CBGL: Fast Monte Carlo Passive Global Localisation for 2D LIDAR sensors

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***Abstract*— Lorem Ipsum is simply dummy text of the printing and typesetting industry. Lorem Ipsum has been the industry's standard dummy text ever since the 1500s, when an unknown printer took a galley of type and scrambled it to make a type specimen book. It has survived not only five centuries, but also the leap into electronic typesetting, remaining essentially unchanged. It was popularised in the 1960s with the release of Letraset sheets containing Lorem Ipsum passages, and more recently with desktop publishing software like Aldus PageMaker including versions of Lorem Ipsum. Lorem Ipsum is simply dummy text of the printing and typesetting industry.**

***Index Terms*— global localisation, 2D LIDAR, monte carlo, scan–to–map-scan matching**

I. Introduction

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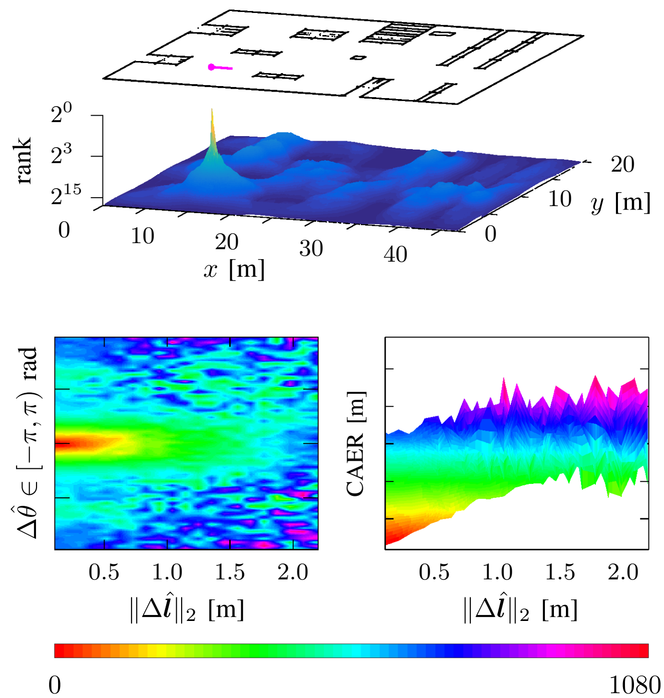

Fig. 1: Top: a map of an environment, the pose of a panoramic 2D LIDAR sensor (magenta), and the corresponding rank field below them. Bottom: distribution of CAER values by location and orientation error of all sensor pose estimates corresponding to the rank field above, for estimate distances up to 2.0 m. CBGL leverages the relationship of proportionality between the pose estimate error and the value of the CAER metric for pose estimates in a neighbourhood of the origin (and the relationship of indifference outside of that neighbourhood): pose hypotheses dispersed within the map and ranked ascendingly according to the value of that metric produce a $\texttt{r}$(ank)-field, which may be used to identify quickly and uniquely a pose estimate of the sensor

II. Definitions and Problem Formulation

Definition I. *Range scan captured from a 2D LIDAR sensor.*—A conventional 2D LIDAR sensor provides a finite number of ranges, i.e. distances to objects within its range, on a horizontal cross-section of its environment, at regular angular and temporal intervals, over a defined angular range [1]. A range scan $\mathcal{S}$, consisting of N_s rays over an angular range λ, is an ordered map $\mathcal{S} : \Theta \rightarrow \mathbb{R}_{\geq 0}$, $\Theta = \{\theta_n \in [-\frac{\lambda}{2}, +\frac{\lambda}{2}) : \theta_n = -\frac{\lambda}{2} + \lambda \frac{n}{N_s},\ n = 0, 1, \dots, N_s{-}1\}$. Angles θ_n are expressed relative to the sensor's heading, in the sensor's frame of reference.

