A Bimodal Approach for Land Vehicle Localization

Seong-Baek Kim, Kyung-Ho Choi, Seung-Yong Lee, Ji-Hoon Choi,
Tae-Hyun Hwang, Byung-Tae Jang, and Jong-Hun Lee

ABSTRACT—In this paper, we present a novel idea to integrate a low cost inertial measurement unit (IMU) and Global Positioning System (GPS) for land vehicle localization. By taking advantage of positioning data calculated from an image based on photogrammetry and stereo-vision techniques, errors caused by a GPS outage for land vehicle localization were significantly reduced in the proposed bimodal approach. More specifically, positioning data from the photogrammetric approach are fed back into the Kalman filter to reduce and compensate for IMU errors and improve the performance. Experimental results are presented to show the robustness of the proposed method, which can be used to reduce positioning errors caused by a low cost IMU when a GPS signal is not available in urban areas.

Keywords—Inertial measurement unit (IMU), GPS, photogrammetry, stereo-vision.

I. Introduction

An inertial measurement unit (IMU) provides position, velocity, and attitude information at a high output rate but has a time-dependent accumulation error as a drawback. Global Positioning System (GPS) provides an accurate position, velocity, and time information at a low output rate but has a satellite visibility limitation in urban canyon areas. By integrating these two navigation systems, we are able to capitalize on the strengths of both while minimizing their weaknesses [1], [2]. In particular, the integration of GPS and a high cost IMU is required to provide position and attitude with sufficient accuracy for land vehicle applications. However, there are the limitations of government restrictions and a high price in using a high performance IMU. Therefore, recent research and studies have emphasized on using a low cost IMU and Differential GPS integration with the benefit of economic aspects and a rapid increase of computing power [2], [3].

Based on the idea that feature points from image sensors can provide positioning information, we present an image-based bimodal approach to reduce positioning errors caused by poor sensibility of a low cost IMU during a GPS outage.

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Seong-Baek Kim (phone: +82 42 860 5886, email: kimstar100@etri.re.kr), Kyung-Ho Choi (email: khchoietri@etri.re.kr), Seung-Yong Lee (email: lsy9892@etri.re.kr), Ji-Hoon Choi (email: cjh63356@etri.re.kr), Tae-Hyun Hwang (hth63339@etri.re.kr), Byung-Tae Jang (email: jbt@etri.re.kr), and Jong-Hun Lee (email: jong@etri.re.kr) are with Telematics Research Division, ETRI, Daejeon, Korea.

II. A Bimodal Approach for Land Vehicle Localization

Direct georeferencing is a process of taking the direct measurements of image exterior orientation parameters using a GPS/IMU integration scheme [4]. Provided the orientation and position of imaging sensors, direct georeferencing takes the form described in [3], [4] as,

$$r_i^m = r_{(D)GPS/IMU}{}^m + C_b{}^m (s_m C_c{}^b r_i^c + r^b) . \quad (1)$$

We propose an image-based bimodal approach to compensate for the poor performance of a low cost IMU. A block diagram describing our approach is shown in Fig. 1.

- Basic Assumptions

In our experiments, there are two basic assumptions. First, the vehicle should move slower than a given speed so that a point in the current frame exists in the following frame. This guarantees locating the known 3D point in the next frame, allowing the system to estimate the vehicle's 3D location without GPS information. Second, there exists a rectangular area, as shown in Fig. 2, in which a feature point lies within a certain error boundary. By selecting a feature point in this area, the system estimates the vehicle's 3D location for better accuracy.

