One Wheeled Electric Personal Transporter

K. Ram Kumar, C. Suriyakumar, L. Vishnuvardan, S. Vignesh, C. Vigneswaran

Abstract - Inpresent scenario, every individual has a two wheeler and they are using this even for reaching short distances. By this, conventional resources like petrol are consumed more and more. Not only the depletion of resourses, it produces more environmental pollution hazards. To overcome this issue, comparatively unconventional energy resourses should be used. For this we have developed a electric operated unicycle., The outcomes this research paper is to design, build and control a self-balancing electric unicycle are presented. The design of the mechanical and electrical components is discussed, followed by a derivation of the dynamics of a generic unicycle. A linear control strategy to stabilize the unicycle is implemented on the physical system and a simulated model is derived from the system dynamics. Finally, comparisons of the results from simulations conducted on a model of the unicycle as well as experimental results are presented.

Keywords: one wheeled electric vehicle, robotic system, stabilization, state feedback control

I. INTRODUCTION

As the price of petroleum products shoots up, there is an imminent need for cheaper and more efficient form of transport. Even major industries and factories that span over large areas restrict the use of transport by their employees within their premises to avoid the risk of contamination due to emissions. Manufacturers have a great need for competence in the field of hybrid vehicle technology or even fully electrical vehicle technology as a step towards fulfilling these goals. These new vehicles are complex machines and require engineering competence in many fields; mechanics, vehicle dynamics, automatic control, power electronics, battery technology, software engineering, network and communication engineering to name a few.The above problem and that of space constraints is overcome with the concept of a self balancing personal transporter. It wsorks on the inverted pendulum principle and employs the use of electromechanical components to keep its rider upright only on one wheel. Due to the unstable nature of an inverted pendulum, it has been an excellent platform for control theory experimentation. The two wheeled self balancing robot, has become popular due to its responsive yet precise movement. This project aimed to be a feasibility study and preparation for building one wheeled self balancing vehicle.

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K. Ram Kumar, UG Students, Department of Production Engineering, PSG College of Technology, Coimbatore, India.
C. Suriyakumar, UG Students, Department of Production Engineering, PSG College of Technology, Coimbatore, India.
L. Vishnuvardan, UG Students, Department of Production Engineering, PSG College of Technology, Coimbatore, India.
S. Vignesh, UG Students, Department of Production Engineering, PSG College of Technology, Coimbatore, India.
C. Vigneswaran, Asst Prof., Department of Production Engineering, PSG College of Technology, Coimbatore, India.

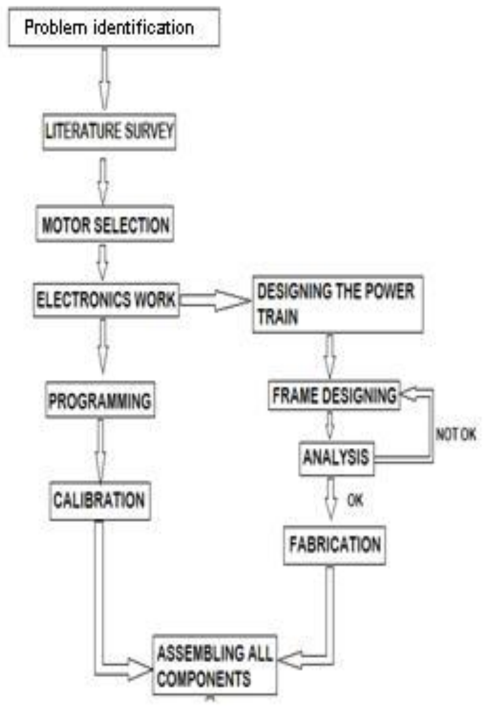
The vehicle is similar to the Segway Personal Transporter, invented and released in 2001 by Dean Kamen with the intention to revolutionize city transportation. This kind of vehicle contains many of the technologies required to build a hybrid or electric car. 2

II. OBJECTIVE OF THE PROJECT

The main purpose was to design and construct a fully functional one wheeled balancing transporter which can be used as a means of transportation for a single person. It should be driven by natural movements; forward and backwards motion should be achieved by leaning forwards and backwards. Turning should be achieved by tilting the handlebar sideways. To provide unmetered operation the vehicles' energy source was designed to be a battery. One of the goals was to implement, easy recharging of this battery.
More specifically, the project goals are stated as follows:

- Speed should be controlled by the rider leaning forwards and backwards.
- Turning should be controlled by tilting the handlebar.

