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ULTRASONIC HYBRID MAP FOR NAVIGATION OF MOBILE ROBOT

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Abstract: Paper deals with principles of ultrasonic hybrid map proposed for indoor mobile robot system. This map is applied in navigation of mobile robot. At the beginning, paper presents brief description of indoor mobile robot system used for testing and developing of algorithms. Major section of paper deals with map creating. In the first step, it is local metric map with probabilistic model of ultrasonic sensor. In the second step, it is global metric map, which is created by connection of local metric maps. In the last step, it is simplification of environment representation from global metric map to topological map. In this manner ultrasonic hybrid map is created and it can be used in both reactive and global navigation of mobile robot.

Keywords: mobile robot, metric map, topological map, hybrid map

1 INTRODUCTION

Mobile robots can be utilized in many places of human life. Generally, they are used as service robots. Definition of service robot is unclear and complicated, but it is possible to claim, that service robot performs such tasks, that help, assist or completely replace human in various activities. Reason of service robotics development is to raise human productivity.

Mobile robots can be designed for various environments. Essential tasks, that every robot has to perform is to localize and navigate itself in environment. For successful achievement of these tasks, robot needs some sensors. These sensors are used for perceptions likewise humans do. In world of mobile robotics exist many sensors, but generally we can divide them in two groups:

Sensors used for localization (GPS, encoders, INS, gyroscope, accelerometer, magnetic compass, etc.)

Sensors used for navigation (ultrasonic sensors, laser rangefinders, infrared sensors, visual systems, proximity sensors, contact sensors etc.)

Moreover, for specific applications, it exists many others high specialized sensors. And next, with application of some mathematic methods, sensors used for navigation can also be used for localization. It seems difficult, but majority of mobile robots use for its navigation and localization some specific and abstract representation of environment. This representation is called map of environment.

There are three types of these maps. First type is metric map. Metric map represents environment with grid, in which every cell represents exactly specified size of environment. Key problem is to set appropriate size of the cell. If size of cell is too small, then number of cells is too big and there are great demands on CPU performance and memory. If cell size is too big, representation of environment is not so accurate and it can cause problems within navigation and localization.

Second type is topological map. Topological map represents environment in graph structure. There are no metric properties stored in this map. Graph consists of places and edges. Edges represent passages between two places. Advantages of topological map are lower consumption of CPU performance within path planning and lower memory consumption within map creating.

Third type is hybrid map, which combines two antecedent types. It means, that robot is globally planning its path in global topological map, but for its reactive navigation and obstacle avoidance it uses local metric map. Local metric map is used in places of global topological map. Combination of particular types of maps improves robot possibilities for localization, navigation and it also decreases demands on CPU performance. This combination is near to human reflection.

2 INTRODUCTION

Mobile robot used for experiments is indoor mobile robot. Robot has three wheels, two of them are driven, so it is a differentially driven robot (Miková 2008). Kinematics scheme and configuration of sensors can be seen on Fig. 1. Circular construction of robot enables rotation around axis z without intervention of robot to the environment. Sensorial system consists of nine ultrasonic sensors and nine infrared sensors. Seven forward ultrasonic sensors are used for construction of local metric map, two backward sensors are used just for obstacle avoidance like all of nine infrared sensors. Ultrasonic sensors used in mobile robot are MUST01 sensors with detection range from several decimetres up to 5 (3 metres guaranteed) metres with 0,1% accuracy over entire range at stable temperatures. Beam angle is 15° and repetition rate is 10Hz astable (for our experiments repetition rate was 600ms stable).

