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Full Length Research Paper

Development of an automatic self balancing control system for a tree climbing robot

Hamed Shokripour[1]*, Wan Ishak Wan Ismail[1] and Zahra Moez Karimi[2]

[1]Department of Biological and Agriculture Engineering, Faculty of Engineering, University Putra Malaysia 43400 Serdang, Selangor, Malaysia.
[2]Department of Computer Engineering and Information Technology, Amirkabir University of Technology, Hafez Ave, Tehran, Iran.

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The purpose of this project was to design, fabricate and test a self balancing control system for a four wheeled climbing robot. A HM-RF transparent wireless data link module was used for transferring the data between the remote control and robot. A programmed microcontroller ATmega16 was used to generate an appropriate signal for each of the remote control buttons. The control system balances the robot during the climbing by separately adjusting the rotation speed of each DC motor proportional to the tilt angle of the robot frame. Pulse-width modulation technique was used to control the speed of DC motors. A two axes tilt sensor was used for concurrently measuring the tilt angle of the robot in both X and Y axes. A microcontroller ATmega64 was used to analyze the received data from the tilt sensor and the remote control and to generate an appropriate PWM signal for each DC motors. For programming, the microcontrollers were used in Bascome IDE interface in basic language. An electronic board was designed to connect the sensor, data receiver and motors to the microcontroller. The robot tested in field and maximum tilt angle was 8 and 6° for Y and X axes, respectively.

Key words: Agricultural robot, tree climbing, speed controller, remote control, PWM.

INTRODUCTION

A mobile robot is an autonomous system which operates in a real world environment. The control system of such a robot must perform complex information processing tasks in real time (Xu et al., 1997). Mobile robots are expected to carry out various tasks in all kinds of application fields such as manufacturing plants, warehouses, nurse service and agriculture**Error! Reference source not found.** (Jing, 2005). Traditional farming has been very labour intensive. Robotics and intelligent machines are becoming popular in agriculture sector recently (Sistler, 1987). Many agricultural operations, such as precise fertilization, plant disease detection, spraying and selective harvesting can be routinely performed by robots (Belforte et al., 2006). In recent years, harvester robots have been among the noteworthy topics studied by researchers. Until now, different robots have been designed for harvesting some greenhouse crops such as cucumbers, mushrooms and tomatoes (Kondo et al., 1994, 1995; Reed et al., 1995).

One of the first problems of harvesting the trees productions is that the fruits are not within the workers' reach. The strategies for harvesting trees fruits are

*Corresponding author. E-mail: hamedshokripour@gmail.com. Tel: 0098-9183134900.

climbing the tree or using some equipment of machine to harvest the fruits. The applications of climbing robots range from automatic cleaning systems for windows and building exteriors to inspection of hazardous environments and autonomous vehicles for space applications (Sameoto et al., 2008).

Oil palm has become the world's number one fruit crop because of its high level of fruit production (Adetan et al., 2007). In traditional methods of harvesting the oil palm trees with a height of about 9 m, a sharp curved knife which is attached to the end of a bamboo pole is used. Since this method is time consuming, difficult and dangerous, it is not desirable for a farmer. This traditional harvesting method consumes a lot of time and energy; therefore, the production cost of these crops is increased. Many attempts have been made to mechanize the harvesting of oil palm bunches.

The use of mobile robots for tree care is inevitable. Tree crops offer a special set of opportunities and challenges for mobile robots (Blackmore et al., 2005). There have been many different designed robots for climbing trees and poles (Baghani et al., 2005; Kawasaki et al., 2008; Yazdani et al., 2004; Sadeghi et al., 2008).

The purpose of this project was to design and fabricate a control system and a remote control for a four-wheeled climbing robot for oil palm trees. The main task of the control system was to keep the robot balanced during the climbing process by separately controlling the speed of each wheel. Without this control system, the robot will become unbalanced and get stuck to the tree after climbing a few meters. The two main factors that cause the robot to become unbalanced are: (1) the irregularities of the tree trunks surface and (2) the different speeds of the DC motors that turn the wheels under different loads (Boskovich, 2005).

MATERIALS AND METHODS

A HM-RF transparent wireless data Link module consists of two parts, both of which can send and receive data wirelessly. The first part was used by the remote control to send the commands of the operator and the second part was installed on the climbing robot to receive the commands from the remote control. The data transfer between these parts by a radio frequency range between 310.24 and 929.27 MHz. This paper focuses more on the processes needed to transfer the data from the HM-RF module to the microcontroller and analyzing them.

