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DEVELOPMENT OF SENSOR LOGIC FOR LOPIFIT

*Note: Sub-titles are not captured in Xplore and should not be used

Sowmya Manda
dept. Electrical engineering
Andhra University
Visakhapatnam, India

Dr. Mallikarjuna Rao Pasumarthi
dept.Electrical Engineering
Andhra University
Visakhapatnam, India

Abstract— **This paper explores the sensors with modern transportation systems have led to innovative and efficient solutions for city transport. This paper presents a MATLAB simulation of a sensors-enhanced treadmill bicycle, known as the Lopifit, which blends the benefits of walking with the convenience of cycling. This paper presents the dynamic behavior of a sensor-enhanced treadmill bicycle (Lopifit). It incorporates sensors for speed, incline, and heart rate monitoring. The simulation captures real-time sensor data, simulates bicycle motion, and computes performance metrics, providing a valuable tool for optimizing Lopifit design, evaluating user experience, and analyzing exercise effectiveness. The model's flexibility allows for scenario testing under various conditions, contributing to the development of smarter and more efficient treadmill bicycles. This abstract briefly highlights the main components and objectives of the MATLAB simulation for the sensor equipped Lopifit bicycle.**

Keywords—: **MATLAB simulation, treadmill bicycle, Lopifit, sensors, performance optimization.**

INTRODUCTION

Sensors hold immense significance in treadmill bicycles like the Lopifit, as they are integral to the overall functionality and safety of these innovative devices. They fulfil several essential roles, enhancing the user experience and ensuring the smooth operation of the equipment:

Speed Tracking: Sensors are instrumental in tracking the user's speed while using the treadmill bicycle. This capability enables users to maintain a consistent pace and gain insights into their workout progress. By providing real-time speed data, sensors contribute to more effective and goal-oriented exercise sessions.

Battery Monitoring: Sensors are responsible for continuously monitoring the battery status of the treadmill bicycle. This function is crucial as it keeps users informed about the remaining charge, preventing unexpected power failures during use. Battery sensors ensure that users can plan their workouts without interruptions due to insufficient power.

Safety and Control: Sensors play a pivotal role in maintaining user safety and control. By constantly monitoring variables such as speed, they enable the treadmill bicycle to make dynamic adjustments, ensuring that the equipment operates within safe and user-defined limits. This proactive safety feature helps prevent accidents and injuries.

In summary, sensors are indispensable components of treadmill bicycles like the Lopifit. They not only provide users with valuable performance data but also contribute to safety and control mechanisms that enhance the overall user experience. Through real-time monitoring and data feedback, sensors empower individuals to engage in effective, safe, and goal-oriented workouts, making treadmill bicycles a valuable tool for fitness and mobility.

In this chapter of the book, we delve into the practical application that involves the utilization of sensors. We will provide an in-depth exploration and discussion of the various sensors employed in this context. To facilitate the simulation process, we have seamlessly integrated the model with a comprehensive sensor system simulation plan. The outcomes obtained from these simulations underscore the reliability and effectiveness of the proposed model.

The Lopifit treadmill bicycle is an innovative hybrid transportation solution that combines the benefits of walking with the efficiency of cycling. It features a unique design where a treadmill belt is integrated into the bicycle's frame, allowing the rider to walk on it while propelling the bicycle forward. To enhance the functionality and safety of the Lopifit, advanced sensors and control systems are integrated, simulated using MATLAB.

Working procedure of the sensors for treadmill bicycle (Lopifit):

Hall Effect Sensors:

In Breaking: - Hall Effect sensors can be used to monitor the position or speed of a rotating part in a braking system. For example, in an anti-lock braking system (ABS), a Hall Effect sensor can detect the speed of each wheel. So, in MATLAB, connect the sensors to a micro controller or data acquisition hardware, read the sensors output, and interprets the sensors readings for the break control.

In Motor: - Hall Effect sensors are often used in brushless DC motors to determine the rotor position, which is crucial for controlling the motor's operations. In MATLAB, the Design control algorithms that use data from Hall Effect sensors to precisely control the motors speed and directions.

Rotational motor Sensors (Treadmill bicycle Lopifit): Treadmill bicycle (Lopifit) many various rotational motion sensors, such as Encoders, or Gyroscopes, to detect the user's movement and adjust the motor's speed accordingly. There sensors provide data on the rotation of the treadmill's belt or the bicycle's wheels. So, in MATLAB, these sensors using appropriate hardware interface like arduino or raspberryPi and write customs scripts or functions to analyze the sensors data. This might involve measuring speed, distance or even generating virtual environments for user interaction.

SYSTEM MODEL

Creating system models for sensors in MATLAB typically involves mathematical representations of sensors behaviour.

