# Developing Autonomous Mobile Robot Navigation using Machine Vision System as a Learning Tool in Engineering Education

**Anawat JANTASEN[a], Sirasit NASAKAT[a]**
**Piyanun RUANGURAI[b*] & Chaiyaporn SILAWATCHANANAI[a]**
[b]*Department of Teacher Training in Mechanical Engineering, Faculty of Technical Education, King Mongkut's University of Technology North Bangkok, Thailand*
[a]*Department of Mechanical Engineering Technology, College of Industrial Engineering Technology, King Mongkut's University of Technology North Bangkok, Thailand*
*piyanun.r@cit.kmutnb.ac.th

**Abstract:** Teaching in Engineering program is a big challenge for future teacher because traditional teaching such as talk, and chalk does not suitable for new generation of engineering students. A good design course will integrate STEM teaching model to drive activities. In addition, teacher need to be focus on following the learning outcomes of the course. Therefore, the developing the tool for support learning must answer all learning outcomes. In this study realize the development a tool for teaching in robotic course base on learning outcomes. The key to this paper is to develop the autonomous mobile robot navigation using machine vision as a tool for using STEM teaching model in this course.

**Keywords:** robotic course, learning outcome, mobile robot, engineering education

## 1. Introduction and Literature Review

Nowadays, Generation students have been changed from Millennials (Generation Y) to Generation Z students. There have share some behavior, but there still have many huge different characteristics. The higher education institutions are still using the previous design environments which are helpless the new Generation students' interest in learning. Thus, the time to prepare for changing a design environment for suitable with Generation Z students. One of the topics is that Generation Z students prefer to learn the various applications more than only practical example (Seemiller & Grace, 2017).

Mobile robotic can use in wildly age from child to higher education. For children, they can learn concept of basic physic and technology such as using LEGO©. For high school student, mobile robot can use for teaching a basic programing and basic workshop course. For undergraduate students, they can learn more complex topics such as control system and robot kinematic through mobile robots (Gacovski, 2011). In recent year, many research works proposed several mobile robot platforms for teaching the basic concept in Engineering course. For example, wheeled mobile robot was conduct for laboratory in Master program (Fabregas et al., 2016). Some researcher using the type of mobile robot that use in agricultural application for teaching robotic and navigation content (Bautista, & Wane2018). Moreover, the researcher applied hands-on activities-based STEM methods though the mobile robots and a WEB-responsive software to teaching basic programing (Bacca-Cortes et al., 2017).

