Intelligent Low Cost Mobile Robot and Environmental Classification

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ABSTRACT
In this paper low cost mobile robot is designed and developed. A tree diagram of material selection is used to help designer to determine the requirements of mobile robot process design. 5 pieces of low price infrared sensors and 8 bits low cost microcontroller-based system are utilized to process sensors signal and driving actuators to guide mobile robot movement. Fuzzy-Kohonen Network (FKN) method is embedded into the mobile robot as pattern recognition approach of 21 environmental classifications. We have fully implemented the system with a real mobile robot and made experiments for evaluating the mobile robot ability. As a result, we found out that the environment recognition is done well, that mobile robot successfully identified several environmental situations. Furthermore, our method is adaptive to noisy environments and produce satisfactory performance.

Keywords
Low cost mobile robot, pattern recognition, fuzzy-kohonen network, environmental recognition

1. INTRODUCTION
There has been some success with autonomous mobile robot navigation in indoor environment over the past few years. Nevertheless, all of the success has come at the price of expensive robot hardware. Even an entry level navigational robot costs well into a high cost. The potential usefulness of robots that have the ability of autonomous navigation makes research in this area a worthy field to pursue. With autonomous navigation, self-driving vacuum cleaners and lawn mowers could replace today's self-propelled ones. Even autonomous transportation vehicles could come into being. The cost of a robot development system remains relatively expensive, due to its low volume, which can be circularly attributed to it high cost [1].

The increasing interest in robotic systems indicates that employing inexpensive and simple mobile robots could perform special tasks in large-scale area more efficiently [2]. In [3] describe development of a low cost mobile robot which does unsupervised learning for recognizing environments from behavior sequences with low cost sensor. In [4] provide a swarm based fuzzy logic control (FLC) algorithm that integrates groups of low-cost robots, which are equipped with limited-range communication ability and relatively inexpensive sensors. In [5] describe a real-time, low-cost system to localize a mobile robot in outdoor environments. In the interest of designing low cost mobile robot, it is important to develop a simple intelligent technique which is able to recognize environments only with low cost sensors.

The ability of a mobile robot to localize itself is critical to its autonomous operation and navigation. A mobile robot that navigates using maps must be able to accurately localize itself. The visual sensors provide the richer source of useful information about the surroundings. However, a problem of visual sensors is that they are slow in computing data and are expensive in cost [3]. While reactive control can rapidly adapt to dynamic environments, it is vulnerable to local minimum traps due to no prior map information on the environment. Much research has been done to circumvent this problem [6][7][8]. Model-based control and hybrid control combining reactive and model-based has been proposed to overcome the drawback. But the conventional hybrid method requires a continuous modeling of the new environments [8][9]. On the other hand, metric models need to memorize much more information than is needed for navigation. Therefore a mobile robot should be intelligent and adaptive to unknown and unstructured environments, it needs to learn to recognize new environment by itself. Nevertheless, there are some limitations in low cost mobile robot application, such as memory and speed due to it use low cost microcontroller. As a proposed solution, this paper propose a simple fuzzy-neural control method to recognize environments and to realize the low cost mobile robot in real-time with low sensitive and local sensors. Moreover, to replace the general fuzzy controller, thus many complex useless fuzzy controls rules become unnecessary.

2. LOW COST MOBILE ROBOT DESIGN
In mobile robot design, physical model is part of engineering art [10][11][12]. To make the mobile robot prototype, engineer needs the creation of interactive, kinetic and behavior-based art of the mobile robot. In this work, to help in designing process, the tree diagram of material selection is applied to determine the need of mobile robot requirement. A tree diagram/structure is a graphical representation of the separation of broad, general information into increasing levels of detail. The tool ensures that action plans remain visibly linked to overall goals, that actions flow logically from identified goals, and that the true level of a project's complexity will be fully understood. In this work, the tree diagram as depicted in Fig 1, is to breakdown the system into the small part, thus it will help in decision to choice the mobile robot material, sensor, actuator, energy source, software and method.

Building the mobile robot mechanicals from its base components is a difficult job. One of the greatest difficulties is designing the propulsion system, for indoor mobile robot nearly always consist of electric motors. Planning an electric drive system requires knowledge in choosing a suitable actuator for the size and weight of the mobile robot, due the actuator motor can contain a built in gearbox. The mobile robot made in two-circle body, where the form below with a diameter of 20 cm as it used to place sensors, batteries, and DC motor with gearbox. At levels above, the diameter is 10 cm where it used for placing microcontroller and DC motor drivers.

