Inertia Motorized Wheel Balancing Robotic Motorcycle

Said Kafumbe[1], Ravichandran Danthakani[2], Emad Abd-Elrady[3]
Faculty of Engineering Technology and Science
Higher Colleges of Technology, UAE
skafumbe@hct.ac.ae[1], rdanthakani@hct.ac.ae[2], eabdelrady@hct.ac.ae[3]

Abstract

In this ongoing work, inertia generated from a rotating disc will be used to balance and enable a robotic mini-bike vehicle designed around 2-motorised wheels. This also helps to compensate the mini-bike when it loses balance with applications to future autonomous alternatives to hover boards and Segway's. This system will use an embedded system target, a motor driving shield, wheel-rotating motors, an encoder, a MEMS gyro/accelerometer, servos, and distance as well as rotation speed sensors. The motor vehicle operating on 12V batteries will use of sensors to avoid obstacles of 10cm sizes and the rotating inertia wheel for balance is able to withstand a tilt angle of ±15° depending on the inertia torque. The motorized structure is capable of measuring a height of 10 cm and length 30 cm and weighs 300g. The structure is made from robotic joints built from 3D-printed parts made of drillable parts, the speed of wheels up to 200rpm can be achieved at 9V. Direct current (DC) motors with current rating of 6A at 12V, a 48:1 gear ratio is capable of providing wheel speed of 200rpm at 9V, will be used to move the system. The motor bicycle is being used in the detection of mines using electromagnetic field generated from thin films attached to the wheels.

Keywords
Electromagnetic field, Self-Balance, Obstacle avoidance, Wi-Fi and Mines.

1.1 Introduction

People working in the Mines are subjected to risking their lives. It is utmost important to remove the mines by using detectors, thus keeping the workers safe and away from explosions [1-2]. The balance wheel robot is a mine detector that can be used in hazard instead of human and it can go to places and check if there is any mine in the ground. Once it detect a mine, it sends information to the worker through application in his phone [3]. Use of Robotic is a solution that can be used to automatically monitor land mine, create historical record of data and prepare protection plan as well as observe any abnormal behaviors by alerting the users, thus protecting the human from hazard or dangerous environment.

Previous work related to self-balanced wheels has been reported [4-5]. Firstly, a control system design was used for two-wheel self-balanced robot, based on stepper motor [6]. It was a basic control system for two-wheel self-balancing robot with complex structure and made use of many sensors. The price of this system was very expensive. The goal of the project in this paper is to develop a high performance, low cost control system for a two-wheel self-balancing robot. This project employs novel filtering algorithms and control strategies to reduce the cost. This paper presents a low-cost stepper as a drive unit to build mobile car and to realize self-balancing control of car by means of appropriate control strategy, which can eliminate high disturbances of stepper. The experimental setup shows the control strategy in this paper to achieve satisfactory results.

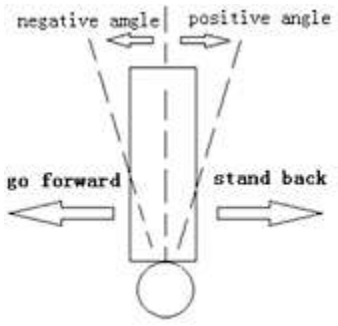

Figure 1. Balance principle of the two-wheel self-balanced robot

Result was that the balance principle of two-wheel self-balancing robot can be achieved as shown in Figure 1. When the robot goes forward, the robot intermediate tilts towards back because of inertia, then the wheel should go back to correct the intermediate inclination angle error.

The static or initial state of robot is unstable, because the center of gravity of the system is higher than the fulcrum. Using dynamic system which takes angle in the vertical direction to control the object and control the angle in small scope to achieve near balance. After adjusting PD regulation parameters, the dynamic balance of the robot has been very sensitive. The robot can quickly become stable and keep the stability for long time.

Secondly, a straight-driving and turning compound control of the self-balancing two-wheeled robot was developed [7]. Self-balancing, straight-driving and turning control in two-dimensional plane are the core technologies of the self-balancing two-wheeled robot. Various controllers have been applied to the robot, showing different performance. Reference considers the robot as an inverted pendulum. The modeling and control method of the robot is designed based on the inverted pendulum because they are similar in physical and mechanical structure according to the similarity theorem as shown in Figure 2.