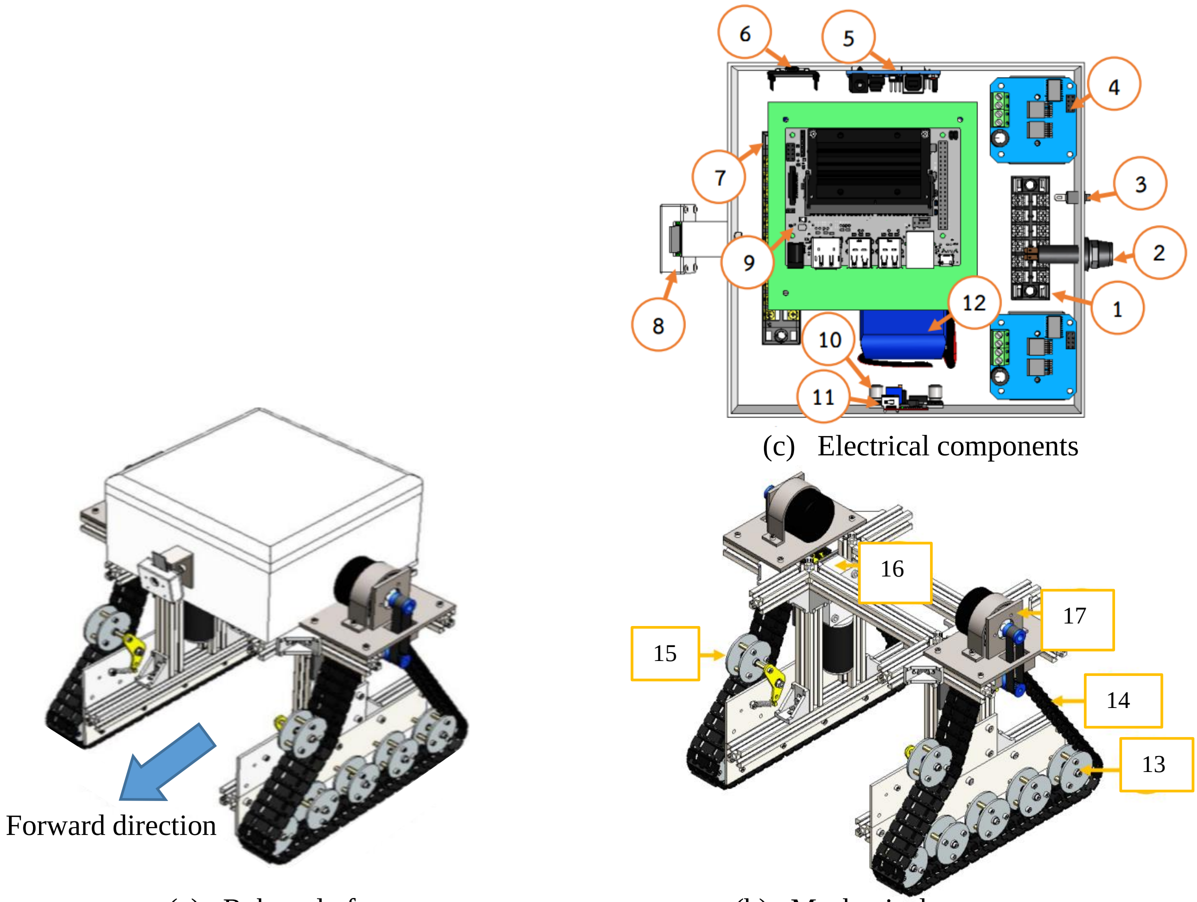
In recent years, new technology called machine vision plays importance role in automation system as a sensor. Machine vision system are helping to develop robotic applications in the section of industrial, household and agriculture. For instance, collaborative robotics for packaging utilizes machine vision to detect object and determine pose of the object, then applying a pick and place robot (Martinez-Franco & Alvarez, 2021). The example of using in agricultural application, the robotic mower avoid obstacle by using machine vision system (Inoue et al, 2019).

In this study, as the robotic with machine vision technology have wildly used in many applications, thus we realize on how to support student learning in robotic with machine vision concept. The main contribution is to develop the autonomous mobile robot navigation using machine vision as an interactive teaching tool for Generation Z students. The pedagogy is using hands-on activities to drive the learning activity based on STEM education. The development of autonomous mobile robot that use in the robotics course can be applied in various scenery such as agriculture, industrial, and household. Thus, students get a chance to create the solution to solve the various problems in the real world via the mobile robot.

## 2. Development of Autonomous Mobile Robot with Machine Vision

The development of autonomous mobile robot with machine vision was design to use in learning robotic course in purpose to support learning outcomes of the robotic course. Both mechanical and electrical components of robot are described in Figure 1 which consist of:

*Number 1 and 7*: Screw terminals
*Number 2*: Fuse
*Number 3*: Power switch
*Number 4*: DC motor driver
*Number 5*: Arduino Uno board
*Number 6*: ESP32 board
Number 8: CSI camera
*Number 9*: Jetson Nano
*Number 10, 11*: DC voltage regulator
*Number 12*: Li-po battery
*Number 13*: Road wheel
*Number 14*: Track
*Number 15*: Idler wheel
*Number 16*: DC Motor
Number 17: Encoder



(c) Electrical components
(a) Robot platform
(b) Mechanical components

*Figure 1*. Components of robot

The diagram of system architecture is shown in Figure 2. Jetson Nano is utilized as a minicomputer for handling a machine vision and the robot control. The operator can edit a high-level programming or manually control the robot via WIFI. For low-level programming, Arduino Uno is used for acquiring the signals of two encoders, then computing the speed of the frame's robot based on two-wheeled differential robot's kinematics. ESP32 is implemented for providing the pulse width modulation (PWM) command based-on Fuzzy algorithm, also send the performance of speed control.

