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A proposal to use selected mechatronic devices in bicycles to improve travel safety

Abstract

The conceptual design of the smart bike was developed to implement new technologies to the constantly developing bicycle market. The electronic systems described and presented are focused on the issue of safety when using a bicycle in public space. The implemented safety systems consist of lighting elements, such as front and rear position lights, direction indicators and brake light, as well as an obstacle detection system, twilight sensor, speed and mileage measurement. All electronic components are integrated into the spatial model of the illustrative design, the outline of which is included in the content of the project. The presented concept has great potential for further development and work focused on creating a complete, ecological and safe means of transport for the twenty-first century.

Keywords: bike, mechatronics, transport.

Propozycja wykorzystania wybranych urządzeń mechatronicznych w rowerach w celu poprawy bezpieczeństwa podróży

Streszczenie

Projekt koncepcyjny inteligentnego roweru został opracowany w celu wdrożenia nowych technologii na stale rozwijającym się rynku rowerowym. Opisane i przedstawione systemy elektroniczne koncentrują się na kwestii bezpieczeństwa podczas korzystania z roweru w przestrzeni publicznej. Zaimplementowane systemy bezpieczeństwa składają się z elementów oświetleniowych, takich jak przednie i tylne światła pozycyjne, kierunkowskazy i światło hamowania, a także system wykrywania przeszkód, czujnik zmierzchu, pomiar prędkości i przebiegu. Wszystkie elementy elektroniczne są zintegrowane z modelem przestrzennym projektu ilustracyjnego, którego zarys jest zawarty w treści projektu. Przedstawiona koncepcja ma duży potencjał do dalszego rozwoju i prac ukierunkowanych na stworzenie kompletnego, ekologicznego i bezpiecznego środka transportu na miarę XXI wieku.

Słowa kluczowe: rower, mechatronika, transport.

1. Introduction

An analysis of various types of bicycles commonly found around the world shows the need to implement new, personalized accessories and parts for even the smallest group of customers (Kapousizis et al., 2023; Novak, 2016). Bicycles are used in many areas of everyday life, and their versatility, comfort, ease of use, and safety are indisputable (Boot et al., 2024). Users of such equipment can be as young as three years old, and the upper limit is late old age, so each of them will need a set of accessories and technologies tailored to their needs in order to fully exploit the potential of their skills and abilities (Avina-Bravo et al., 2022).

This work was motivated by the desire to design and find appropriate solutions in the world of cycling, adapted to the realities of our fast-paced world. The project is based on proposing an electronic system that controls the vehicle's lighting, provides additional safety support, and monitors and collects data on the current status of the bicycle (Omri et al., 2024; Gómez-Suárez et al., 2022). For this purpose, an appropriate programming platform that meets the design requirements and reliable and compatible electronic components will be used (Henao et al., 2021).

The topic will be complemented by a comprehensive bicycle design, with particular attention paid to the individual components of the electronic system and their location (Novak, 2016). A visualization of the finished product will be presented using a spatial modeling environment.

A bicycle is clearly defined in traffic regulations. It is a vehicle with a maximum width of 0.9 m, powered by the muscular strength of the person riding it. Additionally, it may be equipped with an auxiliary electric drive, activated by pressing the pedals; the supply voltage must not exceed 48 V. The continuous rated power may be a maximum of 250 W, which gradually decreases when the speed exceeds 25 km/h (Jannah et al., 2025).

The electronic system is an indispensable part of the smart bike design. It allows the use of various types of sensors and actuators to improve the functionality and safety of the vehicle (Luo et al., 2024; Eisenman et al., 2007). The systems installed in cars are connected to an on-board computer patented by the respective brand. Pioneering solutions, security measures, and individual programming effectively prevent unauthorized users from making any changes outside of an authorized service center (Fischer et al., 2024).

The automotive industry has a huge budget and staff, and also mass-produces the technologies it develops. The bicycle market needs simpler, widely available, and affordable solutions (Reggiani et al., 2022; Beeking et al., 2024; Lee et al., 2025). At the same time, it has significant limitations that must be met by the control unit.

The Arduino programming platform seems to be the right solution in this case. Arduino is an open-source project, where both the hardware and software are made available by the copyright owner to users for further research, modification, improvement, and distribution of their own solutions (Kumar, Motupalli, 2020; Luo et al., 2024). Arduino is a miniature computer system with the ability to program and operate on input and output data using appropriate instructions (Henao et al., 2021).

2. Purpose and scope

The project was developed with the aim of presenting the design of a modern, smart bicycle equipped with systems supporting cyclists in everyday use. The main objective of the project is to create an electronic system that sends signals to the user and receives information from the environment in order to improve safety and ergonomics when using the bicycle.

The basis of the electronic system is a control unit. The microcontroller of such a unit must be able to handle all installed input and output devices, so it is necessary to adjust it in terms of the number of inputs and outputs, both digital and analog. Required number of inputs/outputs: digital – 12, analog – 2 using the I2C bus. The following are also required: easy and quick access to modify the software, compact dimensions in relation to the bicycle frame, a lightweight and miniature power source, and high compatibility with accessory devices.

The current system for detecting objects in front of the vehicle should inform the cyclist of a possible hazard on the road with sufficient advance warning of approximately three seconds. This is sufficient time to perform a maneuver to prevent an unexpected collision. The distance sensor should therefore be adjusted in terms of measurement range so that it is effective at both low and high speeds. An equally important parameter is the frequency of measurements, so as not to cause too much delay – at least 30 measurements per second. Compact dimensions and low weight will be additional advantages.