A control system for keeping the balance of a four-wheeled tree climbing robot involves the following:

(1) A means of sensing for the tilt angle related to both X and Y axes.
(2) An ability to calculate the appropriate speed for each wheel.
(3) An ability to generate the same speed for each motor with respect to the calculated speed.

An ATmega64 microcontroller from ATMEL Company was used as the arithmetic and logic unit of the robot. It provides 53 programmable input/output lines, 64K Bytes of in-system reprogrammable flash memory, 2K Bytes EEPROM, and 6 PWM channels with programmable resolution from 1 to 16 Bits. Its operating voltages and speed range are 4.5 - 5.5 V and 0 - 16 MHz respectively. Pulse width modulation (PWM) technique has a wide range of applications. It can be used in embedded control systems to control the mechanical equipment that works on servomotors and in DC motor drives to control the speed of the motor. There are several classical methods to generate a PWM modulated signal (Scott et al., 1995). The PWM duty cycle is the fraction of time that a system is in an "active" state. The speed of motors can be controlled by varying the duty cycle of the sent signal to them. If the duty cycle is 50%, then the on time is half a cycle. When the duty cycle is zero, the average DC voltage value becomes 0% and motor is off. Figure 1 shows a PWM pulse with 25% duty cycle.

A ZTC 245 AN TTL tilt sensor was used to measure the tilt angle of the robot. This sensor measures the tilt angle of the robot frame for both X and Y axes concurrently. The tilt angle is measured relative to a hypothetical XY coordinate plane that makes zero degree angles with the horizon.

The tilt sensor and HM-TR module send their data to the microcontroller for analyzing and generating an appropriate PWM signal for each DC motor to keep the robot balance. In a climbing process, the microcontroller decreases the speed of the upper wheels until the lower wheel reaches the same level with the other wheels. It makes the robot balance by decreasing the speed of the lower wheels when the robot is coming down the tree.

Hardware of control system

The hardware of the self-balancing climbing robot's control system comprises three parts: power, digital circuit and analog circuit.

The 12 V tractor battery was used as the power source for this robot in order to have the maximum torque and speed from the DC motors and keep the tractor engine running to generate maximum amperes for driving the motors during the climbing process. A LM7805K linear voltage regulator was used to convert the 12 V direct current of the power source to 5 V direct current required for the microcontroller, data HM-RF module and tilt sensor.

The digital portion of the control system consists of memory and processor. The software, as the controlling algorithm, is stored in the memory and executed by the processor. The analog part is responsible for controlling

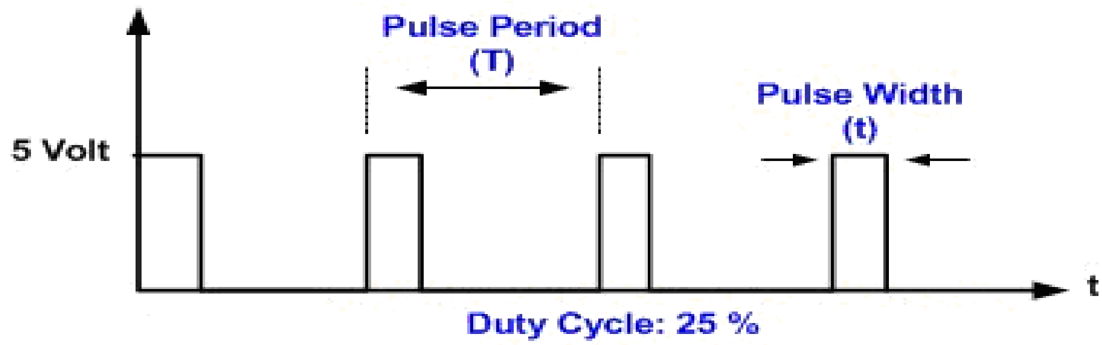

Figure 1. Pulse with 25% duty cycle.

the motors' speeds. The analog system converts data from analog to digital and vice versa. The tilt sensor sends the data to the microcontroller in Transistor–Transistor Logic (TTL) way of communication. The two voltage levels of the TTL circuit are 0.2 V for low level (logical '0') and 2.4 to 5 V for the high level (logical '1') (Saha et al., 2010).

