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Bicycle Testing With Integrated Force Measurement

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1 Abstract

This research report presents the design and implementation of a bicycle testing system for the project "ZEETA"- State adaptation for single-track electric traction drives. The system is embedded with a treadmill and a test rig designed to measure the forces exerted on a bicycle during operation using the KD40S Integrated Force Measurement Sensor. The force sensor is mounted on the test rig and the end of a trolley handle mounts on the test rig to capture real-time force data. This setup aims to provide a comprehensive understanding of the forces that act on a bicycle, which can be used to improve bicycle design, enhance rider performance, and ensure safety. The report details the design considerations, methodology, and potential applications of the system.

2 Introduction

The ZEETA project[10] focuses on the development of an electrically powered, single-track trailer designed to operate without exerting forces on the towing two-wheeler. This innovative approach aims to encourage the use of bicycles, contributing to more sustainable mobility. However, achieving such a design poses significant challenges in scientific and technical domains, particularly in system dynamics, state detection, and control adaptation.

To ensure precise force control, the project integrates and develops advanced methodologies in system design, sensor fusion, machine learning, and adaptive control technology. A central focus of the ZEETA project is state estimation for the trailer, which forms the foundation for force control adaptations that dynamically respond to varying environmental conditions and riding dynamics. To accomplish this, the project employs a combination of model-based sensor fusion techniques and data-driven approaches derived from machine learning. These methods are systematically developed, integrated, and evaluated.

Ultimately, the project aims to demonstrate strategies for adaptive control in diverse initial

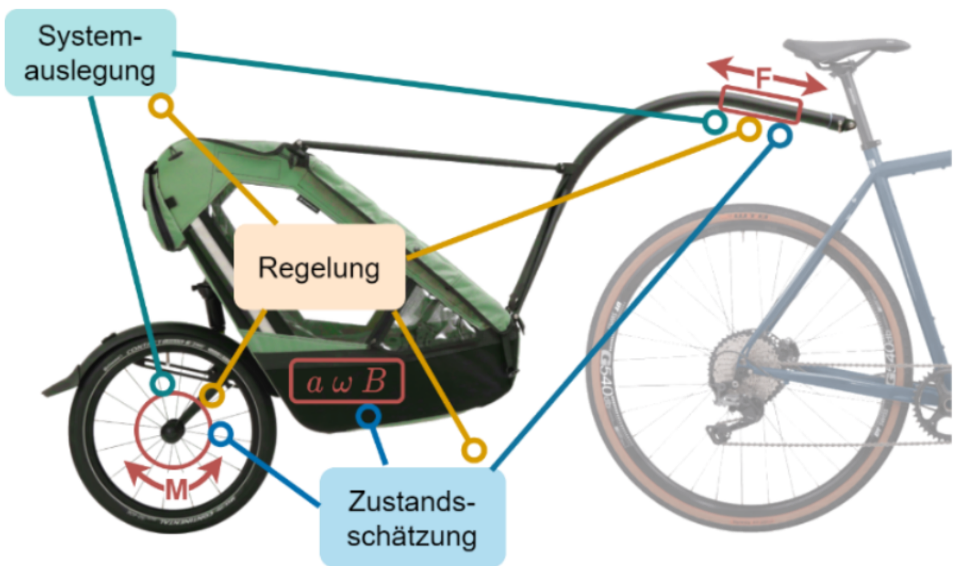

Figure 1: Bicycle-Trailer Dynamics and Control Schematic

scenarios, guided by the accurate detection of the trailer's state. By addressing these challenges, ZEETA advances the potential for reliable and efficient trailer designs, enhancing the practical usability of bicycles in modern transportation systems.

2.1 Background

Bicycles are one of the most widely used modes of transportation and recreation globally. Understanding the forces acting on a bicycle during operation is crucial for optimizing design, improving performance, and ensuring safety of the rider. Traditional methods of determining the force on bicycles often involve complex setups and are limited in their ability to capture real-time data. The integration of advanced force sensors, such as the KD40S, with a treadmill-based test rig offers a novel approach to accurately measure and analyze these forces.

2.2 Objectives

The primary objectives of this research are:
1. Design a test platform embedded with a treadmill for bicycle testing.
2. Integrating the KD40S force sensor into the test rig for accurate force measurement.
3. Measure and analyze the forces exerted on the bicycle during operation.
4. Provide information on bicycle design and performance optimization.

3 Literature Review

3.1 Force Measurement in Bicycles

Previous studies have explored various methods for measuring forces in bicycles, including strain gauges, load cells, and piezoelectric sensors. However, these methods often require complex calibration and are limited in their ability to capture dynamic forces in real-time.

3.1.1 Traditional Bicycle Testing Methods

Traditional Bicycle Force Testing Methods include:
1. Static Load Testing: Static load testing involves applying a stationary load to various parts of the bicycle to assess their strength and ability to withstand forces without deforming or breaking. This method is essential to ensure that the bicycle components can handle the weight and stresses encountered during normal use. The test typically involves placing weights on specific areas, such as the frame, fork, and handlebars, and measuring any deformation or stress. By analyzing the results, manufacturers can determine if the components meet safety standards and design specifications[1].

2. Fatigue testing: Fatigue testing subjects bicycle components to repeated cycles of loading and unloading to simulate real world usage. This test is crucial for assessing the durability and lifespan of the parts under continuous stress. During fatigue testing, components such as the frame, wheels, and crankset are repeatedly loaded with forces similar to those encountered during riding. The test aims to identify any potential weak points or failure modes that may develop over time. By understanding how components respond to cyclic loading, manufacturers can improve the design and materials used to enhance the longevity and reliability of the bicycle[2][4].

3. Impact testing: Impact testing evaluates the ability of bicycle components to absorb shocks and prevent damage from sudden impacts, such as hitting a pothole or curb. In this test, a weight is dropped onto the bicycle or its components to simulate impact forces. The test assesses the strength and resilience of the components, ensuring that they can withstand sudden shocks without failing. Impact testing is particularly important for critical components such as the frame, fork, and wheels, which must absorb and dissipate impact energy to protect the rider and maintain structural integrity[7].

4. Tensile testing: Tensile testing measures the maximum force that a material or component can withstand before breaking. This test is essential to assess the strength of the materials used in bicycle construction. During tensile testing, a sample of the material or component is subjected to a controlled tensile load until it reaches its breaking point. The test provides valuable data on the material's tensile strength, elongation, and mechanical properties. By understanding these properties, manufacturers can select the appropriate materials and design components that meet the required strength and performance criteria[8].

5. ISO 4210 standards: The ISO 4210 standard outlines various test methods for bicycles, ensuring that they meet safety and performance requirements. The standard includes frame and fork impact tests, fatigue test, and horizontal and vertical force tests. These standardized tests provide a comprehensive evaluation of the bicycle's structural integrity and performance. Compliance with ISO 4210 standards ensures that bicycles are safe for riders and capable of withstanding the rigors of everyday use. Manufacturers must adhere to these standards to ensure the quality and safety of their products.

Performing an ISO 4210 test involves a rigorous evaluation of bicycles to ensure compliance with safety and performance standards. Although specific procedures may vary depending on the part being tested, such as the frame and fork, the general process adheres to ISO 4210 guidelines. Test methods often involve evaluating factors such as strength, durability, and overall performance. These tests are designed to guarantee the resistance and durability of individual parts and the bicycle as a whole[6].

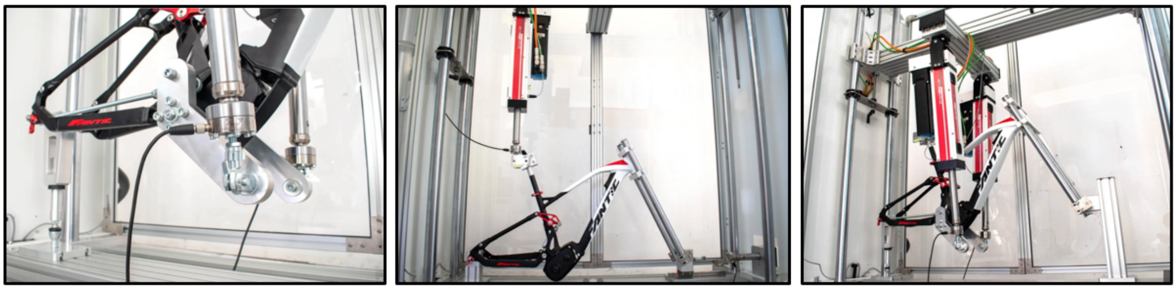

Figure 2: ISO 4210 standard test setup

6. EFBE TRI-TEST: The EFBE TRI-TEST is a comprehensive testing protocol developed by EFBE Prüftechnik GmbH. This protocol includes standard tests based on international standards, as well as additional tests for specific types of bicycles, such as full-suspension bikes and electric bikes. The EFBE TRI-TEST® covers a wide range of mechanical and performance aspects, including fatigue testing, impact testing, and stiffness measurements. By subjecting bicycles to these rigorous tests, manufacturers can ensure that their products meet high standards of safety, durability, and performance[4].

These traditional bicycle force testing methods are crucial to ensure that bicycles are safe, reliable, and capable of withstanding the demands of everyday use. Each test provides valuable data that helps manufacturers design and produce high-quality bicycles that meet the needs of riders.

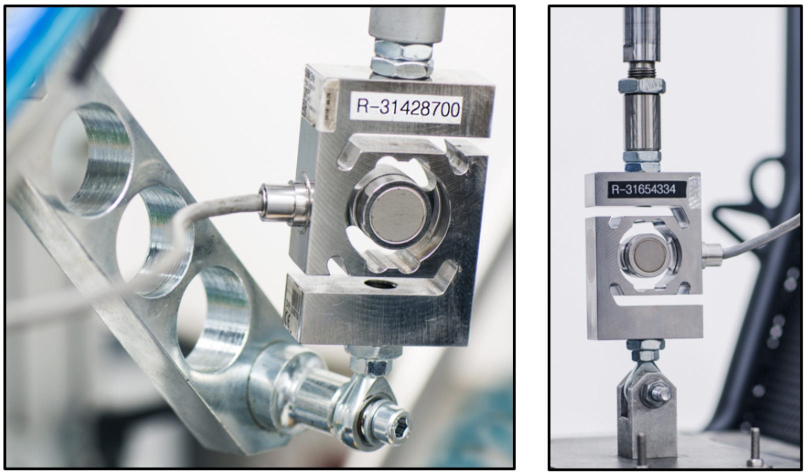

Figure 3: EFBE TRI-TEST using load cell

3.1.2 Force Measurement Technologies

Force measurement technologies are essential for accurately quantifying the forces applied to objects in various applications, ranging from industrial processes to scientific research. These technologies utilize specialized sensors and instruments to convert mechanical forces into measurable electrical signals. Integrated force measurement relies on advanced sensor technologies, such as:

1. Load Cells: Load cells are the most common type of force measurement sensors. They are designed to measure tensile and compressive forces by converting the mechanical force into an electrical signal. The load cells typically use strain gauges, that are bonded to a deformable structure. When a force is applied, the structure deforms, causing a change in the electrical resistance of the strain gauges. This change is proportional to the applied force and is measured by a data acquisition system[4].

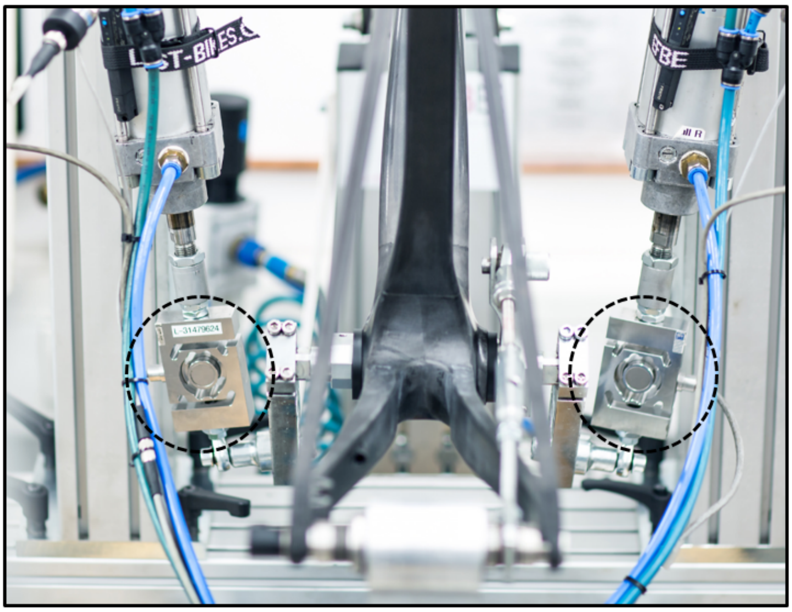

Figure 4: Load cell usage during testing

Applications: Weighing systems (e.g. scales, industrial weighing), Material testing machines, Structural health monitoring,Robotics and automation.

2. Strain gauges: Strain gauges are sensors that measure the strain (deformation) of an object when subjected to force. They consist of a thin, conductive material arranged in a grid pattern and bonded to the surface of the object. When the object deforms, the strain gauge also deforms, causing a change in its electrical resistance. This change is measured and used to calculate the applied force.

Micro-Measurements® strain gauges were used in the development of a bicycle power meter at Nanyang Technological University, Singapore. The strain gauges were used to measure the actual torque applied by the cyclist responsible for the power output. The strain gauge was mounted on a separate sensor member that can be easily retrofitted between exiting bicycle crank sets. The main challenge was to provide an accurate measurement of torque by eliminating the non-contributing forces and moments on the system. The research aims to develop a cost-effective solution for an accurate power-measurement device for a cyclist[9].

Applications: Structural testing and analysis, load monitoring in bridges and buildings, aerospace and automotive testing, biomechanics research.

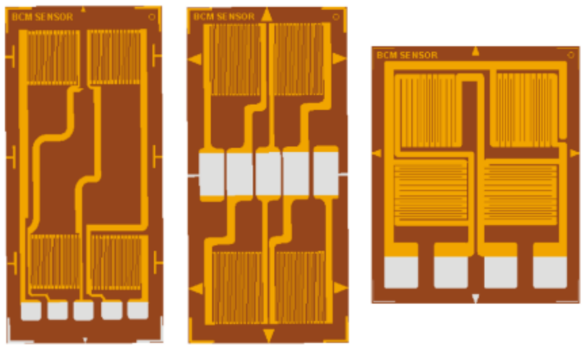

Figure 5: Full-Bridge Strain Gauges

3. Piezoelectric Sensors: Piezoelectric sensors use the piezoelectric effect to measure force. When a piezoelectric material (such as quartz or certain ceramics) is subjected to mechanical stress, it generates an electrical charge proportional to the applied force. These sensors are highly sensitive and can measure dynamic forces with high precision.

This paper explores using vibrations in bicycles as an ambient energy source to power onboard devices like computers and sensors. Measurements reveal that, although vibration energy decreases with speed, it remains sufficient to collect energy in any location on the bicycle. A piezoelectric harvester with a voltage switching circuit was developed, which successfully collected sufficient energy during field tests[3].

Applications: Vibration and shock measurement, dynamic force measurement in industrial processes, medical devices (e.g., force sensors in surgical instruments), and acoustic emission testing.

Figure 6: Piezoelectric Sensors

4. Hydraulic and Pneumatic Force Transducers: Hydraulic and pneumatic force transducers use fluid pressure to measure force. In hydraulic transducers, a force is applied to a piston, causing a change in fluid pressure. This pressure change is measured and converted into an electrical signal. Pneumatic transducers operate similarly but use compressed air instead of hydraulic fluid.

Applications: Heavy machinery and construction equipment, Automotive testing (e.g., brake force measurement), Industrial automation, Load testing in cranes and hoists.

5. Optical Force Sensors: Optical force sensors use light to measure force. These sensors typically use fiber optics or other optical components to detect changes in light intensity or wavelength caused by mechanical deformation. Optical sensors are immune to electromagnetic interference and can be used in harsh environments.

Applications: Structural health monitoring in civil engineering, Medical devices (e.g., force sensors in minimally invasive surgery), Aerospace and defense applications, Research and development in material science.

6. Capacitive Force Sensors: Capacitive force sensors measure force by detecting changes in capacitance caused by the deformation of a dielectric material between two conductive plates. When a force is applied, the distance between the plates changes, altering the capacitance. This change is measured and used to calculate the applied force.

Applications: Touch-sensitive devices (e.g., touchscreens, pressure-sensitive buttons), Robotics and automation, Industrial process control, Consumer electronics.

7. Magnetic Force Sensors: Magnetic force sensors use the principles of magnetism to measure force. These sensors typically use Hall-effect sensors or magnetostrictive materials to detect changes in magnetic fields caused by mechanical stress. The resulting changes in the magnetic field are measured and converted into an electrical signal.

Applications: Automotive applications (e.g., force sensors in power steering systems), Industrial automation, Medical devices (e.g., force sensors in prosthetics), Research and development in magnetic materials.

3.2 Integrated Force Sensors

The KD40S force sensor is a state-of-the-art device capable of measuring forces with high accuracy and reliability. Its compact design and ease of integration make it an ideal choice for bicycle testing applications.

3.3 Treadmill-Based Testing

Treadmill-based testing offers a controlled environment for bicycle testing, allowing for consistent and repeatable measurements. The integration of force sensors with treadmills has been explored in other fields, such as biomechanics, but its application in bicycle testing is relatively novel.

3.4 Applications in Other Industries

Force measurement systems are widely used in industries such as automotive, aerospace, and sports science. For example, in automotive testing, integrated sensors measure forces on suspension systems to optimize performance and safety. Similarly, in sports science, force plates analyze athlete biomechanics to improve training outcomes. These applications demonstrate the potential of integrated force measurement in bicycle testing.

4 System Design and Methodology

4.1 System Overview

The testing system comprises the core components such as:

4.1.1 Treadmill

Simulates real-world cycling conditions with adjustable speed and incline. The treadmill is equipped with a powerful motor and advanced electronic components, including a circuit board and wiring, which are essential for its efficient operation. These components ensure that the treadmill runs smoothly and can handle various positions such as horizontal and inclined.

Figure 7: Treadmill

4.1.2 Bicycle Test Rig

Houses the bicycle and integrates with the treadmill to maintain stability during testing. Additionally, the test-rig is designed to withstand increased vibrations during operating conditions, ensuring stability and reliability throughout the testing process. This robustness guarantees accurate and consistent performance evaluations even under demanding circumstances. KD40S

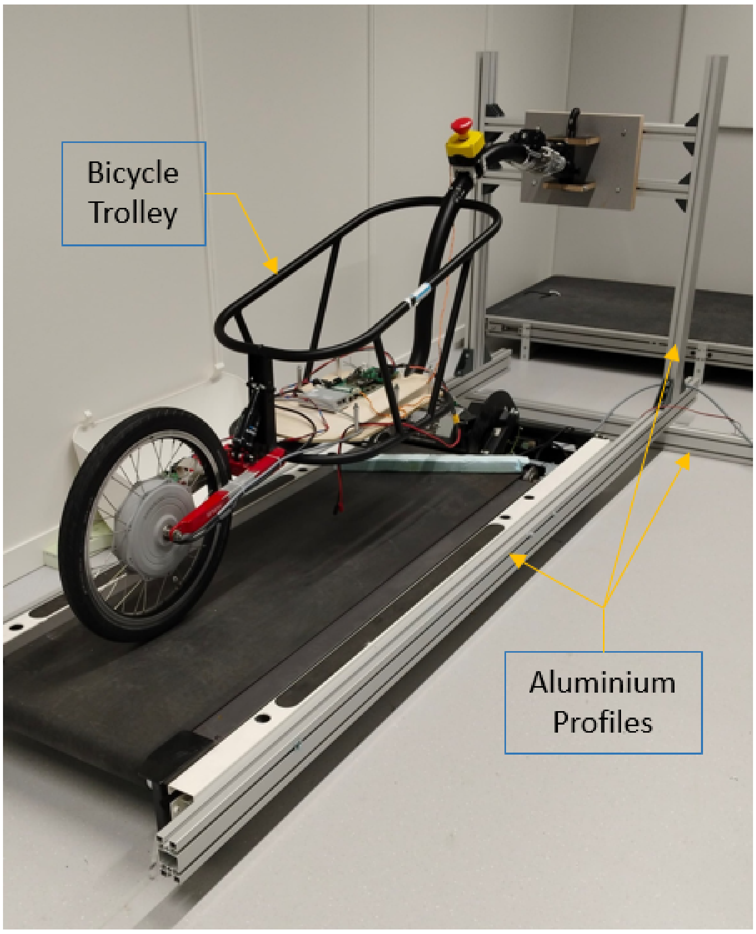

Figure 8: Treadmill assembly with aluminium profiles assembled

Force Sensor Mounted at the end of a trolley handle assembly, it captures the tri-axial forces (X, Y, Z) exerted on the bicycle's wheel.

