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Defining the Boundary of Regions in Thematic Map Using Flexible Ellipse Shape Region

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ABSTRACT

Mapping is the technique to assign the resources and display the normal data distribution of an environment. The problems of the available map technique are in term of rigid structure or rigid perception of robot heading. Indirectly the available map used a lot of memory space. Therefore, a new technique of map called flexible ellipse shape region is proposed. Its ellipse boundary is flexible (non-rigid) to accommodate the normal data distribution of an environment. Besides that it allows the perception of robot heading to map the normal data distribution of an environment from 0° until 360°. The objective of this research is to know the performance of the map when compared with grid map, perception based map and flexible region map in terms of memory space, accessing time and the accuracy of the map. The experiments were conducted by using Amigobot mobile robot in an L-shaped environment. Amigobot is embedded with directional sensor which is sonar sensor and non-directional sensor light which are sensor and a temperature sensor. The results show that the flexible ellipse shape region technique is at an advantage when mapping non directional data where it succeed to reduce the usage of memory space by 0.27%, 3.95% and 54.55% when compared to the grid map, perception based map and flexible region map. Consequently, the flexible ellipse shape region also used less accessing time when compared to the perception based map and flexible region map in situation where the number of region created is lower. As a tradeoff, it is found that the accuracy of mapping for the flexible ellipse shape region is lower by 12.4% and 1.8% when mapped the directional and non-directional sensor data when compared to the flexible region map.

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INTRODUCTION

Mapping is typically used to determine a robot pose in robotics field. A lot of research has been done in this area. Sebastian Thrun in (Thrun, 2002) has describe in detail the characteristics of different mapping technique (mostly for indoors environment). Other than determining the robot pose, map is also use to have awareness of a robot surrounding (Toda *et al*., 2012, Mansley *et al*., 2011). The latter use of a map is described as *thematic map* (Radhadevi, 2013, Fauvel *et al*., 2013)or a map that represents the spatial pattern for normal data distribution of an environment. Usually the *thematic map* is used to identify the status of normal data distribution with respect to where the sensor measurement is taken in an environment. Example application of such map is for monitoring application (Boehm *et al*., 2013)or for adaptation or learning (Miskon and Russell, 2009, Taib *et al*., 2011).

The application as stated above will face problems if it does not use a map as a reference to detect the changes of an environment because the normal data distribution of an environment varies from place to place or from time to time. However there is limitation to use a map as a reference to map the normal data distribution of an environment especially to the application which needs the consideration on the size of memory space used for storage. The problems of swarm robotics (Howden, 2013, Fehervari *et al*., 2013) and micro robotics (Shaojie *et al*., 2012, Achtelik *et al*., 2012, Ming *et al*., 2013) in term of power supply, physical size and physical weight of the robot is taken seriously. As an example a flying micro robot (Jaramillo *et al*., 2013)restricted to carry the power supply. So, even though the price of memory is reasonable nowadays, the designers of these types of robots still thinking of ways how the robot's resources such as usage of memory space could be reduced. If the usage of memory space can be reduced means more area can be mapped.

Another problem is the conventional map such as grid map needs to be predefined and have a rigid structure (non-flexible). This will cause these maps to use a lot of memory space. For an example in (W. B. D. Fox and S, 1999), the size of grid cells is (15cm x 15cm) while the size of an environment is (30m x 30m). Therefore

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number of grid cells created is equal to 7.2 million. Indirectly to manage and process a large number of grid cells demands more time, more energy and high speed computer. Based on the example as stated above, if the robot with minimal physical size use grid map to mapping the normal data distribution of an environment, this will reduced the size of the environment to be mapped, demands more energy and resources such as memory space. This is the reason why the perception based map has been introduced.

Perception based map refers to the position where the robot acquires the data. One example for perception based map is called point obstacle (Kleeman, 2005, Yipu *et al*., 2012). The laser of measurement should be indexed and perceived at closely space points to get a good representation of point obstacle. This is important to enable a high percentage of overlapping of the map to make sure the representation of point obstacle is correct. Another example of perception based map is described in (Punarjay Chakravarty *et al*., 2007) and used for novelty detection. Robot will navigate by the following path and the information which is perceived from the route is mapped onto the position of robot. When compared with the grid map, this map saves a lot of usage of memory space by only storing the sensor measurement which perceived on the robot path. However, some quantities of features such combustible chemical concentration and ambient temperature can have the same value of sensor measurement around an area such as a lab environment and a vast desert. For example laser range finder repeated a similar distance measurement in a long corridor and the histogram feature of images taken by a camera in a monotonous colored room which will look the same (Miskon, 2009). According to the example situation, the perception based map use a lot of memory space whilst the similarity of sensor measurement could be merged together and indirectly reduce the usage of memory space. Hence the flexible region map (Miskon and Russell, 2009) have been introduced to deal with this problem.

Flexible region map is defined using rectangular shapes. The rectangular edge of the map is only aligned and parallel to 0°, 90°, 180°, 270° of robot heading. The rectangle structure of flexible region map is able to grow, merge and shrink. That means this type of map has a flexible structure. The advantage of flexible region map is it can map the similar sensor measurement in a region and indirectly reduce the usage of memory space. However, if all the sensor measurement has a different reading, the usage of memory space for the flexible region map is same as perception based map. Furthermore, in consequence the rectangular edge of the flexible region map aligned and parallel only at 4 discreet values (0°, 90°, 180°, 270°) of robot heading, the flexible region map has a problem in term of memory space to represent the normal data distribution of an environment in certain case. As an example, if the normal data distribution is not in the range of 4 discreet values (0°, 90°, 180°, 270°) of robot heading, the number of region created by flexible region map is increased and indirectly increased the usage of memory space.

From the review, it can be concluded that the available map such as grid map, perception based map and flexible region map have a problem in term of memory space when mapping the normal data distribution of an environment. So due to the problem, the ellipse boundary called flexible ellipse shape region is proposed because from the best of the author's knowledge there is no work has been given to investigating the performance of ellipse boundary as map representation of normal data distribution of an environment. Other reason is the ellipse boundary of flexible ellipse shape region can mapped the normal data distribution from 0° until 360° and indirectly reduces the usage of memory space. Besides that, another issue in the field of mapping is the accessing time. From the best of the author's knowledge the study on this performance parameter has not been conducted yet, so the performance of flexible maps in term of accessing time is unknown. In this research, it is hypothesized that the flexible types of maps demand more accessing time compared to the grid map because when the normal data distribution of an environment is mapped using the flexible mapping technique, the accessing time to get the information from the map is not as direct as conventional grid map. Then the issue to be study was accuracy of map. The accuracy of map in this research is defined as how accurate the map can represent the normal data distribution of an environment. When using the flexible mapping technique, the boundary of the maps could change. Hence the measurement of the accuracy of map or how accurate the boundary created to bound the area of similar data distribution is need to study. If the similar normal data distribution of an environment are map using flexible region map and flexible ellipse shape region the accuracy of map of flexible region map is higher than flexible ellipse shape region because the total area of flexible region map is more than flexible ellipse shape region.