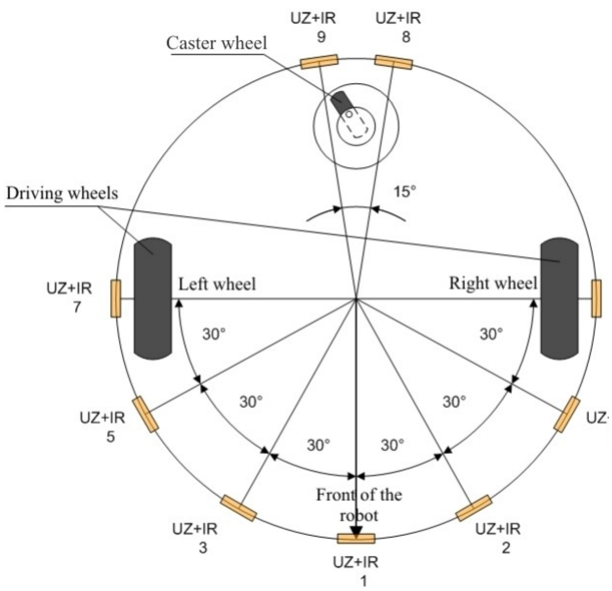

Fig. 1. Kinematics scheme of mobile robot and configuration of sensors.

Outputs from ultrasonic sensors are analog 0-5 VDC. That's why Advantech I/O card is used. Moreover, for interpretation of measured distances, it is need to know transfer characteristic (Fig. 2, Tab. 1).

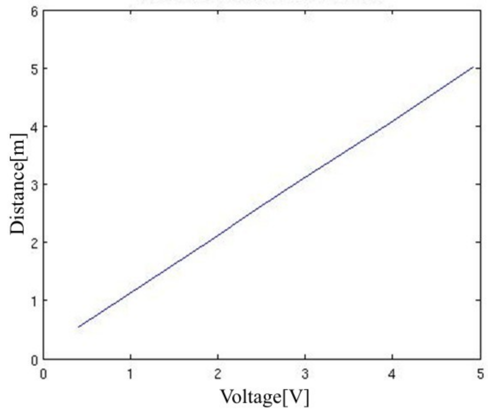

Fig. 2. Transfer characteristic of ultrasonic sensor MUST01.

Voltage [V]	0.415	0.910	1.420	1.920	2.425	2.935	3.450	3.970	4.460	4.920
Distance [m]	0.550	1.050	1.550	2.050	2.550	3.050	3.550	4.050	4.550	5.020

Table 1. Transfer characteristic of ultrasonic sensor MUST 01.

Because the robot is differentially driven with negligible influence of wheels slippage and friction, its estimation of position is derived from number of wheels revolutions. That's why there are used incremental encoders MR ENC type L with 1024 impulses per revolution. Incremental encoders are placed on motor shaft. Because there are used motors Maxon RE40 with gearbox GP42C (15Nm, 43:1), every revolution of wheel evokes 1024*43 pulses. Moreover, the position of mobile robot is derived from odometry, which is based on kinematics scheme (Fig. 3). Inputs are velocities of wheels derived from number of wheels revolutions.

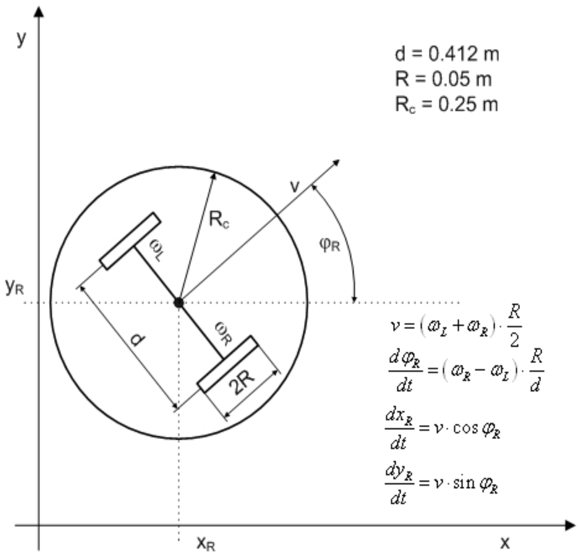

Fig. 3. Kinematics scheme used for odometry.

3 LOCAL METRIC MAP

Local metric map of environment is created following data from ultrasonic sensors. For single ultrasonic sensors, we can divide area covered by this sensor in four regions (Fig. 4) (Murphy 2000) (Hanzel 2007).