1. **Hall effect sensors for Breaking & Motor:**

Hall Effect sensors detect the presence and strength of a magnetic field. For breaking model, it has a sensor responding to a changing magnetic field like due to a magnet on the wheel. For motor, it can detect the magnetic field generated by the motor's rotor. The output voltage (V_{out})of Hall Effect sensors can be modeled as a function of the magnetic field strength (B) and other sensors - specific parameters:

$$V_{out} = K * B \quad (1)$$

Here, 'K' is the sensitivity factor of the sensors.

2. **Ideal Rotational Motion Sensors:**

An Ideal Rotational motion sensor can be modeled as an encoders or tachometer providing angular velocity (ω) or positions (θ) information, for a treadmill bicycle (Lopifit) model, it as providing angular velocity (ω). The relationship between angular velocity (ω) and time (t) can be modeled as:

$$\omega(t) = \frac{d\theta(t)}{dt} \quad (2)$$

In a specific sensor with a known resolution like pulses per revolution, use that to convert angular velocity to sensor output. So, in MATLAB, the implementation these models as functions or scripts of modeling magnetic fields strength.

3. **Current sensors for battery and motor:**

current sensors are used to measure the current flowing through a conductor. An Ideal current sensor could be represented as:

$$I_{out} = K * I \quad (3)$$

Where,

I_{out} is the output of the current sensor.

K is the sensitivity of the current sensor.

I is the actual current flowing through the conductor like from the battery or to the motor.

PREVIOUS WORK

Millions of individuals rely on bicycles as a primary mode of transportation, yet the fundamental design of the bicycle has seen limited innovation over the years. Minimal research has been dedicated to optimizing the bicycle's structure for superior human comfort. Moreover, most design modifications have been evaluated primarily in the context of racing, where numerous uncontrollable variables can impact the outcomes. Consequently, there is a pressing need to investigate the energy output associated with various bicycle designs while ensuring that any design changes do not compromise the bicycle's sleek and non-bulky appearance. One innovative solution is the "treadmill bicycle," a fusion of traditional bicycle and treadmill technologies. This unique invention enables individuals to simultaneously accomplish two essential tasks: transportation, a fundamental daily activity, and exercise. The treadmill bicycle operates solely on human effort, eliminating the need for external power sources and thereby saving time that would otherwise be spent on separate exercise routines.

physical exertion compared to a conventional bicycle. This design enhancement not only enhances efficiency but also distinguishes it from conventional bicycles. Furthermore, the treadmill bicycle offers economic benefits as it is more cost-effective than a traditional bike, primarily due to its reliance on human propulsion. Additionally, it is environmentally friendly, as it does not consume any fuel, contributing to reduced carbon emissions and environmental sustainability. In summary, the treadmill bicycle represents an innovative and multifunctional solution to modern transportation and fitness needs. It combines practicality, efficiency, and affordability while promoting a greener and healthier lifestyle. Further research and development in this direction could potentially revolutionize the way we perceive and utilize bicycles in our daily lives.

PROPOSED METHODOLOGY

In past cases, there is no sensors were used in the treadmill bicycle model and the work was design in two ways mainly, System Design and Mechanical Design for the practical purpose.

The Lopifit (treadmill bicycle) with sensors is an innovative hybrid transportation solution that combines the benefits of walking with the efficiency of cycling. It features a unique design where a treadmill belt is integrated into the bicycle's frame, allowing the rider to walk on it while propelling the bicycle forward. To enhance the functionality and safety of the Lopifit, advanced sensors and control systems are integrated, simulated using MATLAB.

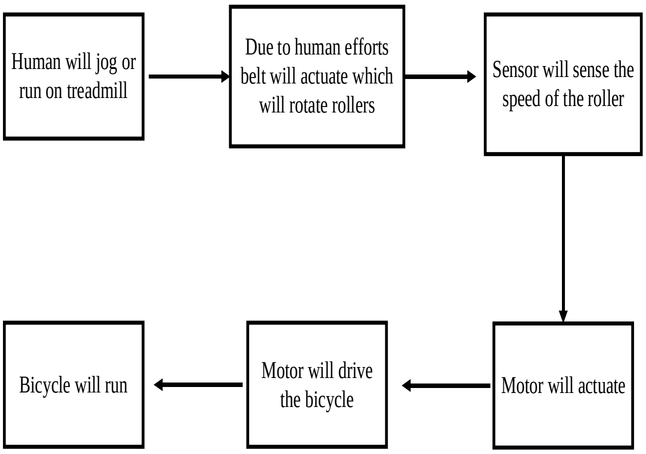


Fig.1.Block Diagram

In this paper, an application is considered such as Treadmill bicycle (Lopifit) by using sensors in MATLAB Simulink and those sensors models are discussed and presented below.
The ideal rotational motion sensor is utilized to accurately measure the rotation of the treadmill belt, facilitating precise speed and distance calculations. Hall sensors within the motors detect the position of the rotor, enabling precise control of the motor's power output and ensuring efficient propulsion. Additionally, Hall sensors are also used in the braking system to detect when the rider initiates braking, facilitating a smooth and responsive deceleration process.
In a MATLAB simulation of the Lopifit with these sensors, various scenarios can be tested and optimized below:

I. HALL SENSOR IN MOTOR

The majority of Brushless DC (BLDC) motors come equipped with Hall sensors, which serve the crucial function of determining the motor's commutation timing and rotational speed. Nevertheless, it is important to acknowledge that the installed Hall sensors may not always align perfectly within a BLDC motor. This misalignment, if left unaddressed, can result in torque fluctuations due to incorrect commutation timing and inaccurate speed feedback. This issue has been well-documented in existing literature, and various potential solutions have been proposed. One such solution involves the utilization of a Hall-effect-sensor-based position observer to mitigate torque ripple in Permanent Magnet Synchronous Machines (PMSM). Empirical validation, encompassing both hardware implementation and simulation, has demonstrated the effectiveness of this algorithm. However, it is worth noting that this algorithm was initially intended for PMSM motors and has not been adapted for BLDC motors.
In an effort to tackle this challenge in the context of BLDC motors, an auxiliary circuit was devised. This circuit serves the dual purpose of minimizing noise interference in the Hall sensor signals and accurately capturing time intervals. The circuit's implementation was executed using a Field-Programmable Gate Array (FPGA), and empirical results affirm its successful functionality. This study holds significant value as a reference point for the development of integrated circuits for BLDC motor control. Nonetheless, it is important to emphasize that this study did not delve into the simulation aspect of Hall Sensor Misalignment. In a distinct approach, with a specific focus on the commutation behavior of BLDC motors, a simulation model was conceived and developed using MATLAB/Simulink. This model offers an efficient solution for addressing the variable sampling system inherent to BLDC motors, stemming from the limited resolution of Hall sensors. Regrettably, this simulation model did not encompass the consideration of Hall sensor misalignment within a BLDC motor.
In conclusion, these various studies and approaches shed light on the challenges associated with Hall sensor misalignment in BLDC motors. While significant strides have been made in addressing this issue, there remains an opportunity for future research to bridge the gap and develop comprehensive solutions that account for both misalignment and commutation behavior in BLDC motors.

The Proposed Simulation Model

As previously discussed, the majority of BLDC simulation models typically offer only speed output, leaving the determination of the Hall sensor's output reliant on the rotational angle. To address this, an integrator can be incorporated into the model to accumulate the rotational speed and derive the rotational angle. Calculating the modulus of the rotation angle necessitates the use of a remainder block, which comprises components such as a divider, rounder, and adder. Subsequently, the Hall sensor's output can be determined using a relational operator.

Figure 2 illustrates the functional blocks of the model for simulating the Hall sensor's output, with sensor A serving as an example. In this representation, a single relational operator suffices, taking two inputs into account. The first input represents the normalized modulus of the rotation angle (normalized with respect to 2π), while the second input is set to 0.5, denoting the normalized value of π (also normalized with respect to 2π) utilized as a threshold in the relational operation. Likewise, the output of Hall Sensor B (or C) adopts one value when the rotational angle exceeds $5\pi/3$ ($\pi/3$) or falls below $2\pi/3$ ($4\pi/3$), and another value otherwise.

For a comprehensive understanding, the functional blocks pertaining to the simulation of Hall sensors B and C are presented in Figure 3. A comparison between Figures 2 and 3 reveals that two relational operators are employed for each of Hall sensors B and C, whereas only one is necessary for Hall sensor A. This limitation, however, will be addressed in the model proposed in the following section.