For all the reason as stated above, the objective of the research is to address an investigation on the performance of different type of thematic maps in terms of memory space, accessing time and accuracy of map when using different type of sensor. Then the contribution of the research as follows :

1. Ellipse boundary is proposed as a map boundary to represent the normal data of environment.
2. A new technique to measure the confidence region of the map is proposed. The diameter of confidence region is based on the step size (100mm) of the mobile robot.

System Overview:

This section provides an overview of the whole system. A functional system as a schematic diagram is shown in
Fig. . This system consists of two main system i.e. navigation and referencing/thematic mapping system.

In the navigation system, the mobile robot used is Amigobot. Its provides position and heading information system (x mm, y mm, θ°) of the robot to the main controller. The position of the robot is determined using odometry and sonar sensor information (Robotics, 2005b) while the accumulated position error is corrected using approach by particle filter localization (Robotics, 2005a). The robot will navigate using point to point technique. Every 100mm of travel, the robot will take the measurement of the sonar/ambient temperature/ambient light sensor. The Amigobot is embedded with eight sonar sensor while the other sensor such as light sensor and temperature sensor are carries by Amigobot .

In this section, the main contribution is in the development of the thematic mapping system. In developing the thematic mapping system, its require two type of information that is position of the mobile robot and normal data distribution from sensor measurement. After that all the data is clustering and mapped the similar data measurement using flexible ellipse shape region. Then the detail about flexible ellipse shape region will be described later in next section.

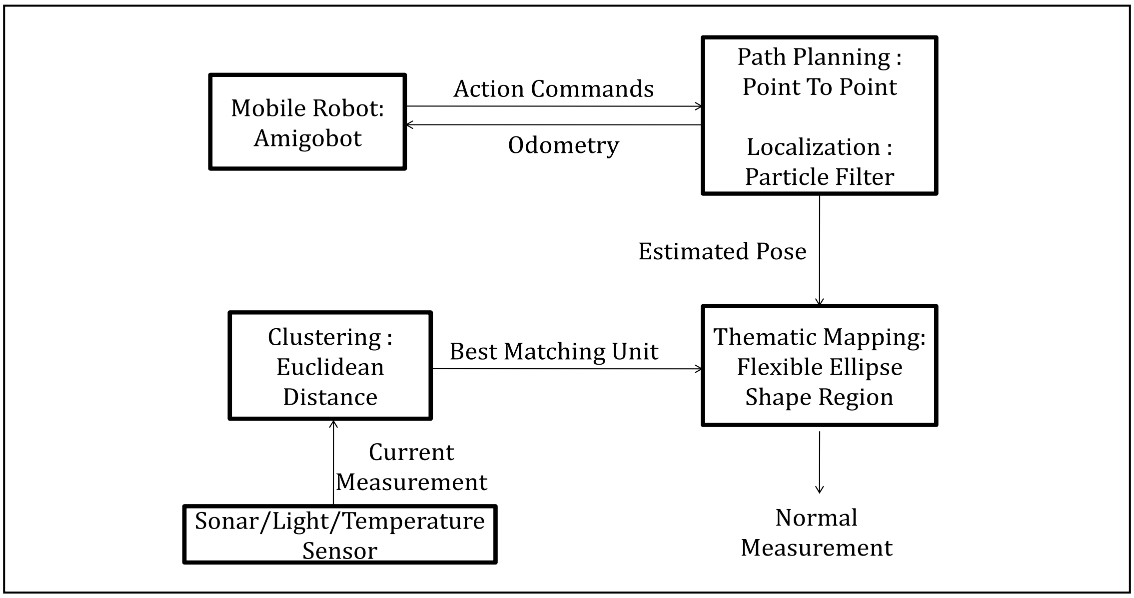

Fig. 1: System overview of the research with its main system component for performing mapping normal data distribution of data using a flexible ellipse shape region.

Flexible Ellipse Shape Region:

This section described a detail description about flexible ellipse shape region. The flexible ellipse shape region is the main contribution in this thesis. Firstly the region tolerance, R_T of flexible ellipse shape region will be described. Secondly the process to create the flexible ellipse shape region is discussed. There are three processes to create the flexible ellipse shape region. The processes are initiation of a region, expansion of a region and mergence between two regions.

Region tolerance, R_T:

Region tolerance, R_T is defined as the maximum permissible difference between measurement taken at current position and measurement of a region when it is initially created. In the merging process the region tolerance is categorize with 3 types :-

1. Positioning of boundary – The minimum distance between neighbouring regions.
2. Similarity of length – The length of major axis or minor axis between neighbouring regions.
3. Angle of ellipse – The differences angle between region p and region q.

All categorize of the region tolerance, R_T is described in detail at the merging process section.

Initiation of a region:

A region is initiated by creating a major axis, q_{uu} and minor axis, q_{vv} of an ellipse from the reference point (midpoint of the robot) based on the position of the sensor as shown in Fig. 1 where 0° is initial robot heading of an Amigobot. The diameter value of initial ellipse is depending on the step size of the robot (step size for an experiment is 100mm). An initiated region is created when its follow the requirement :-

1. The mobile robot perceives a normal data distribution at the current position.
2. When mobile robot mapping a normal data distribution at current position, there is no existing region.

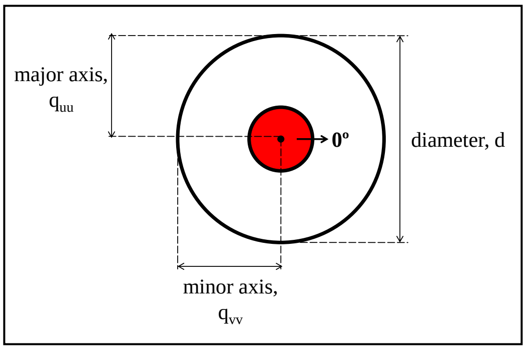

Fig. 1: Initiation of a region. The diameter of an initial region is depending on the step size of robot (step size for an experiment is 100mm). The red circle is a mobile with the initial angle is 0°. The sensor position is at the centre of the robot.

