Exploration in the VisualSLAM

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Abstract. This paper deals with the exploration strategy for the robot that maps its neighbourhood using a stereocamera. The mapping algorithm detects the significant features, finds correspondences in both images, matches them together and computes their 3D coordinates. The first part of this paper is focused on the selection of the goal points that the robot will examine. This is an important issue in the Simultaneous Localization and Mapping (SLAM) algorithms, because it is preferable for the robot to explore the largest area possible in a short amount of time. The main part of the paper is focused on the movements of the stereocamera to observe the area on the sides of the robot during the forward motion.

Keywords: SLAM, visualSLAM, significant features, robot exploration

1 Introduction

An important part of the autonomous robotics is the map creation. Recently, the area of outdoor robots that use the human-like maps has increased, but the autonomous map creation is still important. Mainly in the indoor environments, where no maps exist and probably never will exist, it is important for the robot to create its own representation of the place where it is supposed to move. Such a map will be used not only for the navigation from one place to another, but also for the interaction with various items in the robot surroundings. One of the first mapping techniques were the ones by Elfes and Moravec [4] where the occupancy grids for the map creation were used. Another work on the robotic mapping were the papers by Smith and Cheeseman [7], where uncertainties in the robot motion and sensing were described and the Extended Kalman Filter SLAM were described for the first time. The first implementations of the EKF SLAM were done by Moutarlier and Chatila [5]. Other early papers on this topic were written by Leonard and Durrant-Whyte [2] and also by Renken [10]. Another advance was the use of the particle filter and mainly the Rao-Blackwellized particle filter by Montemerlo [3].

The higher level of map making is the exploration strategy where the robot chooses the goal points. An example of the path planning in the landmark based-map is mentioned in the work by Taylor [8]. Another method od map making is shown in the paper by Joho [1], where places with best view are chosen for the robot equipped with the laser scanner. The approach for occupancy grids that is widely used is by Yamauchi [11] or by Sim [6]. More sophisticated approach is decribed in [9], where the entropy is used.

2 Goal Point Selection

The selection of goal points is a crucial task in SLAM algorithms. It is important to arrange for a robot to first make a rough map of the neighbourhood and then specify it. The key point in the SLAM algorithms is the loop-closing. This is the only way for a robot to correct the odometry errors that arise during the exploration. The more the robot rides and especially turns, the more uncertain its position is. The goal,therefore, is to prevent the unnecessary wandering among close observed features. In the ideal case, the robot should go to the furthest feature (obstacle), observe its surroundings and continue to the second furthest obstacle. But it has to prefer going to the unknown area and not returning to the previously explored place. To arrange this, it is not sufficient to select the obstacles only acording to their distance. This could cause that the robot goes back and forth between two obstacles. Therefore, the way proposed here is to choose obstacles according to their distance from the explored borders and the travel cost to this border.

As the robot moves, it marks the borders between the visited and therefore traversable area and the unvisited unknown area. The detected features will lie behind this border (or above the traversable area - lights, ceiling, etc.). The distance to the closest point on the border will be computed. The larger this distance will be, the bigger will the attractive power of the point be. Then, the shortest path from the point on the borders to the robot will be computed. This will represent the repulsive force of the detected point. The resulting attractive force is therefore computed as

$$A_P = d(P_p, P_b) - \eta G(v_S, P_b) \quad (1)$$

where A_P is the attractive power of the point P, $d(P_p, P_b)$ is the distance from the point P_p which is projection of the point P to the traversable area to its closest point on the border P_b. $G(v_S, P_b)$ is the cost of travelling from the current robot position v_S to the border point P_b, η is the weight of this value. It is recommended to set it between 0 and 0.5.

The point with the highest attractive power will be the next goal point for the robot. We can assume, that this point will be the one detected in the last observation. This will push the robot away from the explored area. In the case that no point will have the distance $d(P_p, P_b)$ bigger then chosen constant $\mathcal{K}$, the robot will switch to the second part of the exploration, the map specifing. In this part the mapping will be based on the frontier-based exploration, and the robot will go to the closest obstacle. If during this part of the exploration robot detects some point with bigger distance then $\mathcal{K}$, it will be switched back to the first phase of exploration.