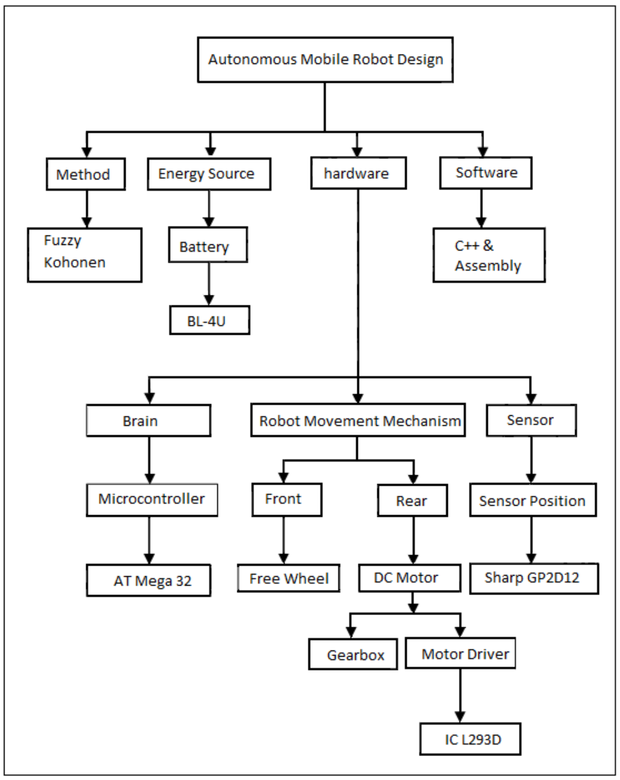


Fig 1: **Tree diagram of material selection**

Application of the local and low cost infra-red sensor has been implemented large area in robotic research, such as measuring a distance [13], obstacle detection and avoidance system [14], and the environmental mapping [15]. According to [16], the placements of sensor in mobile robot application are special issue. In this work, the mobile robot move forward and detecting obstacle in front of it. To covering the large area, mobile robot is designed as a circle-shaped with the placement of the sensor is 45^o respectively. The infra-red sensor (Sharp GP2D12) produces a nonlinear analog voltage depending on distance. Since the output of the sensor is non-monotonic at 10 cm, this requires that sensor must never be within 10 cm of an object. The distance input from the infra-red sensors are converted from analog to digital using ADC. Conversions of these values use a resolution of 8 bits with the following formula:

$$Digital\ data = \frac{Vin}{Vref}\ x\ 255 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where 255 declared the maximum value for a resolution of 8 bits binary format with the condition of input voltage (Vin) reaches a maximum value is not exceeding the reference voltage (Vref). The minimum distance for obstacle detection is about 15 cm. The sensitivity of sensors would also depend on emitter diode intensity which is relative to emitter diode quality and battery level.

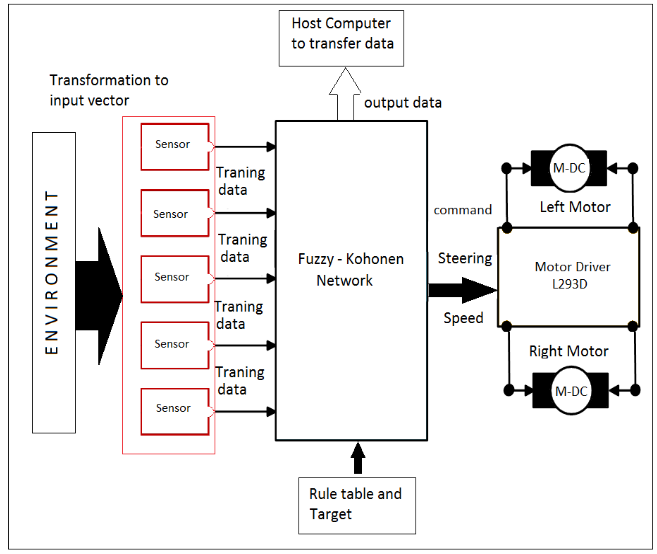


Fig 2: Mobile robot platform

Fig. 2 shows a block diagram of embedded mobile robot platform and control system based on FKN method. In block diagram mobile robot is responsible for generating motor steering and speed command in response to onboard controller.