Figure 2. The self-balancing two-wheeled robot

The mathematical model and coupling characteristic of the self-balancing two-wheeled robot system is derived based on the system modeling theory. Considering motion in two-dimensional plane, the straight-driving and turning compound control system of the robot is proposed in a systematic way based on the special symmetric structure of the system.

To realize the best driving performance, the parameters of the controllers can be optimized in practical product development on the basis of mechanical structure of the robots and the driving experience of the drivers.

Thirdly, a balancing and driving control of a ball robot using fuzzy control [8]. In the beginning, the robot, which looks like a ball-shaped robot or using balls as the wheels or ball-bot, uses sensors and balancing fuzzy control algorithm adopts with angles of the wheels and the encoder data. The performance of the designed control system has verified through real experiments with the suggested ball robot. There is no need to rotate the robot body when changing the driving direction of the ball robot. The advanced modeling of the ball robot is consistent with the 4-wheeled structure and you can get the relative stability of the load. Also, as it can rotate in the same place, it is suitable for indoor environments as shown in Figure 3 and 4.

It's a robot with 4-wheeled structures and the position of the rolling ball engine is in the center of the ball. Ball-bot's body diameter is about 300mm-416mm, the height is 470mm, the weight is 25kg and it's in cylindrical shape. The ball used is a 10 pounds bowling ball whose circumference is 68.5cm and the diameter is 21.5cm.

Figure 3. Two types of ball robot

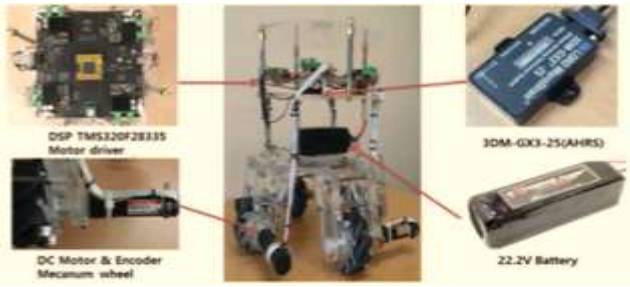

Figure 4. Ball robot's hardware composition

In the work presented herein, a balance wheel self-control robot moves automatically when the person control it to monitor landmine, create historical record of data and prepare protection plans as well as observe any abnormal behaviors by alerting the users. For the robot is being programmed by MATLAB and comes with metal detector sensor, camera and alarm. The proposed robotic device is as sketched in Figure 5, it consists of three main modules: the detection module, intervention module and the controller module. Pressure sensors are used to detect the mines under the land, the detector module will analyze the sensor data and generate the coordinates of the mines. Distribution maps is being used for data analysis and determine the places. The intervention module is an alarm system that will be trigger ON when the robot sensor feels the electric field or senses the metal of the land mine. This project aims to reduce death rates and injuries caused by the landmine explosion. And to protect human from hazard or dangerous environment.

Figure 5. Motorcycle balancing wheel

This project is differs from other 3 projects where in the 3 projects needs human to control it, but this project is self-controlled by use of programmed microcontroller board built in it. Also the size of t project is small and easy to move anywhere and it can be used any workshop environment.
The main objectives of this project is to use MATLAB to analytically simulate the mini-bike robot vehicle's overall behavior and create a model to program the hardware components, develop control algorithm, design robotic motorcycle parts and joints using 3D-software like tinker-card or solid-works and print them using a 3D printer. Finally assemble a mini-bike robotic motorcycle vehicle and detect metallic films buried under surfaces using electromagnetic fields.

2. Methods and Materials

The steps followed during the development of the motorized robot involved the design, modelling, simulation as well as 3D manufacture of parts and assemble of the system.

2.1 System Block Diagram

The system is a combination of sensors/transducers, a microcontroller and motors. This is given in the block diagram as shown in Figure 6.