- Detailed Procedures

The bimodal approach starts right after a GPS blockage

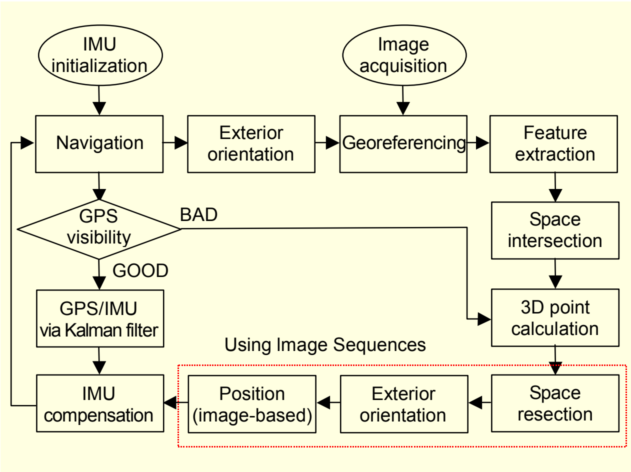

Fig. 1. Proposed bimodal approach.

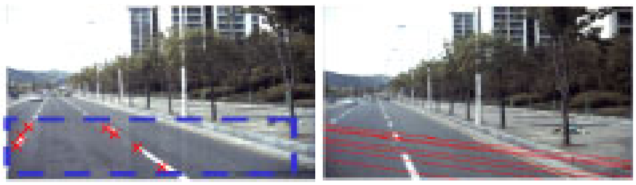

Fig. 2. Feature extraction in a rectangular area and epipolar geometry.

happens, and the detailed procedure is described as follows:

i) select the last stereo frame captured before the GPS outage and denote it as *frame1,*

ii) find a feature point located within the rectangular area in *frame1*, calculate the 3D coordinate using an intersection and locate the same feature point in the next frame using resection,

iii) estimate the location of the vehicle based on the 3D and image coordinates, and

iv) check if the GPS signal is available in the next frame. If not, repeat the procedure.

Then, this positioning information is fed back into the Kalman filter to be combined with data from the IMU. In our approach, the following state transition and measurement equations are applied to estimate and compensate for a low cost IMU [5],

$$\begin{bmatrix} \dot{x}_i \\ \dot{x}_f \end{bmatrix} = \begin{bmatrix} F_{11} & F_{12} \\ 0_{6\times 9} & 0_{6\times 6} \end{bmatrix} \cdot \begin{bmatrix} x_i \\ x_f \end{bmatrix} + \begin{bmatrix} G \\ 0_{9\times 6} \end{bmatrix} \begin{bmatrix} w_g \\ w_a \end{bmatrix}, \tag{2}$$

$$\begin{aligned} Z &= P_{IMU} - P_{image\,based} \\ &= P_{IMU} - (C_m^b (r_i^m - C_b^m (s_m C_c^b r_i^c + r^b))), \end{aligned} \tag{3}$$

where detailed expressions of the matrix and vectors in (2) are provided in [1]; C_m^b is the rotation matrix between the mapping and GPS/IMU frame; r_i^m is the vector to the mapping frame for a target; C_b^m is the rotation matrix between the GPS/IMU and mapping frame; s_m is a scale factor between the image and mapping frame; C_c^b is the rotation matrix between the imaging sensors and GPS/IMU frame; r_i^c is a vector of the image frame to the target; and r^b is the offset vector between the GPS/IMU and imaging sensors.

III. Experimental Result

For the experiment, a vehicle with an LN-200 IMU (3°/h, 300 μg), dual frequency Trimble GPS receiver and video cameras was driven for 10 min in downtown Daejeon, S. Korea, as shown in Fig. 3. The system located the last frame with a favorable GPS and found feature points to be tracked in the next frame. The driving speed of a moving vehicle is closely related with the performance of image capturing devices. In our experiments, our system captures 15 frames/s and the speed is around 50 km/h.

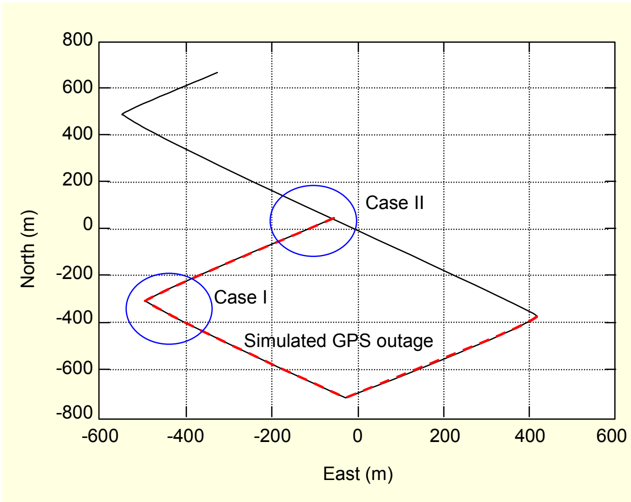

Fig. 3. Vehicle trajectory for data analysis.