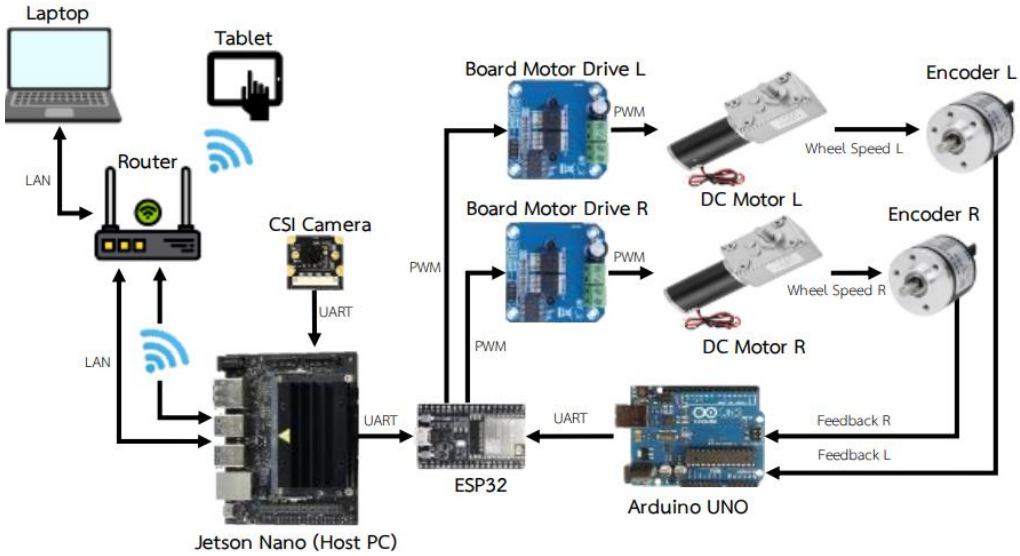


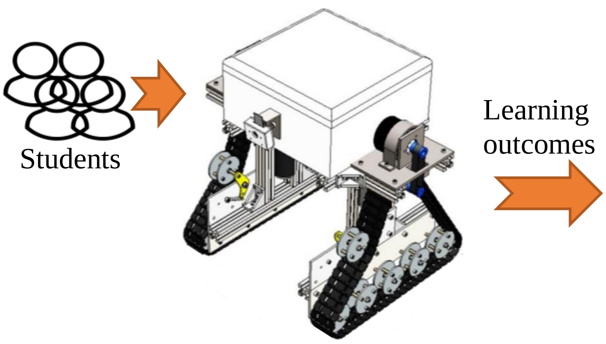

*Figure 2.* System architecture of robot

## 3. Conceptual framework

In this section provide into two subsections. First section presents an expected learning outcomes of the robotic course to train undergraduate engineering students. Second section describes the content of using autonomous mobile robot as a tool for teaching in robotic course.

### *3.1 Learning Outcomes*

Learning outcomes define like guidance tools for guiding teachers' direction to support students to be able to achieve at the end of the program (Mahajan & Singh, 2017). Normally, the design of course learning outcomes are based on Bloom's Taxonomy. In this study, the autonomous mobile robot was developed as a tool for learning in robotic course to encourage students to achieve the goal of robotic course. At the end of this course, students need to be able to design the Mechanical and Electrical systems, analyze the kinematic of the robot, create programs for a control system, and apply machine vision to robot guidance. The learning outcomes of this course shows in Figure 3.




- Design a mobile robot in mechanical and electrical systems
- Analyze the kinematic of the robot.
- Control the motion of robot by programming
- Apply the machine vision for robot guidance

*Figure 3.* Course learning outcomes

### 3.2 *Course learning activities*

The content of this course based on the course learning outcomes has four main topics which the student be able

- Design a mobile robot in mechanical and electrical systems
- Analyze the kinematic of the robot.
- Control the motion of robot by programming
- Apply the machine vision for robot guidance

The first topic states that the learner is able to design a mobile robot in term of mechanical and electrical systems. For example, the content gives students ability to select the suitable DC motor with the physic law. The maximum velocity of robot is pre-defined then the required angular velocity is obtained by (1), where $\omega$ is the required angular velocity, $r$ is the driven wheel radius and $v$ is the linear velocity of robot.