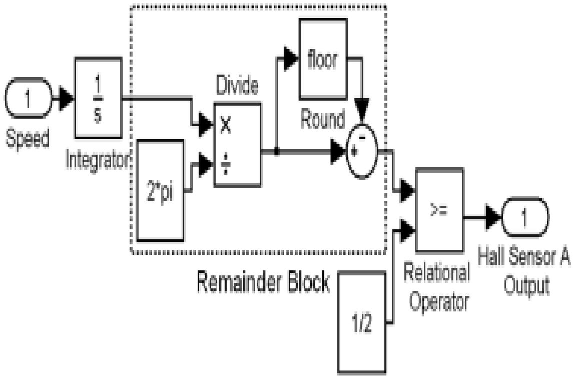


Fig.2 Simulation model of Hall-sensor

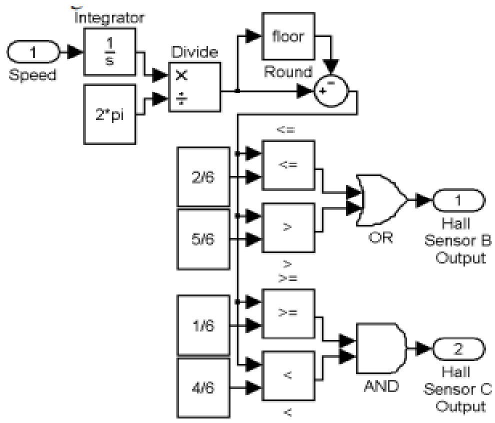


Fig.3. Simulation model of Hall-sensor B and C

The Proposed Hall Sensor Misalignment Effect Simulation

As depicted in Figures 2 and 3, there exists a disparity in the requirement for relational operators within the model when comparing Hall sensor, A to Hall sensors B and C. In light of the cyclic-symmetric characteristic inherent in the rotation angle, it becomes feasible to harmonize these models, ensuring they all utilize the same number of relational operators. To achieve this, we introduce an equivalent model, as illustrated in Figure 4, wherein each sensor output necessitates just one relational operator. Notably, all three relational operators share a common threshold value of 0.5. This simplification is made possible by the deliberate adjustment of the cumulative rotational angle input to the remainder block of Hall sensor B (C), offsetting it by 4π/3 (2π/3) as appropriate.

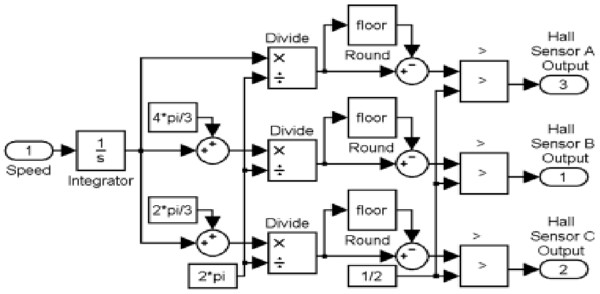


Fig.4. Equivalent simulation model

In an ideal scenario, Hall sensors should be meticulously installed at their designated positions within BLDC motors. However, it is common for the actual installation positions of these Hall sensors to deviate from their prescribed locations. The accuracy of simulated output signals from these misaligned Hall sensors is paramount, as these signals serve as the foundation for subsequent processes during the development of a BLDC motor and its associated control circuit. This reliance on complete system simulation necessitates that the simulated signals faithfully mirror the misalignment. In our representation, the dotted lines represent the prescribed positions of the Hall sensors, while the dashed lines indicate the actual positions they occupy.

We have assumed that Hall sensor A remains well-aligned, whereas Hall sensors B and C experience deviations from their prescribed positions, denoted as $\Delta\theta$ and $\Delta\varphi$, respectively. It is imperative to incorporate this misalignment into the simulation when generating Hall sensors' output signals. When considering the deviation angle $\Delta\theta$ within the functional blocks associated with Hall sensor B, a revised model emerges, as illustrated in Figure 5. In this updated model, the normalized deviation angle is incorporated into each threshold of the two relational operators, ensuring a more accurate representation of the misalignment effect.

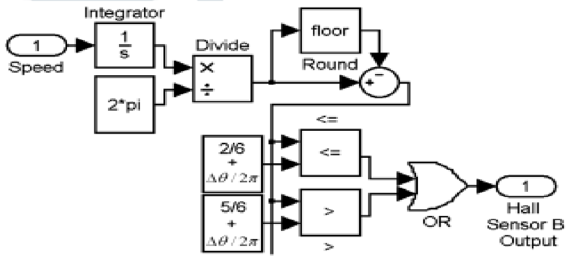


Fig.5 Misalignment simulation model of Hall-sensor B

While the model presented in Figure 5 aligns with intuitive reasoning, further simplification is feasible, building upon the model's evolution from Figure 3 to Figure 4. Recognizing that the movement between the rotor and each Hall sensor is inherently relative, it becomes possible to streamline the model by subtracting the normalized deviation angle directly from the input cumulative rotation angle. This alternative approach is not only conceptually straightforward but also more practical to implement. The corresponding model is depicted in Figure 6.

Up to this point, we have operated under the assumption that Hall sensor A is correctly installed without any positional error. However, as illustrated in Figure 6, it becomes evident that if there were a deviation angle associated with Hall sensor A as well, it could likewise be subtracted from the input cumulative rotation angle, ensuring a comprehensive and adaptable model.