If the robot is not be able to step on any part of the borders because it would mean the colision with the obstacle the exploration and the map making will be completed. However, only the main part of the exploration will be completed. We assume that the robot uses the cameras to detect the points and this means that even a small change of the light can cause discovering of the other points. So the map making in fact will continue as long as the robot will move in the map.

3 Choosing the Direction of View

We assume that the stereocameras of the robot are on the pan-and-tilt unit that can turn left and right in the angle cca 90° and up and down. This equipment is quite common in the robotics so our assumption is not unqualified. The important thing here is that such a unit allows a robot to go in one direction and look in the other direction. Looking on the sides allows the robot to explore more areas and to discover free spaces behind corners.

For the SLAM algorithm it is important for the robot not to turn often. Every turning of the robot has a negative influence on the accuracy of the localization. Therefore, it is suitable to only turn the stereocamera and not the whole robot. This means that we can use the stereocamera to watch the interest points while approaching the selected goal point. The points connected by the edge that are close to each other but differ a lot in their depth (distance from the camera plane) can be considered the interest points (Fig. 2). We can assume that the edge connecting such two points is wrong and therefore it is neccessary to explore the space between them and seek other points for better approximation of the surface.

The level of interest depends on:

- the angle of the edge to the point of view - the smaller the angle, the bigger the level of interest
- the viewing angle of the both end points of the edge - the smaller it is, the bigger is the level of interest
- the distance of the edge to the point of view - the smaller it is, the bigger is the level of interest
- the length of the edge - the bigger it is, the bigger is the level of interest

The importance of the length of the edge will be ommitted here as it depends on the size of the robot and on the requirements for the map. The angle of the edge can be aproximated by the ratio r of distances to both points. This can be combined with the distance to the edge. The thresholds for the ratio have to be set empirically. For example, if $r \in \langle 0, 0.5 \rangle$, the edge will be marked as potentially interesting. If $r \in (0.5, 0.95\rangle$, the edge will be marked as potentially interesting, but it will not be observed by the cameras at this time. If $r \in (0.95, 1\rangle$, the edge will not be marked as interesting, because its distance is too big, or the edge is too short.

The ratio r has to be combined with the viewing angle φ. This will prevent marking the edges that will be observed from point too close to the one of the enpoints as interesting. If the edge satisfies both requirements, it will be marked as interesting and the robot will turn the cameras to observe it. So the conditions that the edge has to fulfill to be marked as interesting and observed are

$$r \in \langle 0, 0.5\rangle \wedge \varphi \in \langle 0, \pi/6\rangle \quad (2)$$

where $r = p_c/p_f$. The further point is p_f and p_c is the closer point. The value $\pi/6$ is again set empirically.

If the edge fulfills only the weaker condition $r \in (0.5, 0.95\rangle$, the edge will be marked as interesting, but since it is not too close or the edge is not too long, it will be observed next time.

It is important to state here that the level of interest has to be recomputed as the robot moves and sees the points again. This is because the robot can move to the place from where the points will have similar depth without seeing any other point between them. This means that these two points can not be longer considered as interest points. On the other hand, if the edge was once marked as non interesting, there is no need to recompute it again. This is because robot already saw the points from the viewpoint from where their depths were similar without seeing any point between them.

The locus of points that fulfills the first condition will form the circle (more exactly the interior of the circle), that is called Apollonian circle. The second condition also forms the Apollonian circle as seen on the Fig. 1.

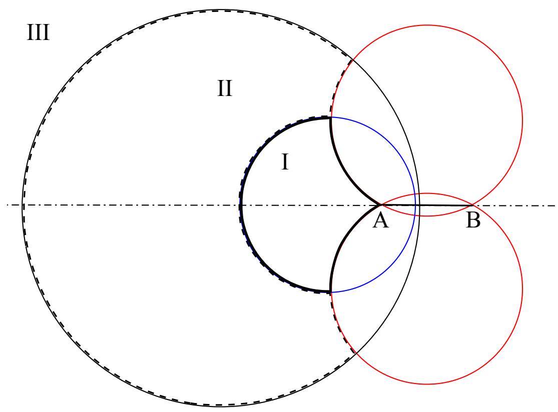

Fig. 1. The Apollonian circles of the points A and B. If the robot is inside the area I, the edge $A - B$ is marked as interesting and it will be observed by cameras. From the area II the edge will also be marked as interesting, but it will not be observed. Outside these two areas the edge will not be marked.

