Development of Positioning System Based on Auto VRS-GPS Surveying

Choi, Hyun1), Kim, Young-Jong2), Park, Woo-Sik3)

Abstract

There has been a need for replacing human labors with a robot in such dangerous and hard jobs of various construction sites. For that reason, many researches have been made about the high quality robot, which performs its duty instead of human labors. This study is about auto surveying system development based on VRS-GPS which enables autodriving in dangerous areas where it’s difficult for humans to measure directly. This study is about the auto-surveying system development, based on VRS-GPS, which enables auto-drive in dangerous areas, whereas difficult for humans to measure directly. The GPS is made with GRXI and SHC250 controllers of the SOKKIA company. The auto surveying system is composed of DPS module, geomagnetism sensor, bluetooth, gimbals, IMU, etc to automatic drive via enter into a route of position. The developed auto surveying system has installed the carmeras for front and vertical axis as well as systems to grasp situation of surveying with smartphone in real time. The result from analysed RMSE of auto surveying system and VRS-GPS surveying is 0.0169m of X-axis and 0.0246m of Y-axis.

Keywords: VRS-GPS, Geomatics information, Auto surveying system, Geomagnetism sensor, IMU

1. Introduction

The expressway network connecting every part of the country begins with Gyeongin Expressway and with the Ulsan Industrial Complex as the beginning point of approximately 1,000 industrial complexes. This describes that the Republic of Korea has achieved the industrial progress, well as stood at the high progress status. At grand scale construction sites, such as expressway or industrial complex sites, 1 person survey system, called GPS, was introduced to get away from the existing survey systems of the Total-Station, required many people. The GPS survey equipment, which are mostly expensive, huge and heavy, requires 3 or more equipments, since there should be installed equipments, which one fixed at 2 or more base stations and the other at an unknown point; therefore, GPS hardly is a 1 person survey system. As a solution to the inconveniences the National Geographic Information Institute under the Ministry of Land, Infrastructure and Transport is operating 51 regular observatories throughout the country to make it suitable for the real 1 person survey.

Recently, research on automatic positioning system is lively proceeding with unmanned helicopter in its center. In order to build an automatic system, the research is essentially held under the structure of GPS combinations. This concludes that the robot and the GPS are in an indivisible relationship. In 2003, Kim and Kim(2003) designed an autonomous mobile control system to load it on a robot car and conducted a research that the car doing an autonomous drive with the pre-programmed system. They received the input data of...
transverse and longitudinal control necessary for driving via satellite by a GPS receiver and for the live time and the correction input sensor they used a magnetic compass and a 3-side gyro. The autonomous drive of the robot car proved that it was possible by just using the GPS data. Lee et al. (2010) suggested using a mathematical model to control the moving robot. Also, there was a research in 2009 about an underwater cleaning robot and its envisioned the propulsive performance of the robot of joystick and computer (Choi et al., 2009). To interpret coordinates of the robot, they express it through a fixed coordinate of a certain place on the Earth and a fixed coordinate in the body of the underwater robot.

To examine the VRS-GPS related research in Korea, Choi et al. (2004) has suggested an optimization plan of the system composition, operation and application to improve the general satellite positioning system services through an effective usage of GPS regular observatory. Also, to solve the problem of increasing position errors proportional to distances from the base station, when RTK (Real Time Kinematic) surveying using GPS, the National Geographic Information Institute have built VRS (Virtual Reference System) RTK system, which is a type of Network RTK (Kim et al., 2008). Yun et al. (2010) carried out a survey with the VRS service, offered by the National Geographic Information Institute. They evaluated the result of the survey with the result of cadastral topographic control point and the accuracy and the result of Total-Station survey and suggested the possibility of utilizing the VRS survey. Choi and Kim(2012) acquired data through means of the hypothetical base station on the cadastral control point, they analyzed it by comparing with the result from observing the cadastral control point for utilizing the Total-Station with the repetition method.