2.1 Controller Platform

Mobile robot controller often serves as the "brain" of a mechatronic system, it is self-contained computer, and it can be programmed to interact with both the hardware of the system and the user. Even the most basic micro-controller can perform simple math operation, control digital outputs and monitor digital inputs. In this work, low cost micro-controller is used as a mobile robot controller. An AVR micro-controller series is deployed as the main processing for mobile robot. ATMEGA 16 with clock at 16 MHz using the internal RC oscillator provides the necessary computational power to have a real time sensory system. They have 16 kilobytes of programmable limited flash memory and 1 Kbyte internal SRAM, the benefit features of low power consumption approximately 1.1 mA in active mode is considering to provide long term autonomy to the mobile robot. This low cost microcontroller has a four pulse width modulation (PWM) channel, which are used for controlling the robot movement mechanism via actuator.

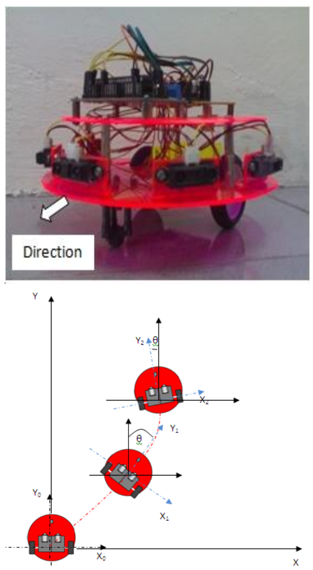
2.2 Actuator

Mobile robot platform utilize 2 types of tire as actuator which are front wheel and rear wheel as shown in Fig 3 (a). The front wheel use free wheel and the rear wheel use DC motor integrated with a gear box. This gearbox is applied to reduce a torque and power consumption. To drive the rear wheel (consists of two motors- right and left) at the same time. DC motor driver use in mobile robot is IC L293D. Section pin EN

(Enable) on the IC L293D will get the pulse width modulation (PWM) data from a micro-controller. PWM data is the conversion of data from the percentage of duty cycle into digital data. PWM value conversion using a resolution of 8 bits using following formula:

$$PWM\ data = duty\ cycle\ (\%)\ x\ 255 \quad ......(2)$$

This PWM data will adjust a speed of wheel according to the value of duty cycle. The illustration of the mobile robot movement is shown in Fig. 3 (b).



(a) Real mobile robot (b) Movement mechanism

Fig 3: Mobile robot movement

2.3 Energy Source

Energy source is important issue especially in mobile robot. The energy source for mobile robot require to rechargeable, lightest and powerful, due to weight ratio implication in torque and power consumption. In this work, Lithium-Ion battery is satisfying with the requirement since it is lightest and powerful battery in the market. One of type lithium-ion battery is BL-4U with the specification type: Li-Ion, capacity: 1000 mAH, weight: 23.3g, voltage: 3.7 volt. Since the mobile robot need 5 volt operating voltage, two BL-4U batteries are employed with series configuration, this configuration is resulting 7.4 volt and supplying 1000 mAH. The voltage from this configuration is needed to reduce according to operation voltage by IC regulator LM 7805.

3. FUZZY KOHONEN NETWORK

3.1 FKN Structure

Artificial neural network (ANN) and fuzzy logic are two different methods which are used to present human intelligence in doing data processing, although the implementation of the approach has a different perspective. As in individual system, both methods have unique features with limitations of each mutually contradictory. The ability of the learning is advantages in ANN, however ANN cannot explain the reasoning process undertaken, while fuzzy logic has no learning ability, but can explain the reasoning process is carried out according to the rules in the knowledge base. Therefore, each method only has the ability to solve one aspect of the problem, but cannot provide a total solution. Recently, it has a lot of exciting research to hybrid between ANN and fuzzy logic [17][18][19]. The result of this integration is generating a new method which is Neuro-Fuzzy. This method is essentially uses fuzzy logic learning algorithms derived from the ANN to determine the basic parameters in the data sample. It provides a better solution than the individual method [20].