The tilt sensor measures the tilt angle from +45 to -45° for both X and Y axes concurrently with one decimal point degree of accuracy. The tilt sensor was installed at the corner of square frame of the robot so that the sensor on the X and Y axes are parallel with the sides of the robot square frame. It sends its data to the microcontroller in ASCII code format in a collection of 16 bytes data.

The HM-RF transparent wireless data Link module uses RS232 logic level for transferring data to the microcontroller. The RS232 physical specification gives a logic 1 at receiver input as -3 to -25 volts and logic 0 as +3 to +25 V. Since the ATmega64 microcontroller can receive and analyze the data on the TTL logic level, a MAX232 IC was used for converting the data of the HM-TR module to TTL logic level. It can generate the necessary RS-232 voltage levels of approximately -10 and +10 V internally from a single + 5 V power supply. It can reduce RS-232 inputs which may be as high as ± 25 V to standard TTL levels 5 V. Figure 2 shows the electronic circuit which was designed for transferring data from the HM-TR module to the microcontroller.

The data are transferred from pin 4 of the HM-RF module to pin R1-IN of MAX 232 IC. After converting these data to TTL format, MAX232 transfers them from its R1-OUT pin to pin E0 (RXD0) microcontroller. Every second, the microcontroller sends a collection of information by HM-RF module to the remote control to show the last status of the DC motors and the robot to the operator. The microcontroller sends the data in TTL format to pin T1- IN of MAX 232 IC. The MAX 232, after converting them to RS232 format, transfers them to the HM-RF module for sending to the remote control.

The microcontroller can determine the position of each wheel of the robot relative to other wheels by analyzing the received data from the tilt sensor. This climbing robot has four wheels which were mounted in the middle of each side of the square frame of the robot. A set of two climbing robot wheels was placed along the X and Y axes respectively. If the value of the tilt angle on X axis is positive, the microcontroller understands that wheel number 1 places above wheel number 2 and if the value of angle is negative, it understands that wheel number 2 is placed above wheel number 1. Figure 3 shows the schematic design of this robot and position of the wheels related to X and Y axes of the tilt sensor. The tilt sensor sends its data to the microcontroller via a TTL half-duplex way. Pins numbers 3 and 4 of the sensor are RX (TTL) and TX (TTL) respectively which are connected to pins D3 (TXD1) and D2 (RXD1) of the microcontroller, respectively. Pins D2 and D3 of the microcontroller were used because each one has a universal asynchronous receiver/transmitter (USART) device. It is a piece of microcontroller hardware that transforms data between parallel and serial formats.

The microcontroller generates a high frequency PWM signal zero of volts and five volts for controlling the speed of the DC motors. An electronic circuit was designed and fabricated for turning the DC motor off and on using PWM signal and also for converting the 5 V direct current PWM signal to 12 V direct current signal to drive the motors.

