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MULTIPLE INDOOR ROBOT LOCALIZATION USING INFRARED BEACONS

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Abstract: *Mobile robot localization based on active artificial landmarks is well established robust technique in indoor mobile robotics. This paper explores the extension of the method to multiple robot localization, with the key idea of using the robots themselves as the artificial landmarks, supplying other robots in the group with its estimate of position. The method uses nonlinear version of Kalman filter for determination of position estimate in 2D space, x-y coordinates and angle with respect to global coordinate system, with the estimate represented by mean values and corresponding covariances. Simulation results based on model well verified with the real system suggest that while only small reduction of number of fixed active landmarks can be achieved, the main advantage of the method is in increased robustness of localization technique with respect to obscured landmarks fields of view.*

Keywords: Mobile robot, Indoor localization, Kalman filter, Infrared beacons.

1. Introduction

Determination of autonomous mobile robot position – localization – is essential task in robot navigation. There is a number of approaches to the task, most common ones include some kind of landmark detection, with active artificial landmarks being the most reliable in spite its disadvantage of the need to put such landmarks into environment.

In past few years the focus of robotic community moves towards the multiple robots cooperation, used e.g. for advanced mapping, when a group of robots maps the surrounding areas with either vision or rangefinder based systems and such information is fused to get complete map of environment (Saeedi et.al. 2011). Regarding localization, artificial landmarks approach is ideal for multiple robots, see e.g. Park & Kee (2011), proposing an indoor localization system for a wide service area divided into multiblocks for reliable sensor operation.

The idea behind the method introduced in this paper is to place active artificial landmark onto each robot in the group, creating moving beacon, that can serve as additional source of information for localization. On contrary to relative localization (Mao, 2013), the moving beacon information is fused with the static beacons to enhance the robustness of global localization.

2. Infrared Beacons Based Localization

Infrared beacons based localization determines the position $\mathbf{x}_k = \left[x_k^R, y_k^R, \varphi_k^R \right]^T$ of the robot on 2D plane in *k* step using the model of the robot response to actions $\mathbf{u}_k = \left[u_k^t, u_k^r \right]$ represented by translational u_k^t and rotational u_k^r velocities and the measurement of relative angle between the robot and detected beacon,

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placed in known position $\mathbf{x}_{bi} = \left[x_{bi}, y_{bi}\right], i = 1, 2, ..., N$, see Fig. 1. The position of the robot is represented by simple unimodal Gaussian approximation.

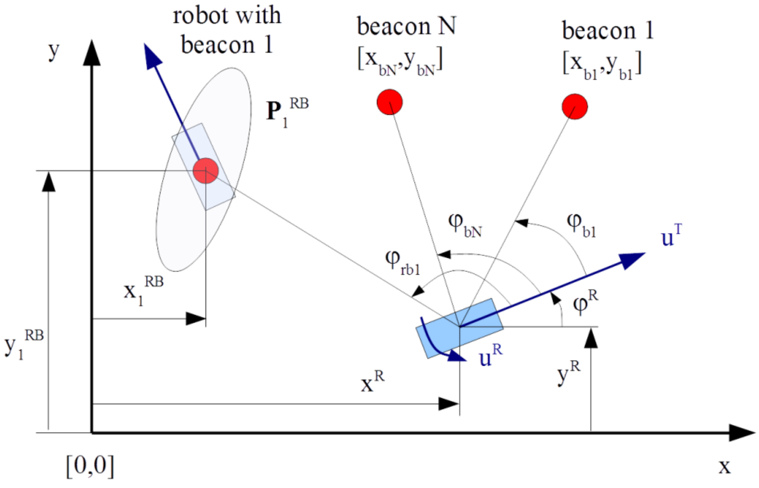

Fig. 1: Robot state definition, static beacons and additional robot with beacon attached.

The model is defined in (1) and (2), where $\mathbf{v}_k$ is white Gaussian process noise with zero mean and covariance matrix $\mathbf{V}_k$, $\mathbf{y}_k$ is system output, $\mathbf{w}_k$ is corresponding measurement noise with zero mean and covariance matrix $\mathbf{W}_k$ and f and h are continuously differentiable nonlinear functions. The state transition function f defines how the state changes when action is applied:

$$\mathbf{x}_{k+1} = f\left(\mathbf{x}_k, \mathbf{u}_k\right) + \mathbf{v}_k = \begin{bmatrix} \cos\varphi_k^R u_k^t \Delta t + x_k^R \\ \sin\varphi_k^R u_k^t \Delta t + y_k^R \\ u_k^r \Delta t + \varphi_k^R \end{bmatrix} + \mathbf{v}_k \tag{1}$$

and for N measurements of beacon relative angle the output is:

$$\mathbf{y}_k = \begin{bmatrix} h_1\left(\mathbf{x}_k, \mathbf{x}_{b1}\right) \\ \vdots \\ h_N\left(\mathbf{x}_k, \mathbf{x}_{bN}\right) \end{bmatrix} + \begin{bmatrix} \mathbf{w}_{1k} \\ \vdots \\ \mathbf{w}_{Nk} \end{bmatrix} \tag{2}$$

with single beacon measurement

$$h_1\left(\mathbf{x}_k, \mathbf{x}_{b1}\right) = \left[\operatorname{atan2}\left(y_k^R - y_{b1}, x_k^R - x_{b1}\right) - \varphi_k^R\right] \tag{3}$$