In our experiments, features were manually chosen within a rectangular area to minimize error propagation. We calculated the 3D coordinates of the feature points and kept them as references for the next frame. The required time to find the 3D location for each frame is presented in Table 1. For intersection and resection, it requires less than 1 second, which is good enough for real-time applications.

Table 1. Processing time to calculate a 3D location.

	Intersection	Resection
Time (s)	0.111	0.04

With the known 3D and image coordinates of the feature points, we estimated the position information by $P_{image\ based}$ in (3). In our filtering scheme, IMU measurements are calibrated and compensated by either GPS measurements with an update of 1 Hz or image-based measurements with an update of 15 Hz.

To analyze the performance of the proposed idea, we simulated a GPS adverse environment for 120 seconds, which is indicated by the red dashed line in Fig. 3. The trajectory was deliberately selected to have the characteristics of straight and curved roads, labeled cases I and II. In Fig. 4, enlarged views of cases I and II are shown to present performance comparisons with conventional methods. In case I, the errors of a pure IMU solution grow around 82 m to the north and 53 m to the east. The IMU/odometer integration approach also shows errors of 43 m to the north and 36 m to the east. The proposed bimodal approach shows errors of 2.15 m to the north and 2.14 m to the east.

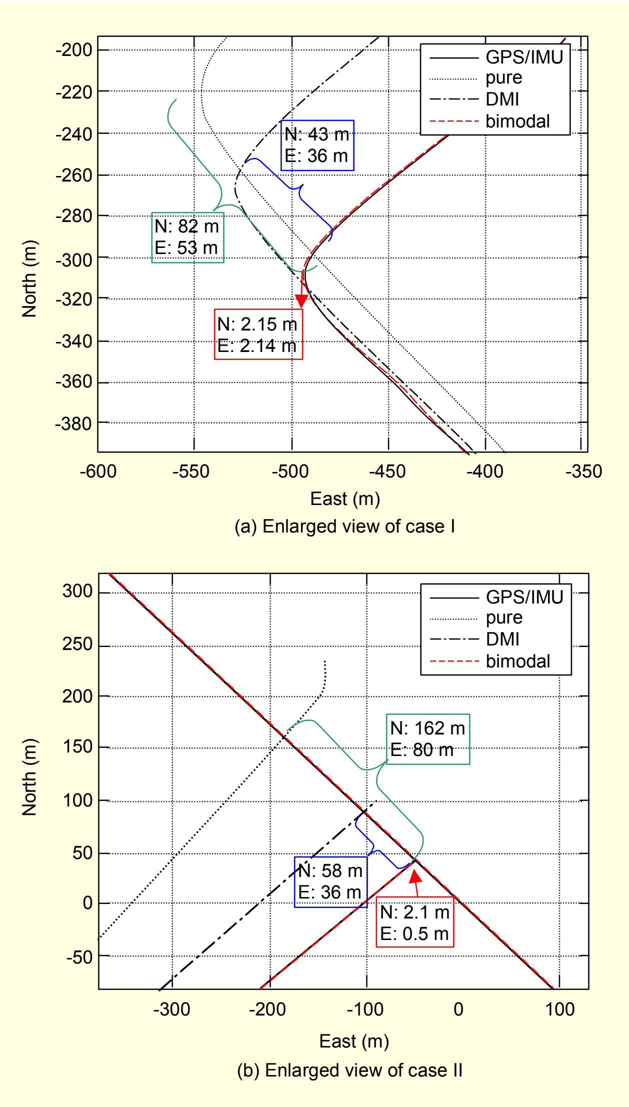

Fig. 4. Enlarged view of positioning errors for cases I and II.

