Estimation of Vehicle Trajectory in Urban Area
by GPS and Vision Sensor

JoonHoo Lim, Kwang Ho Choi, Hee Sung Kim, Je Young Lee, Hyung Keun Lee
School of Electronics, Telecomm. & Computer Eng. Korea Aerospace University
200-1, Hwajon-dong, Deokyang-gu, Goyang-city, Kyunggi-do, Korea
limjh@kau.ac.kr; sahnhare@kau.ac.kr; hskim07@kau.ac.kr; jeylee@kau.ac.kr; hyknlee@kau.ac.kr

MinWoo Kim
Communication & Control System Development team, Hyundai-rotem
462-18, Sam-dong, Uiwang-shi, Gyeonggi-do,437-718, Korea
MinwooKim@hyundai-rotem.co.kr

ABSTRACT
In urban environment, GPS(Global Positioning System) cannot provide positioning solutions continuously due to insufficient number of visible satellites. In order to overcome this weak point in urban positioning, recent research works began to focus on hybrid positioning methods that augment GPS with other sensors. As an extension of existing hybrid positioning methods, this paper proposes an efficient method that combines GPS and vision sensor. The proposed method utilizes colour separation and labelling algorithm to identify lane edges on the road. Once edge points are identified, they can be used to estimate the heading of vehicle without requiring any external information on vehicle’s trajectory and road lanes. The estimated vehicle heading can be combined with insufficient number of GPS measurements to maintain accuracy of the vehicle’s trajectory. To evaluate the performance of the proposed method, the experiment results with field-collected real measurements are demonstrated.

KEYWORDS: GPS, Vision, Positioning, Urban condition

1 INTRODUCTION

Recently, hybrid positioning methods have gained many attentions to overcome shortcomings of GPS(Global Positioning System) and to improve accuracy and availability in urban environments. As widely known, GPS accuracy heavily depends on the number of visible satellites. In urban environments, however, the number of visible satellites easily becomes less than 4. To overcome the shortcoming, GPS is often combined with other sensors such as INS(Inertial Navigation System), vision sensor, and so on (Langel et al., 2010; Soloviev et al., 2010).

The most popular configuration for hybrid positioning is the combination of INS and GPS to obtain navigation information at high update rate with improved accuracy. But implementation cost is very high and INS accuracy degrades over time due to unbounded positioning errors caused by uncompensated gyro and accelerometer errors (Grejner-Brzezinska et al., 1998; Kim et al., 2011).

The integration of GPS, INS, and vision sensors was also considered. An example of this integration is the 4S-Van (Yoo et al., 2005) which provides improved accuracy than the integration of GPS and INS. In addition, the integration of three different sensors was applied to robots and unmanned vehicles using SLAM(simultaneous localization and mapping) algorithm (Agrawal et al., 2006; Wang et al., 2008). Recently, the integration of GPS, INS, and polyhedral vision sensor was considered in (Kim et
As an extension of the existing hybrid positioning methods, this paper proposes a new method that combines GPS and vision sensor. As compared with existing methods, the proposed method is advantageous since it can be implemented by a low-cost monocular webcam and a low-cost GPS receiver.

The key feature of the proposed method is the utilization of edges of road lane. Once edge points are identified, they are used to estimate the heading of the vehicle without requiring any external information on vehicle's trajectory and road lanes. The estimated vehicle heading can be combined with insufficient GPS measurements to maintain accuracy of the vehicle’s trajectory.

To explain the proposed GPS/vision hybrid positioning system, several key topics will be described briefly in the order of coordinate systems, camera calibration, computation of vision sensor parameters, lane detection, and relative position and heading estimation. To evaluate the performance of the proposed method, the experiment results with field-collected real measurements are demonstrated.

2 GPS/VISION HYBRID POSITIONING

To design a hybrid positioning system, clear definition and discrimination of related coordinate systems are required as an essential pre-requisite. For GPS/vision hybrid positioning, six different coordinate systems are utilized as depicted in Figure 1.

- e : Earth Frame (XYZ)
- n : Navigation frame (NED) of current time instant
- b : Body frame (x_b, y_b, z_b) of current time instant
- s : Vision sensor frame (x_s, y_s, z_s) of current time instant
- r : Road lane frame (x_r, y_r, z_r)
- p : Image pixel frame (p_x, p_y)

To extract metric information from 2D images, camera calibration is required for 3D computer vision (Roger et al., 1987). For the purpose, camera calibration is executed by GML camera calibration toolbox (Web-1).
If the camera calibration is completed, the 2D coordinate values with respect to the p-frame and the 3D coordinate values with respect to the r-frame should be utilized.

\[ T_C'(X' + A_{y'}) = 0 \]  

(1)

where

\[
T(k) = \begin{bmatrix}
sp_x(k) & -f \\
sp_y(k) & f
\end{bmatrix}
\]

\[
X' = \begin{bmatrix}
x_r \\
y_r \\
0
\end{bmatrix}
\]

\[
A_{y'} = \begin{bmatrix}
0 \\
0 \\
-h
\end{bmatrix}
\]

\[
C_r' = \begin{bmatrix}
\cos(\theta)\cos(\psi) & \cos(\theta)\sin(\psi) & -\sin(\theta) \\
-\sin(\psi) & \cos(\psi) & 0 \\
\sin(\theta)\cos(\psi) & \sin(\theta)\sin(\psi) & \cos(\theta)
\end{bmatrix}
\]