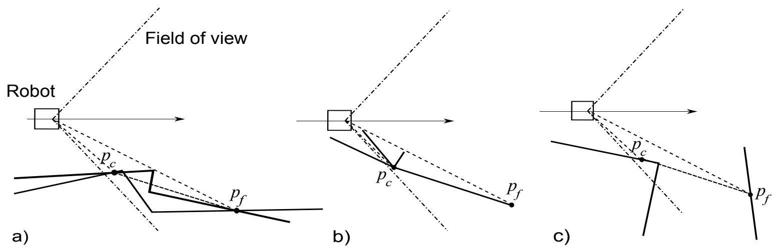

Fig. 2. The examples of the various kinds of surface shapes shown in 2D. There is a robot and its field of view (FOV) shown together with the direction of the robot's move. The points p_c and p_f are closer and further interest points connected by edge (bold dashed line) in the map. The bold solid line shows the possible shapes of surfaces. On the Fig. a) there is the corner between the points p_c and p_f. On the Fig. b) there is an example of the four possible configurations of the thin obstacles (e.g. doors). Only the last one corresponds to the surface shape correctly. On the last Fig. c) there is an exapmple of the two points that are not connected directly in the reality, but they were connected by the edge in the map. This mistake can be corrected by the robot finding other points between these two points.

3.1 Watching of the Pair of the Interest Points

The behavior of the robot should be similar to the behavior of the human when entering new area. The humans look left and right to see as much space as possible and they even can slow down their walk to observe the explored space better.

When the robot detects a pair of the interest points, it will try to keep the closer point in its field of view. This means that from the point c_s the robot will start the rotation of the pan-and-tilt unit. If the velocity v is be too big and the angular rotation of the cameras is not be able to catch turning the stereo-camera to keep the closer point in its field of view, it will slow down its speed v accordingly. The rotation will continue until the cameras reach the maximum angle, which we assume is $90°$. After the robot gets to the point c_m, where the closer point leaves its field of view the cameras will start to turn back to the normal position. The angular velocity of the camera ω and the velocity of the robot v have to be synchronized so in the point c_l the border of the field of the view goes through the further point and is perpendicular to the direction of the movement of the robot. The images here show full rotation of the cameras, but if the robot does not detect any other points between p_c and p_f the cameras will return to the normal position after the edge is recomputed as non-interesting.

The best viewing point the observing the pair of the points of interest would probably be from the line perpendicular to the center of the edge between two points. However, this line does not have to intersect the planned path of the robot or the intersection could be far away. This means that this approach is not suitable, so instead of this, we use the one described previously. The other issue that needs to be solved is the point where to turn the cameras back to the normal

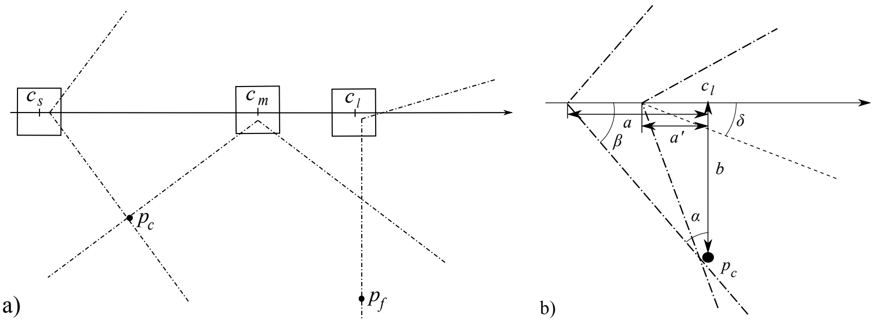

Fig. 3. a) The example of the robot moving from left to right as is indicated by an arrow. On the point c_s the robot starts to turn cameras to right to keep the point p_c in its FOV. On the point c_m the robot lost the point p_c from its FOV and started to turn the cameras back. On the c_l the border of its FOV is perpendicular to the direction of the movement and goes through farther point p_f. At this point the robot loses the point p_f from its FOV. b) The robot starts to turn right in the distance a from the point where the line perpendicular to the direction of the robot intersects the point p_c. In the distance a' the robot is turned in the angle α.

position. The ideal solution would be to keep the cameras turned in their maximum angle until the farther point disappeares. But this would be dangerous, because the robot would not be able to see the space in front of it. On the Fig. 4 we can see that if we start to turn the cameras back after the closer point disappears, the difference between the areas explored using these two ways is minimal compared to the travelled distance.

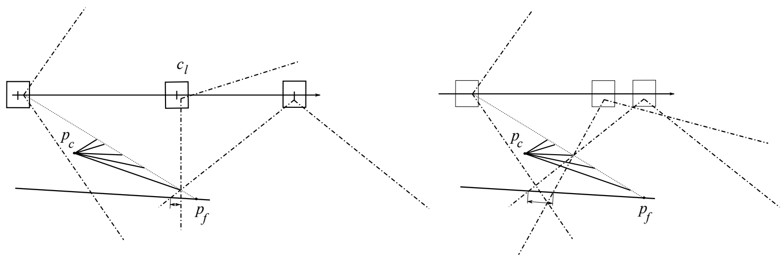

Fig. 4. The difference between the explored area between the robot which is turning its cameras back and the robot that keeps the cameras in the perpendicular position.

The distance a, where the point p_c dissapears from the sight of the robot is

$$a = b\frac{\cos\beta}{\cos\alpha} \tag{3}$$

The angle, that the robot has to turn is then

$$\delta = \frac{\varphi}{2} - \arctan\frac{b}{a} \tag{4}$$

The point c_l can happen to be in front of the point c_m. This would mean, that the robot has to start to turn the cameras before the closer point leaves the field of view. But such behavior is undesirable because it would decrease the explored area, so the starting to turn back at point c_m will have the higher priority than the property that the robot has to see the farther point from the perpendicular angle at the point c_l.

3.2 Alternating Between Left and Right Sides

It is easily conceivable that during the exploration the robot has to look on the other side to explore a new pair of points before it finishes the exploration of the pair of points on the first side.

We can set the human behavior as an ideal example of the exploration. If a human during his walk needs to explore areas on his both sides, he starts to explore the closer one and when he thinks that the other would disappear from his field of view, he remembers the explored area so far, quickly turns head to the other side and explores this side. And again, when he thinks the border of the explored area can disappear, he remembers the explored area on the second side and turns back to see the borders of the previously explored area on the first side. If the two areas (points) are on the levels that are too close, the speed of walking can be decreased up to stopping to explore the areas around him better.

Similarly to the humans, the robot will explore the closer point and start to turn the camera to the other side to explore another point. If it finds that its velocity is too big and it does not catch the other point, it will slow down its speed v accordingly or it can even stop if the two points are on the same level.

A robot is not able to remember the explored area in the way the humans do and then to find the borders again. But it can mark the point P on the edge between two points of interest which was seen from the place from where the border of its field of view was perpendicular to the direction of its movement. After the robot finishes the exploration on the other side, it has to turn back to see this point again. This means, that the farthest position from where the robot can see this point is c_f. This point P_A is the replacement for the remembered borders of the area explored by a human.

4 Vertical Movement of the Cameras

During the exploration, there it can happen that one point from the pair of the interesting points is above the field of view (FOV) of the robot. This situation can also occur when the robot approaches the projection of the point

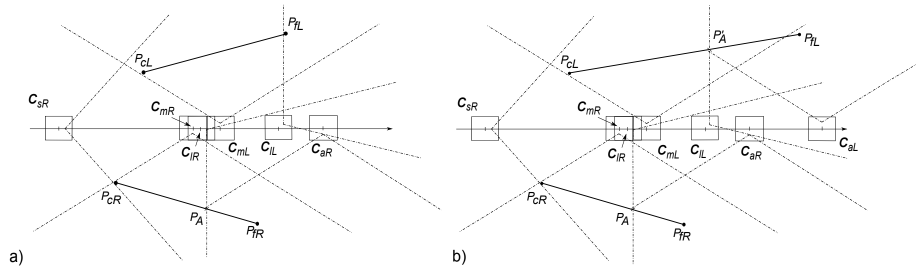

Fig. 5. The robot on the Fig. a) turns the cameras right to watch point p_{cR} as in the previous figure. But between points c_{mR} and c_{mL} it has to slow down and turn cameras 180° left to watch point p_{cL} on the oposite side, which is almost on the same level as the point p_{cR}. As the robot did not complete the exploration of the edge $p_{cR} - p_{fR}$ it marked the point p_A where the perpedicular border of FOV intersected the edge and after exploration of the edge $p_{cL} - p_{fL}$ it turned right to get the point p_A to its FOV again and completed the exploration of the edge $p_{cR} - p_{fR}$. There is a similar example on the Fig. b) but the robot had to turn right to complete the exploration of the right edge before it completed the exploration of the left edge. Therefore it marked the point P'_A on the left edge and after completing the exploration of the right edge it turned back to the left edge to finish its exploration.