Expansion of a Region:

A region expansion occurs when the process fulfilled their following condition. This section will discuss the condition of expansion and the calculation to expand. The size of a region could be expanded if fulfill the following condition :-

1. The value of current sensor measurement taken is similar to the value of sensor measurement of initial region (M_c=M_i).
2. The difference value of position (using equation (1)) between current sensor measurement (x_c,y_c) and centre of initial region (x_i,y_i) is less than region tolerance, R_T. In the expansion process the region tolerance, R_T is equal to the step size of the robot, 100mm.

$$\boldsymbol{d_{ci}} = \sqrt{(\boldsymbol{x_c} - \boldsymbol{x_i}) + (\boldsymbol{y_c} - \boldsymbol{y_i})} \quad (1)$$

3. When all the requirement of expansion has been fulfilled, the distribution of data was mapped into a flexible ellipse shape region using equation (2) and equation (3).

$$x(t) = \bar{x} + q_{uu}\, cos\, t\, cos\, \theta - q_{vv}\, sin\, t\, sin\, \theta \quad (2)$$

$$y(t) = \bar{y} + q_{uu}\, cos\, t\, \sin\theta - q_{vv}\, sin\, t\, \cos\theta \quad (3)$$

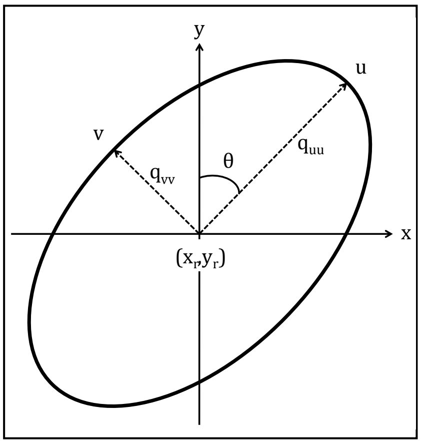

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Fig. 2: The ellipse, q_{uu} is the major axis, q_{vv} is the minor axis, θ is the angle of ellipse (positive value of θ is defined as clockwise angle from y-axis to u-axis and vice versa) and (x_r,y_r) is the reference point.

θ is defined as orientation of region (positive value of θ is defined as clockwise angle from y-axis to u-axis and vice versa, see Fig. 2), t is angle of point for ellipse boundary from 0 until 2π, $\bar{x}$ and $\bar{y}$ are mean of region, q_{uu} is major axis and q_{vv} is minor axis of region. After that the condition of the merging process will be discussed.

Merging Two Regions:

Merge is one of the process to combine two neighbouring region called region p and region q. The calculation to merge two neighbouring region is same as expansion of a region. Merge will happen if fulfill the following 4 conditions :-

1. Firstly the angular differences between region p and region q, θ_{pq} that is calculated using equation (4) must be less than the region tolerance, R_T (angle of ellipse).

$$\theta_{pq} = \theta_p - \theta_q \quad (4)$$

2. Secondly the distance of nearest point, d_{pq} (as shown in
3. Fig. 3) between two neighbouring is calculated using equation (5) must less than region tolerance, R_T (positioning of boundary).

$$\boldsymbol{d_{pq}} = \sqrt{(\boldsymbol{x_p} - \boldsymbol{x_q}) + (\boldsymbol{y_p} - \boldsymbol{y_q})} \quad (5)$$

However the position of nearest point between two neighbouring regions is unknown. The position of nearest point between two neighbouringregions can be identified if followed step a until step c :-

a. Initially find the θ_α (angle region q from region p) using equation (6) where (x_{cp},y_{cp}) is a midpoint of region p and (x_{cq},y_{cq}) is a midpoint of region q.

$$\theta_\alpha = 90^\circ - \tan^{-1}\left(\frac{y_{cq} - y_{cp}}{x_{cq} - x_{cp}}\right) \quad (6)$$

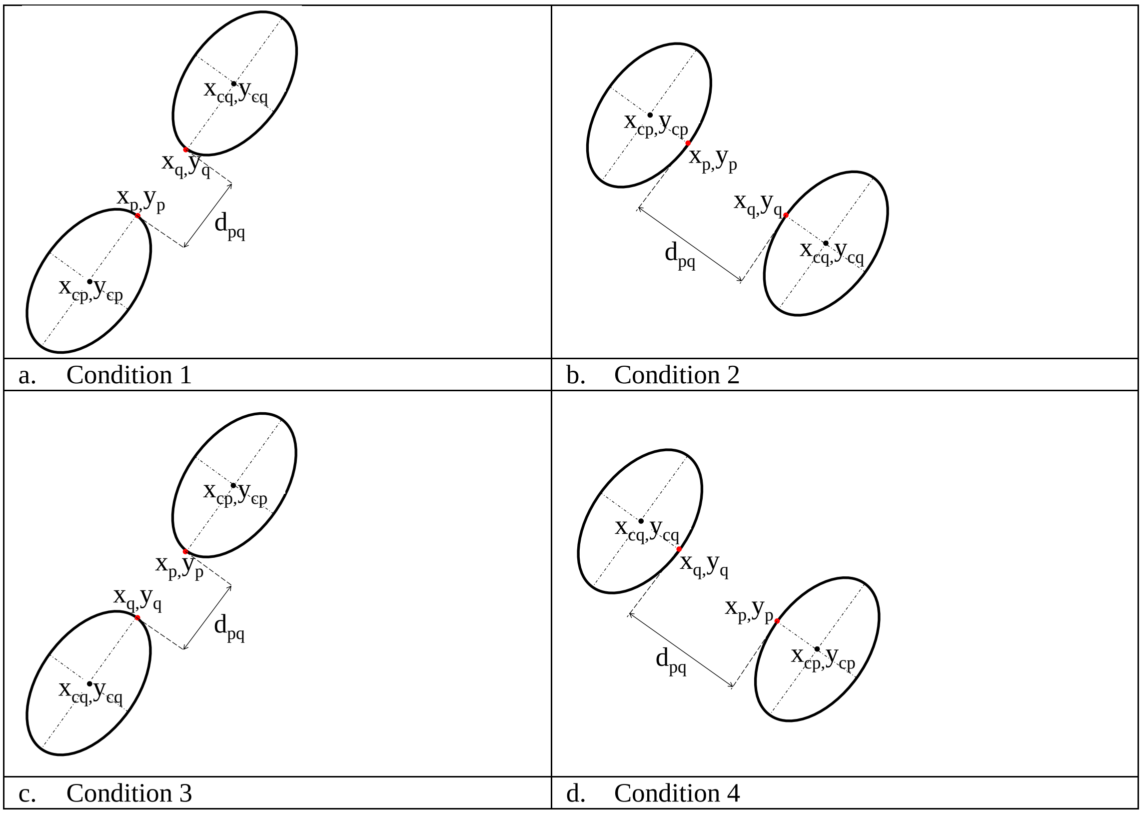

Fig. 3: There are 4 conditions to get the angle of nearest point between two neighbouring region called region p and region q. The centre of region p called (x_{cp},y_{cp}) and centre of region q called (x_{cq},y_{cq}). The nearest point (red dot) between two region called (x_p,y_p) for region p and (x_q,y_q) for region q. The nearest distance of two regions is known as d_{pq}. The two regions must have a similar data measurement, M_p equal to M_q, to fullfill the merging process. This figure is refer to Table 1.

b. Then find the angle of nearest point for region p, t_p and region q, t_q. There are 4 conditions to get the angle of nearest point as shown in

c. Fig. 3. The conditions are shown in Table 1.

Table 1: The 4 conditions to get angle of nearest point for region p, t_p and region q, t_q. This table is refers to Fig. 3.