As the state can not be determined exactly, the state estimate is used instead, defined by its mean $\hat{\mathbf{x}}_k$ and covariance matrix $\mathbf{P}_k$. Nonlinear version of Kalman filter, either EKF or UKF can be used to find such estimate, see the details in Krejsa & Vechet (2012).

3. Multiple Robots Localization

The simple extension for multiple robots localization is trivial, all the robots will receive successive measurements from all the beacons. The beacon identification problem is solved by one way communication from the robot to the beacon, therefore the only issue with the extension is to select one robot as the group leader, communicating with the beacons, while other robots receive the issued emitting command and consequently read the relative angle measured.

This simple approach can be further extended by placing additional beacon on top of each robot. The motivation is straight-forward: such dynamic beacon can provide other robots with additional information, that is particularly advantageous in cases when some of the beacons are out of receivers field of view, or remaining visible static beacons are in undesirable geometric configuration (keep in mind that only bearing information is available for infrared beacons, not the distance).

However, some issues arise when dynamic beacons are introduced. First of all, the communication between the robots has to enable to transmit and receive the estimate of *i-th* robot position $\hat{\mathbf{x}}_{ik}^{RB}$, $\mathbf{P}_{ik}^{RB}$. As the robots have to receive the beacon identification commands anyway, it is not difficult to extend the communication protocol. Second issue arises with the increased number of beacons increasing the time delay in single round through all the beacons, therefore the number of robots is limited due to technological limitations. The last remaining issue arises from the uncertainty in dynamic beacon position. The measurement from dynamic beacons therefore has to be handled differently, taking into account the covariances $\mathbf{P}_{ik}^{RB}$.

In Extended Kalman filter correction step, the update is given as:

$$\begin{aligned}\hat{\mathbf{x}}_{k+1|k+1} &= \hat{\mathbf{x}}_{k+1|k} + \mathbf{K}_{k+1}\tilde{\mathbf{y}}_{k+1} \\ \mathbf{P}_{k+1|k+1} &= \mathbf{P}_{k+1|k} - \mathbf{K}_{k+1}\mathbf{H}_{k+1}\mathbf{P}_{k+1|k}\end{aligned} \tag{4}$$

where Kalman gain $\mathbf{K}_{k+1} = \mathbf{P}_{k+1|k}\mathbf{H}_{k+1}^T\mathbf{S}_{k+1}^{-1}$ needs the partial derivatives of measurement function *h* and $\mathbf{S}_{k+1} = \mathbf{H}_{k+1}\mathbf{P}_{k+1|k}\mathbf{H}_{k+1}^T + \mathbf{W}_{k+1}$. The covariance matrix $\mathbf{W}_{k+1}$ for static beacons is simply consisting of variances in each beacon detection, see Krejsa & Vechet (2012) for technical details. For dynamic beacons there are two variances that need to be taken into account. The one from the measurement itself and the one from the uncertain position of the dynamic beacon. The state of the beacon carrying robot is available, it consists of the mean $\hat{\mathbf{x}}_{ik}^{RB}$ and covariance matrix $\mathbf{P}_{ik}^{RB}$. Due to the nature of infrared beacons and corresponding receiver, the information about the angle is irrelevant, therefore the problem is narrowed to determination of the variance in position. To do so, let's extract the position information $\mathbf{x}_{ij}^{RBP} = \hat{\mathbf{x}}_{ik}^{RB}(1,2) = \begin{bmatrix} x^{RBP} & y^{RBP} \end{bmatrix}^T$ and $\mathbf{P}_{ik}^{RBP} = \mathbf{P}_{ik}^{RB}(1,1)...\mathbf{P}_{ik}^{RB}(2,2)$. With position of the robot we are investigating being $\mathbf{x}_k^R = \hat{\mathbf{x}}_k^R(1,2) = \begin{bmatrix} x^R & y^R \end{bmatrix}$, the variance is determined as:

$$\mathbf{W} = \mathbf{C}\mathbf{P}_{ik}^{RBP}\mathbf{C}^T \tag{5}$$

where matrix $\mathbf{C}$ corresponds to unit vector perpendicular to the direction vector from the robot to dynamic beacon, calculated from the means of corresponding position estimates. In particular $\mathbf{C} = \begin{bmatrix} -y^{RBP} + y^R & x^{RBP} + x^R \end{bmatrix}$.