X': 2D lane position on the road frame, \( X' \): 3D lane position on the road frame

h : height of vision sensor from body frame
s : scale factor
f : focal length of vision sensor
C_r': coordinate transformation matrix (road to sensor frame)

\( \psi \): angle of between road and body frame, \( \theta \): angle of between body and sensor frame

Eq. (1) describes the relationship between the vision sensor parameters, the 3D lane coordinates with respect to the r-frame, and the 2D pixel coordinates with respect to the p-frame. As shown in Eq. (1), a scale factor is required for the conversion from the pixel units to the distance units. For the purpose, Eq. (2) is utilized.

\[
x_s p_x - f p_y = 0 \rightarrow s_s = \frac{p_x}{s, p_x}
\]

(2)

\[
x_s p_y + f z_s = 0 \rightarrow s_y = -\frac{z_s}{x_s p_y}
\]

In general, an image frame contains more than two lanes. To detect lane edges in image frames, labeling is performed by Open CV library (Gary et al., 2008). It is written in performance-optimized C and C++ code. Based on the ratio of red, green, and blue colours, road lanes are detected at first. Thereafter, edges are detected by the labeling method which distinguishes the objects contained in different images (Pitas, 2000). After 4 lane edges are detected, they are accumulated to a vector equation as shown in Eq. (3).

\[
Z = \begin{bmatrix}
Z_1 \\
Z_2 \\
Z_3 \\
Z_4
\end{bmatrix} = \begin{bmatrix}
h_{pos(1)} & h_{ang(1)} \\
h_{pos(2)} & h_{ang(2)} \\
h_{pos(3)} & h_{ang(3)} \\
h_{pos(4)} & h_{ang(4)}
\end{bmatrix} \begin{bmatrix}
\delta x \\
\delta y \\
\delta a \\
\delta \theta
\end{bmatrix} + \begin{bmatrix}
h_{m(1)} & 0 & 0 & 0 \\
0 & h_{m(2)} & 0 & 0 \\
0 & 0 & h_{m(3)} & 0 \\
0 & 0 & 0 & h_{m(4)}
\end{bmatrix} \begin{bmatrix}
\delta p_{(1)} \\
\delta p_{(2)} \\
\delta p_{(3)} \\
\delta p_{(4)}
\end{bmatrix} = H \delta X + v
\]

(3)

where,

\[ \delta X = x - \hat{x} : \text{estimation error of x-coordinate value} \]
\[ \delta y = \hat{y} - y : \text{estimation error of } y\text{-coordinate value} \]
\[ \delta z = \hat{z} - z : \text{estimation error of } z\text{-coordinate value} \]
\[ \delta \psi = \hat{\psi} - \psi : \text{estimation error of heading angle} \]
\[ \delta \theta = \hat{\theta} - \theta : \text{estimation error of pitch angle} \]

Based on Eq. (3), the heading and the lane position can be estimated by detected edges. By subtracting the estimates obtained from two successive image frames, position increments of the vehicle can be estimated.

3 EXPERIMENT

To evaluate the performance of the proposed method, two experiments are performed. For the experiment, it is assumed that the length and width of lanes are known. One experiment corresponds to the vehicle with no motion and the other corresponds to moving vehicle. Data processing of all the experiments is performed by Eq. (3). Figure 3 shows the experimental environment which depicts the locations where the GPS antenna and the vision sensor are mounted. The GPS receiver is a U-Blox AEK-4T and the vision sensor is a Logitech HD Pro Webcam C910.

The static experiment results are depicted from Figure 4 to Figure 7. In Figure 4, the thick dots correspond to the GPS-only position estimates and the dotted line corresponds to the position estimates by the proposed method. Figure 5 shows the condition of the proposed method. Figure 6 and 7 illustrate positioning error to the north and east directions. Throughout the static experiment, it can be seen that the accuracy of proposed method is similar to the accuracy of the GPS-only method.
The kinematic experiment results are depicted from Figure 8 to Figure 11. It can be seen in Figure 10 and Figure 11 that the kinematic positioning error by the proposed method is bounded within 7 meters during 9 seconds where no GPS measurements are utilized in position estimation. However, it can be seen that the error of the kinematic experiment is larger than those of the static experiment. This accuracy degradation is analyzed to be caused by inaccurate heading estimation. As shown in Figure 12, the GPS heading does not vary largely. However, the vision heading varies quite a lot. It seems that the vision heading contains both random and bias terms. The other source of accuracy degradation is the inaccurate estimation of lane length. It is assumed that lane length is constant but the actually extracted lane length between two edges changes due to unclear road lane marks. The effects of these two error sources need to be investigated further more in near future.
4 CONCLUSION

This paper proposed an efficient GPS/vision hybrid positioning method. The proposed method utilizes colour separation and labelling algorithm to identify lane edges on the road. Once edge points are identified, they can be used to estimate the relative position and heading of the vehicle with respect to the road lanes without requiring any external information on vehicle’s trajectory. To evaluate the performance of the proposed method, the experiment results with field-collected real measurements are demonstrated. It was shown that the accuracy of the proposed method is around 1 meter in the static experiment and within 7 meters in the kinematic experiment. The accuracy degradation in the kinematic experiment is analyzed to be affected by inaccurate heading and lane length which needs to be investigated by further study.

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REFERENCES

Gary Nradski & Adrian Kaebler. Learning OpenCV. O’Reilly Media Publishers, United States of America(September 2008), chapter. 1–2, 5,7,11–12.
Pitas I., Digital image processing algorithms and applications. John Wiley & Sons Publishers, United States of America (February 2000), chap. 6.5.


Web sites: