Fusion Engineering and Design xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Research on localization and alignment technology for transfer cask

Jingchuan Wang [a,b,*], Ming Yang [a,b], Weidong Chen [a,b]

[a] Department of Automation, Shanghai Jiao Tong University, Shanghai, China
[b] Key Laboratory of System Control and Information Processing, Ministry of Education of China, Shanghai, China

HIGHLIGHTS

- A method for the alignment between TB and HCB based on localizability is proposed.
- A localization method based on the localizability estimation is proposed to realize the cask's localization accurately and ensures the transfer cask's accurate docking in the front of the window of Tokmak Building.
- The experimental results show that the proposed algorithm works well in the indoor simulation environment. This system will be test in EAST of China.

ARTICLE INFO

Article history:
Received 18 September 2014
Received in revised form 27 May 2015
Accepted 30 June 2015
Available online xxx

Keywords:
Localization
Navigation
Alignment
Transfer cask

ABSTRACT

According to the long length characteristics of transfer cask compared to the environment space between Tokmak Building (TB) and HCB (Hot Cell Building), this paper proposes an autonomous localization and alignment method for the internal components transportation and replacement. A localization method based on the localizability estimation is used to realize the cask's localization and navigation accurately. Once the cask arrives at the front of the TB window, the position and attitude measurement system is used to detect the relative alignment error between the seal door of pallet and the window of TB real-time. The alignment between seal door and TB window could be realized based on this offset. The simulation experiment based on the real model is designed according to the real TB situation. The experiment results show that the proposed localization and alignment method can be used for transfer cask.

1. Introduction

During plasma discharge in Tokmak Building (TB), the internal components may be suffered from contamination of gamma-ray and tritium [1]. The transfer cask carrying pallet and alignment pins is used to navigate between TB and HCB, and to dock at the window of TB for components replacement. The casks may contain different in-vessel components (e.g. blanket modules, diverters, and etc.) and are designed for a maximum load of 80ton approximately [2]. However, due to the harsh environment, all the transportation operation should be carried automatically or remotely controlled, such as the localization and navigation of the casks and the alignment of the sealed door of cask [3,4].

In this paper a localizability estimation method in probabilistic grid map for the transfer cask is proposed. Based on paper [5], the Fisher Information Matrix (FIM) of cask localization is transformed into discrete form, and a static localizability matrix suitable for off-line estimation based on known grid map is obtained. On this basis, the impact factor of locally sensed unknown obstacles is adopted to modify the static localizability matrix, and a dynamic localizability matrix is proposed for on-line estimation to deal with unexpected dynamic changes of environments. This matrix describes both the localizability index and localizability direction of cask quantitatively. Based on the localizability analysis, an improved particle filter localization algorithm is presented and implemented.

For the huge size and heavy weight of a transfer cask, the alignment between the transfer cask and the windows of TB has to be extremely precise. So, an alignment method is proposed based on the eight laser sensor's measure also.

2. System description

The casks transfer the internal components and devices between the various ports of the TB and HCB. As shown in Fig. 1, the transfer cask consists of two parts: container, and hovercraft.

The hovercraft which locates under the container and carries the whole system, navigates between TB and HCB. For the autonomous

* Corresponding author at: Department of Automation, Shanghai Jiao Tong University, Shanghai, China.
E-mail address: jchwang@sjtu.edu.cn (J. Wang).

http://dx.doi.org/10.1016/j.fusengdes.2015.06.160
0920-3796/

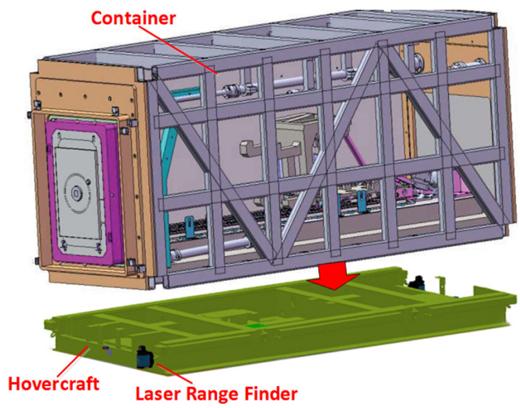

Fig. 1. System description of transfer cask.

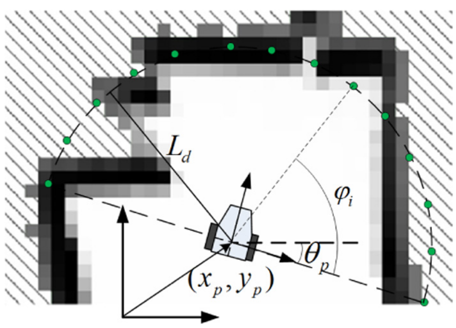

Fig. 2. Scan model of laser range finder.

navigation, the Laser Range Finder is fixed in the front of the hovercraft, which is used to gather the environmental information. The container will complete its alignment by the adjustment of hovercraft [6].