1.The test rig is precisely constructed using extruded aluminum profiles with an anodized E6/EV1 finish. These high-quality profiles are rigidly assembled to the treadmill, ensuring stability and durability, by securely fastening them with bolts and nuts. This setup guarantees a robust and reliable testing environment, perfect for accurate and consistent performance evaluations.

2.Extruded aluminum is extensively utilized across various industries due to its lightweight, strength, and versatility. The anodizing process enhances the metal surface by creating a durable, corrosion-resistant anodic oxide finish. This anodic layer is non-conductive and provides several key benefits:

- Increased surface hardness, which improves durability.
- Enhanced lubrication, making the material easier to work with.

- Better adhesion for paint and adhesives, ensuring long-lasting finishes.

Anodized aluminum is commonly employed in architectural applications, consumer electronics, automotive parts, and numerous other fields due to these advantages.

3.The E6/EV1 designation refers to a specific type of anodized finish according to the DIN 17611 standard. E6 indicates the type of anodizing process used, which a specific electrolytic coloring process providing a uniform and consistent finish. EV1 denotes the color of the anodized finish, which is a natural, silver-colored finish often referred to as "clear anodized."

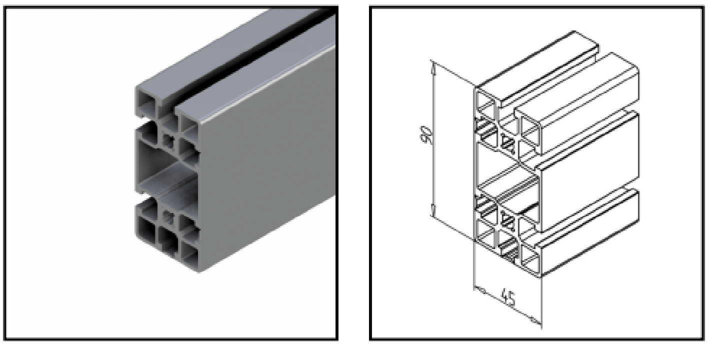

Figure 9: Aluminium profile

4.1.3 Sensor Integration

The KD40S[5] is a multi-axis force sensor engineered for precision measurement in dynamic environments. Key specifications include: Force Range:

- Rated force Fx: 500 N
- Optional configurations for higher loads (up to 1 kN).
- Accuracy: ±0.5% of full scale, with temperature compensation (-10°C to 70°C) to minimize drift.
- Sampling Rate: 1 kHz, enabling real-time data capture for transient force analysis.
- Output Signal: 1 mV/V (compression = positive signal).
- Protection Rating: IP65/IP67 (dust/water-resistant).
- Size: 34mm (height) × 40mm (length) × 10mm (width).
- Material: Aluminum alloy
- Mechanical Interface: M6×1 for mounting/force transfer.

The KD40S sensor is calibrated to measure forces up to 500 N with an accuracy of ±0.5% full scale. Its compact design and high sampling rate (1 kHz) ensure precise real-time data acquisition. The sensor is coupled to the treadmill test rig and the trolley handle assembly is assembled to it, which mimics human grip dynamics, allowing for realistic force transmission.

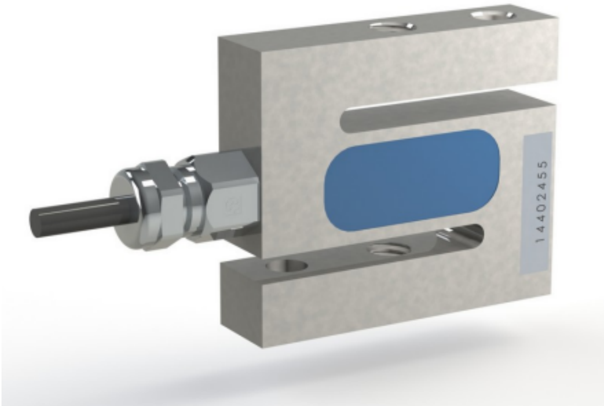

Figure 10: Force Sensor KD40s 500N

4.2 Embedded Electronics for Motor Speed and Rotation Monitoring

To enhance the functionality of the treadmill-based bicycle testing platform, an embedded electronic subsystem was developed to measure the rotational speed and total revolutions of the treadmill motor. This subsystem integrates a microcontroller, an infrared slot sensor, and an OLED display to provide real-time monitoring of motor dynamics. The collected data supports synchronized analysis with the KD40S force sensor measurements.

Component	**Description**
STM32G431 Nucleo-64 MCU	ARM Cortex-M4 microcontroller with SPI, EXTI, timers
Infrared Slot Sensor (10 mm)	Detects shaft interruptions to generate rotational pulses
0.96-inch RGB OLED Display	SPI-based display for real-time visualization
Modified Motor Shaft	Groove machined for optical pulse detection

4.2.1 Mechanical Modification of the Motor Shaft :

A precision groove was machined into the exposed treadmill motor shaft to enable accurate detection of rotational pulses. The groove ensures that the infrared slot sensor receives a clear optical interruption once per rotation. The specifications of the groove are. The sensor was mounted using a custom bracket to maintain a fixed clearance of 1–2 mm between the shaft and the optical slot, ensuring stable pulse generation even at high speeds.

- Width: 2–3 mm
- Depth: 1–1.5 mm
- Positioned on the outermost accessible region of the shaft

4.2.2 Infrared Slot Sensor Integration

The infrared slot sensor operates on the principle of optical interruption. An IR LED emits light across a narrow slot, which is received by a phototransistor. When the machined groove passes through the slot, the beam is interrupted, generating a digital pulse. Each pulse corresponds to one full rotation of the motor shaft. The sensor output is connected to the STM32 external interrupt pin (EXTI), enabling precise pulse counting.