The lighting included in the construction of the bicycle must meet the basic functionality of accessory lights intended for use in traffic. A front headlight that produces bright white light that does not dazzle other road users, with two lighting modes – flashing warning light and continuous light illuminating the area in front of the vehicle. The rear light is red and has at least one flashing signal mode. An integrated brake light is also required, with continuous illumination and greater intensity than the position light. In addition to the standard light control button, the lighting system reacts to changes in the intensity of ambient light. This means that the lights are automatically switched on or off from dusk to dawn and when entering tunnels and overpasses. The measuring range of such a photocell must be at least 0 to 250 lux and read the measurement 10 times per second.

Turn signals are not legally required as necessary equipment for the use of a bicycle, but they have a very significant impact on safety while riding. Signaling maneuvers is crucial for good communication between road users and pedestrians. Taking your hands off the handlebars is not safe, especially when turning, so the use of turn signals is justified. For simple and uniform communication, orange LED lights with intermittent operation should be used at both the front and rear of the vehicle.

Measuring the speed of a vehicle is very important for other electronic subsystems. They rely on its correct reading: the obstacle detection system, the functioning of the brake lights, the display of the current speed and the distance traveled. The main criterion for selecting a sensor is its measurement frequency, which must be at least 7 measurements per second.

3. Smart bike components

The Arduino Uno R3 board was selected for the project, as it meets the design requirements in terms of available inputs and outputs, offers compact dimensions and high peripheral device compatibility, and has an open programming environment, allowing users with knowledge of electronics and C programming languages to modify the software.

An alphanumeric LCD display with a working area arranged in two rows of 16 characters was used to display the basic current parameters of the vehicle. To facilitate operation and reduce the number of microcontroller pins required, the screen is equipped with an I2C converter module soldered to the connector, making it possible to control the display using the SDL and SDA lines of the I2C bus. The content is displayed in black against a green backlight, and the contrast can be adjusted using a built-in potentiometer.

The first line shows the current vehicle speed in the center and the battery charge level on the right edge. The second line shows the distance traveled, and on the left side, the current mileage, which is reset when the central unit is turned off, while on the right side of the display, the total mileage calculated and recorded during all trips is shown.

The display is mounted in an ergonomic position for user comfort and ease of use, as well as in a low-collision location, as the housing containing the display and other electronic components is mounted in the steering bridge Figure 1. The housing itself has transparent plexiglass to prevent dirt and moisture from getting inside the display, while remaining unnoticeable for comfort of use. The screen wiring runs through the inside of the bridge, going directly to the bicycle frame, where the Arduino board is mounted.

Reading the current speed in various types of vehicles is standard practice. For the user, this is a simple message informing them whether the speed achieved is satisfactory in relation to the planned travel time or compliance with traffic rules. However, the correlations that arise between different electronic systems are invisible – only the effects of the correct functioning of such a system are visible.

The first of the dependencies involving speed measurement is cooperation with an obstacle detector. The aim is to make the speed of the vehicle dependent on the distance to the obstacle, thus enabling the creation of an intelligent system that will alert the cyclist early enough about an approaching obstacle, regardless of the speed reached. When using a proximity sensor alone, it is only possible to determine the distance from which the alarm is triggered. This is a very imprecise method due to the frequent and large differences in bicycle speed.

Figure 1. Location of the LCD display on the bicycle handlebars

(source: own study)

The second connection is the functioning of the brake light system, which activates when the speed is reduced. This solution avoids the use of additional equipment in the form of a limit switch, which, like any mechanical component, has limitations such as declared service life, weight and size, and the use of an additional digital microcontroller input.

Speed is measured using a Waveshare module equipped with an AH49E Hall sensor with adjustable sensitivity. The integrated circuit is characterized by low output noise, which eliminates the need for external filtering. It also contains precision resistors that ensure increased temperature stability and measurement accuracy. The output voltage depends on the supply voltage, which should be between 2.3 and 5.3 V, and varies in proportion to the magnetic field strength. The module has 4 pins: VCC – power supply (2.3-5.3 V), GND – power supply ground, AOUT – analog output, DOUT – digital output.

The Hall effect sensor module connected to the D8 digital input of the Arduino board counts the frequency of occurrence within the measurement range of a magnet attached to the rim of a bicycle wheel. If the magnetic element is detected by the sensor, a short high signal is sent to the microcontroller, which starts measuring time until the next high state appears. In order to calculate the speed, it is necessary to enter the circumference of the wheel mounted on the vehicle into the controller – this will allow the creation of a relationship between the occurrence of one high signal and the distance traveled at that time.

Assuming that the bicycle will be equipped with 700x35C wheels and 35-622 tires, the approximate circumference of the entire wheel is 2.168 meters, which means that this distance is covered in the time between two high states of digital input D8.

The resulting bicycle speed v [m/s] is used to operate the obstacle detector and brake light. The information provided to the user via the LCD display is additionally converted into speed V in km/h.

An important issue when deciding to use and ensure the efficient functioning of a sensor utilizing the Hall effect is its proper placement. The sensor itself detects the presence of a magnetic field at a maximum distance of 12 mm. The magnet mounted in the holder and attached to the spokes of the bicycle wheel is 3 mm away from the Hall sensor when it passes it, so no reading should be missed and its effectiveness should remain at a satisfactory level. The sensor module is built into a housing with a clamp, and the whole unit is enclosed, leaving only a small opening for the measuring element to protrude towards the rotating wheel. The connection cable is ultimately routed in the armor, close to the front shock absorber, and then passes through a hole with a seal to enter the interior of the bicycle frame Figure 2.

Figure 2. Location of the speed measurement system

(source: own study)

The obstacle detector is designed to improve user safety when moving among other vehicles and traffic participants. It is a support system for the often-imperfect sense of sight. The distance sensor must therefore have sufficient sensitivity and maximum measurement distance to effectively inform the user of a possible hazard in advance.

The speed measurements used to select the appropriate distance sensor were made using a GPS satellite system and the Strava mobile app. The speed graphs for each route are shown in Figure 3.

Route 1 (Trasa 1) with a total distance of 20.6 km, was covered in favorable conditions with a lot of elevation changes, completed alone and focused on achieving a specific goal. The graph shows an average speed of 19.5 km/h. The maximum speed achieved was 48.1 km/h, but it is not repeatable, while a regularly occurring value of around 40 km/h can be read.

Route 2 (Trasa 2) took much longer to complete, with a result of 38.9 km. The trip consisted of a group of two people and was focused solely on recreation. The average speed achieved fluctuates around 12.7 km/h, and the highest speed achieved is 41.4 km/h. Again, the repeatable high speed is slightly lower than the maximum and is around 30 km/h.

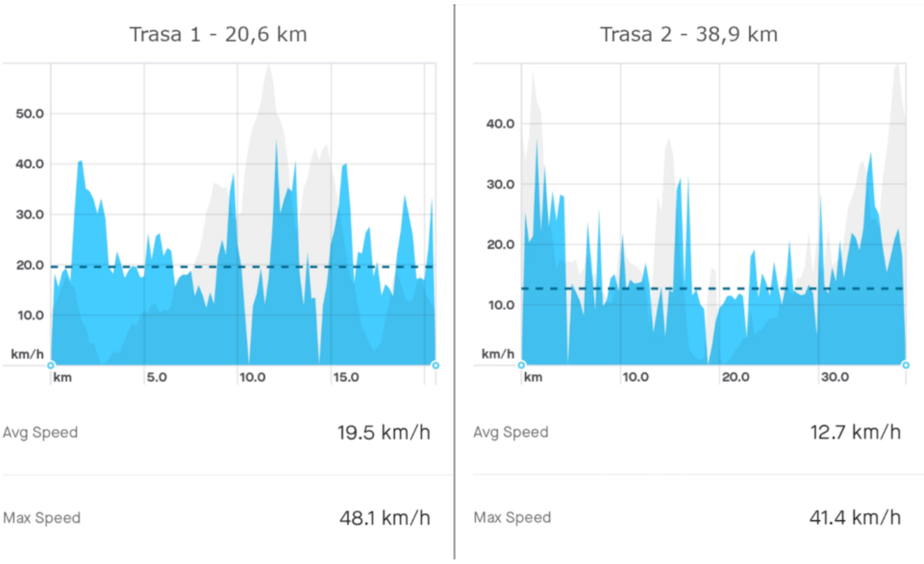

Figure 3. Speed measurement using a GPS system

(source: own study)

For the purposes of the project, the maximum speed was set at 50 km/h. Using Figure 3, it can be seen that for the assumed speed, the vehicle travels 41.67 meters in 3 seconds. To ensure optimal system performance and utilize the full measurement range, a sensor with a maximum range of 40 meters should be used.

A laser sensor compatible with and dedicated to many open-source programming platforms was used for the obstacle detection system. The TeraRanger Evo 40m is a versatile, long-range Time-of-Flight (ToF) distance sensor designed for navigation and obstacle avoidance in robotics Figure 4. It offers the ability to detect objects up to 40 meters away, with a refresh rate of up to 240 Hz. The sensor is very lightweight, weighing only 12 grams, and has compact dimensions. The set includes one selected, replaceable stand for mounting on a surface, which also serves as a connection interface for I2C/UART projects.

The system operates primarily by maintaining an appropriate relationship between the speed of the bicycle and the distance to the detected obstacle. Speed should be interpreted as the time needed to approach an object that poses a threat to the user. The project assumes that the time needed for the cyclist to react appropriately is 3 seconds from the moment an undesirable object appears on the vehicle's path. The system adjusts the distance read from the U2 sensor depending on the current speed indicated by the U1 sensor and interprets whether to send a warning signal to the user and in what form.

Calculated on the basis of the assumed speed v = 25 km/h and the corresponding distance value vm = 20.83 m/3s, the coefficient k is approximately 1.2. For the obstacle detection system, each speed measurement v is divided by the coefficient k to obtain the variable x. This variable is compared with the distance value s read from the Terabee laser distance sensor. The result of the comparison is considered in terms of four possible situations.

The first situation occurs when, for a given calculated variable x, the time needed to approach the obstacle is greater than 3 seconds. This means that the optical and acoustic alarm signals remain inactive – digital outputs D12 and D13 are in a low state.

The second situation occurs when the time it takes for the cyclist to approach the object is less than or equal to 3 seconds, but greater than 2 seconds for the calculated variable x. An optical alarm signal is triggered in the form of a flashing red LED located on the housing next to the main display. The digital output of controller D12, responsible for controlling LED7, is triggered by a signal corresponding to a flashing frequency of 2.5 Hz with a period of 0.4 s. Both the high and low states last for 0.2 s.

The third situation is possible when the time needed to reach the obstacle is less than or equal to 2 seconds, while at the same time it is greater than 1 second for the variable value x. An optical alarm signal is triggered in the form of a flashing LED7 and an intermittent, loud audible signal generated by the BUZ1 buzzer connected to the D13 digital output. Digital outputs D12 and D13 are triggered by signals with the same time parameters – frequency 2.5 Hz, period 0.4 s.

Situation four describes the behavior of the alarm system when, for a given variable x, the time remaining to contact the object is less than or equal to 1 second. This is a critical situation, so the warning LED continues to flash as in the previous situations, while the acoustic alarm changes to a continuous, loud buzzer sound.

In an ideal laboratory experiment, where a bicycle with an intelligent obstacle detection system is traveling at a constant speed toward a stationary obstacle, each situation involving an active alarm signal should last one second and cyclically go through successive alarm stages.

In order to fulfill its task, the obstacle detector was mounted at the front of the bicycle, perpendicular to the ground, so that the laser beam would maintain the correct angle, even at long distances. Placing the sensor on the frame, i.e., on the head of the bicycle frame, instead of on the handlebars, allows for greater stability of readings, as the movement of the handlebars is more chaotic than the road on which the vehicle is traveling. The distance sensor is located in a housing that prevents foreign objects from entering the structure. The connection cables run directly through the inside of the bicycle frame to the microcontroller connectors.

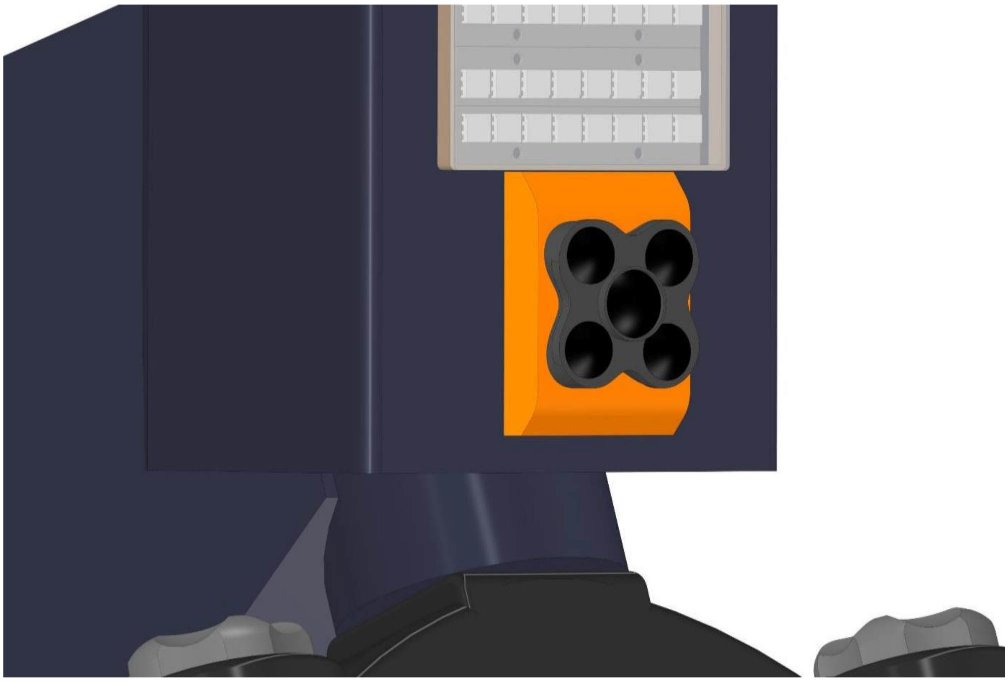

Figure 4. Obstacle detector mounting location

(source: own study)

The lighting system used in the project consists of:

- Integrated, intelligent LED modules;
- Light intensity sensor;
- Buttons and switches.

Modules equipped with individually addressed WS2812B RGB LEDs are an intelligent LED light source. The integrated single LED controller allows for addressing of modules connected in series in such a way that the color of each LED can be set separately. The LEDs used are manufactured in the SMD5050 standard – the size of the LED is 5 x 5 mm. Each of them consists of three basic colors: red, green, and blue, which can achieve up to 256 brightness values, i.e., over 16.7 million color combinations.

The communication protocol consists of a single signal line, so it is a serial protocol, also known as non-return-to-zero (NRZ). It is a simple code in which logical 0 and logical 1 are encoded by different durations. Data is sent in 24-bit frames containing GRB components in descending order. For Arduino clocked at 16 MHz, the acceptable tolerance is 150 ns – this is a few clock cycles. In reality, the WS2812B controller allows for greater flexibility, but the most important thing is to maintain a minimum duration of 1250 ns. The appropriate libraries available for download and initialization in the microcontroller have encoded timing characteristics for the operation of the modules.

The main switch, used to cut off the power supply connected to the Arduino board, is based on the MRS-101 rocker switch, with the following specifications:

- Switching mode: OFF – ON;
- Switch type: bistable;
- Contact arrangement: SPST (NO-C);
- Contact rating: 3 A at 250 VAC;
- Service life: 10,000 cycles.

The switch controlling the operation of the turn signals is a small Canal MR3-H rocker switch. A rectangular type with the following parameters was used for the project:

– Switching mode: ON-OFF-ON;
– Switch type: bistable;
– Contact rating: 10 A at 250 VAC;
– Initial contact resistance: max. 20 mΩ;
– Dielectric strength: 1000 VAC for 1 minute;
– Temperature range: from -20° to +85° C;
– Service life: 10,000 cycles.

Control button for front and rear lighting – model PBS-33B. Technical parameters:

– Switching mode: OFF – ON;
– Initial state: normally open;
– Switch type: normally open, monostable with automatic return;
– Contact load capacity: 1 A at 250 VAC;
– Initial contact resistance: max. 20 mΩ;
– Dielectric strength: 1000 VAC for 1 minute;
– Temperature range: from -20° to +85° C;
– Service life: 50,000 cycles.

The main switch for the entire electronic system is built into a panel located on the steering bridge, providing easy access for activating or deactivating the system, as shown in Figure 1. The lighting controls, both for the turn signals and the main lights, are located on the handlebar, close to the left handle and brake lever, in an ergonomic position for the thumb Figure 5.

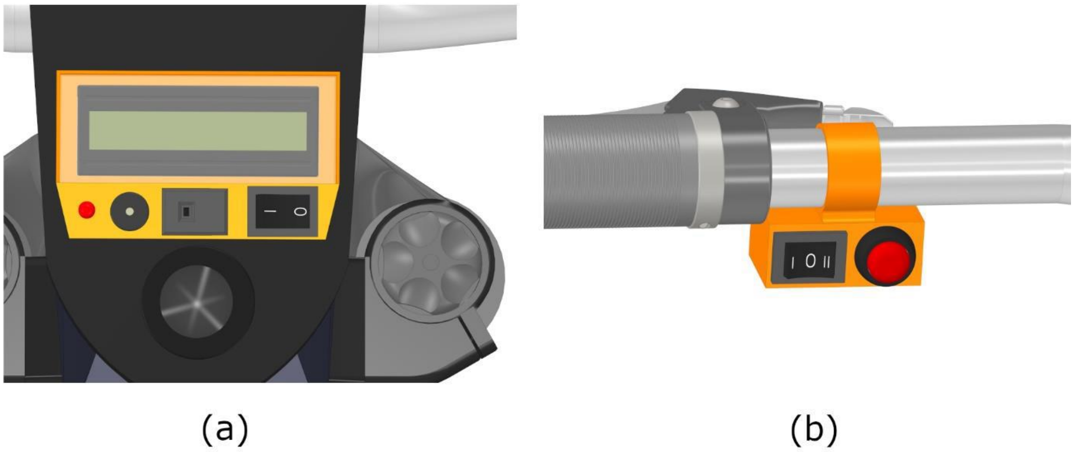

Figure 5. Buttons and switches: a) main switch, b) lighting control

(source: own study)

The rear light consists of a NeoPixel Stick 8 strip equipped with 8 WS2812B modules. The ready-made LED assembly saves a lot of space, as the length of the set is about 3 times shorter than individual modules placed in series.

One lighting strip performs two basic functions:

– position light;
– brake light.

The position light uses half of the available LEDs, arranged every other one in the set. This saves energy, but also emphasizes the brake light, which uses all LEDs.

The brake light functions independently and takes precedence over the position light. This means that all LEDs on the strip light continuously when the appropriate condition is met.

The NeoPixel Stick 8 strip requires a single 5 V power source, the GND pin must be connected to ground, and for communication with the microcontroller, the DIN pin must be connected to the D3 digital output.

The rear light is built into a housing on a long arm attached to the seat tube instead of the seat post to avoid changing the position of the rear light when the saddle height is changed, thus reducing the frequency of movement of the power cables. The position light is located vertically in the center of the bracket, between the turn signals, and has a red plexiglass lens with a high light transmission coefficient Figure 6.

The front lighting of the bicycle mainly serves to illuminate the road ahead of the vehicle, so in order to create an effective light source, the LED6 front headlight module consists of 4 NeoPixel Stick 8 strips connected in series, placed in a housing with a transparent lens that focuses the light beam. The front headlight can also serve as a signal for other road users when there is no need to illuminate the road ahead of the vehicle. The front lighting operates in two modes and is controlled manually using the same button as the rear light. The color of the light can be freely adjusted thanks to the use of three-color LEDs, but for the clearest and most ergonomic effect, it is programmed to a cool white color.

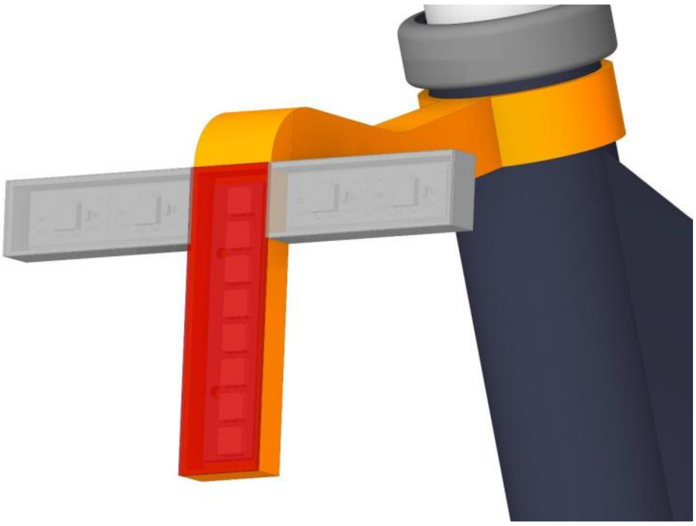

Figure 6. Installation of position lights

(source: own study)

The front lighting is located in a housing with a glass lens that focuses the light, creating a more orderly beam of light rays, affecting the intensity and efficiency of the headlight. The front light is directed slightly towards the ground to minimize the risk of dazzling oncoming traffic and to maximize the lighting potential. The headlight is mounted on the head of the bicycle frame, between the handlebar stem and the obstacle detector Figure 7, so that the cables remain hidden inside the frame along their entire length.

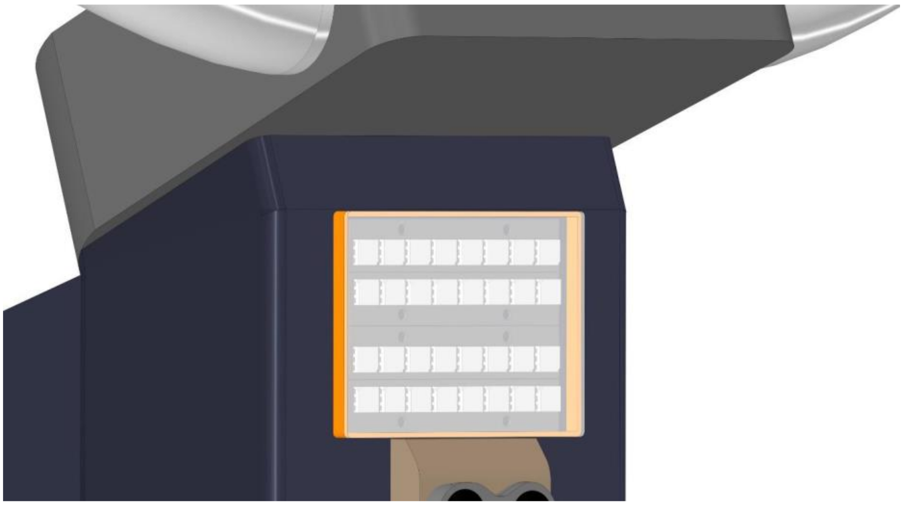

Figure 7. Location of the headlight

(source: own study)

The WS2812B LED modules responsible for the turn signals are divided into two sections:

- front section;
- rear section.