3. Localization method

As shown in Fig. 2, $\boldsymbol{P} = [x_p, y_p, \theta_p]$ is the cask's position. After drawing the circle with center P and radius equal to the scan distance of LRF, we can get the boundary of laser scan as:

$$(x - x_p)^2 + (y - y_p)^2 = L_d{}^2 \quad (1)$$

In Fig. 3, the cask is put at the reference position: $\boldsymbol{P}_0 = [x_0, y_0, \theta_0]$. r_i is the measurement of No. i laser ray.

As the indicator of unknown obstacles, we define:

$$s_i = 1 - p(A|r_i) \quad (2)$$

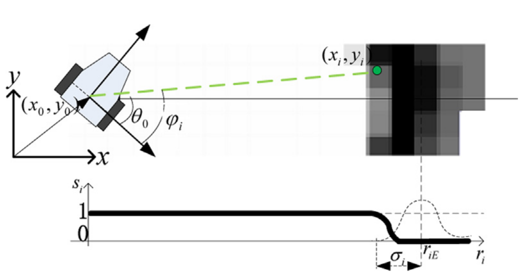

Fig. 3. On-line laser ray's data.

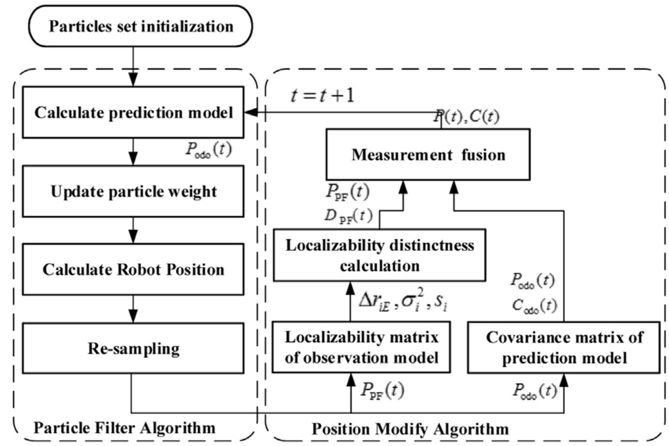

Fig. 4. Framework of improved particle filter localization.

It is the probability of laser rays scan the unknown obstacles. The relationship between s_i and r_i is also shown in Fig. 3. Then, the dynamic localizability matrix $D(P)$ could be calculated as:

$$\boldsymbol{D}(\boldsymbol{P}) = \sum_i^n \frac{1 - s_i}{\sigma_i{}^2} \begin{bmatrix} \dfrac{\Delta r_{iE}{}^2}{\Delta x^2} & \dfrac{\Delta r_{iE}{}^2}{\Delta x \Delta y} & \dfrac{\Delta r_{iE}{}^2}{\Delta x \Delta \theta} \\ \dfrac{\Delta r_{iE}{}^2}{\Delta x \Delta y} & \dfrac{\Delta r_{iE}{}^2}{\Delta y^2} & \dfrac{\Delta r_{iE}{}^2}{\Delta y \Delta \theta} \\ \dfrac{\Delta r_{iE}{}^2}{\Delta x \Delta \theta} & \dfrac{\Delta r_{iE}{}^2}{\Delta y \Delta \theta} & \dfrac{\Delta r_{iE}{}^2}{\Delta \theta^2} \end{bmatrix} \quad (3)$$

The eigenvalue and eigenvector of $D(P)$ is $\left\{\lambda_D^i, \boldsymbol{p}_D^i\right\}_{i=1,2,3}$

Based on the localizability matrix $D(P)$ of the LRF observation model, an Improved Particle Filter (IPF) localization method [7] is used for the transfer cask navigation. The IPF framework is shown in Fig. 4.

On one hand, this algorithm estimates the belief of laser range finder observations using the localizability matrix of observation model. On the other hand, it also estimates the belief of the odometer data using the covariance matrix of prediction model. Thus, based on these two indicators, the predicted cask position is modified according to the observed information.

3.1. Localizability matrix estimation

Based on Eq. (3), The localizability matrix $\boldsymbol{D}_{\mathrm{PF}}(\boldsymbol{P})$ of observation model for particle filter algorithm can be defined as:

$$\boldsymbol{D}_{PF}(\boldsymbol{P}) = k_P D(\boldsymbol{P}) \quad k_P < 1 \quad (4)$$

$$k_P = 1 - \frac{1}{\log \ n_P} \quad (5)$$

3.2. Covariance estimation of prediction model

Transfer cask could be regarded as a mobile robot, the kinematic model of differential-drive mobile robots [8] is:

$$\begin{bmatrix} v \\ \omega \end{bmatrix} = \boldsymbol{C} \begin{bmatrix} \omega_R \\ \omega_L \end{bmatrix} \quad \boldsymbol{C} = \begin{bmatrix} r_R/2 & r_L/2 \\ r_R/b & -r_L/b \end{bmatrix} \quad (6)$$

v, ω, linear velocity and angular velocity; ω_R, ω_L, angular velocities of right and left wheels; r_R, r_L, the radius of the right and left wheels; b, the distance of right and left wheels.

Let, $L_R = Tr_R\omega_R$, $L_L = Tr_L\omega_L$. They are the distance of two wheels travel in a period T.