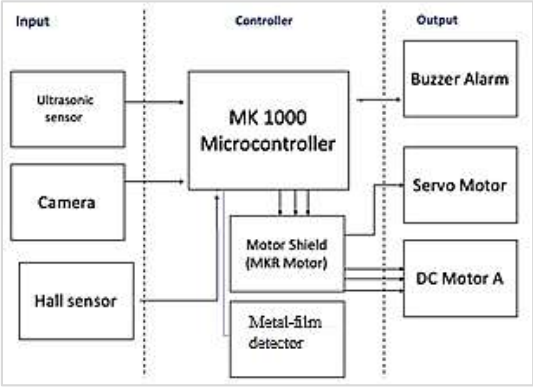

Figure 6. Completed system block diagram

On the input side there is the ultrasonic sensors that detect the distance of the closest object in front of the robot, a camera is used to record images and convey them in real time as the robot moves through hazardous environments, as well as a hall sensor to measure the speed of the inertia of rotating wheel that has inbuilt magnets.

The controller is based on the MKR1000 board equipped with an ATSAMW25 system on chip microcontroller capable of functioning at 5V and sourcing 7mA current at its ports. The ports are able to receive and transmit voltage signals up to 3.3V and they are connected to the motor shield and to the metal detector module. The metal film detector is fitted to enable detection of thin metal structures using electromagnetic field. The motor shield is based on the motor carrier which houses motor drivers for DC and servo motor.
The output side has the DC motors, the servo motors and a low impedance buzzer to sound the alarm upon mine detection. The DC motors for inertia balancing of wheels. The motor at no load has 7500 rpm with a stall torque of 150g-cm while the motorbike wheels with 1:100 gearbox has 320 rpm at stall torque of 2200 g-cm and when magnetic robot speed encoder readers was attached. The servo motor had 180 degree sweep control by pulses generated from the microcontroller capable to steer the bike forward.

2.2 System Circuit Connection

The wiring circuit of the system is shown in Figure 7. It consists of the input side made of the ultrasonic sensor, hall sensor and metal detector. The output components are connected to the microcontroller using the digital ports. The microcontroller is also connected to the motor shield which is then connected to the DC as well as servo motors.

Figure 7. System wiring diagram

2.3 System Flowchart

The system flowchart is shown in Figure 8. Initially the minibike is reset and powered. The inertia sensor is read so that it balances the bike as it starts moving. The obstacle sensors are then read so that if there is obstacle the minibike stops otherwise it will keep moving, at the same time checks the presence of the mine using the metal detector. An alarm will then be sounded if any mine is detected otherwise the bike will keep moving and repeatedly checks the inertia balance, obstacles and mine presence and thus act accordingly.

Figure 8. System flow diagram

2.4. Testing, Modeling and Simulation

Several testing, modelling and simulations were performed on the system to ascertain its performance. Initially the individual components were tested to ensure they were operating properly. The assembled system was also tested under different conditions.
In general the nature of testing involved component testing, assembling parts from 3-D printout and system assembly, system modelling and simulation as well as testing. Most of these are in progress and ongoing with available results that will be discussed in the sections to follow.

3. Result and Discussion

The results from the various testing, modelling and simulations are shown in the figures as well as the discussions that follow.

3.1 Motor test

This was done to ensure the motors were operating as expected. This was done by generating pulse signals using pulse width modulation from a microcontroller port and applying these to the motors. The speed of the motor was varied by varying duty cycle of the pulses, and the direction of rotation was changed back and forth to check the maximum achieved speed.

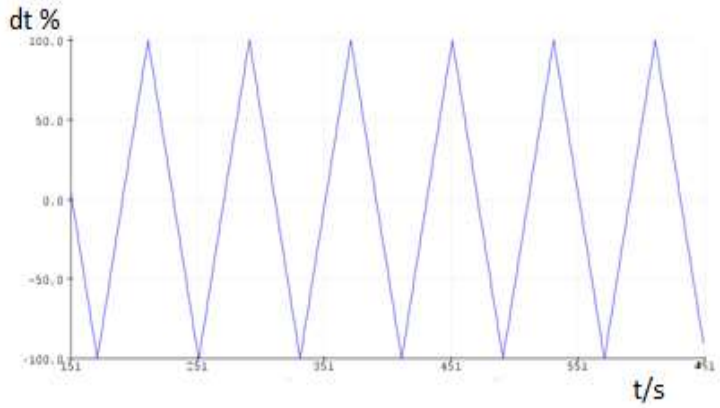

Figure 9. Motor speed in % duty cycle (d.t) and direction test over time (t) in seconds

The change in duty cycle (d.t in %) with time (t in seconds) as DC motors are swept back and forth are shown in Figure 9. From the plot the motor starts at low duty cycle or zero speed rising to the highest duty cycle of 100% when the speed is highest. This was done both in the forward and backward directions (100% to -100%). The behavior was the same for both motors.