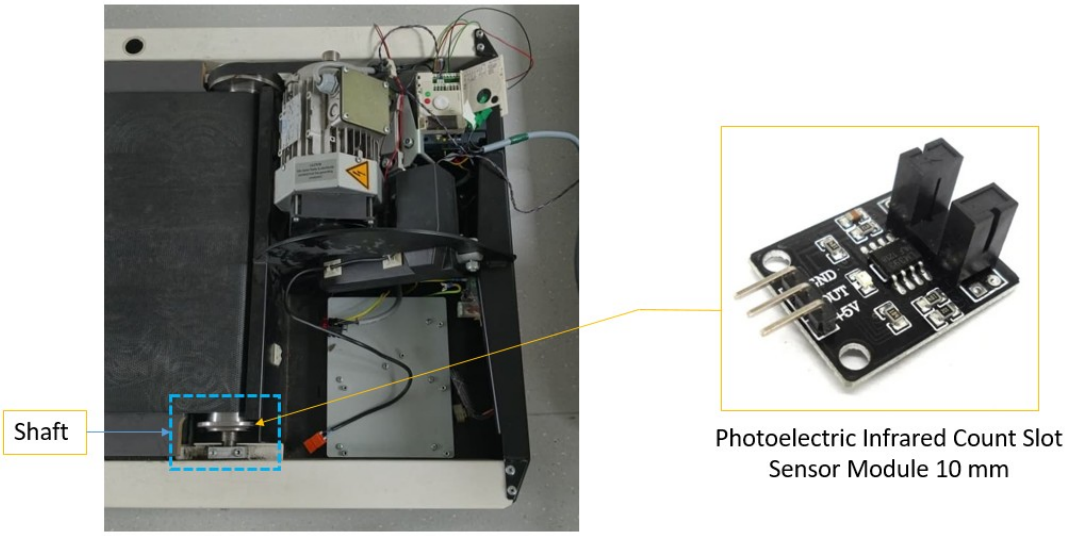

Figure 11: Treadmill shaft with a mounted IR sensor

4.2.3 Microcontroller Processing

The STM32G431 Nucleo-64 microcontroller performs the following tasks:

- Counts pulses from the IR sensor using an interrupt-driven GPIO pin
- Computes the rotational speed (RPM)
- Tracks the total number of rotations
- Sends data to the OLED display via SPI (Serial Peripheral Interface)

The RPM is calculated every 1 second using:

$$RPM = pulse\_count \times 60$$

where `pulse_count` is the number of pulses detected in one second.

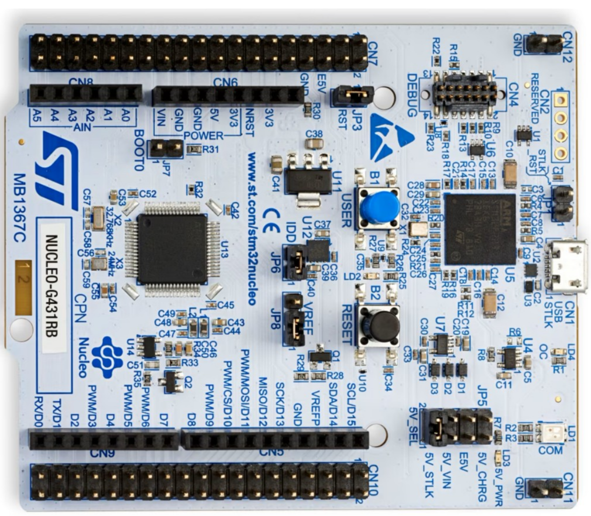

Figure 12: STM32G431 Nucleo-64 microcontroller

4.2.4 Software Development Using STM32CubeIDE

- **STM32CubeMX Device Configuration**: Used to graphically configure GPIO pins, SPI interface, EXTI interrupts, and system clock settings. This tool automatically generates initialization code, reducing development time and minimizing configuration errors.
- **HAL (Hardware Abstraction Layer) Libraries**: HAL drivers were used for SPI communication, GPIO interrupt handling, and timing functions. These libraries simplify low-level hardware interactions and ensure portability across STM32 devices.
- **Integrated Debugger**: The Nucleo-64 board's onboard ST-LINK debugger allowed real-time debugging, breakpoints, variable inspection, and step-by-step execution. This was essential for validating pulse detection accuracy and ensuring stable RPM calculations.
- **Project Build and Compilation**: The IDE uses the GCC ARM toolchain to compile the C code into a binary executable. Build automation ensured consistent firmware generation during iterative development.
- **Serial and Memory Monitoring**: STM32CubeIDE provided live variable monitoring, enabling verification of RPM values, pulse counts, and display update timing during treadmill operation.

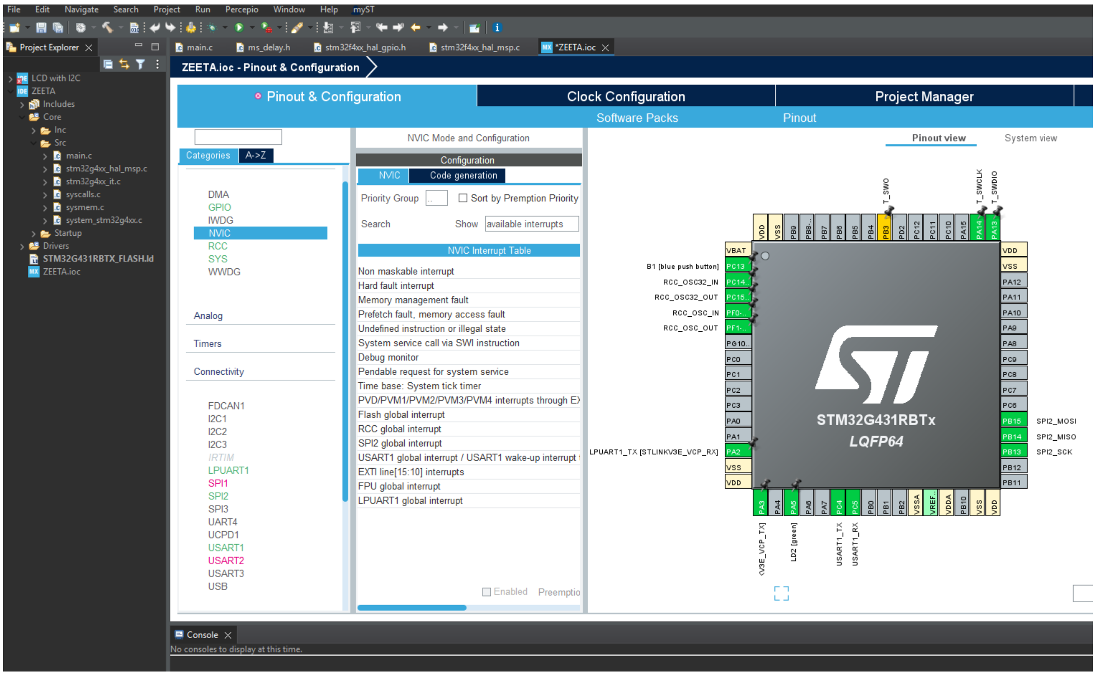

Figure 13: STM32 CubeIDE

STM32CubeIDE played a crucial role in streamlining the development workflow, enabling rapid prototyping, efficient debugging, and reliable deployment of the embedded firmware.