Fig.6. Equivalent misalignment simulation model

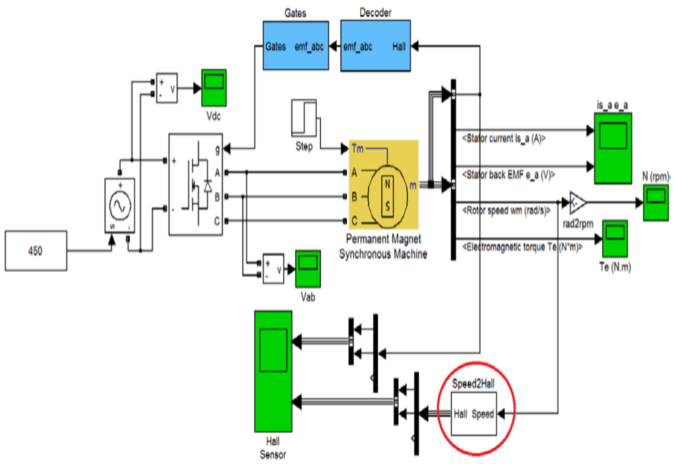


Fig.7. the simulation of the "Brushless DC Motor Fed by Six-Step Inverter model" with the proposed Hall sensor module.

II. IDEAL ROTATIONAL MOTION SENSOR.

A perfect rotational motion sensor can be defined as a device capable of converting a varying parameter observed between two mechanical rotational points into a control signal that accurately represents acceleration, angular velocity, or position (angle).

An ideal rotational motion sensor would likely refer to a device that measures the rotational motion of the Lopifit's wheels or pedals. This information is crucial for various purposes, such as tracking speed, distance, and possibly even power output and it would be strategically placed on a part of the Lopifit that rotates as the user walks and propels the vehicle. In this case, it could be placed on the axle of one of the wheels or on the pedal cranks.

These sensors work by detecting changes in magnetic fields as a rotating magnet passes by. A magnet could be attached to a rotating part of the Lopifit, and a magnetic sensor would be placed nearby to detect each rotation.
Once the sensor detects the rotational motion, it generates electrical signals that are sent to a microcontroller or other processing unit. The signals would be analyzed to calculate the rotational speed (RPM) and direction (clockwise or counterclockwise). The microcontroller could then convert the RPM data into speed and distance information based on the known specifications of the Lopifit's wheels. This data could be displayed on a screen for the user or transmitted to a smartphone app via Bluetooth or other wireless communication methods.

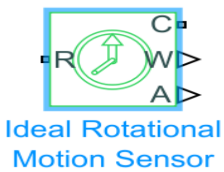


Fig.8. Ideal Rotational Motion sensor

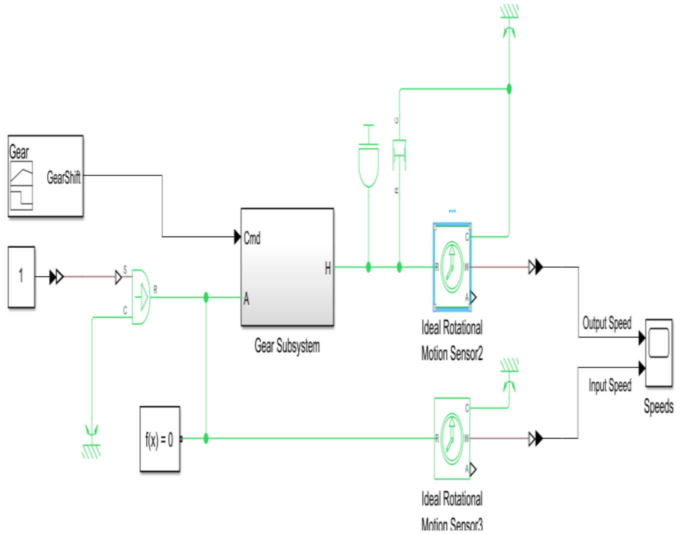


Fig.9. The simulation of the "Gear model" with the proposed Ideal Rotational Motion sensor module

III. HALL SENSOR IN BRAKING

A Hall sensor is a type of magnetic sensor that detects changes in the surrounding magnetic field. In the context of a treadmill bicycle like the Lopifit, a Hall sensor can be used in the braking system to detect the rotation of a wheel or a specific component, which in turn can be used to control the braking mechanism.
The braking mechanism could be electronically controlled brakes that apply pressure to slow down or stop the rotation of the wheel. This could be achieved through various means such as friction pads, electromagnetic brakes, or other braking systems.
When the Hall sensor detects the appropriate conditions for braking, it initiates the braking mechanism. This helps the user slow down or come to a complete stop, providing control and safety during the ride.
In summary, the Hall sensor in the braking system of a treadmill bicycle like the Lopifit detects the rotation of a wheel or specific components using changes in the magnetic field. This information is then used to control the braking mechanism, enhancing the user's ability to control their speed, and ensuring a safe and smooth riding experience. The specifics of the implementation can vary depending on the design of the bicycle and the braking system used.