III. METHODOLOGY



IV. INVERTED PENDULUM PRINCIPLE

An inverted pendulum is a pendulum, which has its centre of mass above its pivot point. It is often implemented with the pivot point mounted on a cart that can move horizontally and may be called a cart and pole. Most applications limit the pendulum to 1 degree of freedom by affixing the pole to an axis of rotation.

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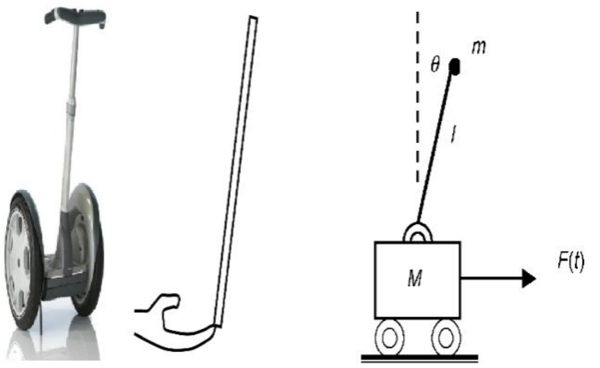

Fig. 1: The inverted pendulum principle.

Whereas a normal pendulum is stable when hanging downwards, an inverted pendulum is inherently unstable, and must be actively balanced in order to remain upright; this can be done either by applying a torque at the pivot point, by moving the pivot point 3 horizontally as part of a feedback system, changing the rate of rotation of a mass mounted on the pendulum on an axis parallel to the pivot axis and thereby generating a net torque on the pendulum, or by oscillating the pivot point vertically.

Pivot point in a feedback system is achieved A simple demonstration of moving the by balancing an upturned broomstick on the end of one's finger. The inverted pendulum is a classic problem in dynamics and control theory and is used as a beThis kind of vehicle contains many of the technologies required to build a hybrid or electrical car.2

a)3 Dynamics of the 2DOF system:

The dynamics of the unicycle are developed from the inverted pendulum model used extensively in Driver and Thorpe [2004] and further developed in Fong and Uphill [2009], Huang [2010] and Lauders and Hollis [2006] include the translational motion of the pendulum. However, these derivations are inconsistent with regards to coordinating frames and non-conservative forces. Therefore an extensive verification process was undertaken to derive the dynamics of the UNICYCLE. This process was based on the dynamics derived in Nakajime et al. [1997] and through coordinated transforms, verified with the papers discussed above.

The following assumptions have been made in the derivation of the dynamics, with reference to the coordinate system and directions.

• Motion is restricted to the x-y-plane.

• A rigid cylinder is used to model the chassis and a vertically orientated thin solid disk used to model the wheel.

• Coulomb friction arising from the bearings and tire ground contact is neglected, and hence only viscous friction are considered.

• The motor is controlled via an intelligent controller in “current mode” such that the input into the plant is a torque command.

• There is no slip between the tire and the ground. The model is defined in terms of coordinates f and q, where:

• f - rotation of the frame about the z-axis.

• q - Rotation of the wheel relative to the frame angle. The origin of the right-handed coordinate frame is located at the centre of the wheel, as shown in Figure. The positive x-direction is to the left and positive y is upward. Anticlockwise rotations about the z-axis are considered positive. The zero datum for the measurement of the frame angle f is coincident with the positive y-axis and the wheel angle q ismeasured relative to f. Figure

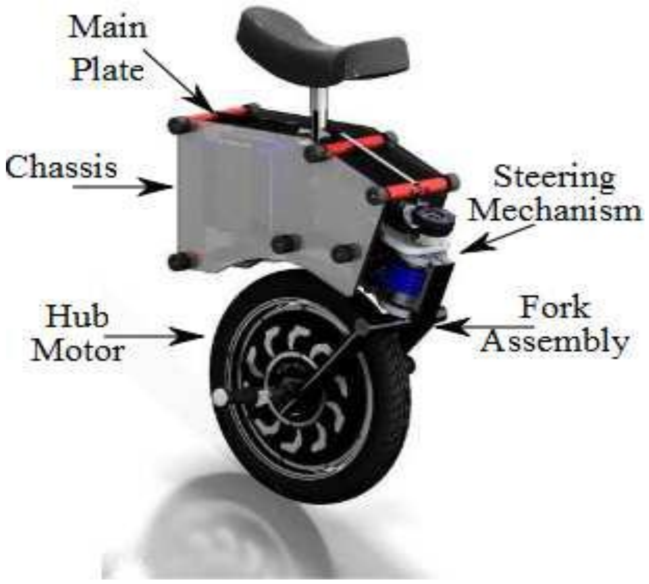

Fig. 2: One Wheeled Electric Personal Transporter

V. ELECTRONIC DEVICES

a) arduinouno:

The main controller for this project is Arduino Uno which uses Atmel At mega 328 microcontroller as it combines 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, 23 general purpose I/O lines, 32 general purpose working registers, three flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, a byte-oriented 2-wire serial interface, SPI serial port, 6-channel 10-bit A/D converter (8-channels in TQFP and QFN/MLF packages), programmable watchdog timer with internal oscillator, and five software selectable power saving modes. The device operates between 1.8-5.5 volts.

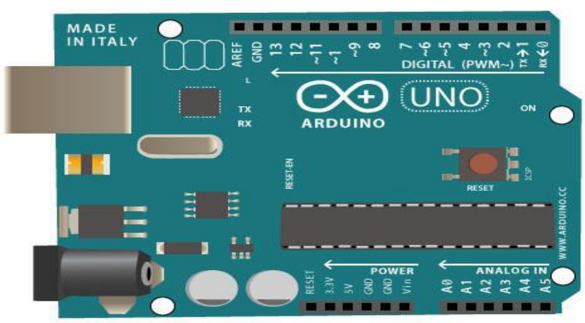

Fig. 3: Arduino Uno

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Arduino is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software. It's intended for artists, designers, hobbyists, and anyone interested in creating interactive objects or environments. The open-source Arduino environment as shown in Figure 3.10 makes it easy to write code and upload it to the I/O board. It runs on Windows, Mac OS X, and Linux. The environment is written in Java and based on Processing, avr-gcc, and other open source software.

b) circuit diagram

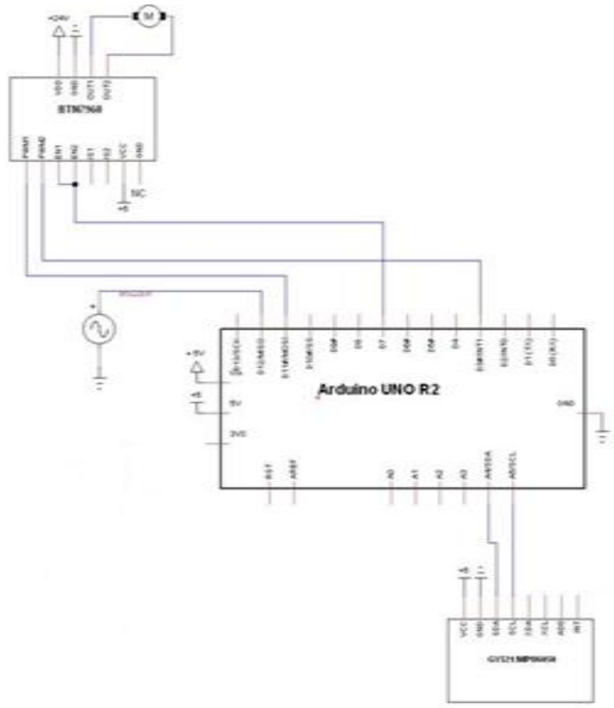

Fig. 4: Circuit Diagram

c) arduino ide

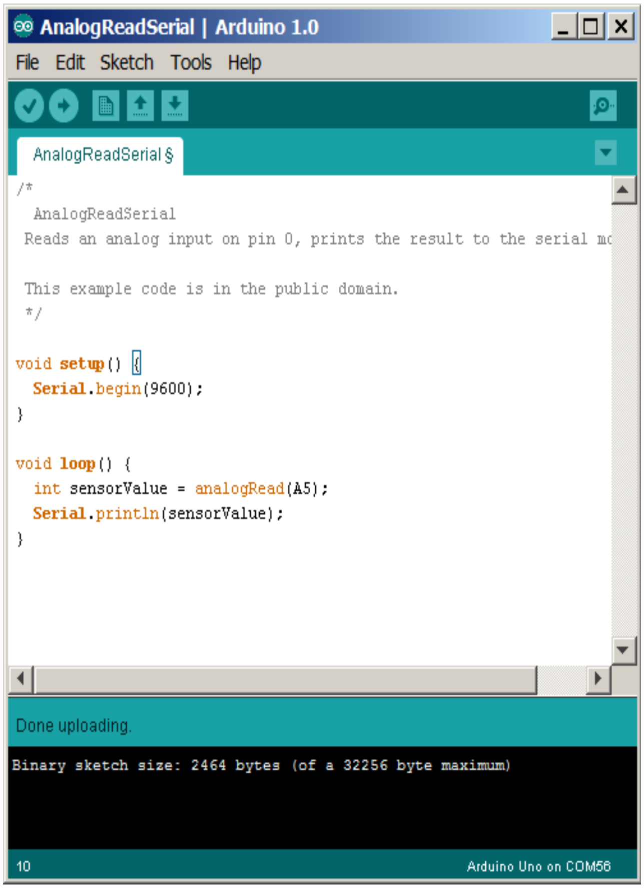

Fig. 5: Arduino Ide

d) IMU (Inertia Measurement Unit) sensor:
IMU sensors are one of the most inevitable type of sensors used today inall kinds ofelectronic gadgets. They are seen in smart phones, wearable's, game controllers, etc. IMU sensors help us in getting the orientation of an object, attached to the sensor in three dimensional space. These values usually in angles. Thus, they are used in smart phones to detect its orientation. IMU sensors, thus have prolific number of applications. It is even considered to be an inexorable component in quad rotors.
MPU 6050:

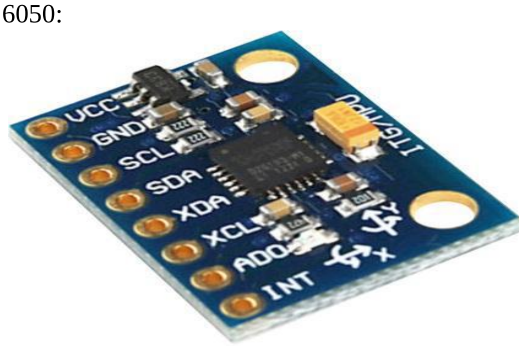

Fig. 6: MPU 6050

- The MPU-6050 is the world's first integrated 6-axis Motion Tracking device
- It combines a 3-axis gyroscope, 3-axis accelerometer, and a Digital Motion Processor™(DMP) all in a small 4x4x0.9mm package.

- It uses a standard I2C bus for data transmission.
- It is highly accurate and low cost (Rs 350).

VI. MOTOR DRIVER

Fig. 7: NISI IBT-2

NISI IBT-2 motor driver is used to drive the 24V motor. It is a H-bridge dc motor driver comprising of two BTS 7960 ICs. The 7960 ICs are half bridge motor drivers. Hence, two of them are combined to form a H-bridge.

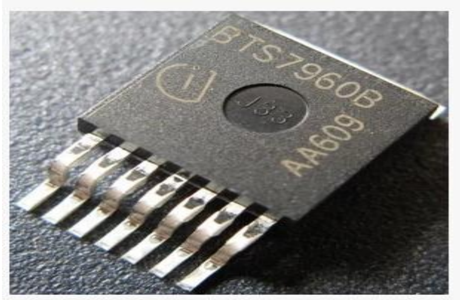

Fig. 8: BTS 7960

SPECIFICATION:
Operating voltage - 5 V
Max voltage - 27.5 V
Max current - 43 A
PWM frequency - 25 kHz

BTS 7960 Have a good protection circuit such as:
1) Undervoltage Shut Down:To avoid uncontrolled motion of the driven motor at low voltages the device shuts off. if the Supply voltage VUV(OFF) dropped under 5.4V , The Motor driverwill switched Off , Andwon'tincreased turned on until the Supply voltage to 5.5V Or more .
2) Over temperature Protection: The BTS 7960 is protected against over temperature by an integrated temperature sensor. Overtemperature leads to a shutdown of both outputstages.
3) CurrentsLimitation: The current in the bridge is measured in both switches, High and Low side, if The current reaching the limit current (Iclx) the switch is deactivated and the other switch is activated for a certaintime(Tcls).

VII. MOTOR SELECTION

Table 1: differentiation of motors.

TYPE	ADVANTAGES	DISADVANTAGES	TYPICAL APPLICATION	Typical Drive
Stepper DC	Precision positioning and high holding torque	Costly motor and controller	Used in printers	Multi-phase DC
Brushless DC motor	Long lifespan , Low maintenance, High Efficiency.	High Initial Cost and requires a controller	Hard drives CD/DVD players Electric Vehicles	Multi-phase DC
Brushed DC motor	Low cost, Simple speed control.	High maintenance, Limited lifespan	Automotive starters, Power steering, etc.	Direct PWM

There are many types of dc motors available in the market. The following three types of motors can beused in our project therefore; we have compared them and have tabulated their advantages and disadvantages in the following table.

After doing the comparison we have decided to use brushed dc motor because, It is low cost, simple to control using direct PWM controller and the cost of the controller is also comparatively less.

VIII. MOTOR SIZING

The following are design criteria for motor sizing according to the project objectives;
Desired top speed (Vmax) - 10km/hr.
Maximum driver weight - 70 kg.
Gross vehicle weight (GVW) - 12 kg. (assumed)
Weight on wheel (WW) - 82 kg.
Radius of wheel/tire (Rw) - 9 inch
Desired acceleration time (ta) - 05 seconds.
Maximum incline angle (α) - 10 degree

To choose motors capable of producing enough torque to propel the vehicle, it is necessary to determine the total tractive effort (TTE) requirement for the vehicle:

$TTE = RR + GR + FA$

Where:

TTE = total tractive effort [N]
RR = force necessary to overcome rolling resistance [N]
GR = force required to climb a grade [N]
FA = force required to accelerate to final velocity [N]

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a) Step One:Determining Rolling Resistance

Rolling Resistance (RR) is the force necessary to propel a vehicle over a particular surface. The worst possible surface type to be encountered by the vehicle should be factored into the equation.

RR = WW* g *Crr

where:

RR = rolling resistance [N]

WW = Weight on wheel [kg]

Crr = Rolling Friction Coefficient

RR = 82 * g * 0.002 (Crr value for bicycle tire on concrete)

=g* 0.16 N

b) Step Two: Determining Grade Resistance

Grade Resistance (GR) is the amount of force necessary to move a vehicle up a slope or "grade". This calculation must be made using the maximum angle or grade the vehicle will be expected to climb in normal operation.

To convert incline angle, α, to grade resistance:

GR = WW* g * sin(α)

where:

GR = grade resistance [N]

WW = Weight on wheel [kg]

α = maximum incline angle [degrees]

GR = 82 * g * sin(10)

= g* 13.94 N

c) Step Three: Determining Acceleration Force

Acceleration Force (FA) is the force necessary to accelerate from a stop to maximum speed in adesired time.

FA = WW * g *Vmax / (g * ta)

where:

FA = acceleration force [N]

WW = Weight on wheel [kg]

Vmax = maximum speed [m/s]

ta = time required to achieve maximum speed [s]

FA =82 *g* 2.8 / (9.81*5)

= g* 4.6 N

d) Step Four: Determining Total Tractive Effort

The Total Tractive Effort (TTE) is the sum of the forces calculated in steps 1, 2, and 3.

TTE = RR + GR + FA

= (0.16 + 13.94 + 4.6) * g

= 18.7 * 9.81

= 183.4 N

e) Step Five: Determining Wheel Torque

To verify the vehicle will perform as designed in regards to tractive effort and acceleration, it is necessary to calculate the required wheel torque (Tw) based on the tractive effort.

Tw =TTE x Rw

where:

Tw = wheel torque [Nm]

TTE = total tractive effort [N]

Rw = radius of the wheel/tire [m]

Tw = 183.4 * 0.2286

= 41.8 Nm.

Therefore, the motor must be able to provide 41.8 Nm of torque to the wheel through the power train.

Specification of the motor :

Type - Brushed DC motor.

Made by - Hyoseong Electric Co., Ltd.

Used for - Electronic power steering in 'Hyundai i20' car.

Voltage - 12 V to 24 V.