C	If					t_p	t_q
1	$\theta_\alpha = \theta_p$	and	$(\theta_p > 0)$and $(x_{cq} > x_{cp})$	or	$(\theta_p < 0)$and $(x_{cq} < x_{cp})$	0	180
2	$\theta_\alpha = 90° + \theta_p$	and	$(\theta_p > 0)$and $(y_{cq} < y_{cp})$	or	$(\theta_p < 0)$and $(y_{cq} > y_{cp})$	90	270
3	$\theta_\alpha = \theta_p$	and	$(\theta_p > 0)$and $(x_{cq} < x_{cp})$	or	$(\theta_p < 0)$and $(x_{cq} > x_{cp})$	180	0
4	$\theta_\alpha = 90° + \theta_p$	and	$(\theta_p > 0)$and $(y_{cq} > y_{cp})$	or	$(\theta_p < 0)$and $(y_{cq} < y_{cp})$	270	90

c. Lastly that the nearest point (red dot) as shown in

d. Fig. 3 between two neighbouring regions is calculate using equation (7)and equation (8)where θ is defined as orientation of region (positive value of θ is defined as clockwise angle from y-axis to u-axis and vice versa, see Fig. 2), t is angle of nearest point for ellipse boundary (t_p is for region p and t_q is for region q),$\bar{x}$and $\bar{y}$are mean of region, $q_{uu}$is major axis and q_{vv} is minor axis of region.

$$x(t) = \bar{x} + q_{uu} \cos t \cos\theta - q_{vv} \sin t \sin\theta \quad (7)$$

$$y(t) = \bar{y} + q_{uu} \cos t \sin\theta - q_{vv} \sin t \cos\theta \quad (8)$$

4. Thirdly the length of major axis, *major axis*$_{pq}$ or minor axis, *minor axis*$_{pq}$ (as shown in Fig. 4) between two neighbouring region is calculated using equation (9) or equation (10) must less than region tolerance, R_T (similarity of length).

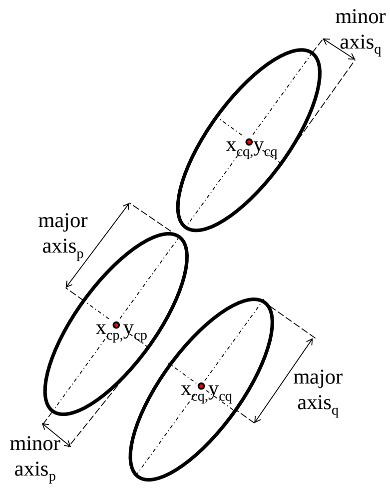

Fig. 4: The major axis (*major axis*$_p$ for region p and *major axis*$_q$ for region q) or the minor axis (*minor axis*$_p$ for region p and *minor axis*$_q$ for region q) of both regions is about the same size.

$$major\ axis_{pq} = major\ axis_p - major\ axis_q \quad (9)$$

$$minor\ axis_{pq} = minor\ axis_p - minor\ axis_q \quad (10)$$

5. Fourthly the sensor measurement both of the region, M_p and M_q must same such as shown in (11).

$$M_p = M_q \quad (11)$$

Performance Indices:

Maps have their own advantages and limitations. Therefore this section describes in detail the performances indices of the maps. Typically the performance of a map is considered in the usage of memory space, the time of accessing data in the map and accuracy of map. In order to calculate the amount of memory space, number of region will be measured. Meanwhile the time of accessing data is calculating by using BigO notation. Lastly the accuracy of map is measured when the total area of map is compared to the confidence region.

Memory space : Number of region:

A region is defined as an area bounded by a boundary which contains data information of environment. The size of the region could be fixing or vary between the other region depending on the type of map use. Usually map based space driven like grid map (Einhorn *et al*., 2011) has fix size regions. On the other hand, map based data driven such as flexible region map (Miskon and Russell, 2009) has a flexible size region. In this case, the size of the region depends on the distribution of the similar data in the map as well as the map that has been explored by the mapper. Number of region represents the amount of memory space required to store information. In (W. B. D. Fox and S, 1999), equation (12) is use to find the number of region for grid map where A_e refer to the area of the environment, A_c refers to the area of each cell for grid map and θ_g refer to the angular grid resolution.

$$No\ of\ region\ (GridMap) = \frac{A_e}{A_c} \times \frac{360^{\circ}}{\theta_g} \tag{12}$$

Meanwhile in (PunarjayChakravarty *et al*., 2007), equation (13) is use to find the number of region for perception based map where L_r refer to the length of route, S_s refer to step size of robot and N_o refer to the number of angle of the robot.

$$Noofregion(PerceptionBasedMap) = \frac{L_r}{S_s} \times N_o \tag{13}$$

Lastly flexible region map depends on the region tolerance, R_T, if region tolerance is high number of region will be decrease and vice versa (Taib *et al*., 2011).

Accessing Time : BigO notation:

In computer science, mathematics and related field, BigO notation is used to explain the complexity or performance of an algorithm. BigO notation basically describes the execution time or memory space required (e.g. on disk or in memory). A detail description of the method has been discussed in (Gayathri Devi *et al*., 2011). Once the number of loop in an algorithm is increased, a lot of time is taken to access the data. So, Algorithm 1, Algorithm 2 and Algorithm 3 are summarize the process to access the data in grid map, perception based map and flexible region map. O(1) describe the algorithm which constantly perform in the same time without depending on the number of input data set. Meanwhile O(n) describe the algorithm which performance directly proportional to the size of the input data. In additional of that, *n* was represented as the number of input size.

Grid Map
I = indexing *r* = number of row *y* = position y *x* = position x
$i = (r \times y) + x$
BigO notation = O(1)

Algorithm 1 : Pseudo code for grid map

Perception Based Map
I = 0 *n* = number of region – 1
for *I* until *n*
if   robot_pose ~= map_pose(*i*)
true
else if
false
end
end
BigO notation = O(n)

Algorithm 2 : Pseudo code for perception based map

Flexible Region Map
I = 0 *n* = number of region – 1
for *I* until *n*
if   robot_pose ~= map_pose(*i*)
true
else if

```
:                       false
:               end
:      end
BigO notation = O(n)
```

Algorithm 3 : Pseudo code for flexible region map

Accuracy of map : Confidence region:

Accuracy of map is defined as how accurate the map can be representing the normal data distribution of an environment. The accuracy of map to representing the normal data distribution of an environment is high when the total area of the map similar/close to the confidence region. As shown in Fig. 5 the author proposed a new method to calculate the confidence region. The confidence region is an area that has similar measurement at the location which perceived the normal data distribution of environment. The confidence region display as a circle (red colour) and the location which perceived the normal data distribution of environment is in the middle of confidence region boundary.

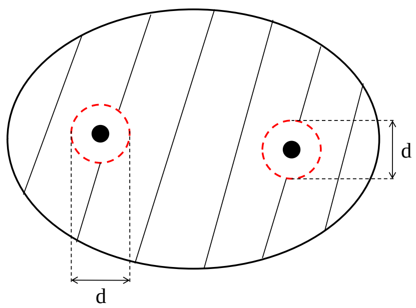

Fig. 5: The confidence region of map display as circle(red colour). Diameter of confidence region, *d* based on the robot step size. Robot step size is 100mm. Error of map is shown as (black shaded).