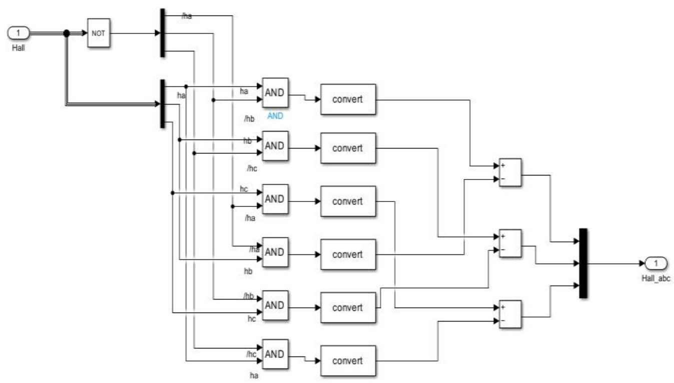


Fig.10. Simulation model of Hall-sensor

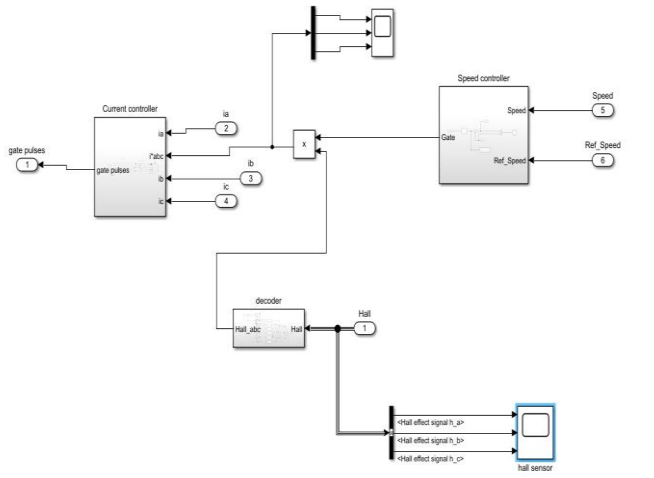


Fig.11. Equivalent Hall effect signal simulation model

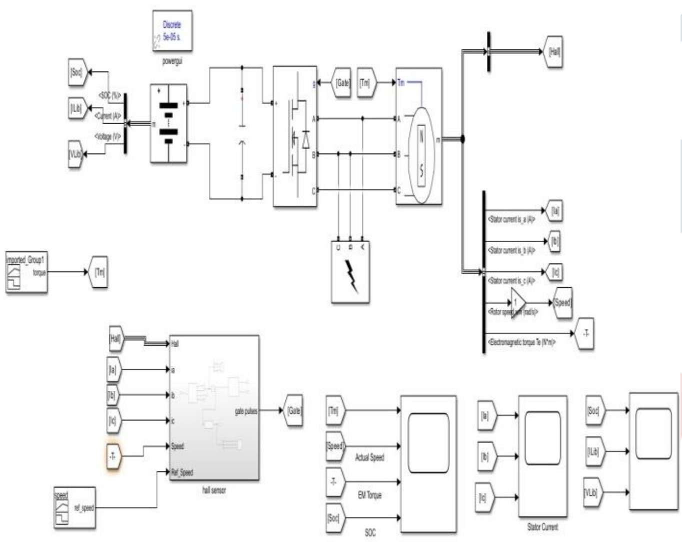
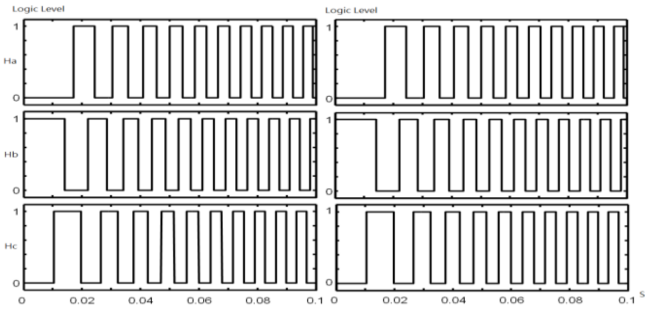


Fig.12. The simulation of the "Braking model" with the proposed Hall sensor module.