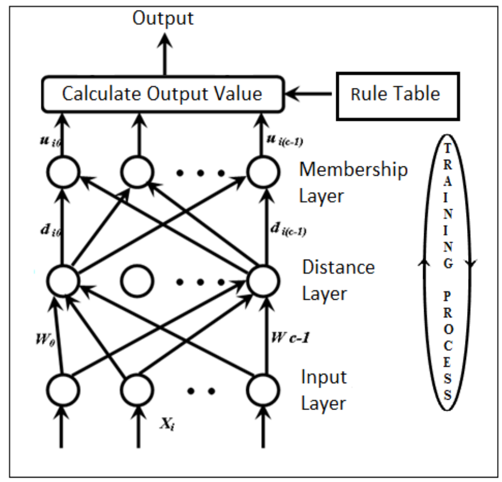


Fig 4: FKCN structure [21]

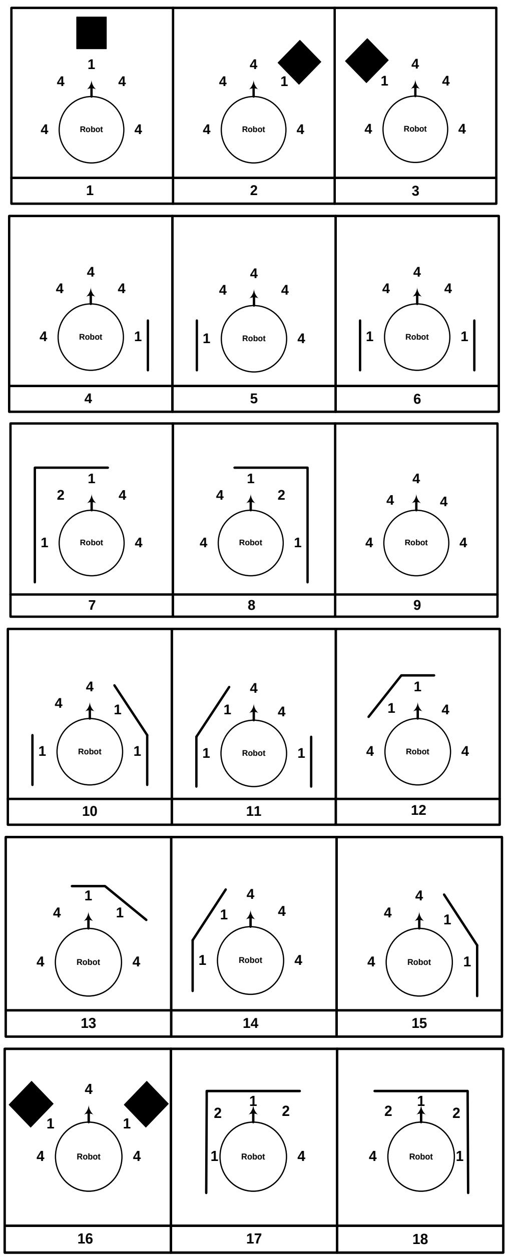
Fuzzy Kohonen Clustering Network (FKCN) is one type of Neuro-Fuzzy method which is the result of integration between fuzzy logic and Kohonen network. Kohonen network has the advantage of pattern recognition mechanism while the fuzzy logic plays a role in managing the input and output process of pattern recognition [20].

Table 1. Comparison between FKCN and FKN

No	Item	FKN	FKCN
1	Learning process	Supervised	Unsupervised
2	Weight assigning	Obtain from experiment	Random and obtain from iteration
3	Size of resource	Small	Big
4	Computation time	Fast	Slow
5	Error of movement	Small	Very small

Kohonen translate well into the process of reasoning based on rules that have been determined. FKCN consists of three layers that are connected between each layer of neurons [21] these three layers are shown in Fig. 4. However, FKCN have a weakness that is taking a long time in training process, to find the weights that meet the good performance. To solve this weakness, in this work the originality of learning process which is unsupervised, reduces to supervised named, Fuzzy-Kohonen

Network (FKN). The differences between two methods are shown in table 1. In order to enable the mobile robot to avoid the obstacles in the unknown and changing environment with reactive action, the better mapping relation between the sensor data input and the speed control output must be established due to the distribution of obstacle is complex. 21 types classification of configuration obstacles used in this study are shown in Fig. 5. The mergers of Fuzzification process with the combination of 21 pattern classification are used in this FKN. This combination produces very small control rules compared with the conventional fuzzy control method.