Total area of confidence region is calculated using equation (14) where *d* is the diameter of confidence region and equal to 100mm based on robot step size.

$$Total\ Area\ of\ ConfidenceRegion = \sum_{i=1}^{n}\left(\left(\frac{d}{2}\right)^2 \times \pi\right)_i \qquad (14)$$

Then the accuracy of the map (%) is calculated using equation (15) where A_{TM} is total area of the map and A_{TC} is total area of confidence region.

$$Accuracy\ of\ Map(\%) = \frac{A_{TM}}{A_{TC}} \qquad (15)$$

Experimental Setup:

This section will give the overview of how the research is conducted. The normal data distribution of an environment in the simulation using Amigobot cannot be conducted because the Amigobot is only embedded with sonar sensor. Other type of sensor such as light sensor and temperature sensor is carried by Amigobot when measured the normal data distribution of actual environment. As can be seen in Fig. 6 the size of actual environment which in L-shape is (5.4m x 4.17m). Inside of the L-shape environment there are 3 boxes at different location with different size of dimension. The boxes 1, 2 and 3 in the L-shape environment are located at position in (x mm, y mm) are (1500, 1000), (3500, 1000) and (970, 2790). The dimension of the boxes are as follows: Box 1-(250 X 540)mm, Box 2-(440 X 390)mm and Box 3-(210 X 380) mm.

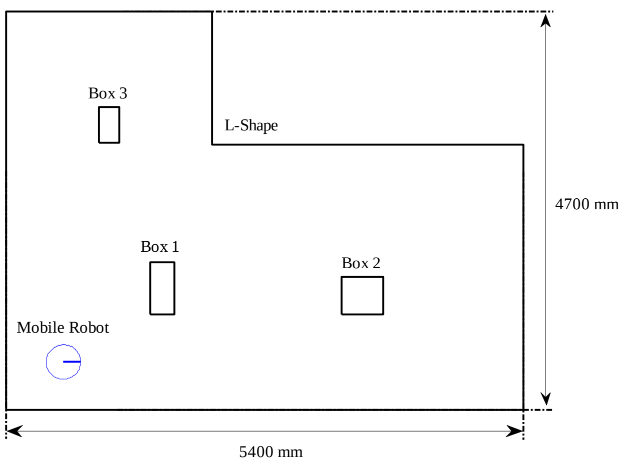

Fig. 6: The environment of experimental setup. The mobile robot now at the starting point (500,500,0°)

Initially in the experiment the mobile robot is located at (x mm, y mm, θ) is (500, 500, 0°). The mobile robot navigates by moving from point to point technique. The robot took the measurement of sonar/ambient temperature/ambient light sensor every 100mm. The data for position of robot and sensor measurements are stored in .txt file. Then the data from .txt file was read and a map was plotted using Matlab R2009a.

One experiments are conducted to investigate the performance of maps i.e. grid map, perception based map, flexible region map and flexible ellipse shape region. The investigation of maps is in term of memory space, accessing time and accuracy of map. The map which uses a lowest memory space, use less time to access the data and have highest accuracy of map is considered the best. As mentioned before the amount of memory space is calculated by measured the number of region created. Meanwhile BigO notation is used to measure the time taken to access the data in a map. Then to measured the accuracy of map, the total area of map is compared to the new technique of confidence region based on the step size of the robot which 100mm per step. The description about the experimental setup is done. Then the result of the experiment is show in next section.

Results:

The first objective of the experiment is to determine the usage of memory space when using different type of sensor measurement with different type of mapping technique. The sensors used in the experiment are sonar sensor, light sensor and temperature sensor. The sensors in this experiment are divided into two category called directional sensor (such as sonar sensor) and non-directional sensor (such as light sensor and temperature sensor). In the experiment the L-shape environment use as shown in Fig. 7. The initial position of the mobile robot in (x mm, y mm, θ°) is (500, 500, 0°). The goals of the mobile robot in this experiment in (x mm, y mm) are (500, 500), (4900, 500), (4900, 2270), (1650, 2270), (1650, 3670), (500, 3670) and (500, 500).

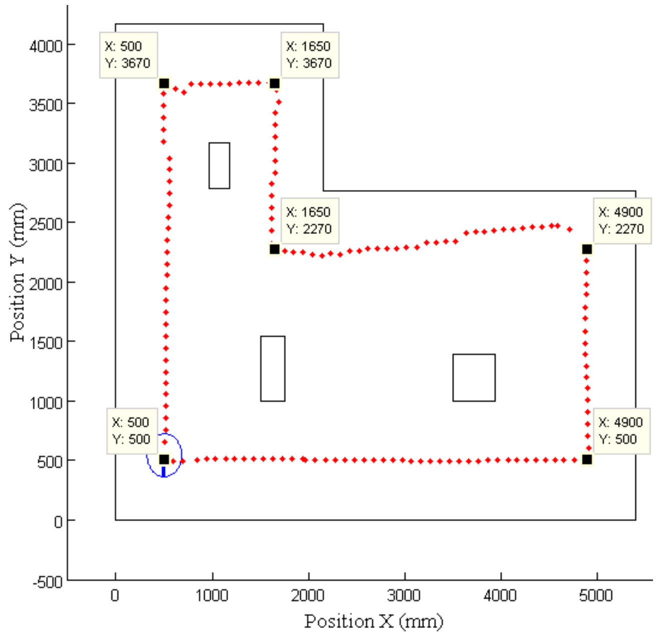

Fig. 7: The environment of an experiment. The goal of the experiment are (500, 500), (4900, 500), (4900, 2270), (1650, 2270), (1650, 3670), (500, 3670) and (500, 500). The red dot is the route of the robot with step size is equal to 100mm. The blue circle is a mobile robot.

Based on the result below as shown in the
Table 2 the usage of memory space for perception based map when mapping the environment between directional sensor data (sonar sensor) and non-directional sensor data (light sensor and temperature sensor) are same. The perception based map only used 6.75% of memory space when compared to the grid map when mapping both type of sensor data. The result in
Table 2shows that the flexible region map used 1.15% of memory space to map directional sensor data (sonar sensor) and 0.49% of memory space to map the non-directional sensor data (such as light sensor and temperature sensor) when compared to the grid map. Meanwhile flexible ellipse shape region used 1.15% of

memory space to map directional sensor data (sonar sensor) and 0.27% of memory space to map the non-directional sensor data (such as light sensor and temperature sensor) when compared to the grid map.

Table 2: The usage of memory space when mapping different type of sensor by using different type of mapping technique.

Type of sensor	Memory Space (no of region)			
	Grid Map	Perception Based Map	Flexible region map	Flexible ellipse shape region
Sonar	2252	152	26	26
Light	2252	152	11	6
Temperature	2252	152	11	6

The second objective of the experiment is to determine the accessing time of map when using different type of sensor measurement with different type of mapping technique. In order to achieve the objective, the accessing time for each type of map is calculated using BigO notation based on its algorithm as shown as Algorithm 1, Algorithm 2 and Algorithm 3 for grid map, perception based map and flexible region map. Based on the result in Table 3 the time to access the data in grid map is less than perception based map, flexible region map and flexible ellipse shape region whether map the directional sensor data or non-directional sensor data. This is because to access the data in grid map is directly using localization index. Meanwhile the time to access the data in flexible ellipse shape region is less than perception based map and flexible region map when map the non-directional sensor data. This is because the number of region created when map the non-directional sensor data using flexible ellipse shape region is less than perception based map and flexible region map.