4. Simulations and Results

The above described approach was implemented in Matlab and number of simulations were performed. Simulation model is based on the model developed for presentation robot Advee (Krejsa et al., 2012) and as such the model was thoroughly modified to correspond with the real robot, including the localization method. Therefore in spite the fact that following results are based on simulation only, we have high level of confidence in overall correctness.

The experiments were organized as follows. Each robot was placed on random initial position. Goals were generated for each robot randomly, whenever the goal was reached the new goal was generated. Motion planner used was simple FSM based with obstacle avoidance, including other robots, no dynamic obstacles apart from the robots were present. Four static beacons were placed in map corners and beacon detection took into account the visibility of the beacon. Independently on beacon visibility the probability of the beacon to be detected was gradually increased in $\langle 0.1, 1 \rangle$ interval. Dynamic beacons visibility was also taken into account and the probability of dynamic beacon to emit the signal was set to 0.5. Experiments were performed in two groups, with and without the use of dynamic beacons.

Example of localization courses with 5 robots without and with dynamic beacons is shown on left of Fig. 2. Ellipses correspond to 99% confidence interval. Localization error is clearly reduced for the case with dynamic beacons and more importantly, the size of confidential ellipses shows that uncertainty is reduced as well.

The overall results are shown on graph in right side of Fig. 2. Total of 1000 simulations were performed for each configuration. Shown results use percentage of maximum error exceeding given limit in distance error; angular error is much smaller, as the available information is angular. The improvement is obvious, however there is not much difference between 3 and 5 dynamic beacons, partially due to the uncertainty in robots position and partially due to delays in data processing caused by higher number of measurements.

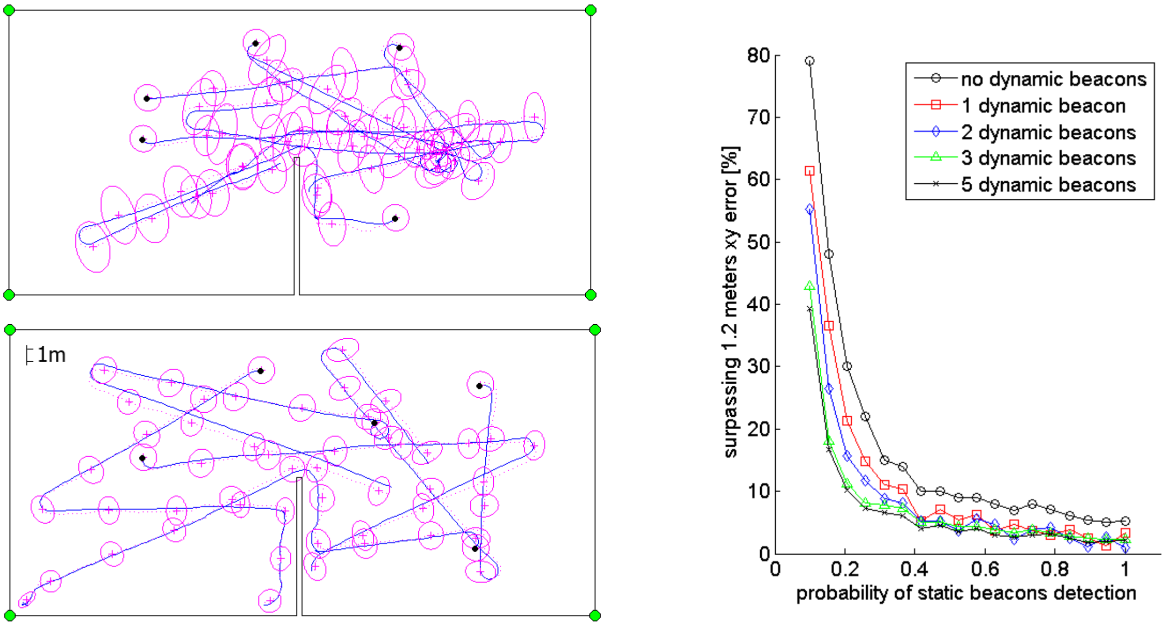

Fig. 2: Example of localization courses of individual robots, with static beacons only (top left), static+dynamic (bottom left). Quality of localization in percentage of surpassing certain maximum error.

5. Conclusions

The paper presented method improving the bearing only beacon based localization for multiple robots by introducing dynamic beacons carried by the robot themselves. Incorporation of dynamic beacon uncertainty in robot position was presented, extracting the necessary variation as linear function of 3D normal probability distribution.

The results show that improvement of precision and robustness is achieved, on the cost of higher technological demands on inter-robot communication. The method is suitable mainly for larger areas with obstacles covering certain portions of static beacons field of view.

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