The front section contains two segments – left and right, each consisting of two LED modules. The left segment, marked LED1, contains LED1-1 and LED1-2 modules connected in series. They are connected to Arduino on digital output D7. The right element, marked LED2, uses two LED2-1 and LED2-2 modules connected in series, connected to digital output D6.

The rear section is also divided into two parts – left and right. The left part, marked LED3, consists of two LED3-1 and LED3-2 modules connected in series to digital output D5. The right part, marked LED4, contains two LED4-1 and LED4-2 modules connected to output D4.

Switch S1 is responsible for controlling the turn signals. When the switch is set to the extreme left position, contact 1 is closed, causing a signal to be sent to digital input D9. Turn signals LED1 and LED3 start working. The flashing occurs at a frequency of 1.25 Hz, with a period of 0.8 s, assuming that the high and low states occur equally at 0.4 s. When switch S1 returns to the middle position and none of its contacts are closed, the operation of turn signals LED1 and LED3 is interrupted.

When switch S1 is moved to the far right position, contact 2 is closed and a signal is sent to digital input D10. At this point, the LED2 and LED4 turn signals begin to flash at a frequency of 1.25 Hz and a period of 0.8 s. The high and low states last 0.4 s each. If switch S1 returns to the middle position, LED2 and LED4 stop working.

The rear turn signals are located in a common housing with the rear position light, which separates the two turn signals from each other, creating a clear gap between them and thus better informing the traffic participant behind the bicycle in which direction the maneuver will be performed. The wires are routed through narrow channels. The front turn signals have their own housing, with an additional white reflective element in the center. The whole assembly is attached to the highest point, the front shock absorber bridge Figure 8b. The wiring, with a reserve length, is routed through sealing grommets to the inside of the support frame via the shortest route.

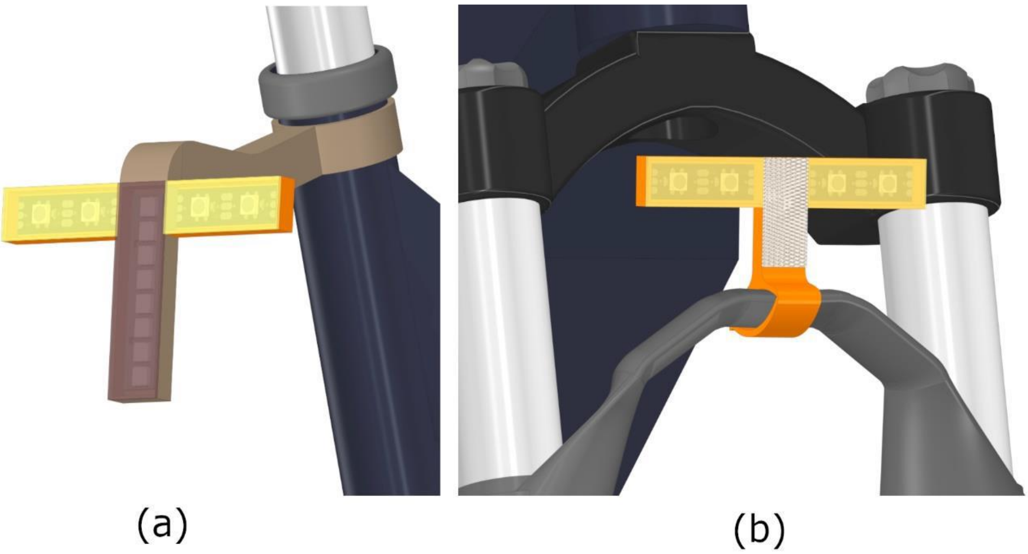

Figure 8. Location of turn signals, a) rear, b) front

(source: own study)

Automatic lighting control requires the use of a U4 light intensity sensor to accurately determine whether the spotlights need to be activated at a given moment. If the controller only used a programmed atomic clock for control, it would be necessary to declare or enter the current date so that, depending on the season, the lights would turn on at dusk. With the appropriate photoresistor circuit, it is possible to enter a variable value which, when exceeded, causes the lighting to turn on or off.

After power is supplied to the microcontroller, it analyzes the readings from the twilight sensor. When the set twilight threshold is exceeded, which suggests that the microcontroller should activate the appropriate lighting mode, it triggers digital outputs D2 and D3. Two switching thresholds are programmed: threshold 1 – triggered when the light intensity falls below 140 lux and above 80 lux, while threshold 2 – interpreted by the microcontroller when the amount of light reaching the sensor is less than 80 lux.

When the first threshold is reached, the microcontroller immediately activates lighting mode 1, then monitors fluctuations and changes in readings from the U4 photoresistor module to check which conditions are met. If the light intensity rises above the upper limit, the T1 countdown begins – this is a delay time during which the controller continuously monitors the level of external lighting in order to eliminate accidental, intense light sources reaching the sensor, such as street lamps or other vehicles. The delay time T1 is set to 5 seconds. If during this time the light intensity falls below 140 lux again, the T1 counter resets and starts counting down again, but if after 5 seconds the external light intensity remains higher, the lighting switches off.

The light intensity sensor is part of a panel built into the steering wheel bridge Figure 9. This location of the photoresistive element eliminates the light source from oncoming vehicles, which, due to its intensity and relatively long exposure time, could effectively interfere with the sensor's operation. When measurements are taken only from sources above the sensor, after dark only street lights have an impact, but when driving, they are passed so quickly that the intensity of the light beam decreases before the delay time T1 or T2 elapses.