4.2.5 OLED Display Integration

A 0.96-inch RGB OLED display is interfaced with the STM32 using the SPI communication protocol. The display is updated every 100 ms to show:

- Current RPM
- Total rotations

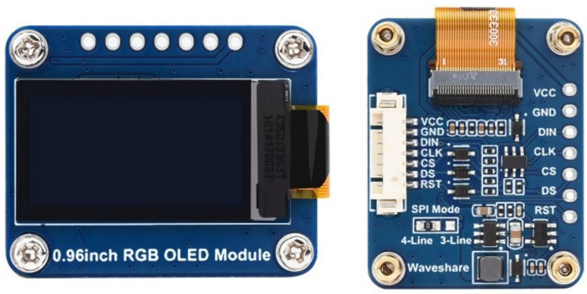

Figure 14: 0.96inch RGB OLED Display Module

This real-time visualization assists in monitoring treadmill performance during testing.

4.2.6 Embedded C Code Implementation

The following C code was developed using STM32 HAL libraries to implement pulse counting, RPM calculation, and OLED display updates:

```
#include "main.h"
#include "ssd1357.h"
#include "fonts.h"
#include <string.h>
#include <stdio.h>

volatile uint32_t pulse_count = 0;
uint32_t rpm = 0;
uint32_t total_rotations = 0;
uint32_t last_time = 0;

// Interrupt callback for IR sensor pulse
void HAL_GPIO_EXTI_Callback(uint16_t GPIO_Pin)
{
    if (GPIO_Pin == GPIO_PIN_0)  // IR sensor on PA0
    {
        pulse_count++;
        total_rotations++;
    }
}

// Calculate RPM every 1 second
void calculate_rpm(void)
{
    uint32_t current_time = HAL_GetTick();

    if ((current_time - last_time) >= 1000)
    {
        rpm = pulse_count * 60;   // pulses/sec     RPM
        pulse_count = 0;
        last_time = current_time;
```

```c
    }
}

// Display RPM and rotation count on OLED
void display_data(void)
{
    char buffer[32];

    ssd1357_Fill(Black);

    sprintf(buffer, "RPM: %lu", rpm);
    ssd1357_SetCursor(2, 2);
    ssd1357_WriteString(buffer, Font_7x10, White);

    sprintf(buffer, "Rotations: %lu", total_rotations);
    ssd1357_SetCursor(2, 20);
    ssd1357_WriteString(buffer, Font_7x10, White);

    ssd1357_UpdateScreen();
}

int main(void)
{
    HAL_Init();
    SystemClock_Config();
    MX_GPIO_Init();
    MX_SPI1_Init();   // SPI for OLED

    ssd1357_Init();   // Initialize OLED

    while (1)
    {
        calculate_rpm();
        display_data();
        HAL_Delay(100);  // Update every 100 ms
    }
}
```

Listing 1: STM32 Embedded Code for Motor Monitoring using SSD1357 Drivers

4.3 Construction

The construction of the entire test rig setup involves several meticulously designed components, all of which are created using NX software. This advanced software ensures unparalleled precision and accuracy, resulting in highly detailed and reliable models. The use of NX software in the design process guarantees that each component is crafted with exacting standards, contributing to the overall efficacy and dependability of the test rig setup.

The drawings for the designed components are created in adherence to DIN (Deutsches Institut für Normung) standards, ensuring precision and compliance with industry norms for machining.

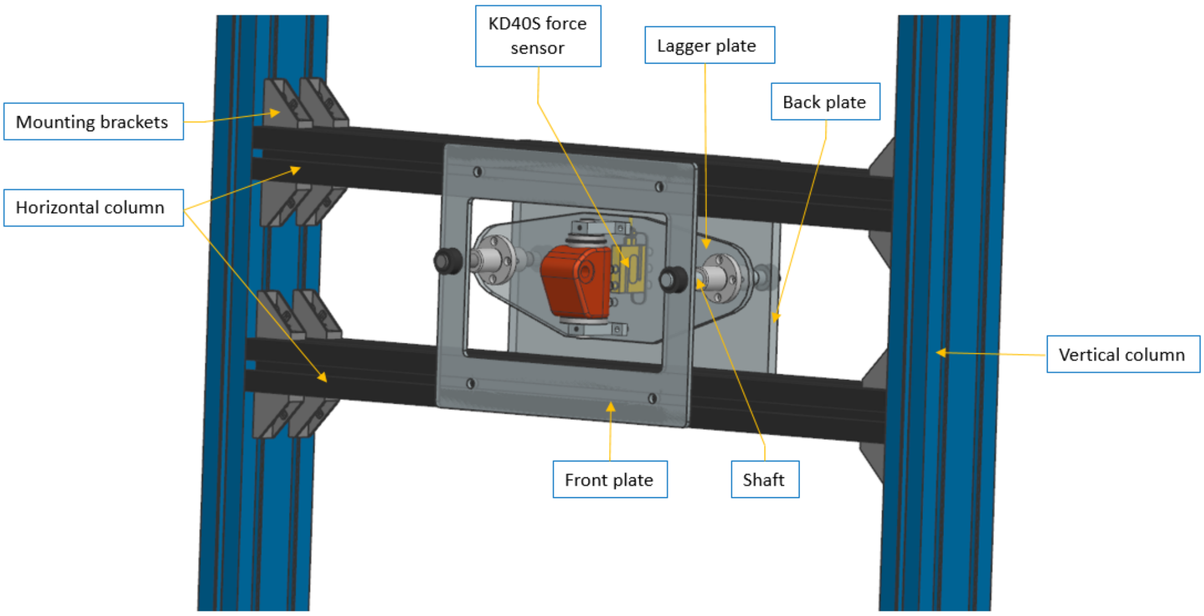

Figure 15: Force sensor assembly

a) Coupling Rod Assembly

1. Aevon Kupplung: A specialized axial coupling mechanism engineered to connect entire bicycle assembly equipped or integrated with various electronics components in it, while accommodating minor angular, parallel, or axial misalignment. Constructed from high-strength materials such as composite polymers, it transmits torque efficiently, dampens vibrations, and reduces wear on connected components.

2. Shaft Holder:A rigid support structure, typically made of machined aluminum, that stabilizes and aligns the shaft portion of the coupling rod within the assembly. It features precision-bored holes to secure the shaft, minimizing deflection and vibration during operational conditions. The holder include anti-corrosion coatings to ensure longevity in demanding environments.