Acquiring spatial data via VRS-GPS is an excellent method. However the system faces many situational restrictions, which requires a lot of personnel, considered as the inefficiency of expanse and time; it calls for the necessity of the new survey system. On these days, there is an arousing necessity on automatic machineries could be substituted with human beings in dangerous area, hard work and simple tasks. To practice those automatic machines to replace human beings, it is necessary to develop high technical robots from a lot of studies and different areas. In Korea, researches are undergoing for aerial survey and bathymetric survey areas for using RC robots, but there is none in topographic survey area that requires a lot of people and time. Also, the main stream of progressing researches on robots is the simple utilization of GPS for autonomous driving, so there are scarcely any researches on precise surveys. Therefore, in our research, we are going to develop a GPS positioning system able to do autonomous driving and analyze the existing VRS survey and its accuracy.

2. Basic Theory

2.1 Graded driving robot model

In this research the mobile robot estimates the user by utilizing the GPS positional information and the geomagnetic sensor azimuth information from distance. The GPS positional information includes error information. In this study Kalman filter is used to correct the error of the positional information caused by GPS. Mobile robot’s theory of mechanism is necessary in order to apply Kalman filter. Fig.1 show the mechanism theory of the GPS Survey robot related Eq.(1).

![Fig. 1. Kinematic system of the GPS surveying robot](image)

\[
\begin{align*}
\Delta x &= \frac{\cos \theta_c (v_x + v_r)}{2} = \cos \theta_c \cdot v \\
\Delta y &= \frac{\sin \theta_c (v_x + v_l)}{2} = \sin \theta_c \cdot v \\
\Delta \theta &= \frac{v_r - v_l}{2d_c} = \omega
\end{align*}
\]

where the motional model of the mobile robot is expressed as \( q = [x, y, \theta], \) 3 vectors. This of \( (x, y) \) stands for the middle position of mobile robot, and \( \theta \) represents the azimuth of the mobile robot for the axis of the normal coordinate. A variable, \( d_c \), is the horizontal distance between the middle position of
the mobile robot, \((x, y, \theta)\) and the wheels of each direction. The Eq. (2) explains the linear velocity and angular speed of the mobile robot.

\[
\begin{align*}
\nu &= \frac{v_r + v_l}{2} = \frac{r(\omega_r + \omega_l)}{2} \\
\omega &= \frac{v_r - v_l}{2d_r} = \frac{r(\omega_r - \omega_l)}{2d_r}
\end{align*}
\]

where \(v_r\) and \(v_l\) are the linear velocity of the contact point of the wheels of each direction and the ground; \(r\) and \(l\) represent the right and the left wheel, respectively; \(\omega_r\) and \(\omega_l\) orderly show the speed of revolution of both wheels; and \(r\) represents the radius of the wheel.

### 2.2 Trace control

In our research, those present position and direction of the mobile robot are expressed as vector \(q = [x, y, \theta]\) by the GPS positional information and the azimuth of the magnetic geomagnetic sensor. The position of the survey point is also read as the vector \(D = [x_d, y_d]\) by the positional information of GPS. The Fig. 2 illustrates the destination of mobile robot through the Cartesian coordinates system.

![Fig. 2. Mobile robots and the measurement point in the cartesian coordinate system](image)

While the mobile robot is moving to the survey point, the modulating control machine by using errors of the distance and angle are used to control the mobile robot. In Eq. (2) to decide on the linear velocity, \(\nu\), and angular speed, \(\omega\), of the right and left wheels are set as Eq. (3) by the modulating control machine;

\[
\begin{align*}
v_r &= K_{\delta r}d_e - K_{\theta} \theta_e \\
v_l &= K_{\delta r}d_e + K_{\theta} \theta_e
\end{align*}
\]

The Eq. (4) explain necessarily control variables of \(d\) and \(\theta_e\), as a distance between the mobile robot and the survey point, and the azimuth difference between the two, respectively;

\[
\begin{align*}
d &= \sqrt{dx^2 + dy^2} \\
\theta_e &= \theta - \theta_d
\end{align*}
\]

Where, \(dx\) and \(dy\) are the horizontal and the vertical distance between the mobile robot and the survey point.