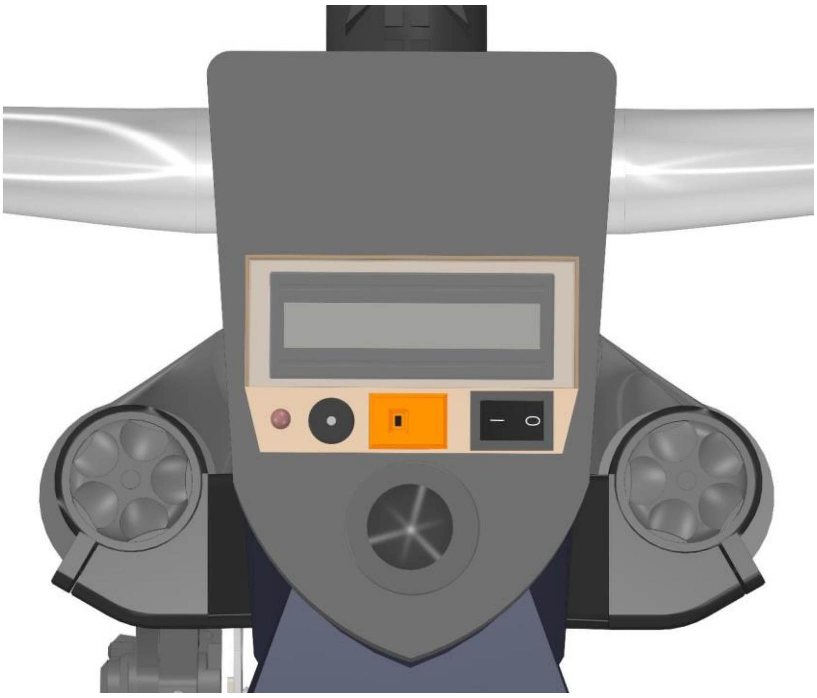

Figure 9. Location of the light intensity sensor

(source: own study)

The main connection diagram shown in Figure 10 contains all electronic system components connected to an Arduino Uno board equipped with an ATmega328 microcontroller.

Assigned digital inputs and outputs of the microcontroller:

- D2 – digital output – LED6 – front headlight;
- D3 – digital output – LED5 – rear position light;
- D4 – digital output – LED4 – right rear turn signal;
- D5 – digital output – LED3 – left rear turn signal;
- D6 – digital output – LED2 – right front turn signal;
- D7 – digital output – LED1 – left front turn signal;
- D8 – digital input – U1 – speedometer (Hall sensor);
- D9 – digital input – S1 – turn signal switch position 1;
- D10 – digital input – S1 – turn signal switch position 2;
- D11 – digital input – S2 – manual lighting control button;
- D12 – digital output – LED7 – obstacle detection system warning LED;
- D13 – digital output – BUZ1 – obstacle detection system warning buzzer.

A4/A5 I2C bus SDA/SCL analog input:

U2 – obstacle detector (distance sensor);

U3 – LCD display;

U4 – automatic lighting control (light intensity sensor).

Assigned analog inputs of the microcontroller:

In addition, the Arduino board has a main switch S0 connected in series between the VIN pin – main power supply, and the power source, thanks to which it is possible to start the entire electronic system with a single switch.

4. Components of a smart bike

The appearance of the single-track vehicle, which is ultimately to be equipped with intelligent electronic systems, does not differ much from a standard bicycle without any electric power-driven amenities. The shape of the smart bicycle presented in the project is similar to many solutions currently available on the market, and it is difficult to confuse it with any other vehicle. A distinctive feature is the support frame, which has been designed with future improvements to the concept in mind and the implementation of an electric drive to assist the cyclist's muscles in situations of increased calorie expenditure. The rectangular shape of the lower tube provides optimal space for equipping the structure with additional, high-capacity batteries, which are the power source for the electric drive Figure 11.