to the traversable area. In this situation, the robot should lift the cameras so that the point is in the center of its FOV. The relation between the distance to projection of the point P and the angle of the camera axis can be computed as follows:

$$\alpha = \arctan\left(\frac{h-l}{d}\right) - \frac{\beta}{2} \tag{5}$$

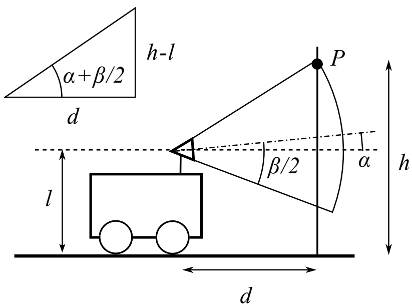

Fig. 6. The robot is observing the point P from the distance d. α is the angle the robot has to lift its camera to get the point P to the field of view.

5 Conclusion

The presented paper shows the way of choosing the most suitable landmark for the observation to explore the unknown area by a robot with a stereocamera using the SLAM algorithm for map making. We also describe the method for observing the interest points which allows the robot to perform the similar behavior as the humans do during the exploration of an unknown environment. This method is based on searching for the interest points and its observing by the cameras on the pan-and-tilt unit. The next work will be testing these proposed methods in the real environment and comparing to the existing methods. The detected points will be also sorted into various cathegories such as floor, walls etc. which will help more sophisticated task planning.

References

1. D. Joho, C. Stachniss, P. Pfaff, and W. Burgard. Autonomous Exploration for 3D Map Learning. In *Autonome Mobile Systeme (AMS)*, pages 22–28. Springer, 2007.
2. J. J. Leonard and H. F. Durrant-Whyte. Simultaneous Map Building and Localization for an Autonomous Mobile Robot. In *Proc. IEEE Int. Workshop on Intelligent Robots and Systems (IROS)*, pages 1442–1447, 1991.
3. M. Montemerlo, S. Thrun, D. Koller, and B. Wegbreit. FastSLAM: A Factored Solution to the Simultaneous Localization and Mapping Problem. In *Proceedings of the AAAI National Conference on Artificial Intelligence*, pages 593–598. AAAI, 2002.
4. H. Moravec and A. Elfes. High Resolution Maps from Wide Angle Sonar. In *Proceedings of International Conference on Robotics and Automation (ICRA)*, pages 116–121, 1985.
5. P. Moutarliere and R. Chatila. Stochastic Multisensory Data Fusion for Mobile Robot Location and Environment Modeling. In *5th International Symposium on Robotics Research*, pages 85–94, Tokyo, 1989.
6. R. Sim and J. L. Little. Autonomous Vision-based Exploration and Mapping Using Hybrid Maps and Rao-Blackwellised Particle Filters. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (2006)*, pages 2082–2089. IEEE, 2006.
7. R. Smith and P. Cheeseman. On the Representation and Estimation of Spatial Uncertainty.
8. C. J. Taylor and D. J. Kriegman. Exploration Strategies for Mobile Robots. In *Proceedings of the International Conference on Robotics and Automation (ICRA)*, pages 248–253, 1993.
9. S. Thrun, W. Burgard, and D. Fox. *Probabilistic Robotics*. MIT Press, 2005.
10. W.D.Renken. Concurrent Localization and Map Building for Mobile Robots Using Ultrasonic Sensors. *Proc. IEEE Int. Workshop on Intelligent Robots and Systems (IROS)*, 1993.
11. B. Yamauchi. A frontier-based Approach for Autonomous Eexploration. In *Proceedings of the 1997 IEEE International Symposium on Computational Intelligence in Robotics and Automation*, pages 146–151, Washington, DC, USA, 1997. IEEE Computer Society.