### 2.3 IMU

The relative motion between consecutive frames are chained together to obtain the absolute pose at each frame. The initial pose is obtained from the IMU (Inertial Measurement Unit), wheel encoders and GPS sensors by moving the robot in a straight line at speeds greater than 1 m/s. The IMU and the wheel encoders are also used to fill in the relative poses, when the visual odometry fails, so it complements the visual pose system. A very simple Kalman Filter is used to fuse global locations and heading measurements from the GPS sensor, thereby avoiding long-term drift.(Agrawal and Konolige, 2006)

### 2.4 The adaptive Kalman filtering algorithm

The Kalman filtering is a well-known technique for state and parameter estimations. It is a recursive estimation procedure that uses sequential sets of measurements. In recent years, the Kalman filter, based localization, became common practises in the robotics literature. The Kalman filter addressed the general problem of estimating the state \(z \in \mathbb{R}^n\) of a discrete-time controlled process that is governed by the linear stochastic difference equation (Vargas et al., 2007)

![Fig. 3. Kalman filter operation diagram, adapted from Welch (Welch and Bishop, 2001)](image)
\[ x_{k+1} = Ax_k + Bu_k \]  
(5)  
with a measurement \( \mathcal{H} \)

\[ z \in \mathcal{R}^n \]
(6)

\[ k + 1 = H_{k+1} + v_{k+1} \]

The random variables \( w_k \) and \( v_k \) represent the process and measurement noise, respectively. They are assumed to be independent to each other, as those \( Q \) and \( R \) processed and measured noise covariance with normal probability distributions, respectively. The Kalman filtering estimation can be expressed as;

**Prediction:**
\[ \begin{align*} 
\hat{x}_{k+1}^- &= A\hat{x}_k \\
\hat{P}_{k+1}^- &= AP_kA^T + BB^T 
\end{align*} \]
(7)
\( (8) \)

**Correction:**
\[ \begin{align*} 
K_{k+1} &= \hat{P}_{k+1}^- (H^T (HP_{k+1}^- H^T + R)^{-1} \\
\hat{x}_{k+1} &= \hat{x}_{k+1}^- + K_{k+1} (z_{k+1} - H\hat{x}_{k+1}^-) \\
\hat{P}_{k+1} &= (I-K_{k+1}H)\hat{P}_{k+1}^-
\end{align*} \]  
(9)
\( (10) \)
\( (11) \)

where \( \hat{x}_{k+1}^- \) is the predicted state vector, \( \hat{P}_{k+1}^- \) is the variance matrix for \( \hat{x}_{k+1}^- \), \( K_{k+1} \) is the gain matrix, \( \hat{x}_{k+1} \) is the updated state vector, and \( \hat{P}_{k+1} \) is the updated error covariance estimation(Welch Bishop, 2001). The prediction equations are responsible for projecting forward in time the current state and error covariance estimates to obtain the a priori estimates for the next step. The equations for correction are responsible for the feedback, i.e., for incorporating a new measurement into the a priori estimate to obtain an improved a posteriori estimate. A complete picture of the Kalman filter cycle with equations is shown in the Fig. 3. The Kalman filtering estimation at a given time \( k \) can be considered, as a weighted combination between the new measurement (observation model) and the predicted state vector, based on the dynamic model and all previous measurements. If too much 'weight' is assigned to the dynamic model, the information from measurements is trusted less and less, which leads to poor position estimation and even to possibly divergence of the filtering process. The approach, envisaged by the fading memory, is based on applying a scale factor \( M \) to the a priori estimate error covariance to deliberately increase the variance of predicted state vectors, resulted in more 'weight' given to actual measurements;

\[ P_{k+1}^- = M (A\hat{P}_k A^T + BB^T) \]  
(12)

The main difference between different fading memory algorithms is on how to calculate the scale factor \( M \). One simple approach is assigning the scale factor as a constant, but this leads to some drawbacks. For example, as the filtering proceeds, the accuracy of pose estimation will decrease as those effects of old data will become less and less. The optimal solution is to use a variable scale factor that will be determined, based on the dynamic and observation model accuracy.

\[ \hat{x}_{k+1} = z_{k+1} - H\hat{x}_{k+1}^- \]  
(13)

For an optimal Kalman filtering, the innovation vector should be a zero mean white noise (Abdelnour et al., 1993).