A Metal–Oxide–Semiconductor Field-Effect Transisto

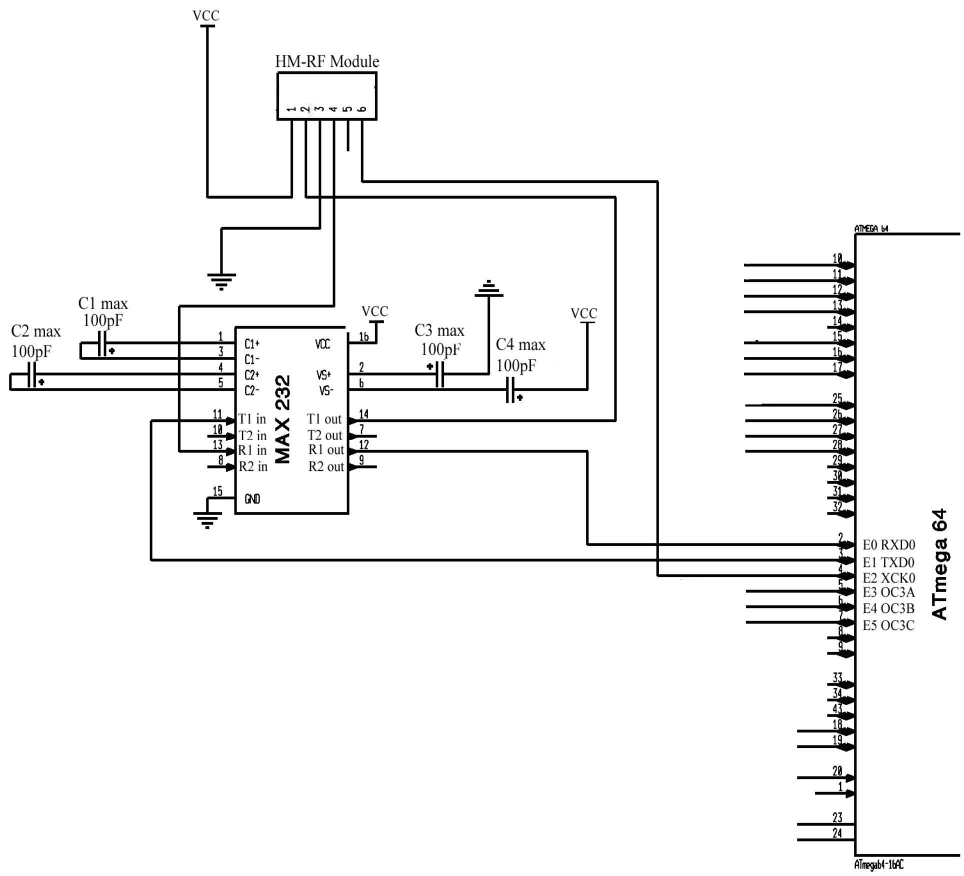

Figure 2. Electronic circuit for transmitting data from HM_RF module to microcontroller.

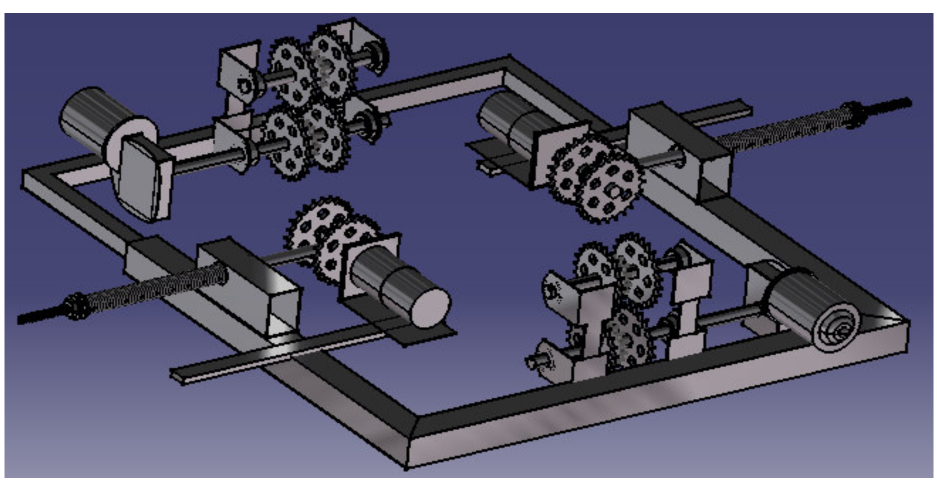

Figure 3. Climbing robot for oil palm tree.

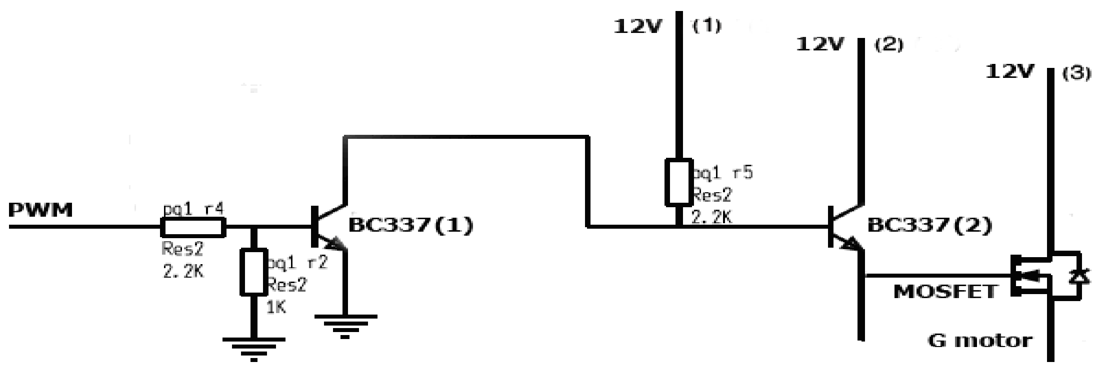

Figure 4. Electronic circuit for switching the DC motors on and off.

