Extended Kalman Filter with Adaptive Measurement Noise Characteristics for Position Estimation of an Autonomous Vehicle

A. Khitwongwattana and T. Maneewarn

Abstract—This paper proposes the position estimation method of an autonomous vehicle on flat terrain, which is based on playback navigation algorithm. The proposed method is sensor fusion using the extended Kalman Filter (EKF) for state estimation from the low-cost Global Positioning System (GPS) receiver and incremental encoder. The Singular Value Decomposition (SVD) is applied to evaluate the adaptive measurement noise covariance in the EKF. This improves the accuracy of estimation to correspond to the errors involved along various portions of the trajectory instead of using fixed values. The result showed that the proposed method can improve an accuracy of position estimation of autonomous vehicle on flat terrain.

I. INTRODUCTION

There are various autonomous vehicle navigation methods such as vision based navigation [1], line following using opto-sensor and magnet based navigation [2]. A Playback algorithm [3] is another way of the navigation system that the vehicle can learn course data by only manually driven on a path without environment modified. The playback algorithm can be applied for an autonomous vehicle that regularly works on the repeated or specified path.

This report focuses on integrating data from a low-cost GPS receiver and dead reckoning to construct a reference path of the playback navigation scheme. By considering the steering encoder gives the steering angle data and the wheel encoder provides the traveled distance of the vehicle. The GPS receiver provides global position and orientation of vehicle. However, the GPS data can subject to degradation in the presence of signal blockage, interference and multipath [4].

The extended Kalman filter has been the extensively used in the field of sensor fusion and navigation [5], [6], [7]. The filter is based upon the principle of linearizing the state transition matrix and the observation matrix with Taylor series expansions. The divergence problem can occur if the theoretical and actual behavior of a filter does not agree [8]. This paper intends to improve estimation by using the pre-record GPS data from several receivers. Data sets were clustered and their covariance matrix is evaluated by the SVD technique. Then, the extended Kalman filter was updated with variable covariance noise measurement instead of using a constant matrix. The result shown adaptive sensor noise covariance can minimize the divergence problem which the actual error of sensor approaches a larger bound than the predicted one.

II. METHODOLOGY

A. Hierarchical Data Clustering

GPS data are clustered into small group along the path using hierarchy clustering (Agglomerative) by considering the similarity between every pair of objects in the data set. The idea of method is firstly consider each data as a distinct (singleton) cluster and successively merges clusters together until a stopping criterion is satisfied.

Mahalanobis distance is used to find the similarity. Where the distance from a group of values with means ($\mu$)

$$
\mu = (\mu_x, \mu_y, \mu_z, ..., \mu_p)^T
$$

and covariance matrix $P$ for a multivariate vector $x = (x_1, x_2, x_3, ..., x_p)^T$. It can define as

$$
D_{mah} (x) = \sqrt{(x - \mu)^T P^{-1} (x - \mu)}. \tag{1}
$$

The object is grouped into a binary, hierarchical cluster tree by linking the pairs of objects that are in close proximity together with determining the Weighted Pair Group Method Using Arithmetic Average (WPGMA). The newly formed clusters were linked into larger clusters until a hierarchical tree is formed. The distance between this closest pair of groups is compared to the threshold value. If the distance between this closest pair is less than the threshold distance, these groups become linked and were merged into a single group. The clustering is continued until the distance between the closest pair is greater than the threshold, then the clustering stops.

B. Evaluate of covariance matrix from SVD

The covariance of two random variables is their tendency to vary together that expressed as (2).

$$
\text{cov}(X, Y) = \frac{\sum_{i=1}^{N} (x_i - \bar{x})(y_i - \bar{y})}{N} \tag{2}
$$

Where $\bar{x}$ is mean(X) and $\bar{y}$ is mean(Y). The covariance matrix is a matrix of covariance (C) between elements of a vector, with elements $C_{ij} = \text{cov}(i,j)$. 

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A. Khitwongwattana is with the Institute of Field Robotics, King Mongkut's University of Technology Thonburi, Bangkok 10140 Thailand (Phone: +66-2-4709339, fax: +66-2-4709691; e-mail: androod@fib fro.kmutt.ac.th).

T. Maneewarn is with the Institute of Field Robotics, King Mongkut's University of Technology Thonburi, Bangkok 10140 Thailand (Phone: +66-2-4709339, fax: +66-2-4709691; e-mail: psew@fibro.kmutt.ac.th).