3. VRS–GPS Automatic Positioning System

For a rapid, stable operation at the construction site the GPS automatic system, this study chose 4-wheel front and rear steering of 42.0cm diameter. Also, we installed the front and bottom side camera to maximize the convenience of 1 person survey. For conducting an accurate survey, a gimbal equipment was applied in which could automatically control the x and y direction. (Fig. 4)

![Fig. 4. GPS auto-surveying system](image)

The GPS, installed in the automatic positioning system, is composed of GRX1 receiver and SHC 250 controller of SOKKIA Company. The GRX1 receiver receives 2 periodicity (L1, L2), one at the time of static survey resulted
Table 1. Spec. of the GRX1 receiver

<table>
<thead>
<tr>
<th>Ch.</th>
<th>72-Ch.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Received signal</td>
</tr>
<tr>
<td>GPS</td>
<td>L1 CA, L1/L2 P-code, L2C</td>
</tr>
<tr>
<td>GLONASS</td>
<td>L1/L2 CA, L1/L2 P-code</td>
</tr>
<tr>
<td>SBAS</td>
<td>WAAS, EGNOS, MSAS</td>
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<tr>
<td></td>
<td>Location accuracy</td>
</tr>
<tr>
<td>Precision stop measurements</td>
<td>H : 3mm+0.5ppm, V : 5mm+0.5ppm</td>
</tr>
<tr>
<td></td>
<td>L1 only</td>
</tr>
<tr>
<td></td>
<td>H : 3mm+0.8ppm, V : 4mm+1.0ppm</td>
</tr>
<tr>
<td>Quick-stop measurements</td>
<td>H : 3mm+0.5ppm, V : 5mm+0.5ppm</td>
</tr>
<tr>
<td>kinematic</td>
<td>L1+L2</td>
</tr>
<tr>
<td></td>
<td>H : 10mm+1.0ppm, V : 15mm+1.0ppm</td>
</tr>
<tr>
<td>RTK</td>
<td>L1+L2</td>
</tr>
<tr>
<td></td>
<td>H : 10mm+1.0ppm, V : 15mm+1.0ppm</td>
</tr>
<tr>
<td>DGPS</td>
<td>0.5m</td>
</tr>
</tbody>
</table>

Management of data

<table>
<thead>
<tr>
<th>Memory</th>
<th>SD/SDHC Card(FAT16/32 type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data memory</td>
<td>RTCM SC104 2.1/2.2/2.3/3.0/3.1, CMR, CMR+, NMEA, TPS</td>
</tr>
<tr>
<td>Data Rate</td>
<td>1Hz, 5Hz, 10Hz, 20Hz</td>
</tr>
<tr>
<td>Communication port</td>
<td>RS-232C (4,800 to 115,200bps)</td>
</tr>
</tbody>
</table>

power supply

<table>
<thead>
<tr>
<th>Standard battery BDC58</th>
<th>Removable, Li-ion Rechargeable batteries, 7.2V, 4.3Ah</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Time (20°C)</td>
<td>Over 7.5 Hr.</td>
</tr>
</tbody>
</table>

that its accuracy lies in H direction 3mm+0.5ppm, V direction 5mm+0.5ppm; the other, when surveying RTK, the accuracy is in H direction 10mm+1ppm, in V direction 15mm+1ppm. The specific data is shown in the Table 1.

4. Experiment and Analyzing Accuracy

4.1 Study area

The big ground of the Kyungnam University was chosen as the study area to test the defects and the accuracy of the developed automatic positioning system at March 15th, 2013. The Fig. 5(a) shows a scene that the automatic positioning system comprehending the pivot, while the smart phones comprehending the accuracy of position. The Fig. 5(b) is a picture of surveying the observation point.

It is possible to check the directions following the experiment progress, by installing the forward concentrating cameras in the area, considered to be impossible or dangerous to do so. The Fig. 6 shows the monitor that the automatic positioning system is keeping its site forward.

The Fig. 7 shows the traces of VRS-GPS automatic positioning system. The Table 2 is an analysis of results

![Fig. 5. Controls of the auto VRS-GPS surveying](image-url)
from automatic positioning system and VRS-GPS survey. The error analysis showed that the 2nd and 4th errors were caused by the reception obstruction of GPS that was excluded from the analysis. The result of analyzing the root mean square of errors shows 0.0169m in X axis and 0.0246m in Y axis.

![Fig. 6. Typical outdoor terrain as seen from the camera](image)

![Fig. 7. Visual odometry integrated with VRS-GPS](image)

4.2 Consideration

The research on robots is steadily at its work in all types of industrial areas. As a result, it shows a great deal of development in terms of military, industry, not to mention in daily life. The study of automatic positioning system related to survey is getting perked up inside and outside of the country, especially showing distinct developments in aerial survey and bathymetric survey. The main stream in this research area is the technological development, using unmanned helicopters and airships in the area of aerial and bathymetric survey, in Korea as well as world-wide. The technology is grafted to the real survey enterprises. This research could be considered as the beginning of new survey system that is developed from the existing one. The research mainly has purposed on the topography condition survey area of poor environments and inefficient work system,

![Fig. 8. Error analysis](image)

### Table 2. Comparison between equipment auto VRS-GPS surveying and VRS-GPS

<table>
<thead>
<tr>
<th>Number</th>
<th>Robot survey</th>
<th>VRS</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N(m)</td>
<td>E(m)</td>
<td>N(m)</td>
</tr>
<tr>
<td>1</td>
<td>287195.6284</td>
<td>159360.4686</td>
<td>287195.6138</td>
</tr>
<tr>
<td>2</td>
<td>287200.4190</td>
<td>159344.8056</td>
<td>287199.2771</td>
</tr>
<tr>
<td>3</td>
<td>287203.1614</td>
<td>159322.9156</td>
<td>287203.1775</td>
</tr>
<tr>
<td>4</td>
<td>287222.8582</td>
<td>159345.7876</td>
<td>287226.9314</td>
</tr>
<tr>
<td>5</td>
<td>287222.8595</td>
<td>159345.7767</td>
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</tr>
<tr>
<td>6</td>
<td>287218.6858</td>
<td>159363.5545</td>
<td>287218.7010</td>
</tr>
<tr>
<td>7</td>
<td>287247.0967</td>
<td>159368.7541</td>
<td>287247.0646</td>
</tr>
<tr>
<td>8</td>
<td>287251.8072</td>
<td>159351.3374</td>
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</tr>
<tr>
<td>9</td>
<td>287256.0889</td>
<td>159331.6238</td>
<td>287256.0768</td>
</tr>
</tbody>
</table>
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where requires too much expanse, time and personnel.

The newly developed automatic positioning system was tested for existing problems of the former system, such as running low batteries, occurring errors when moving on slopes broke out. In this research, the survey was done with the designated route as its standards; that has the obstacle sensor technology under the given route, while a human could directly modify the automatic positioning system through the monitor sent from the system at the real time.

5. Conclusion

We have developed the VRS-GPS automatic positioning system in this research. Following the research, the unification of the survey equipments was made possible, so as getting the basis of minimizing personnel and increasing the work efficiencies.

It is possible to make an efficient judgment by receiving data at the real time, as well as to do unmanned survey in the area difficult to approach. The result of analysis of RMSE, which compared the VRS-GPS survey with the developed automatic positioning system, comes out X as 0.0169m, and Y as 0.0246m. It is able to move the automatic positioning system, based on the input coordinates and in the area, whereas unable to receive GPS. In fact, it is possible to operate via the driving monitor sent from the automatic positioning system.

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References