(MOSFET) was used for each motor as an electronic switch between the 12 V power supply and the motor. This device can support the 12 V and 49 A current but it needs a 12 V current for activation. Since the current of PWM signal is maximum 5 V, it can not drive the MOSFET directly. A BC337 transistor and a 12 V power supply were used for activating the MOSFET. The BC337 transistor was used between MOSFET and the 12 V power supply as a switch which is controlled by PWM signal. The maximum current that BC337 can support is 1 A and it is enough for driving the MOSFET. Figure 4 shows the electronic circuit which was designed for switching the DC motors on and off using PWM signal.

When the PWM signal is in 5 V level, it enables the BC337 (1) switch to be connected, so the current of 12 V (1) power supply goes to the ground and the MOSFET switches off. In the other scenario, the PWM signal is in 0 V level, so the BC337 (1) is off and the current of the12 V (1) power supply can drive the BC337 (2). In this case the current of 12 V (2) power supply can pass through BC337 (2) switch and arrive at MOSFET. This current can activate the MOSFET and therefore the current of 12 V (3) power supply can pass through the MOSFET and drive the motor. This process is repeated many times in each second. The microcontroller can control the speed of the motor by changing the duty cycle of the PWM signal. For the PWM signal the duty cycle is equal to ratio of pulse wide to pulse period of the signal.

Software

The function of the software is to implement a controlling algorithm which uses the data collected from the hardware. The algorithm adjusts the speed of each motor separately such that the robot keeps balance during the climbing process. The tilt sensor measures the tilting angles for both X and Y axes of the robot constantly and sends the data to the microcontroller in a 16 separate byte data collection. The arrangement of this collection is fixed and is explained in the sensor data sheet [16]. The first byte of this collection is number 88 which is the ASCII code of X letter. A special program was written for the microcontroller using Bascome IDE interface for compiling the data received from the tilt sensor and the HM-TR module to calculate the appropriate PWM signal for each motor. When the microcontroller receives the number 88 from the tilt sensor, it understands that this is the first data of a new collection of tilt sensor data. The microcontroller saves these data in a 16 byte array in its memory. Since the microcontroller cannot use the data in ASCII format to do calculation, it converts them from ASCII format to String format. An LCD installed for the robot will show the changes of tilt angle continuously.

When the operator pushes a button on the remote control, the remote control sends three numerical codes to the receiver of the robot. The first number informs the microcontroller that a new command is being sent by remote control and makes the microcontroller ready for receiving the next numbers. The second number is the code of the command that is allocated for specific buttons on the remote controller. By analysing this number, the microcontroller understands what the operator wants the robot to do. The third number is a summation of the first and the second numbers and is called the check sum number. The microcontroller also adds up the first and the second received numbers and compares the result with the check sum. If these numbers are the same, the microcontroller understands that it has received the data from the remote control completely and correctly. In the next, the microcontroller sends the appropriate command for each DC motor based on the value of the second number. To change, the motors rotation direction was used as a miniature intermediate power relay for each motor. The status of the relays is changed by the signals that are sent via microcontroller to them.

```
If Set point = 7 Then
Portc.0 = 1
Portc.1 = 1
Portc.2 = 1
Portc.3 = 1
Goup = 1
End If
```

In this program set point variable is the second number that is sent by remote control to robot. This number determines which commands should be sent to different parts such as motors and relays to cause robot move up, move down or stops. Ports number C.0 to C.4 of the microcontroller was used for controlling the relays of motors. When in program their value is 1; the microcontroller sends a 5 V signal to relay's coil to change the direction of motors rotation so that the robot moves up. When the robot start to moves, the tilt sensor is activated also and the robot is kept balance by changing the value of PWM signal proportional to the value of tilt angle. The robot continues a task until the operator sends a new command by pushing another button of remote control.

The speed of the motor is controlled by the calculated and sent PWM signal for each motor by microcontroller. The value of PWM depends on the value and sign of tilt angle for each X and Y axes. The sign of the tilt angle determines which of the two wheels on each axis is situated on the upper level.

```
If  Goup = 1 Then
If Yangle > 0 Then
    Pwm1b = 1023
    K1 = Yangle × 50
        If K1 > 1020 Then
            K1 = 1023
        End If
K2 = 1023 - K1
Pwm1a = K2
End If
```

In this part of the program, Y angle is the value that was measured by the tilt sensor and sent to the microcontroller. K1 is a variable and Pwm1a and Pwm1b are the values of PWM that are sent by the microcontroller to motors 1 and 2. In this case, the robot was tilted around Y axis and the value of Y angle is positive. For making the robot balance, the speed of motor 1 should be kept at maximum while the speed of the motor 2 should be decreased to make the robot balance. If the value of Y angle will be less than zero, another part of the program calculates and sends PWM signal to motors 1 and 2. In this case the speed of motor 1 decreases and the maximum speed for motor 2 generated to the robot becomes balance.