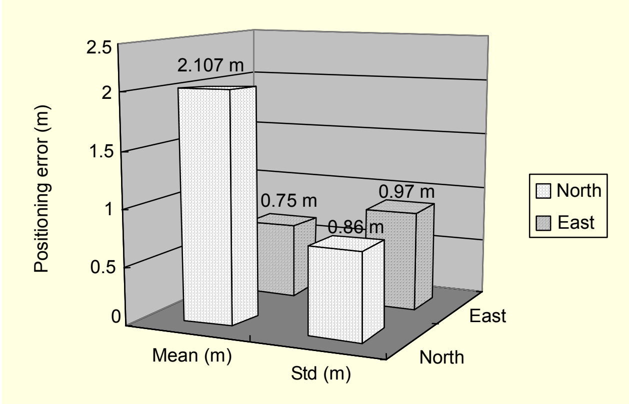

Fig. 5. Positioning errors of the bimodal approach.

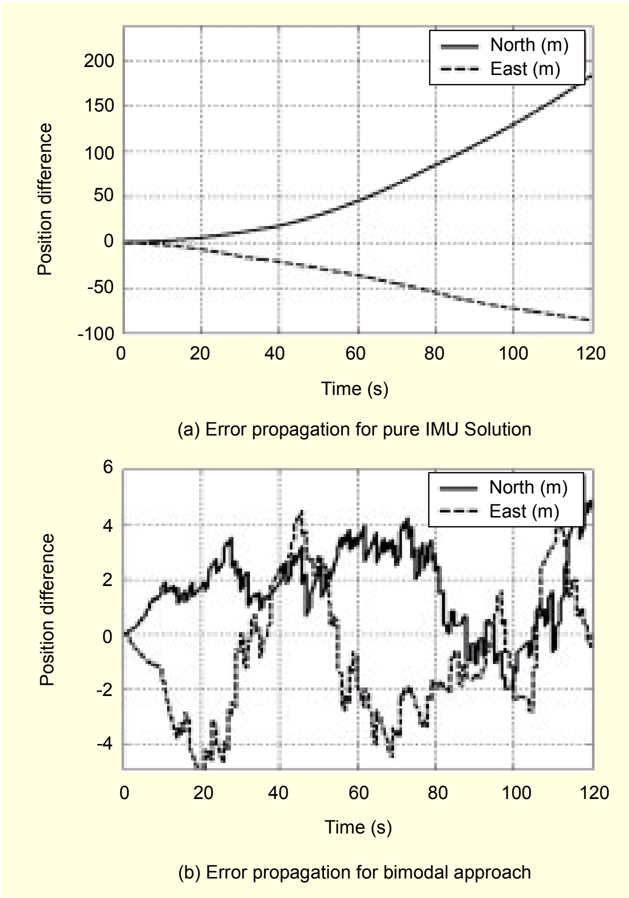

Fig. 6. Error propagation for pure IMU and bimodal approaches.

Figure 4(b) also shows similar results in case II. The errors of the pure IMU grow over 162 m to the north and 80 to the east. However, the errors of the proposed approach show 2.1 m to the north and 0.5 m to the east. For the 120 s GPS outage period, mean and standard deviation values of the bimodal approach are presented in Fig. 5.

Based on the experimental results, we verified that the proposed approach shows less error propagation effects, as shown in Fig. 6, and robustness over the GPS outage circumstances.

IV. Conclusion and Remarks

As the vehicle enters GPS-unfavorable environments, the IMU cannot provide enough information for land vehicle navigation. To overcome this drawback of a low cost IMU, we present an image-based bimodal approach to integrate the IMU and GPS, utilizing the position calculated from an image sequence. The position data from the image-based approach were fed back into the Kalman filter to reduce and compensate for the IMU errors and to improve the performance. Preliminary test results were presented to show the effectiveness of the proposed method. For future research, a probabilistic approach [6] can be adopted to find feature points automatically, and other information, e.g., 2D coordinates from a map for surrounding buildings can be combined to improve the location accuracy.

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