$$v = \omega r \tag{1}$$

As shown in Figure 4, the traction force at the robot track ($F$) must be equal to the friction force ($F_f$) so that the robot can move forward without slip. The friction force between the track wheel and ground is expressed in (1) by considering the coefficient of friction ($\mu$), normal force acting to the ground ($F_n$). Then the minimum required power of DC motor can be calculated by (3)

$$F_f = \mu F_n \tag{2}$$

$$P = F_f v \tag{3}$$

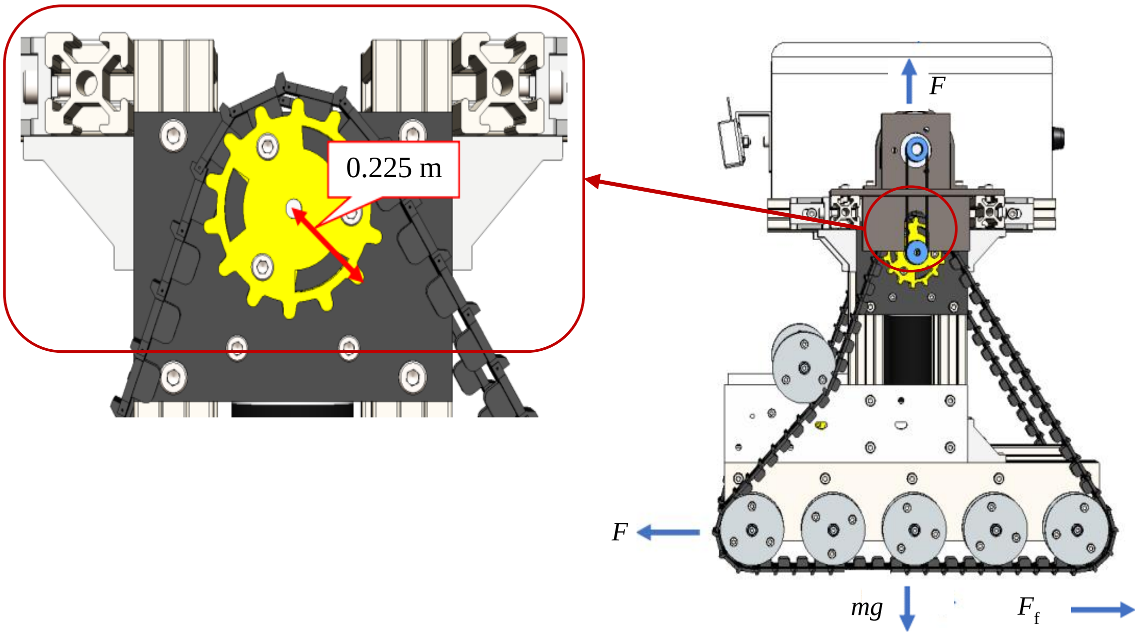



*Figure 4.* Calculation of required power

Next content, the kinematics of the robot that relates the motion of robot's frame to the wheels' velocity. In this work, the differential wheel robot is introduced to the students. The position described in the 2-D Cartesian coordinate and orientation of robot can be mathematically expressed in (4) where $b$ is the distance between each wheel to the center of mass's robot, $R_R$ and $R_L$ are the gear radius of right tracking and left tracking, respectively.

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} \frac{R_R}{2}\cos\theta & \frac{R_L}{2}\cos\theta \\ \frac{R_R}{2}\sin\theta & \frac{R_L}{2}\sin\theta \\ \frac{R_R}{2b} & -\frac{R_L}{2b} \end{bmatrix} \begin{bmatrix} \omega_R \\ \omega_L \end{bmatrix} \tag{4}$$

The current state of robot ($x_r$, $y_r$, $\theta$) and the next state or goal ($x_d$, $y_d$, $\theta_d$) variables are introduced in Figure 5. To move the robot reaching the goal state, two variable distance ($d$) and orientation between two points ($\alpha$) are expressed in (5) and (6), then the control algorithm or motor commands are applied to reduce these two variables be zero.