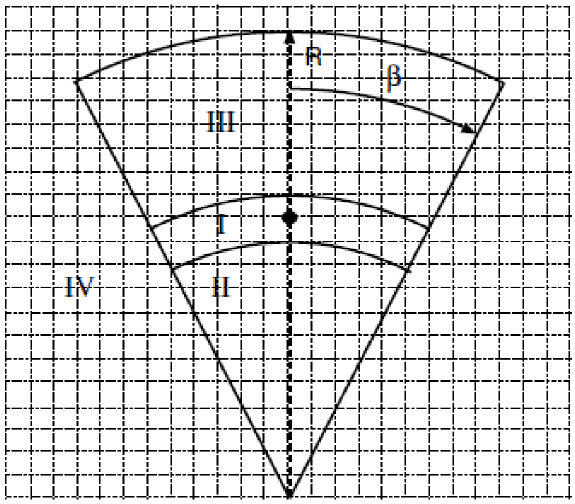

Fig. 4. Four regions within ultrasonic sensor measurement (Murphy 2000).

Region I. stands for detected object. This region has curved shape, because information about obstacle must be propagated through entire arc. Height of this region is specified by resolution of local metric map (thus ultrasonic sensor) and by errors of measurement. In our model, region I. and III. are the same. Region II. is interpreted as free region. It is logical, because if there is another obstacle, region I. will be closer to the ultrasonic sensor. Region III. is theoretically covered by sensor, but practically there is no information about this region based on data from sensor. On the other hand, majority of models join region I. and III. Region IV. is region outside of measurement range. For ultrasonic sensor MUST01 is R equal to 3m and β is equal to 7,5°.

Data from ultrasonic sensor can be written into local metric map with simple additive model. However usage of some probabilistic model is more correct. Model like that is more corresponding to properties of real ultrasonic sensor. Our model is derived from basic Elfes model (Elfes 1989)(Elfes 1992). For region II. is probability of occupation for each cell computed as:

$$P(x,y) = P_\beta . P_R , \tag{1}$$

where:

$$P_\beta = 1 - \left(\frac{\frac{16}{3}.\beta^2 - \frac{2}{3}\alpha.\beta}{\alpha^2} \right) \tag{2}$$

$$P_R = \left(R_{po\,\mathrm{int}} - R_{\min}\right).\Delta_e \tag{3}$$

$$\Delta_e = \frac{p_e}{R_{mes} - R_{\min}} \tag{4}$$

β is angular radius of sensor cone, α is angular width of sensor cone, $R_{po\,\mathrm{int}}$ is radius of actually written point into local metric map derived from position of ultrasonic sensor, $R_{\min}$ is minimal radius derived from minimal measurement range of sensor, R_{mes} is actually measured radius of obstacle derived from sensor data and p_e is range of probability interpreted for region II.

For region I. and III. is probability of occupation for each cell computed as:

$$P(x,y) = P_\beta . P_r , \tag{5}$$

where:

$$P_\beta = 1 - \left(\frac{\frac{16}{3}.\beta^2 - \frac{2}{3}\alpha.\beta}{\alpha^2} \right) \tag{6}$$

$$P_r = 1 - \left(R_{po\,\mathrm{int}} - R_{mes}\right).\Delta_o \tag{7}$$

$$\Delta_o = \frac{p_o}{R_{\max} - R_{mes}} \tag{8}$$

β is angular radius of sensor cone, α is angular width of sensor cone, $R_{po\,\mathrm{int}}$ is radius of actually written point into local metric map derived from position of ultrasonic sensor, $R_{\max}$ is maximal radius derived from minimal measurement range of sensor, R_{mes} is actually measured radius of obstacle derived from sensor data and p_o is range of probability interpreted for region II. Equations (2) and (6) were derived heuristically.

In our model values of probabilities ranging from 0 to 0,4 represent unoccupied space, values of probabilities ranging from 0,6 to 1 represent occupied space, values ranging from 0,4 to 0,6 represent lack of information. It follows, that both p_e and p_o are equal to 0,4. With modification of mutual rate of p_e and p_o, it can be given emphasis on faster record of occupied space or on faster record of unoccupied space. This is important, if robot performs its activities in environment with movable obstacles.