Current - 65 A (Max).

Torque - 3.74 Nm (Max).

RPM - 2000 (Max).

IX. POWER TRAIN

The power transition is done by means of chain drive. Bicycle chain and sprocket is used in the chain drive of the vehicle.

The following are design criteria for power train design;

Motor RPM (Sm) - 1400 (limited to 70% by software)

Radius of wheel (Rw) - 9 inch.

Cirumference of wheel (Cw) - 1.44 m.

Motor toque (Tm) - 3.74 Nm.

Wheel torque (Tw) - 41.8 Nm.

Vehicle Speed (Vmax)- 10 km/hr.

a) Step One: Determining Wheel RPM

Vmax = Sw * Cw * (60/1000)

Sw = (Vmax/ Cw) * (1000/60)

= 115.74 RPM.

b) Step Two: Determining Gear Ratio

R = Sw/Sm

=115.74 / 1400

=1 / 12

also,

R = Tm / Tw

= 3.74 / 41.8

= 1 / 11.2

Therefore the gear ratio should be between 11.2 to12.

Step Three: Choosing The Sprockets

With the help of bicycle sprockets, a gear ratio of 1:11.76 can be achieved in two stages using compound chain drive.

In the first stage, a sprocket (A) of 14 teeth is attached to the motor shaft, this sprocket (A) drives a sprocket (B) of 48 teeth though the chain.

14 / 48 = 1 / 3.43

In the second stage, a sprocket (C) of 14 teeth is attached to 'B' Therefore, both 'B' and 'C' rotates on the same axis with the same RPM. The sprocket 'C' drives a sprocket (D) of 48 teeth. 'D' is fixed to the wheel axil therefore it transmits the power to the wheel.

14 / 48 = 1 / 3.43

Therefore a total reduction of 1 :11.76 is achieved through the compound chain drive.

(1/3.43)*(1/3.43) = 1 /11.7

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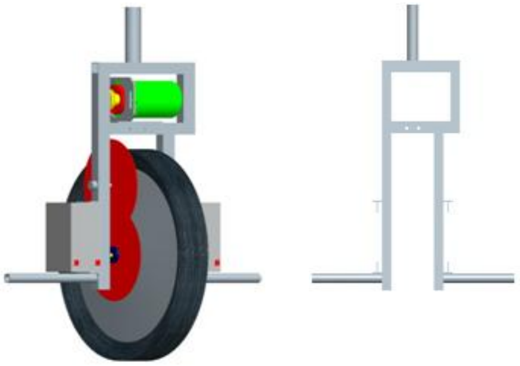

Fig. 9: CADmodelling of frame and one wheeled electric personal transporter

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AUTHORS PROFILE

K. RAMKUMAR is UG student From Department of Production engineering, PSG College of Technology, ANNA university, Chennai. Appart from curricular he is also very good in making short flims and represents in college culturals. He is awarded as a "Best short flim maker" in various inter college competions.

C. SURIYAKUMAR is a UG student From Department of Production engineering, PSG College of Technology, ANNA university, Chennai. Appart from curricular he is also a very good athelet in "Deckethlon", had participated in zonal level competitions and open state for the college. Also being a cricket captain he won 3 trophies in inter college level tournaments.

S. VIGNESH is a UG student From Department of Production engineering, PSG College of Technology, ANNA university, Chennai. Appart from curricular he is also very good in making short flims and represents in college culturals. He is awarded as a "Best short flim maker" in various inter college competions.

L. VISHNUVARDHAN is UG student From Department of Production engineering, PSG College of Technology, ANNA university, Chennai. Appart from curricular he is also a very good Foot ball Player. As a Foot ball team captain of PSG tech, he represents and won ANNA university zonals and won 13 trophies in various inter-college tournaments.

C. VIGNESWARAN, received his bachelor of engineering degree in mechanical engineering from Thanthai periyar Government institute of technology, Anna university, chennai, India and smaster of Production engineering degree in production engineering from PSG college of technology, Anna university, Chennai.Currently he is working as an Asst professor in Department of Production engineering, PSG college of technology, Coimbatore, India. He is also active member in professional bodies like Indian Society of Technical Education, Associate Member in Institution of Engineers. He has published 1 International journals, 3 papers in International conference and 1 paper in national conference.

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