Creating a MATLAB simulation for a treadmill bicycle (the Lopifit) with sensors involves several steps. Below one gives the outline a simplified example of how you can simulate and visualize the system with relevant graphs. This example assumes the access to data or equations for the treadmill's motion, the bicycle's speed, and the sensors behavior. Since the exact specifications of a Lopifit are not publicly available, so by adapt this code according to the specific model or data.

This code will simulate the movement of the bicycle on the treadmill, generate sensor readings with noise, and plot relevant graphs, including the speed vs. distance travelled graph. We can adjust the parameters and noise levels as needed to match your specific model or data.

SIMULATION RESULTS



(a) MATLAB Simulink demonstration (b) proposed models.

Fig.13.Hall sensor signal comparison without misalignment.

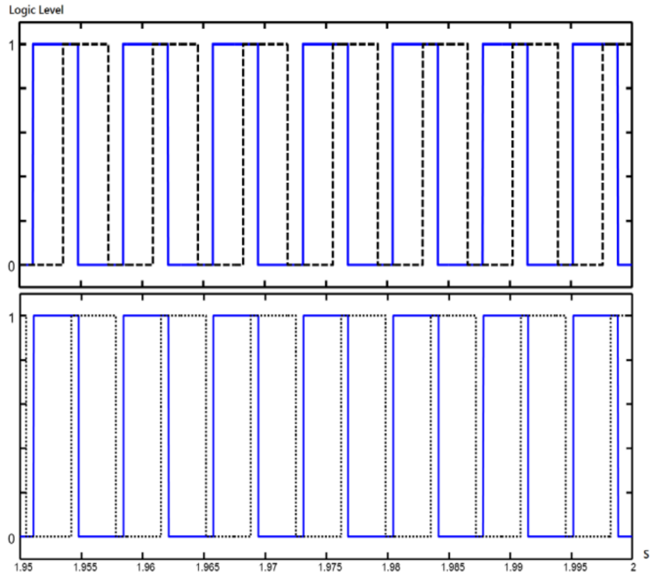


Fig.14. Simulation result of Hall sensor B with misalignment.

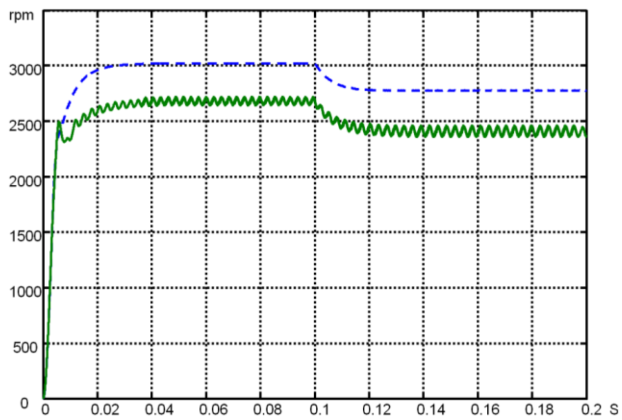


Fig.15. Simulation result of Hall sensor in BLDC motors with misalignment.

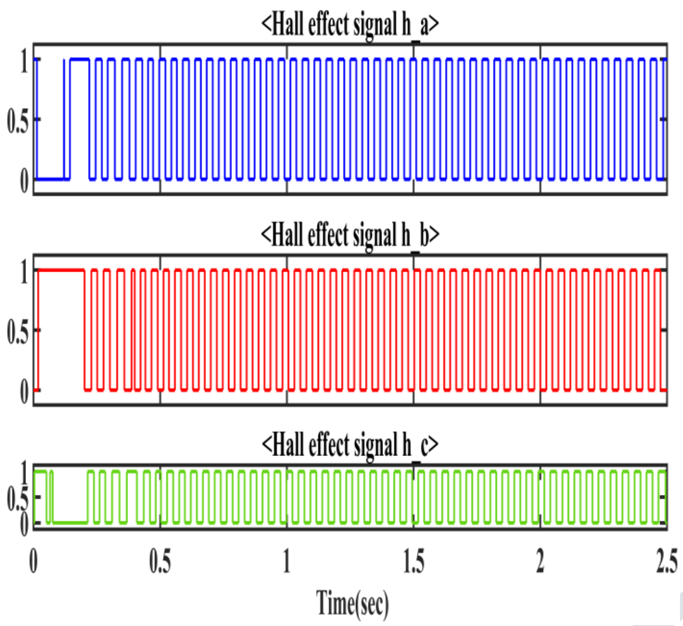


Fig.16. Simulation result of the "Braking model" with the proposed Hall sensor module.