3.2 Motor encoder reading test

This was done to determine encoder readings and counts done as the motor rotates, and to use these in determining the motor speed in counts per second as shown in Figure 9.

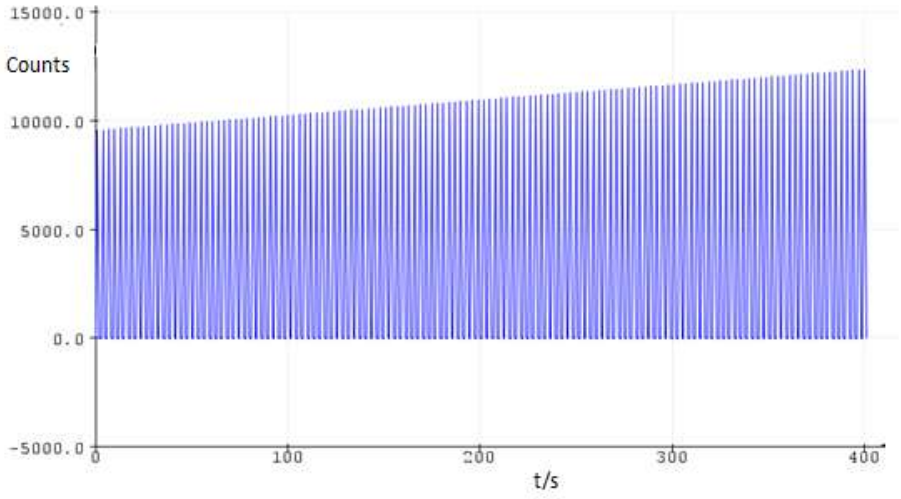

Figure 9. Encoder counts per second as the duty cycle of motor speed is varied with time in seconds (t)

The encoder reads and counts how the motor rotates and is able to measure the speed of the motor in counts per second, for different duty cycles. The motor connections were made in such a way that the motor turning direction is forward or positive resulting in positive encoder counts and positive motor speed counts per second. These could also be reversed for negative readings.

3.3 Servo test

This was done to measure the angular rotation of the servo motor when pulsated signals are applied to it. The servo was able to move in short angular rotations of 5 degrees sweeping from 0 degrees to 180 degrees as shown in Figure 10.