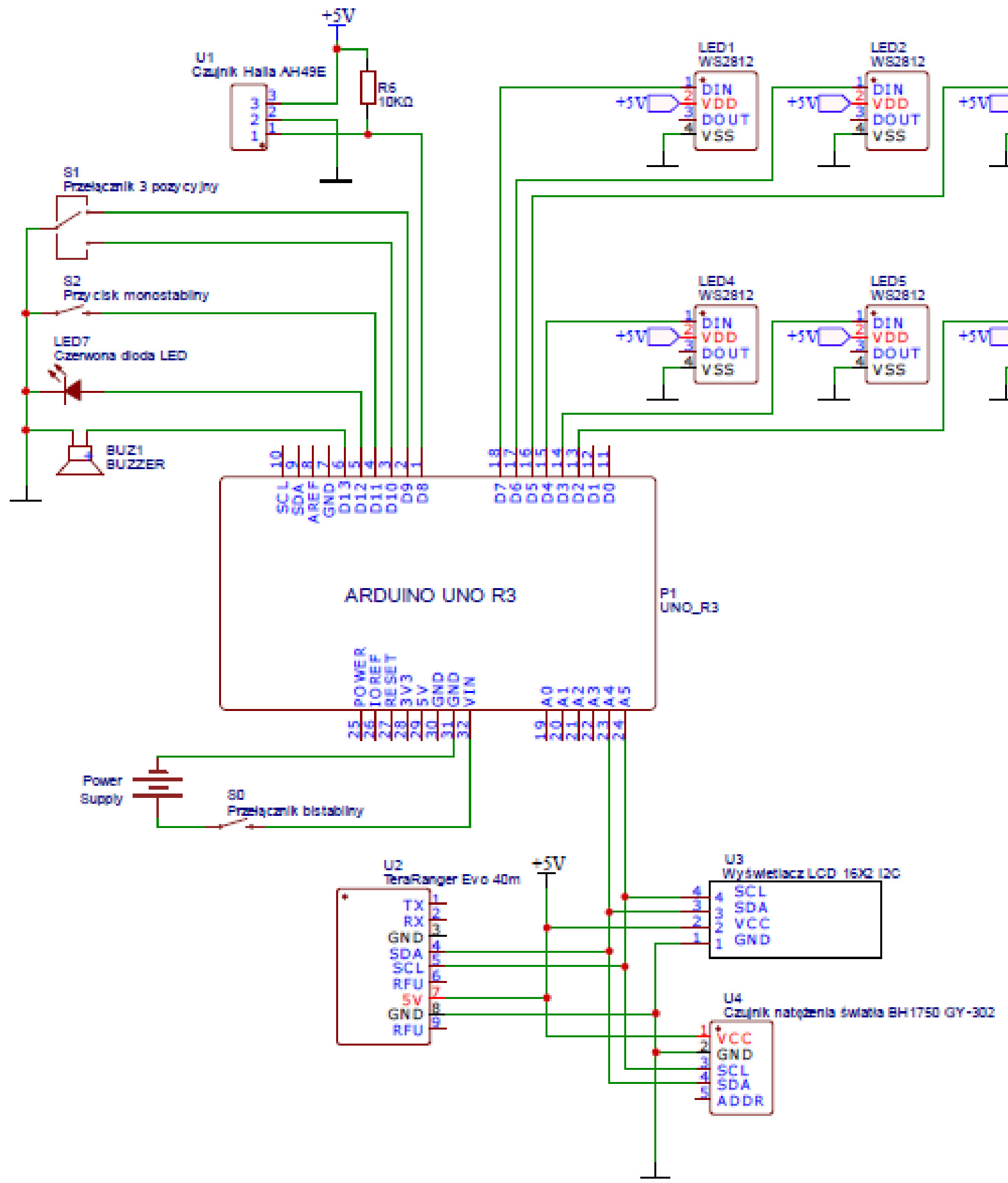

Figure 10. Connection diagram

(source: own study)

Figure 11. Bicycle design

(source: own study)

At the current stage of the project, only the Arduino controller is located inside the bicycle frame, screwed to a prepared bracket in such a way as to ensure convenient access to all connectors of the programmable microcontroller on the printed circuit board. Access to the controller is located on the top of the frame, where a sealed cover is mounted with screws.

A visual representation of the layout of all electronic systems included in the conceptual design of the smart bicycle is shown in Figure 12, which contains detailed groups of systems such as:

- rear lighting, which includes: position light, rear turn signals;
- control panel, including: LCD display, obstacle detection alarms (LED and warning buzzer), main switch, twilight sensor;
- control panel, consisting of: turn signal switch, light switch);
- headlight;
- obstacle detector;
- front turn signals;
- speedometer.

Figure 12. Layout of electronic systems

(source: own study)

5. Conclusions

The proposed topic, "Conceptual design of a smart bicycle", offers a wide range of possibilities for implementing new, innovative solutions or those previously used in other fields of science and technology, which, when simplified and minimized, have the potential to effectively and positively impact the bicycle market. This is a market that is developing rapidly and surprising with its ability to adapt to the prevailing conditions of very fast-paced urban and suburban life. These innovations are needed, especially in cities that are expanding their infrastructure to facilitate the use of two-wheeled vehicles.

The solutions developed for the project focus on improving the safety and ergonomics of bicycle use for people who use bicycles for everyday travel among other road users and pedestrians. This means, among other things, providing the user with a greater sense of psychological comfort by offering technologies that relieve and support their sense of sight, which, in a flood of information, can become a weak point in perceptual-motor function in a critical situation.

The use of a distance sensor that continuously monitors the space in front of the vehicle, processing the signals received by the sensor and then interpreting them in accordance with the control algorithm, issues commands to the executive devices to activate programmed warning signals, alerting the driver to the impending danger. This solution is particularly useful in conditions of limited visibility, for example after dark, when the eyes are constantly exposed to changes in lighting and need a few seconds to readjust to the darkness. In such a case, the obstacle detection system will inform the driver of an undesirable object detected in the sensor's field of view with an optical signal or both an optical and acoustic signal.

The creation of complete lighting on board a bicycle shows that it is essential for safe travel on roads, bicycle paths, or, in exceptional situations, pedestrian paths. Signaling the intention to turn, brake, or generally be present on the road has a huge impact on the safety of all road users, yet two of these signals are not regulated by law and are not used by most cyclists. Using a specially designed lighting system, which, in addition to the standard front headlight and rear position light, also offers front and rear turn signals and an integrated brake light. Turn signals controlled by a switch mounted on the handlebars completely eliminate the need to take your hands off the handlebars while riding, which significantly improves the stability of the vehicle when maneuvering. The brake light is an integral part of the position light and functions independently and completely automatically when a decrease in vehicle speed is detected. An additional element of the lighting system is a twilight sensor, which is responsible for automatically turning on the lights when the intensity of ambient light falls below a specified threshold.

The last element of the electronic system is an LCD display, which collects information useful to the user, such as current speed, temporary distance, total distance, and battery charge level. The displayed data can be used to limit the current speed or draw attention to the number of kilometers traveled in order to suggest the need to visit a bicycle service center for a periodic inspection.

The total estimated cost of purchasing all the electronic components used in the presented concept design does not exceed PLN 1,000 gross per unit. By planning mass production, obtaining wholesale prices or prices directly from the manufacturer for the components, and deducting VAT on goods, it is possible to introduce new technology in bicycles to the market at an affordable price for the end user.

All the systems and components presented, adapted for installation in a smart bicycle, bring certain conveniences and improvements that have been successfully applied in other areas of human life. The manufacturing industry, modern automotive industry, building systems, and many other areas of society are increasingly basing their operations on automation, the use of sensors, and self-adaptation to a given situation. Nowadays, the level of advancement in electronics is admired by enthusiasts and experts in the field, assists people who only use technological goods in their everyday lives, and opens doors for professionals who are constantly looking for new inspiration and solutions.

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