Table 3: BigO notation for the different type of map and *n* is presented as the number of input size.

Type Of Map	BigO Notation
Grid Map	O(1)
Perception Based Map	O(n)
Flexible Region Map	O(n)
Flexible Ellipse Shape Region	O(n)

The third objective of the experiment is to determine the accuracy of map when using different type of sensor measurement with different type of mapping technique such as perception based map, flexible region map and flexible ellipse shape region map. The length and the width of each cell for perception based map are equal to 100mm (based on the step size of the robot).

Based on the results shown in Fig. 8 the total area and accuracy of map for the perception based map is the same and exceeding the limit of total confidence region about 27.3% whether mapping directional or non-directional sensor data. Meanwhile the accuracy of map for flexible region map is equal to 27.8% for directional sensor data and equal to 49.3% for non-directional sensor data. Lastly the accuracy of map for flexible ellipse shape region is equal to 15.4% for directional sensor data and equal to 47.5% for non-directional sensor data. The result for an experiment is already shown in term of memory space, accessing time and accuracy of map. The discussion about all the result in term of memory space, accessing time and accuracy of map in next section.

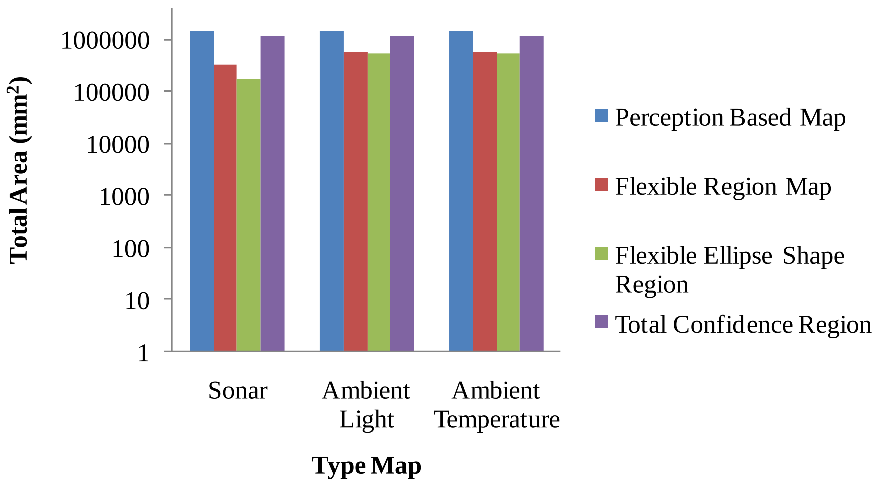

Fig. 8: The total area when mapping different type of sensor by using different type of mapping technique. The log scale of the figure is equal to 10.

Discussion:

Table 2 shows the result of memory space for the experiment when mapping using different type of sensor and different type of mapping technique. The result proves that the grid map has a fixed number of grid cells in an environment. The number of region for grid map is not affected when mapping the different type of sensor data. This is because grid map is a predefined map and used the maximum of memory space. The number of region for grid map is depending on the size of each cell to map whole the environment and it is calculated using the equation (12). The size of whole environments is (5.4m x 4.17m) while the size of each cell of grid map is (100mm x 100mm). Therefore the numbers of region for the grid map by using different type of sensors are equal to 2252.

Perception based map basically is a data driven map. Therefore the number of region for perception based map is always low compared to the grid map. This is because perception based map only mapped onto the position which robot perceived the information that navigate along the following path. Even though perception based map mapped the different type of normal sensor data, the number of region created by perception based map in an environment as shown in
Table 2 is same. This is because the number of region for perception based map depending on the number of location which perceived the information. The result of the perception based map in the
Table 2 can be seen in
Fig. 9. As can be seen in
Fig. 9 there has few region overlap to each other. This is because the distance between two location perceived by the robot is close and less to the length or width of a cell for perception based map. The length and the width of each cell for perception based map are equal to 100mm (based on the step size of the robot).

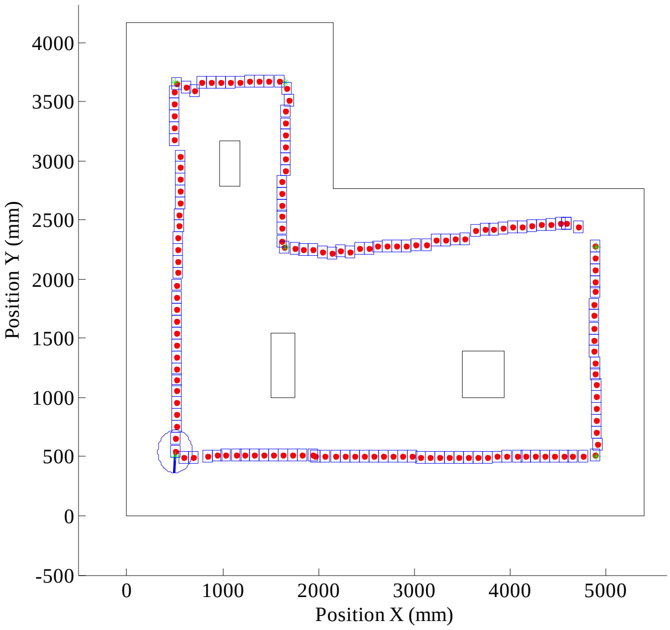

Fig. 9: The perception based map created 152 number of region for mapping normal sonar, light and temperature sensor data. The accuracy of map of perception based map is exceeding the limit of total confidence region about 27.3% when mapping normal sonar, light and temperature sensor data.

Flexible region map and flexible ellipse shape region map is two flexible map which can grow and merge with their neighbouring region if both of the region has similar contents. Both of maps are depending on their region tolerance, R_T. If their region tolerance is increased the number of region is decreased. Both of the flexible maps used low memory space compared to the grid map and perception based map especially when many sensor data have similar reading.

The result in the
Table 2 for the flexible region map is shown in the Fig. 10 when mapping the data of directional sensor data (sonar sensor). Meanwhile Fig. 11 is based on the result in
Table 2 for flexible region map when mapping the non-directional sensor data. As can been seen the result of the memory space when mapping using flexible region map for directional sensor data is more than non-directional sensor data. The reason is the sonar sensor is sensitive to the changing of robot heading. When there is a very little change of the robot heading the sensor measurement at current position is different to the sensor measurement at previous position. So the two neighbouring region cannot merge become a region. That is the reason why the number of region when mapped to the directional sensor data is more than mapped the non-

directional data. The changes of robot heading are usually happen at the corners in the L-shaped environment and created the region such as region 21 at the Fig. 10. Even though the measurement of the non-directional sensor (light sensor and temperature sensor) is not depending to the robot heading, the flexible region map has a problem to map the normal data distribution in certain condition. The problem is if the normal data distribution is not align to 4 discrete robot heading such as 0°, 90°, 180° and 270° the number of region created by the flexible region map is increased. As example this is the reason why region 3 and region 4 in the Fig. 11 cannot be merge and become a region.