Consequently, one reading of ultrasonic sensor is written to local metric map. This model is used for each ultrasonic sensor of the robot. However, one sensors reading is not useful for navigation. That's why multiple readings must be put to correlation. For this purpose, it's used well known Bayesian update rule:

$$P(O \mid NR) = \frac{P(NR \mid O).P(O)}{P(NR \mid O).P(O) + [(1 - P(NR \mid O)).(1 - P(O))]} \quad (9)$$

Where $P(O \mid NR)$ is new empirical probability of occupation of cell, $P(NR \mid O)$ is priory probability of occupation of cell defined from new sensor reading and $P(O)$ is priory probability of occupation of cell defined from local metric map with previous sensors readings. Despite of the simplicity of update rule, it has some disadvantages. If any of priory probabilities is equal to 0 or 1, new empirical probability will not change. This is ineligible in environment with movable obstacles. That's why this rule in our model was modified by means of restriction of probability values. Probability of occupation of cell cannot reach value of 0 or 1. It can be just quite near to these values.

Seeing that robot is moving in environment, this fact must be reflected in local metric map. The movement of robot is divided into two types: translation and rotation. Translation express itself in local metric map as shift of cells in direction of movement. This means that cells in direction of movement, regarding the amount of the movement, are filled with value 0,5. Thus, this cells were not scanned by sensors and robot has lack of information about these cells. Cells in opposite direction of movement, regarding the amount of the movement, are simple deleted. Remaining cells are moved to new positions, that are defined by the amount of the movement. There are two ways, how to achieve rotation of local metric map. First way is complicated and computational hungry. It is rotation of grid structure around its centre. Second way, used in our model, is to rotate robot in local metric map itself. In this regard regions of sensors records are expressed through outlines. Afterwards it is simple to rotate outlines and fill corresponding cells with probabilities.

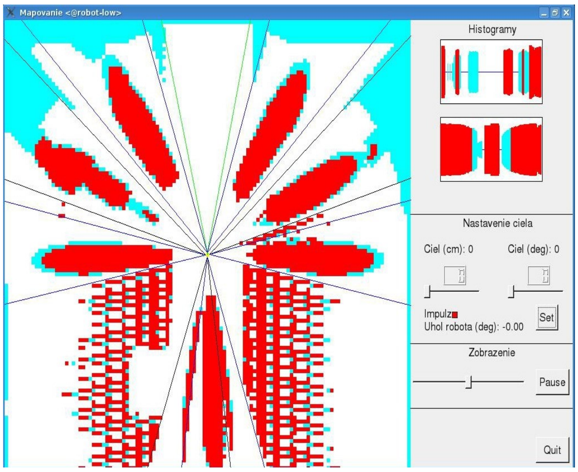

Fig. 5. Example of real environment and one local metric map of this environment.

4 GLOBAL METRIC MAP

The use of the local metric map alone is not very useful for navigation of robot. It can navigate through environment reactively, but for autonomous robot is needed to know and record information about already known environment. Afterwards, this information can be applied in global planning of path (Župa 2008).

Global metric map is constructed as fusion of multiple local metric maps. We assume, that startup position of robot is known and it is predetermined. Local metric maps can be easily and simply connected, because their orientation is equivalent. This property of equivalent orientation is guaranteed by rotation of robot in local metric map. Accordingly, local metric maps are connected in terms of shifts of their centres. In addition there is applied compensation from robot movement in order to preserve perpendicularity of map. For these reasons it is not needed to record positions from which were cells of global map recorded.

After connection of local metric maps in one global metric map, some threshold must be applied. Local metric map is described by probabilities for each cell. In global metric map used for global planning cannot figure probabilities, because global planning usually uses exact mathematical methods without probabilities. After threshold application, area of local metric map is erased from global metric map. Cause of this step are fast changes in local metric map used for reactive navigation, that are not very effective for global planning.