3. Locking Ring: The locking ring is a circular fastening component, typically constructed from hardened steel or composite polymers. It is designed to prevent axial displacement of the Aevon Kupplung during operation, ensuring precise alignment and mechanical stability. The locking ring often features a split design with a clamping mechanism, allowing it to securely fit inside the groove provided in the coupling rod.

4. Coupling rod: The coupling rod is a cylindrical component with two smaller cylindrical extensions on either end of 12mm diameter. These both ends are secured by shaft holders to ensure precise alignment and secure connection between the parts it links.

b) KD405 Force Sensor Assembly

1. Shaft: A cylindrical component of 135 mm length and 12 mm diameter, often precision-ground from stainless steel, that transfers mechanical force or torque to the force sensor. Its surface is polished to reduce friction, and it supports linear ball bearings. The shaft acts as the primary load-bearing element, ensuring accurate force measurement by transmitting input directly to the sensor's strain gauges.

2. Adjusting Rings: The adjustable ring of 12 mm diameter is a cylindrical fastening component typically constructed from durable materials such as hardened steel. It is designed to fit around a shaft and prevent axial displacement, ensuring precise alignment and mechanical stability. The ring often features a split design with a clamping mechanism, allowing for easy adjustment and secure positioning along the shaft. This design enables the ring to sit perfectly inside coupling rod, maintaining the desired position and preventing any unwanted movement during operation.

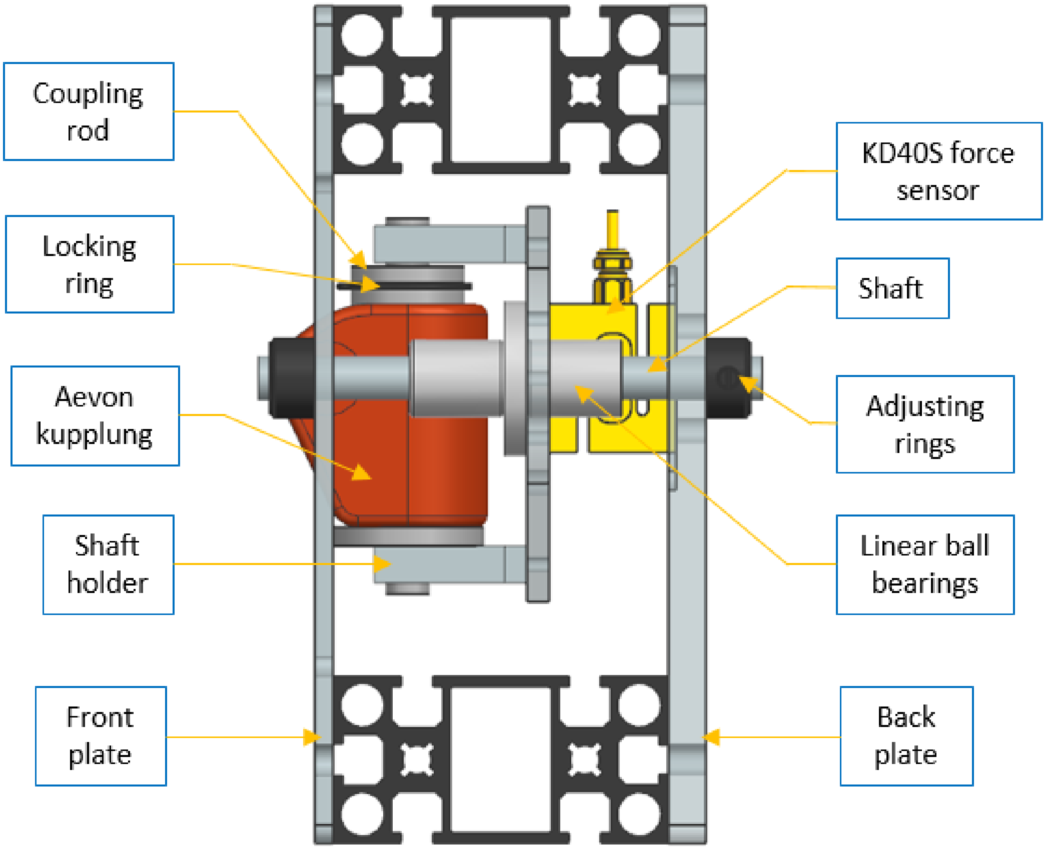

Figure 16: Side view of sensor assembly

3. Linear Ball Bearings: Low-friction bearings housed within a cylindrical sleeve, enabling smooth linear motion of the shaft. Constructed from stainless steel subjected to hardening and coating processes, the bearings reduce wear and energy loss while supporting radial and axial loads. They are often integrated into a retainer cage to ensure even load distribution, enhancing the sensor's responsiveness and durability.

c) Structural and Mounting Components

1. Front Plate: A robust, flat structural component(290 x 225 x 5 mm) positioned at the forward-facing side of the assembly. It serves as a protective barrier for internal components (e.g., sensor, bearings) while providing a mounting interface for external accessories. The front plate is typically precision-machined to ensure alignment with adjacent parts like the horizontal/vertical columns and mounting brackets. Drilled holes enabling secure integration into larger systems. Constructed from high-strength materials such as aluminum alloy, it enhances overall rigidity and resists deformation under operational stresses.

The front plate complements the back plate and lagger plate to form a complete protective and structural framework. While the back plate anchors rear components, the front plate ensures accessibility and secure external interfacing. Together with columns and brackets, these plates maintain system integrity, safeguarding sensitive elements like the KD40S force sensor and linear ball bearings from environmental or mechanical damage.

2. Back Plate: A reinforced horizontal plate (300 x 225 x 10 mm) positioned at the rear of the assembly, providing structural rigidity and serving as an anchor point for columns. It includes a slot or routing channel with a depth of 2mm specifically designed for sensor positioning. This feature effectively arrests rotational movement and ensures accurate placement of the sensor, enhancing overall performance and reliability during testing.