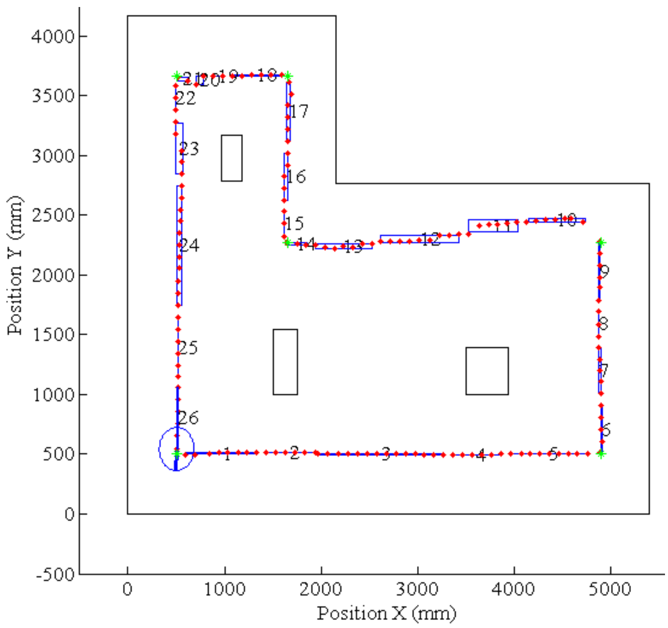

Fig. 10: The flexible region map created 26 number of region for mapping normal sonar sensor data. The accuracy of map of flexible region map is equal to the 27.8% for mapping normal sonar sensor data.

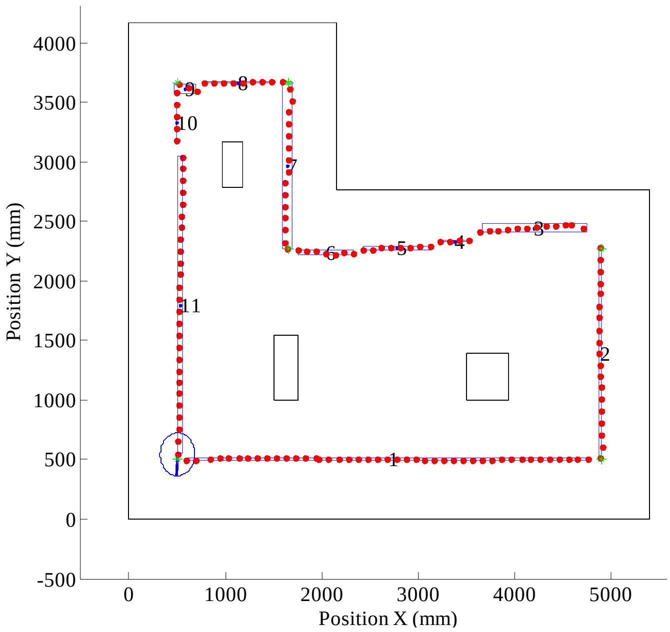

Fig. 11: The flexible region map created 11 number of region for mapping normal light and temperature sensor data. The accuracy of map of flexible region map is equal to the 49.3% for mapping normal light and temperature sensor data.

Fig. 12 show the flexible ellipse shape region when mapping the directional sensor data (sonar sensor) while Fig. 13 show the result of the flexible ellipse shape region when mapping the non-directional sensor data. Both of the figures based on the result in
Table 2. The memory space of the flexible ellipse shape region when mapping the directional sensor data is more than mapping the non-directional sensor data. This is because the directional sensor data is sensitive to the robot heading. If there is a change of the robot heading, the sensor measurement at current position is not same to the sensor measurement at previous position. This cause the increasing to the number of the region created. The robot heading usually changes at the corner of the L-shape environment as shown as the region 20 and region 21 in
Fig. 12. The result when mapped the non-directional sensor data (light sensor and temperature sensor) by using flexible ellipse shape region as shown in Fig. 13 is less than flexible region map as shown in Fig. 11. This is because the flexible ellipse shape region can mapped the normal data distribution from 0° until 360°. However the flexible region map only mapped the data distribution if the normal data distribution is align to the 4 discrete robot heading (0°, 90°, 180° and 270°). The example of the statement is the region 3 until region 6 in Fig. 11 when mapping using flexible region map can be merged and become a region as shown as region 3 in Fig. 13 when mapping using flexible ellipse shape region.

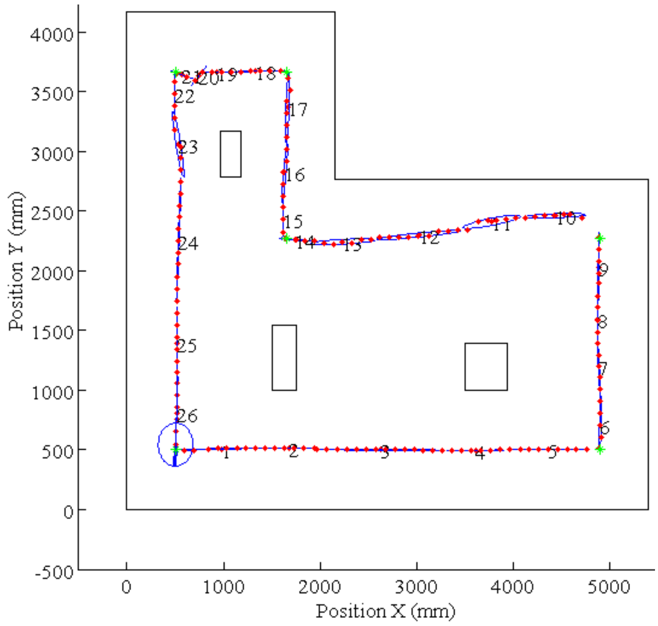

Fig. 12: The flexible ellipse shape region created 26 number of region for mapping normal sonar sensor data. The accuracy of map of flexible ellipse shape region is equal to the 15.4% for mapping normal sonar sensor data.