Definition II. *Map-scan.*—A map-scan is a virtual scan that encapsulates the same pieces of information as a scan derived from a physical sensor. Only their underlying operating principle is different due to the fact the map-scan refers to distances to the boundaries of a point-set, referred to as the map, rather than within a real environment. A map-scan $\mathcal{S}_V^{\boldsymbol{M}}(\hat{\boldsymbol{p}})$ is derived by means of locating intersections of rays emanating from the estimate of the sensor's pose estimate $\hat{\boldsymbol{p}}$ and the boundaries of the map $\boldsymbol{M}$.

Definition III. *CAER as metric.*—Let $\mathcal{S}_p$ and $\mathcal{S}_q$ be two range scans, equal in angular range λ and size N_s. The value of the Cumulative Absolute Error per Ray (CAER) metric $\psi \in \mathbb{R}_{\geq 0}$ between $\mathcal{S}_p$ and $\mathcal{S}_q$ is given by

$$\psi(\mathcal{S}_p, \mathcal{S}_q) \triangleq \sum_{n=0}^{N_s-1} \Big| \mathcal{S}_p[n] - \mathcal{S}_q[n] \Big|$$

Definition IV. *CAER as field.*—A ψ-field on map $\boldsymbol{M}$ $f_\psi^{\boldsymbol{M}} : \mathbb{R}^2 \times [-\pi, +\pi) \rightarrow \mathbb{R}_{\geq 0}$ is a mappping of 3D pose configurations $\hat{\boldsymbol{p}}(\hat{x}, \hat{y}, \hat{\theta})$ to CAER values (def. III) such that if $\psi(\mathcal{S}_R, \mathcal{S}_V^{\boldsymbol{M}}(\hat{\boldsymbol{p}})) = c$ then $f_\psi^{\boldsymbol{M}}(\hat{\boldsymbol{p}}) = c$. In other words a CAER field is produced by computing the value of the CAER metric between a range scan $\mathcal{S}_R$ (def. I) and a map-scan $\mathcal{S}_V^{\boldsymbol{M}}(\hat{\boldsymbol{p}})$ captured from pose configuration $\hat{\boldsymbol{p}}$ within map $\boldsymbol{M}$ (def. II).

Definition V. *Field densities.*— angular density locational density ??

Definition VI. *Rank field.*—Let $f_\psi^{\boldsymbol{M}}$ be a ψ-field on map $\boldsymbol{M}$ and $\mathcal{P} = \{\hat{\boldsymbol{p}}_i\}$, $i \in \mathtt{I} = \langle 0, 1, \dots, |\mathcal{P}| - 1 \rangle$, where the notation $\langle \cdot \rangle$ denotes an ordered set, be a set of 3D pose configurations within map $\boldsymbol{M}$, such that $f_\psi^{\boldsymbol{M}}(\mathcal{P}) = \Psi$. Let $\Psi_\uparrow$ denote set Ψ ordered in ascending order and $\mathtt{I}^*$ be the set of indices such that $\Psi[\mathtt{I}^*] = \Psi_\uparrow$ (where the bracket notation $\Psi[\mathtt{I}] = \Psi$). A $\mathtt{r}$-field on map $\boldsymbol{M}$ $f_\mathtt{r}^{\boldsymbol{M}} : \mathbb{R}^2 \times [-\pi, +\pi) \rightarrow \mathbb{Z}_{\geq 0}$ is a mapping of 3D pose configurations $\mathcal{P}$ to non-negative integers such that if $f_\psi^{\boldsymbol{M}}(\mathcal{P}) = \Psi$ then $f_\mathtt{r}^{\boldsymbol{M}}(\mathcal{P}) = \mathtt{I}^*$ (equivalently: $f_\mathtt{r}^{\boldsymbol{M}}(\mathcal{P}[\mathtt{I}^*]) = \mathtt{I}$). In other words a rank field maps the elements of pose estimate set $\{\hat{\boldsymbol{p}}_i\}$ to the ranks $\mathtt{I}^*$ of their corresponding CAER values in hierarchy $\Psi_\uparrow$.