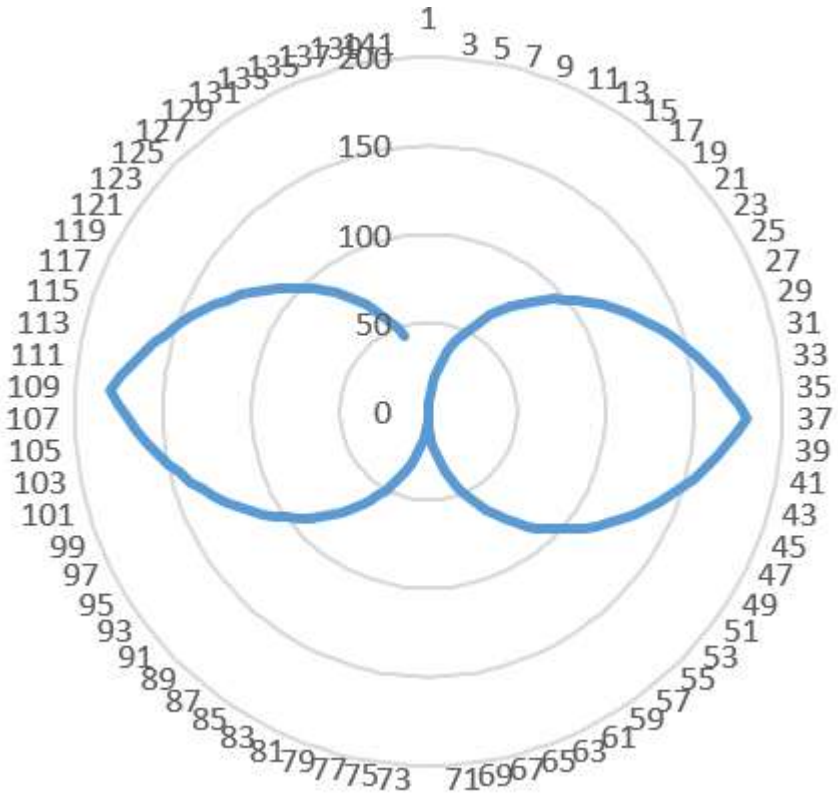

Figure 10. Servo sweep from 0 degrees to 180 degrees

3.4 Hall counts

The hall sensor was tested for its detection of the magnetic field density around the inertia wheel which has inbuilt magnets spinning with the wheel. The sensor was placed next to the inertia wheel to detect its speed. When the hall sensor was close to the magnets the hall counts measured were higher compared to having no magnet around as shown in Figure 11.

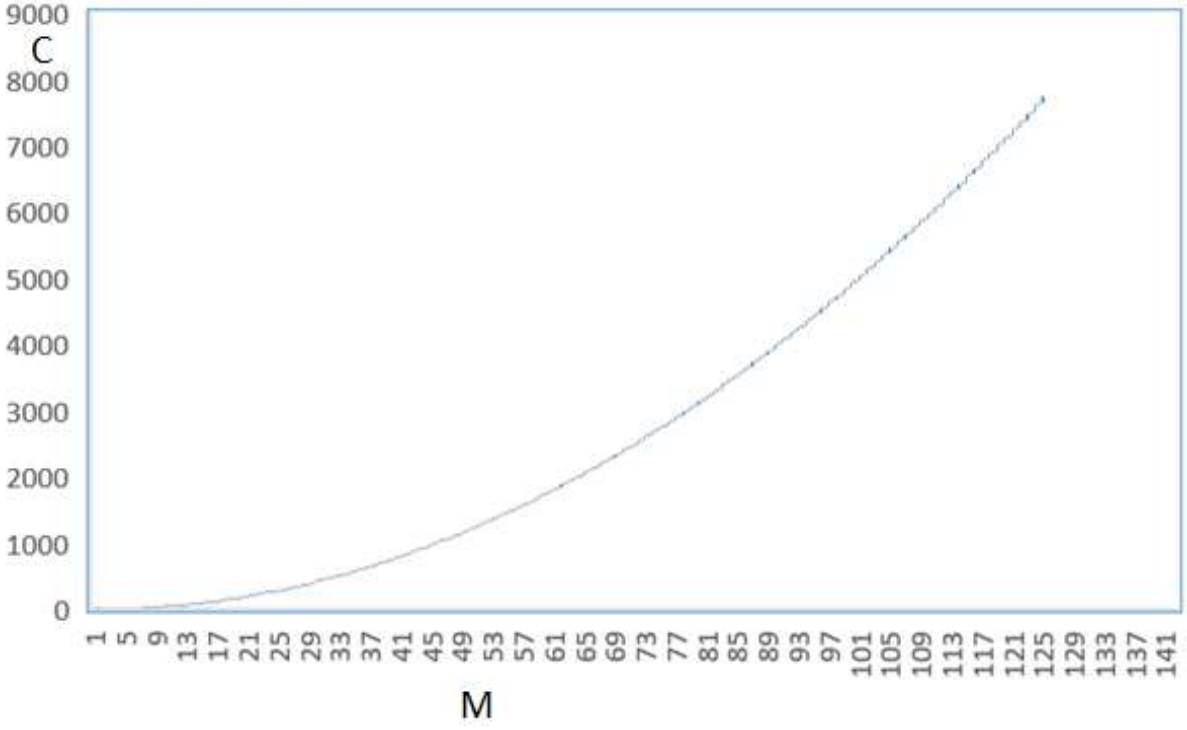

Figure 11. Hall counts C were higher the closer the hall sensor was to the magnetic intensity M in the spinning inertia wheel

3.5 Inertia measurement

The behavior of the minibike was tested under different conditions of acceleration, rotation and magnetic field using an accelerometer, gyroscope and magnetometer module. This was done to note the speed, orientation and effect of the magnetic field on the device. The values in the x, y, z axes were measured to show when the orientation of the bike was so large that it would fall. The magnitude of all the values with time was then plotted in Figure 11 as the minibike orientation was varied.