The speed of motor 3 and 4 is controlled with the same method as motors 1 and 2 proportional to value and sign of the tilt angle for axis X.

The maximum speed of the motor is generated when the value of PWM is 1023. The value of PWM is calculated using equation "K2 = 1023 - K1" and the value of k1 is calculated using the equation "K1 = Yangle × 50". As it can be seen in Figure 5 the motor speed curve is not linear and the less tilt degree causes the higher PWM which consequently generates higher speed for the DC motor. Obviously the PWM and motor speed curve have different slop along the X axis. In other words, although the PWM signal is the determinant factor for motor speed , motor speed does not have the same decreasing trend ratio as PWM while the tilt degree increases.

Conclusions

The main problem being faced by the tree climbing robots is due to the irregularities of the tree trunk surfaces that cause the robots stuck to the tree when climbing. The designed control system in this project was tested with a four-wheeled oil palm climbing robot to control the rotation speed of each DC motor separately to keep the robot balance while climbing the oil palm tree. Figure 6 shows this robot in field test. The PWM technique was used to control the speed of motors by providing intermediate amounts of electrical power between fully-on and fully-off situations. The tilt sensor that was used in this system was measured and the tilt angles of the robot in both X and Y axes with one decimal point degree of

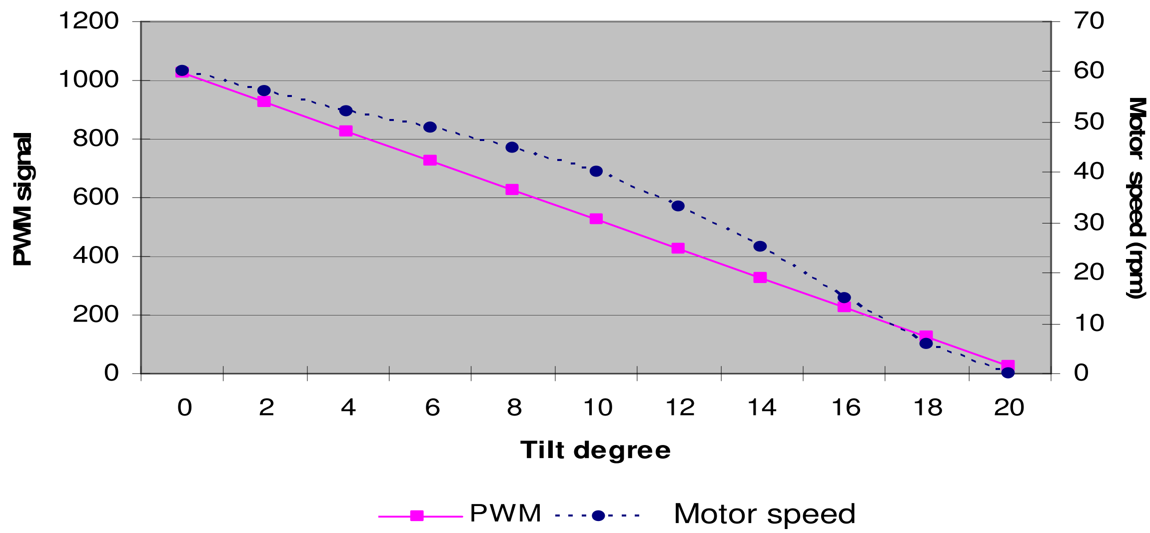

Figure 5. Chart of changes of motor speed and PWM signal to tilt degree ratio.

Figure 6. The climbing robot test in field.

accuracy was sent. The remote control could send the data accurately to the climbing robot and the microcontroller could analyse them and make the appropriate decision. The written software for the microcontroller could analyze received data from the tilt sensors and calculate an appropriate PWM signal for each wheel of the robot to keep the robot balance.

The robot could climb and pass the irregularities of the tree trunk successfully. The maximum tilt angle in climbing tests was 8 and 6 degrees for Y and X axes respectively with 4.6 m. min -1 climbing speed. The less climbing speed caused the less tilting because the robot had more time to balance itself after passing the irregularities.

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