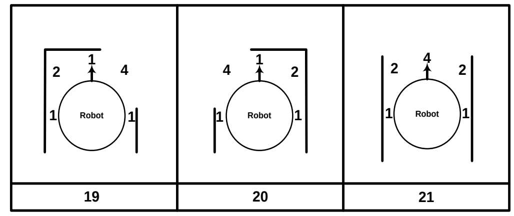


Fig 5: Environmental classifications

3.2 FKN algorithm

FKN algorithm process starts from initialization sensors inputs and DC motors speed as outputs on the microcontroller. The reading distance of an obstacle on the sensor then quantized and becomes the input to the algorithm FKN. The results of the proficiency level algorithm produce the output of the DC motor speed. Several input patterns are used in the training phase. The method for learning rules to determine the distance and similarity between input pattern and initial pattern are described in the following steps:

Step 1: Create input patterns and weight sign. It constructed from current sensor readings are fed to the neural network input. The formula as follow,

$$X_i = \begin{cases} a < Yi \leq b & ;1 \\ b < Yi \leq c & ;2 \\ c < Yi \leq d & ;3 \\ Yi > d & ;4 \end{cases} \quad (3)$$

Where the weight sign 1 is very near, 2 is near, 3 is medium and 4 is far

Step 2: Activate the kohonen network by applying the input vector X_i and find the winner-takes all (best matching) neuron. Calculate the Euqlidian error distance d_{ij} that is responsible for comparing the input pattern X_i with every initial pattern W_j.

$$d_{ij} = \left\|X_i - W_j\right\|^2 = (X_i - W_j)^T (X_i - W)_j \quad (4)$$

Step 3: Compute the similarities between input patterns and every initial patterns. These values are calculated using equation (4) and (5) as a membership degree μ_{ij}. There are three conditions to obtain d_{ij} such as, $d_{ij} = 0$, $e \leq d_{ij} < f$ and $d_{ij} \geq f$, . Where f is a max threshold value and e is min threshold value. These two values are obtained from experimental result. In the case of input patterns do not match with any initial pattern, then the similarity value is represented by membership value μ_{ij} from 0 to 1, by using the following equation,

$$\mu_{ij} = \begin{cases} 1, & d_{ij} = 0 \\ \frac{f-d_{ij}}{f-e}, & e \leq d_{ij} < f \\ 0, & d_{ij} \geq f \end{cases} \quad (5)$$

The membership degree μ_{ij} represents the similarity between X_i and W_j, and $\mu_{ij} \in (0,1)$. The sum of the membership degree outputs μ_{ij} equal to 1.