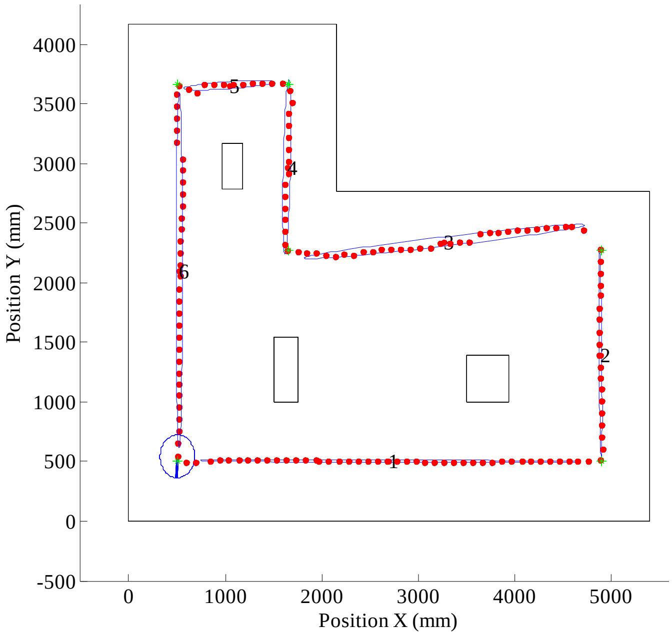

Fig. 13: The flexible ellipse shape region created 6 number of region for mapping normal light and temperature sensor data. The accuracy of map of flexible region map is equal to the 47.5% for mapping normal light and temperature sensor data.

Based on the result in Table 3 the time to access the data in grid map is less than perception based map, flexible region map and flexible ellipse shape region. This is because to access the data in grid map is directly using localization index. However the searching process for the data driven map such as perception based map, flexible region map and flexible ellipse shape region is unable to take directly using localization index. In order to access the data in data driven map the robot firstly must find which region is similar to the current robot pose. So, the data driven map which have less number of region use less time to access the data in the map. In other word flexible maps (flexible region map and flexible ellipse shape region) have less time to access the data when compared to perception based map. In few conditions the flexible ellipse shape region use less time to access the data when compared to the flexible region map if the number of region created for the flexible region map is more than flexible ellipse shape region. This is because the flexible region map is unable to reduce the usage of memory space if the data distribution is not align in 4 discreet robot heading such as 0°, 90°, 180° and 270°.

The result as shown in Fig. 8 show the total area of map for the perception based map, flexible region map and flexible ellipse shape region. The accuracy of map for the perception based map is same whether mapping the directional sensor data or non-directional sensor data. This is because as mentioned before, perception based map only mapped onto the position which robot perceived the information. That means the increasing of total area of perception based map is parallel to the increasing to the total confidence region. However the accuracy of map using perception based map is exceeding the limit of total confidence region about 27.3%. This is because the boundary of perception based map is in square while the boundary of confidence region is in circle. That means the total area of square is always more than circle when mapped the same normal data distribution. As has been noted the length and the width of each cell for perception based map are equal to 100mm (based on the step size of the robot). Since the two locations which perceived the normal measurement by the robot is close to each other, there has few region overlap as can be seen in
Fig. 9.

As shown in the results in Fig. 8 the accuracy of map for the flexible region map is high about 21.5% when mapping the non-directional sensor data compared when mapping directional sensor data. This is because the non-directional sensor data has similar sensor measurement and the two neighbouring region can merge to become a region. Indirectly the total area of the flexible region map is more when mapping the non-directional sensor data. The result in Fig. 8 as shown in Fig. 10 and Fig. 11 when mapping the directional and non-directional sensor data. As can be seen in Fig. 10 there are spaces between region 15, region 16 and region 17. However in the same location there has similar normal sensor data and merge together become region 7 as can be shown in Fig. 11. Hence the total area of flexible region map when mapping the non-directional sensor data is high compared when mapping the directional sensor data and directly increased the accuracy of map. Even though the flexible region map can map the similar normal data distribution from non-directional sensor data, the flexible region map has limitation when the normal data distribution is not align to the 4 discreet robot heading such as 0°, 90°, 180° and 270°. This is the reason why region 3 until region 6 as shown in Fig. 11

cannot merge and become a region. Indirectly the total area and accuracy of map of flexible region map cannot increase.

As shown in the result based on the Fig. 8, the flexible ellipse shape region also has a same pattern when compared to the flexible region map in term of accuracy of map. The accuracy of map of the flexible ellipse shape region when mapping the non-directional sensor data is higher about 32.1% than when mapping directional sensor data. This is cause to the two neighbouring regions merge and becoming a region when mapping the similar data of non-directional sensor data. After become a region, the total area of flexible ellipse shape region is increased and indirectly the accuracy of map of the flexible ellipse shape region increased. The location which represent as region 10 until region 14 such in
Fig. 12 has a similar content when mapping using non-directional sensor data and become region 3 as shown in the Fig. 13. That means more area is map and the accuracy of map is increased when mapping using non-directional sensor data.

Based on the result as shown in Fig. 8 the accuracy of map for the flexible ellipse shape region is lower than flexible region map in this experiment. This is because the flexible ellipse shape region can map the data distribution from 0° until 360° as shown as region in Fig. 13 and indirectly minimize the total area when mapping the non-directional sensor data in this experiment. Meanwhile the flexible region map has a limitation to map the normal data distribution if not align to the 4 discreet value of robot heading as shown as region 3 until region 6 in Fig. 11 when mapping the non-directional sensor data. Indirectly the total area of flexible region map is higher compared to the total area of flexible ellipse shape region. That is the reason why the accuracy of map for flexible ellipse shape region is low compared to the accuracy of map for flexible region map in this experiment.

Conclusion:

In these research two objectives has been achieved. The first objective is to develop and design a new flexible mapping technique using ellipse shape boundary. The second objective is to investigate the performance different types of maps which perceived by different types of sensor using different types of route in an L-shape environment in term of memory space, accessing time and accuracy of map.

The new flexible map is known as flexible ellipse shape region. The advantage of the map is the flexible ellipse shape region can mapped the normal data of environment in any angle of robot perception from 0° until 360°. Another advantage is the boundary ellipse of flexible ellipse shape region can grow and merge. Thereby the size of ellipse boundary of flexible is depending on the normal data distribution of environment and directly reduces the use of memory space.

The flexible ellipse shape region is proven to successfully reduce the usage of memory space and used only 0.27%, 3.95% and 54.55% when compared to the grid map, perception based map and flexible region map when mapped the non-directional sensor data in the experiment.
Besides that, in term of accessing time the grid map use less time to access the data when compared to the perception based map, flexible region map and flexible ellipse shape region. This is because the localization index is used to access the data in grid map. In order to find the data such as in perception based map, flexible region map and flexible ellipse shape region, firstly must find which region is similar to the current robot pose. In other word which map has a less number of regions, the accessing time can also be reduced. That means the accessing time for the flexible ellipse shape region is less than flexible region map and perception based map according the result of memory space in the experiment when mapped the non-directional sensor data.

Then in term of accuracy of map for the perception based map is exceeding the limit of total confidence region about 27.3%. This is because the boundary of perception based map is in square while the boundary of confidence region is in circle. That means the total area of square is always more than circle when mapped the same normal data distribution. Meanwhile the accuracy of map for flexible region map is higher when compared to the flexible ellipse shape region about 12.4% and 1.8% when mapped the directional and non-directional sensor data.

The conclusion is the flexible ellipse shape region succeed to reduce the usage of memory space when compared to the grid map, perception based map and flexible region map. Furthermore the flexible succeed used less the accessing time when compared to the perception based map and flexible region map. Lastly the flexible ellipse shape region has a low accuracy of map when compared to the perception based map and flexible region map.

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