Problem P. Let the unknown pose of an immobile 2D range sensor whose angular range is λ be $\boldsymbol{p}(x, y, \theta)$ with respect to the reference frame of map $\boldsymbol{M}$. Let the range sensor measure range scan $\mathcal{S}_R$. The objective is the estimation of $\boldsymbol{p}$ given $\boldsymbol{M}$, λ, and $\mathcal{S}_R$.

III. Prior Work

IV. Approach

Hypothesis H. Let the unknown pose of a 2D range sensor measuring range scan $\mathcal{S}_R$ (def. I) be $\boldsymbol{p}(x, y, \theta)$ with respect to the reference frame of map $\boldsymbol{M}$. Let $\mathcal{H}$ be a set of pose hypotheses within the free (i.e. traversable) space of $\boldsymbol{M}$: $\mathcal{H} = \{\hat{\boldsymbol{p}}_i(\hat{x}_i, \hat{y}_i, \hat{\theta}_i)\} \subseteq \mathtt{free}(\boldsymbol{M})$, $i = 0, 1, \dots, |\mathcal{H}| - 1$; $\mathbb{S}$ be the set of map-scans (def. II) of $\boldsymbol{M}$ from pose hypotheses $\mathcal{H}$: $\mathbb{S} = \{\mathcal{S}_V^{\boldsymbol{M}}(\hat{\boldsymbol{p}}_i)\}$; and Ψ be the set of CAERs (def. III) between $\mathcal{S}_R$ and the elements of $\mathbb{S}$: $\Psi = \{\psi(\mathcal{S}_R, \mathcal{S}_V^{\boldsymbol{M}}(\hat{\boldsymbol{p}}_i))\}$. Then there exist $\delta_0, \psi_0 \in \mathbb{R}_{>0}$ which define a set of pose

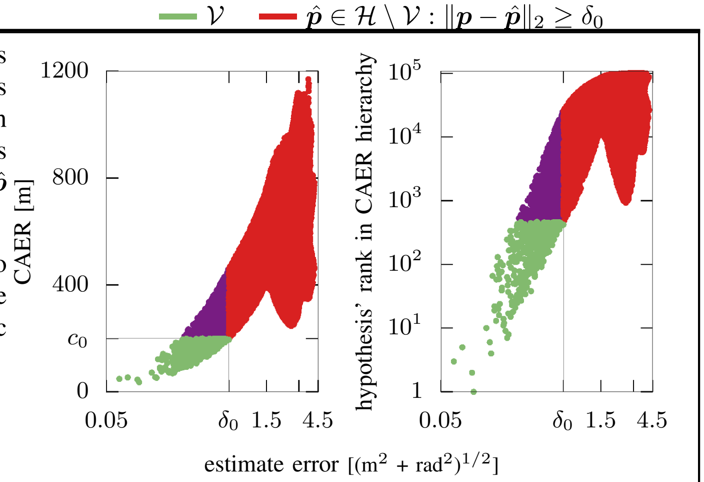

Fig. 2:

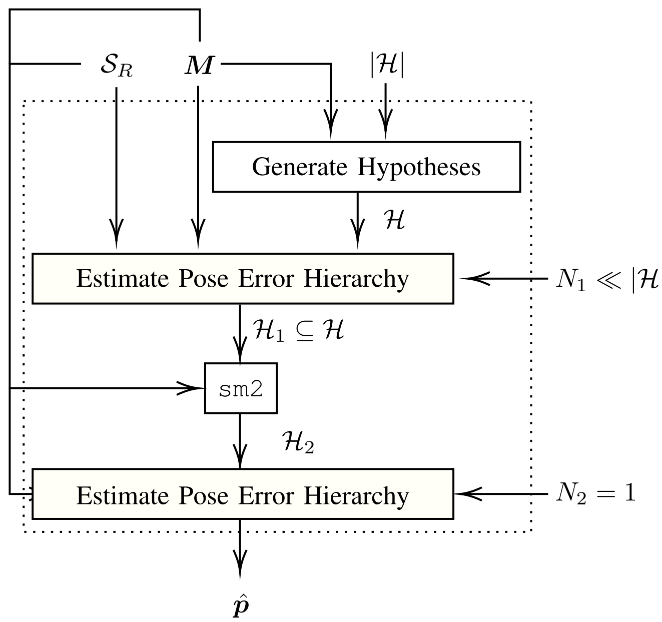

Fig. 3:

estimates $\mathcal{V} \subseteq \mathcal{H}$ such that

$$\|\boldsymbol{p} - \hat{\boldsymbol{p}}_\mathcal{V}\|_2 < \delta_0 \text{ and}$$
$$\psi(\mathcal{S}_R, \mathcal{S}_V^{\boldsymbol{M}}(\hat{\boldsymbol{p}}_\mathcal{V})) < \psi_0$$

for all $\hat{\boldsymbol{p}}_\mathcal{V} \in \mathcal{V}$, for which

$$\psi(\boldsymbol{p}, \hat{\boldsymbol{p}}_\mathcal{V}) < \psi(\boldsymbol{p}, \hat{\boldsymbol{p}}) \quad \Leftrightarrow$$
$$\|\boldsymbol{p} - \hat{\boldsymbol{p}}_\mathcal{V}\|_2 < \|\boldsymbol{p} - \hat{\boldsymbol{p}}\|_2$$

for any $\hat{\boldsymbol{p}} \in \mathcal{H} \setminus \mathcal{V} : \|\boldsymbol{p} - \hat{\boldsymbol{p}}\|_2 \geq \delta_0$.

Remark I. The composition of $\mathcal{H} = \mathcal{V} \cup \mathcal{X} \cup \mathcal{W}$, where $\mathcal{X} = \hat{\boldsymbol{p}} \in \mathcal{H} \setminus \mathcal{V} : \|\boldsymbol{p} - \hat{\boldsymbol{p}}\|_2 \geq \delta_0$ and $\mathcal{W} = \hat{\boldsymbol{p}} \in \mathcal{H} \setminus \mathcal{V} : \|\boldsymbol{p} - \hat{\boldsymbol{p}}\|_2 < \delta_0$. With respect to set $\mathcal{W}$ ... ??

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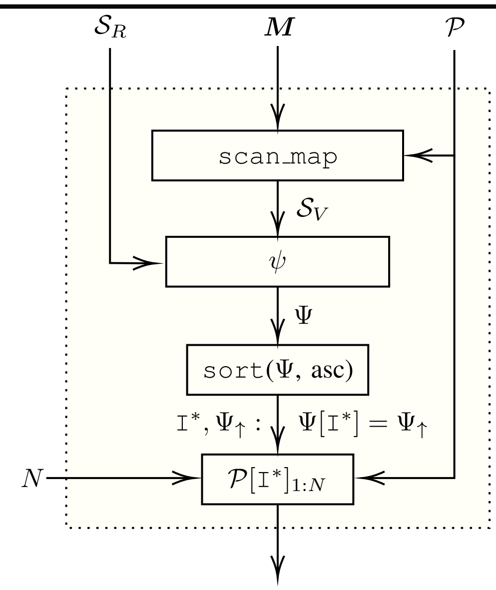

$$\mathcal{Q} \subseteq \mathcal{P}\colon\, \mathcal{Q} = \mathcal{P}[\mathtt{I}^*]_{1:N},\, |\mathcal{Q}| = N$$

Fig. 4:

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V. Results

VI. Characterisation

VII. Conclusions and Future Steps

References

[1] M. Cooper, J. Raquet, and R. Patton, "Range Information Characterization of the Hokuyo UST-20LX LIDAR Sensor," *Photonics*, 2018.