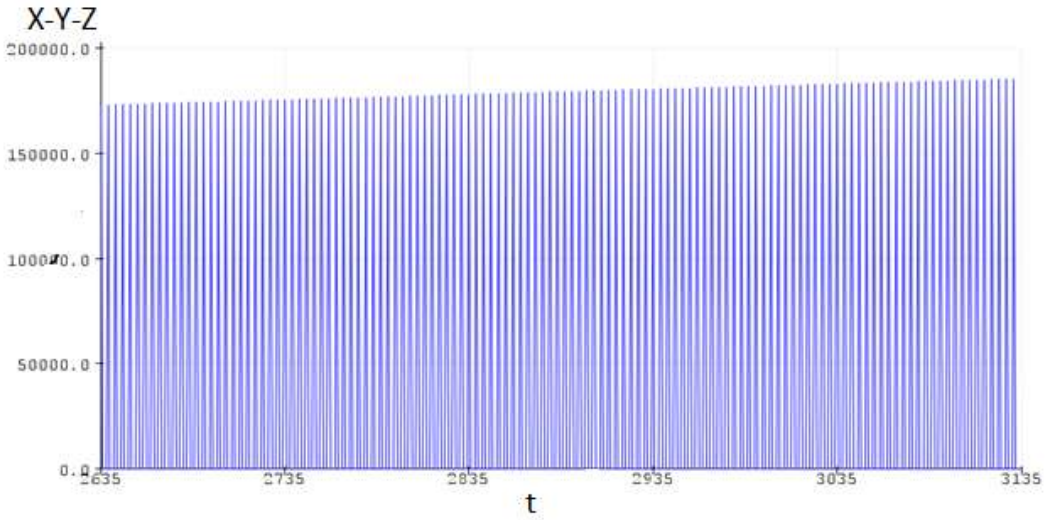

Figure 11. Motorcycle acceleration, orientation, and magnetic measurements magnitude varied with time

3.6 Obstacle test

This was done to detect obstacles in front of the minibike so that motors can be stopped or turned away from the obstacle. The ultrasonic sensor was connected to the microcontroller in search a way that it generated a pulse to the trigger pin setting active the echo pin of the sensor. As such any obstacle infront of the minibike would reflect back the sound waves as echo enabling the microcontroller to measure the flight time and thus the distance of the obstacle from the motorbike. Several obstacles were detected in front of the robot and different sensor reading were taken as shown Figure 12.

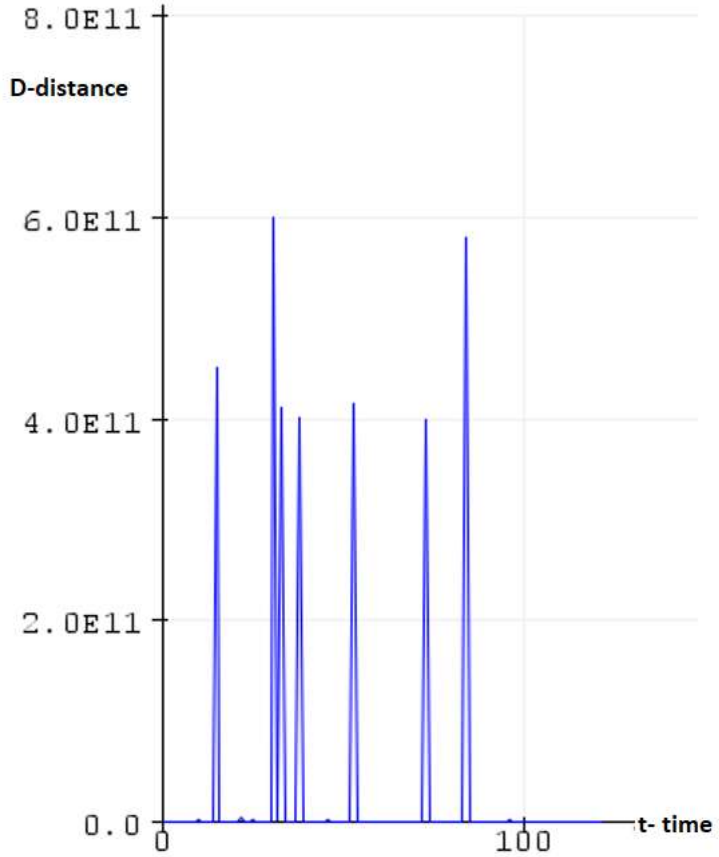

Figure 12. Obstacle detection infront of minibike varied with time

4. Conclusion and future work

Progress achieved this far on the development of a motorized minibike capable of moving using an inertia steering wheel has been presented. The system centered around a system on chip microcontroller and guided by obstacle, metal and magnetic detection sensors uses pulsated signals to control DC and servo motors that propel the motorcycle forward. Testing done this far shows that the sensors