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Declaration
real       :   umax, vright, vleft, vrefright, vrefleft,
u1, u2, u3 … u1
Description
umax  ←  ( u1,u2, u3 … u15 )
If  ( umax = 1)  then
          vright  ←  vrefright
          vleft   ←  vrefleft
else
          vright  ←  ( umax * vrefright )
          vleft   ←  ( umax * vrefleft )
End If
```

Fig 6: Speed algorithms for DC motor

FKN algorithm is looking the calculation of similarity between the current input patterns from the sensors with the prototype pattern of rule's table. The rule's table shows in table 2 is created based on 21 environmental classifications. After the rule base and similarity values are known, and then the speed of the motors can be determined by finding the rule base that has the highest level of similarity. The results are calculated with the reference speed. The algorithm for generating motors speed can be seen in Fig. 6.

Table 2. Rule's table

Number of Rules	IF-Part Prototype pattern					Then-Part Reference speed	
						V Left (%)	V Right (%)
1	4	4	1	4	4	90	60
2	4	4	4	1	4	70	90
3	4	1	4	4	4	90	70
4	4	4	4	4	1	90	80
5	1	4	4	4	4	80	90
6	1	4	4	4	1	85	85
7	1	2	1	4	4	85	55
8	4	4	1	2	1	55	85
9	4	4	4	4	4	95	95
10	1	4	4	1	1	80	90
11	1	1	4	4	1	90	80
12	4	1	1	4	4	85	55
13	4	4	1	1	4	55	85
14	1	1	4	4	4	90	83
15	4	4	4	1	1	83	90
16	4	1	4	1	4	80	80
17	1	2	1	2	4	80	50
18	4	2	1	2	1	50	80
19	1	2	1	4	1	85	55
20	1	4	1	2	1	55	85
21	1	2	4	2	1	85	85

4. RESULTS AND DISCUSSION

In this section, the performance of the mobile robot is evaluated and experimental results are discussed. In order to learn the network, the experiments utilize twenty one environmental patterns, for investigating the influence of FKN technique on the steering, speed and movement performance. As results found, all the test data are correctly identified about 90 % and verified the utility of our technique. Fig. 7 shows the experimental result of mobile robot movement. The mobile robot move in smooth trajectory in complex corridor environment and can avoid collision with the wall.

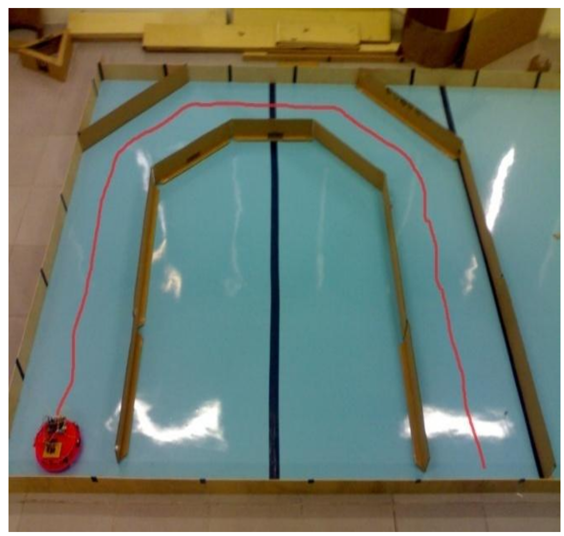
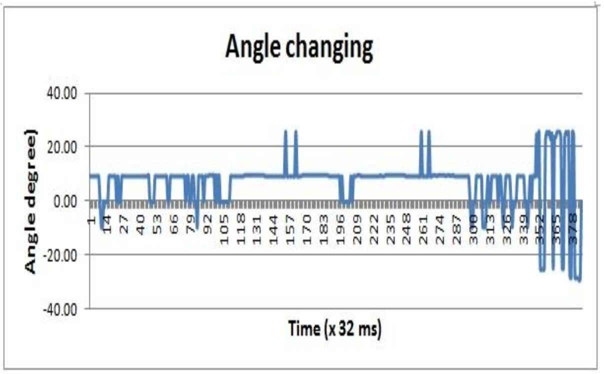
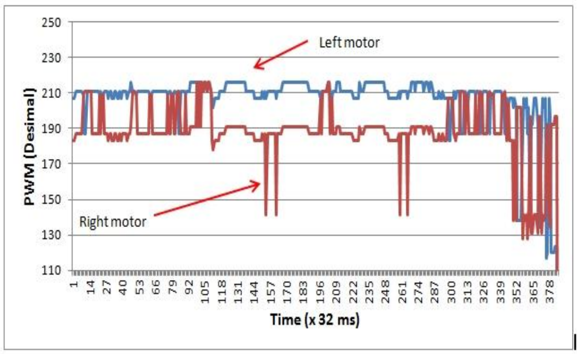


Fig 7: Mobile robot movements

Speed and steering angle control of the mobile robot, due to the environmental changing is shown in Fig 8 (a). Steering angle is the difference between target and head of the mobile robot and provides information about current mobile robot head orientation. In mobile robot navigation, speed control analysis gives information about and robot's left and right speed over the time. Fig. 8 (b) shows left and right wheel speed control. In differential drive mechanism, to take right turn; robot increases its left speed and decreases right speedy and vice versa. From the graph of Fig 8 (b) the value of PWM is starting with unstable direction, due to learning process of FKN and the angle changing between two motors are resulting from the different rotation of the motors.



(a) Steering angle



(b) Mobile robot speed

Fig 8: Mobile robot performance

5. CONCLUSION

In this paper, an autonomous mobile robot based on FKN is proposed which has been developed for low-cost application platform. The design of mobile robot utilize tree diagram in designing process to determine the material and component. This paper also describe the method of FKN can be implemented as an autonomous mobile robot navigation system through pattern recognition approach produced by such methods. The method has been successful embedded on low cost mobile robot. The result shows that the mobile robot is able to recognize the pattern of the several environmental situations through the use of 5 infrared sensors and it has around 120 minutes of autonomy period using Lithium-Ion batteries (BL-4U). Notably, mobile robot based FKN has the ability to explore the environment safely in this long journey without collision and 'dead lock' in danger situation. For the future work, we need to investigate on how to extend and expand the proposed technique that is to make it more general to all unstructured environments taking into considerations both static and dynamic obstacles.

6. ACKNOWLEDGMENT

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