$$d = \sqrt{(x_r - x_d)^2 + (x_r - x_d)^2} \tag{5}$$

$$\alpha = tan^{-1}\left(\frac{y_r - y_d}{x_r - x_d}\right) \tag{6}$$

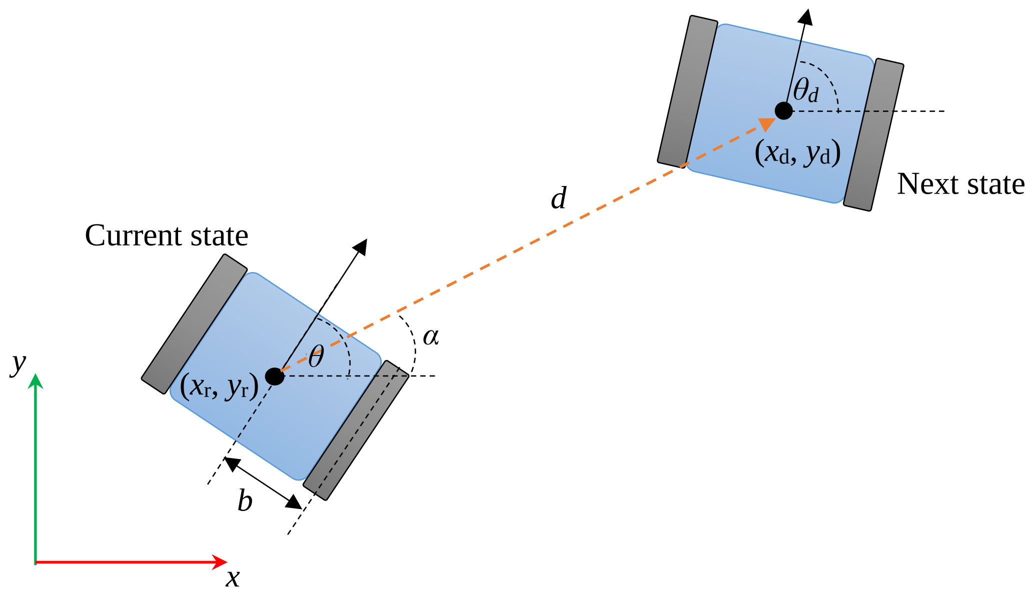



*Figure 5*. Kinematic model of robot

After students finish all activities above, they use all information to design the control system. The outcome of this topic is students be able to write a program to control the robot based on the kinematics of robot. However, there many sensors require to acquire all current states of robot. The vision sensor is one of widely used sensor in industrial applications. Some information can be extracted from image data by using image processing.

The last content, students learn machine vision method to estimate the guidance. Figure 6 shows the video capture of robot traveling along the demonstrating paddy field. Thus, in this situation, students have the procedure for two steps. First is to detecting crop and then to estimate the row as a local guidance for the robot. Students can use raw data of sensors from the recode to train a neural network. At the end of the course, students integrate all the contents in purpose to control robot in the application that they design.

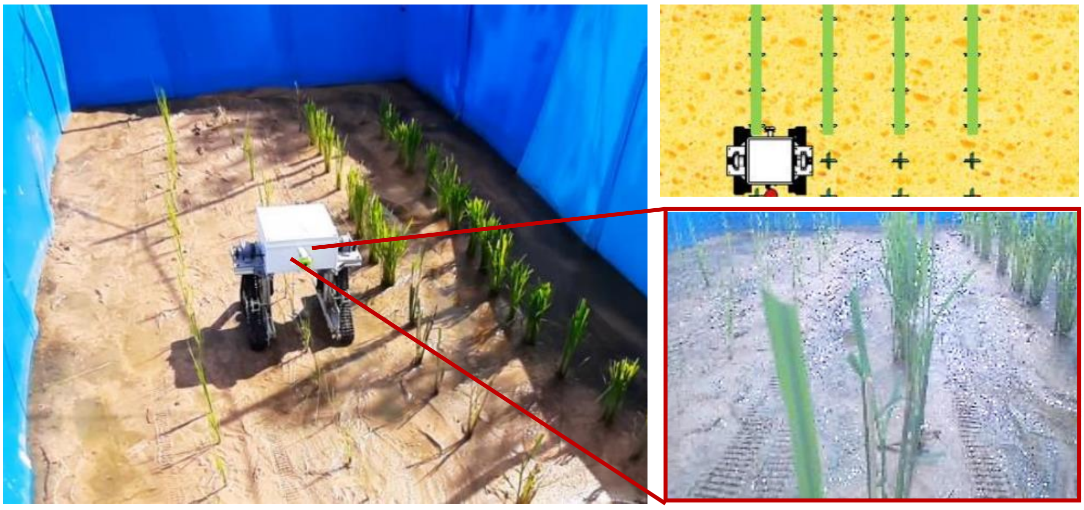


*Figure 6.* Example of learning machine vision

## 4. Conclusion

In this study, we developed a tool which is autonomous mobile robot with machine vision to gain students' achieve based on learning outcomes of robotic course. Students will learn from the basic until complex concept. At the end of study in the course, we expected that students will reach all the goal of course learning outcomes. Moreover, students can create situation in the real world and solve the problems by using mobile robot. The next step of this study, we will use a mobile robot in the class and collect the student perceptions in learning robotic course to determine on the quality and quantity of education.

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