are capable to detect obstacle, monitor magnetic field intensity and use motors to steer the system to full acceleration while keeping a stable balancing orientation. As part of ongoing work the model of the system will be developed, simulated, and the parts three dimensionally printed, assembled, and tested. The metallic detection circuit will be added to the system to detect the presence of mines.

References:

1. Bonsor, K. (n.d.). How Landmines Work Retrieved from *How stuff works*. https://science.howstuffworks.com/landmine5.htm
2. L. ROBLEDO, M. C. (2007, June 11). A survey of land mine detection technology. Retrieved from *internatinal journal of remote sensing*: https://www.researchgate.net/publication/233130505_A_survey_of_land_mine_detection_technology
3. *Arduino Engineering Kit Powered by MATLAB & Simulink with Madhu Govindarajan*. (2018, May 26). Retrieved from Youtube: https://www.youtube.com/watch?time_continue=4&v=h4yw5pue9K0
4. Jianjun, J. -K.-W. (2011, May 23-25). *Research on motion control of wheeled self-balancing robot based on ODE virtual reality technology*. Retrieved from IEEE Xplore: https://ieeexplore.ieee.org/document/5968611
5. *How to use an Arduino to build a robot that balances itself like a Segway*. (2017, May 2). Retrieved from Maker Pro: https://maker.pro/arduino/projects/build-arduino-self-balancing-robot
6. zhang, R. -X.-C.-S.-M.-L. (2013, July 28-30). *Control system design for two-wheel self-balanced robot based on the stepper motor*. Retrieved from IEEE EXPLORE: https://ieeexplore.ieee.org/document/6611417
7. Xia, J. -G.-Z.-D. (2016, July 14). *Straight-driving and turning compound control of the self-balancing two-wheeled robot*. Retrieved from IEEE Explore: https://ieeexplore.ieee.org/document/7512878
8. Yunong, Y. M.-K. (2015, October 28-30). *Balancing and Driving Control of a Ball Robot using Fuzzy Control* . Retrieved from IEE explore: https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=7358812&tag=1

Biographies:

1- Said M. M. KAFUMBE of the Higher Colleges of Technology in Abu Dhabi, United Arab Emirates, is a Faculty of Electrical Engineering with over 25 years of industrial and academic experience. His research interests lie in the fields of autonomous systems development, micro-electro-mechanical systems (MEMS), nanotechnology, and semiconductor technology integration, as well as embedded wireless sensor systems development.

2- Ravichandran Danthakani is currently working as Faculty in Electrical and Electronics Engineering Department at Higher colleges of Technology, Abu Dhabi. His 30years of expertise is blended with industrial and academic experiences. His research interest includes control systems, automation, instrumentation and sensor technology.

3- Emad Abd-Elrady received his BSc and MSc degrees in Electrical Engineering from Ain Shams University, Cairo, Egypt, in 1993 and 1997, respectively. He received his Licentiate and PhD degrees in Electrical Engineering with specialization in Signal Processing from the Division of Systems and Control, Uppsala University, Sweden, in 2002 and 2005, respectively. From January 2006 to March 2009, he was a senior researcher and project leader at the Christian Doppler Laboratory for Nonlinear Signal Processing, Graz University of Technology, Austria, where he was working in a cooperation project with Infineon Technologies. From March 2010 to January 2011, he was a research fellow at The University of Edinburgh, UK. Since February 2011, he has been electronics engineering faculty at Abu Dhabi Women's College, United Arab Emirates. His research interests include adaptive filtering, system identification, adaptive, nonlinear and distributed signal processing, dynamical system modeling, distributed and convex optimization, and wireless sensor networks.