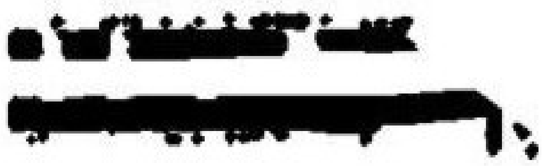

Fig. 6. Example of global metric map (one pixel represents 5x5cm, length of area approx. 20m).

5 TOPOLOGICAL MAP

In most cases, global metric map of environment is very demanding on memory. That's why the structure of global metric map is simplified to topological map. One way how to construct topological map from metric map is to create Voronoi diagram. Then with set of critical points topological map can be created (Thrun 1999)(Siegwart 2004). Usually construction of Voronoi diagram based on metric map is very computational hungry (Niemuller 2003)(Choset 2005). Request on our model, that every step of hybrid map creation must be done online, leads to own method called orthogonal equidistant diagram.

This method seeks for equidistant points between two obstacles in orthographic directions. Thereby way originates discontinuous diagram, which is determined in online mode. Despite of discontinuities in diagram, many continuous lines appear. These lines represent nodes of topological map. Discontinuities of environment (such as doors, passages, etc.) express themselves as discontinuities in map, so they divide environment on nodes.

If every isolated continuous line represents one topological node, then it is possible to search for neighbourhood nodes. Likewise it is possible to find two marginal points of each node. Between these marginal points, it can be created edges between marginal points (thus nodes) and from distance of marginal points, each edge can be priced by value of this distance. For detection of marginal points, some masks are used (Fig. 7).

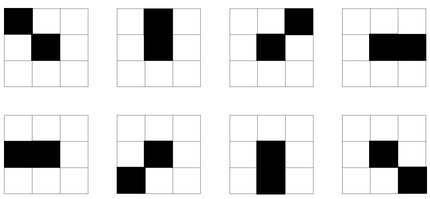

Fig. 7. Examples of masks.

Generally for each marginal point stands:

$$|f(x,y)| = 0 \wedge \sum_{i=-1}^{1} \sum_{j=-1}^{1} |f(x+i, y+j)| = 1785 \qquad (10)$$

Where $|f(x,y)|$ is size of image intensity on position (x,y). Equation (10) says, that marginal point is in the middle of the mask and in its surroundings are seven white points with image intensity equals to 255 and one black point with image intensity equals to 0.

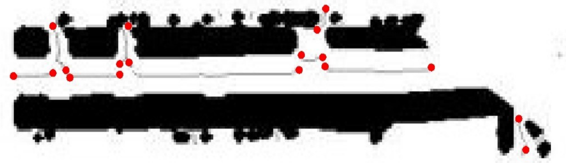

Fig. 8. Examples of found marginal points (red points).

Node of topological map is defined, if there is a connection between two marginal points and the distance between these marginal points is higher than empirically specified distance. Edge of topological map is defined, if there isn't connection between two visible (i.e. no obstacle between them) marginal points and the distance between these marginal points is smaller than empirically specified distance. Moreover, edges and nodes can have distance values between its marginal points. This property can be useful in global path planning.

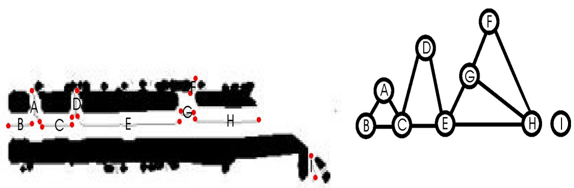

Fig. 9. Example of topological map created from global metric map.

6 CONCLUSIONS

Ultrasonic hybrid map is very powerful and robust tool for autonomous mobile robot navigation. Despite of many drawbacks, map created with ultrasonic sensors is accurate enough to provide resources for mobile robot navigation. Of course, there are sensors which provide more accurately and more precisely information, such as laser scanner or camera, but ultrasonic sensors can be used in many less expensive robots, that's why they are still popular in scientific world.

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