FOR CODING

With sensors-

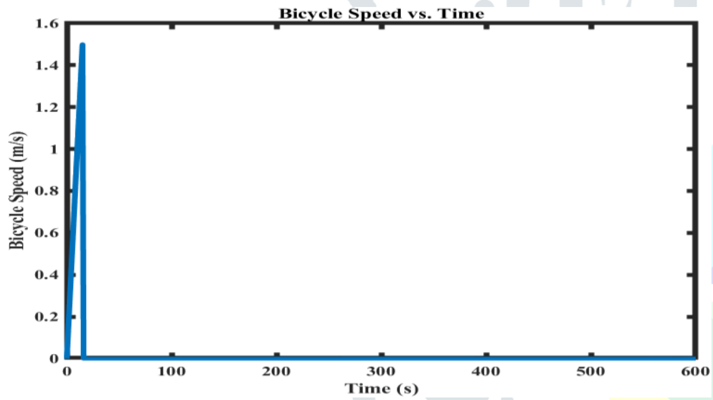


Fig.17. Code result between speed and time for treadmill bicycle (Lopifit).

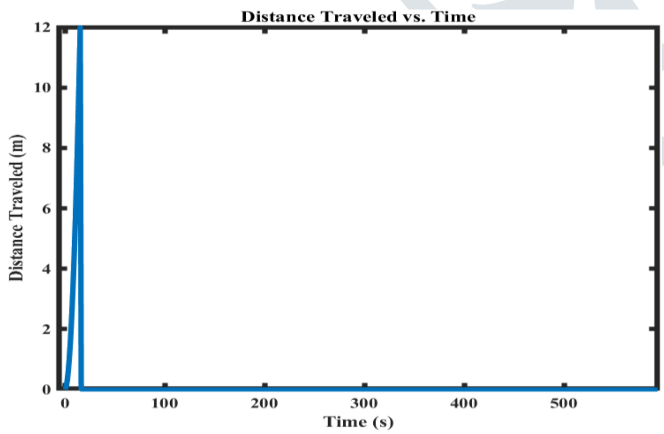


Fig.18. Code result between Distance travelled and time for treadmill bicycle (Lopifit).

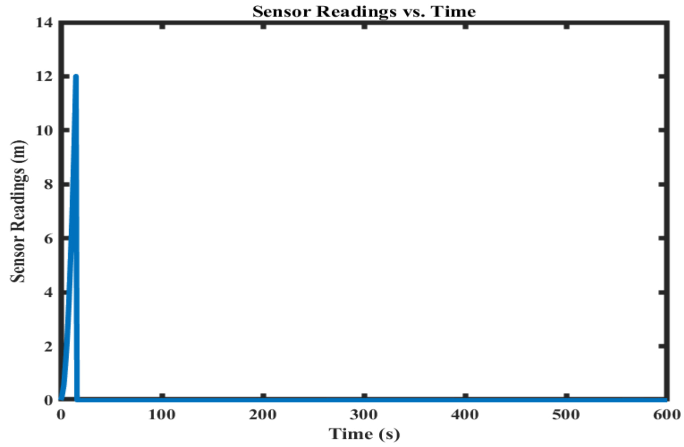


Fig.19. Code result between Sensor readings and time for treadmill bicycle (Lopifit).

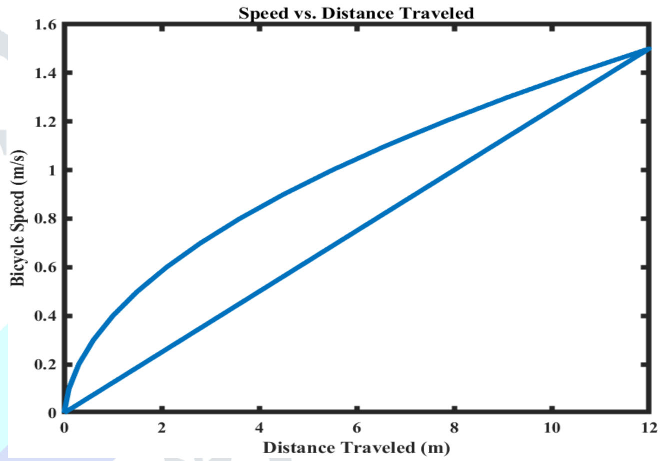


Fig.20. Code result between speed and Distance travelled for treadmill bicycle (Lopifit).

CONCLUSION

In this paper, the integration of sensors such as hall effect sensors in both the motor and braking systems, along with an ideal rotational motion sensor, enhances the functionality and safety of the treadmill bicycle Lopifit. These sensors allow for precise control of motor assistance and braking, ensuring a smoother and more efficient ride. Additionally, the rotational motion sensor contributes to a more comfortable and natural cycling experience by accurately tracking the user's pedaling motion. Overall, the incorporation of these sensors enhances the overall performance and user experience of the Lopifit treadmill bicycle.

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