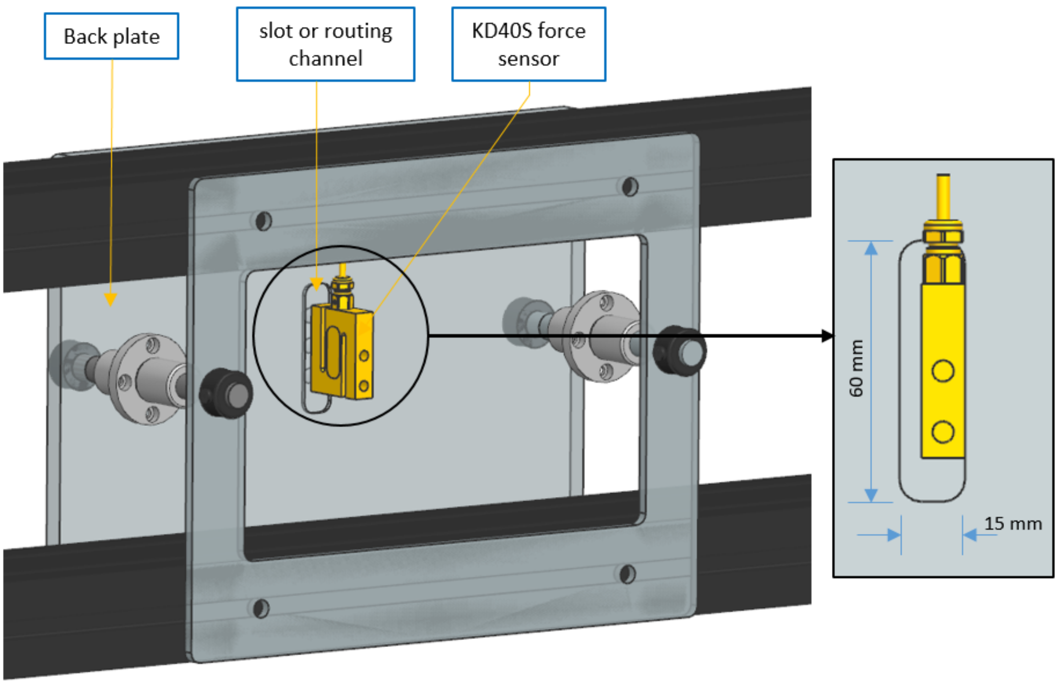

Figure 17: Back plate with slot or routing channel

3. Lagger Plate: The lagger plate is a flat, thick component with dimensions of (320 x 106 x 6 mm), typically fabricated from aluminum alloy. It serves as the foundation for the entire assembly. Linear ball bearings are attached on either side of the lagger plate, providing mass to dampen vibrations and distribute operational loads evenly across the mounting surface. The plate also includes through holes for the modular attachment of the force sensor, ensuring secure and precise positioning.

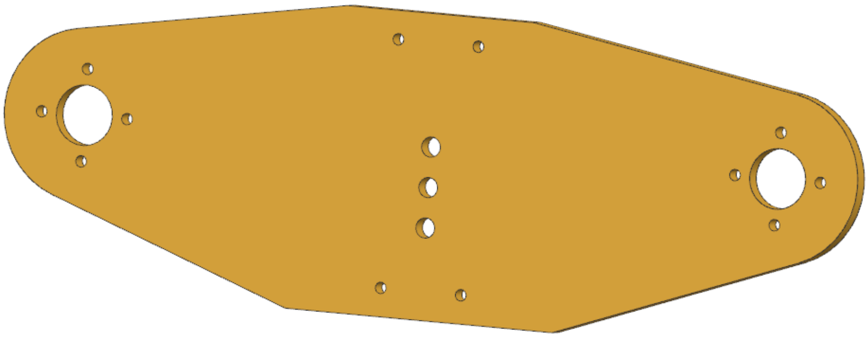

Figure 18: Lagger Plate

4. Horizontal column: A load bearing beam, typically extruded aluminum alloy, that supports the weight of the assembly along the horizontal axis. provides essential support to the structure, maintaining its integrity and stability. It helps resist bending and shear forces, which are critical for the overall strength.

5. Vertical column: Vertical columns are designed to support and transfer loads from the upper parts of a structure to the foundation. This includes dead loads (permanent static loads) and live loads. also provide essential structural stability to buildings and other constructions. They help maintain the integrity of the structure by resisting compressive forces and preventing collapse.

6. Mounting brackets: These brackets are used to connect two aluminum profiles at a right angle. These are secured using bolts and T-nuts that fit into the slots of the aluminum extrusions. The L-shaped design ensures a strong and stable connection, making them ideal support structures.

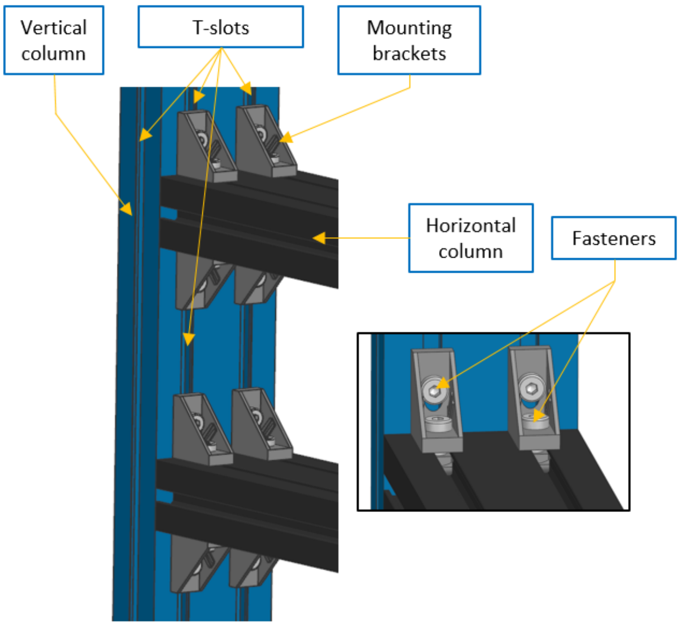

Figure 19: Mounting brackets

5 Results and Discussion

5.1 Force Measurement Data

The force measurement data obtained from the KD40S sensor provides a comprehensive understanding of the forces acting on the bicycle during operation. The data reveals variations in force magnitude and direction, which can be correlated with different riding conditions, such as speed, incline, and rider posture.

5.2 Implications for Bicycle Design

The insights gained from the force measurement data can be used to optimize bicycle design. For example, understanding the forces exerted on the wheel during running condition can lead to the development of more ergonomic designs that reduce rider fatigue and improve comfort. Additionally, the data can inform the design of more efficient drivetrains and suspension systems.

5.3 Performance Optimization

The real-time force data can be used to enhance rider performance by providing feedback on pedaling efficiency, braking force, and steering control. This information can be used to develop training programs that help riders improve their technique and achieve better performance.

5.4 Safety Considerations

The force measurement data can also be used to identify potential safety issues, such as excessive force on the handlebars or uneven force distribution. This information can be used to design safer bicycles and develop guidelines for safe riding practices.

6 Conclusion

The integration of the KD40S force sensor with a treadmill-based test-rig offers a novel and effective approach to bicycle testing. The system provides accurate and real-time force measurement data, which can be used to optimize bicycle design, enhance rider performance, and ensure safety. The insights gained from this research have the potential to significantly impact the bicycle industry, leading to the development of more efficient, comfortable, and safe bicycles. The embedded electronics subsystem significantly enhances the treadmill testing platform by providing accurate, real-time monitoring of motor speed and total rotations. The use of STM32CubeIDE streamlined firmware development, peripheral configuration, and debugging, ensuring a robust and reliable implementation. This data supports synchronized analysis with force measurements, enabling deeper insights into bicycle dynamics under controlled testing conditions.

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