, Writing – review & editing.

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