Pose and Position Estimation of Dozer Blade in 3-dimensional by Integration of IMU with Two RTK GPSs

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Abstract –

Automation system in construction machine such as excavator, loader and other things has been developed to improve the performance and reduce the cost, time and manpower. Dozer is no exception.

Dozer is a crawler equipped with a substantial metal plate known as blade used to push large quantities of soil, sand, or other materials during leveling, digging or conversion work. Dozer can be found on a wide range of sites, which are mines, quarries and road. Therefore, the cost and time consuming in dozer working are highly significant matter.

However, in order to implement the automation system in construction equipment, guidance system for construction working has to be done before. Because the automation system can perform the operation and work better with information such as velocity, pose and posture etc. thorough the sensor. These system is called machine guidance system because guidance system is applied to construction machine. Shortly, if guidance system is done very well, the achievement of automation system could be better. Dozer is also no exception.

This paper will describe the method for estimating the pose and position of dozer blade, namely guidance of dozer, by sensor fusion or integration of inertial measurement unit device with two RTK GPSs. And then the proposed method is verified by experimental result.

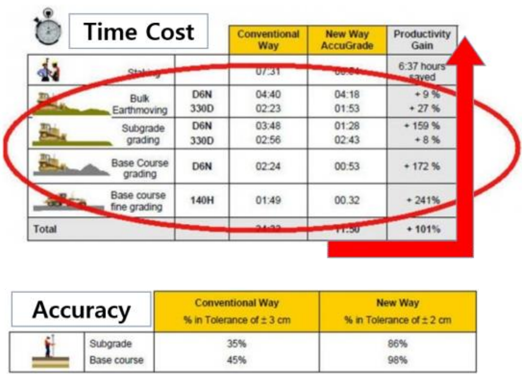
Keywords –

Machine Guidance; Dozer; Sensor Fusion

1 Introduction

Dozer is a crawler equipped with a substantial metal plate known as blade used to push large quantities of soil, sand, or other such material during construction such as grading, leveling, digging or conversion work. [1] Dozer can be found on a wide range of sites which are mines, quarries, road and express construction etc. Therefore, the cost and time consuming in dozer working are highly significant matters.

The automation system of dozer is assistance system for improving the performance such as accuracy and efficiency. A driver drives and commands the construction works through the system interface. After that, system do work according to order by using the information from sensor systems installed in dozer and field. Operator just pay attention to only driving. Blade motions such as lifting, tilting, angling known as pitch, roll and yaw are operated automatically during driving. As mentioned above, consequently, automated dozer brings the enhancement of productivity and efficiency rather than manual. Figure 1 includes the these contents. Komatsu, representative Japanese company wrote a technical paper about dozer automation system which is including the efficiency. [2]



Time Cost		Conventional Way	New Way AccuGrade	Productivity Gain
Staking		07:31	[illegible]	6:37 hours saved
Bulk Earthmoving	D6N 330D	04:40 02:23	04:18 01:53	+ 9 % + 27 %
Subgrade grading	D6N 330D	03:48 02:56	01:28 02:43	+ 159 % + 8 %
Base Course grading	D6N	02:24	00:53	+ 172 %
Base course fine grading	140H	01:49	00.32	+ 241%
Total		[illegible]	[illegible]	+ 101%

Accuracy	Conventional Way % in Tolerance of ± 3 cm	New Way % in Tolerance of ± 2 cm
Subgrade	35%	86%
Base course	45%	98%

Figure 1. The table is presented in Komatsu, Japanese development company: Advanced performance in both cost and accuracy part

The automation system in civil engineering is called machine control. And the system which incorporates the position sensors, motion measuring units and other devices is to provide on-board with information about the movement of machine such as dozer and excavator. And this system is called machine guidance. In this paper, these systems are applied to dozer, so we can name it as a dozer machine control and guidance.

As mentioned above, dozer machine control is a factor that can bring a lot of benefits. In order to implement the dozer machine control, however, machine guidance must be done before. Because, the control can be performed by receiving the movement information like position, orientation, pose and velocity etc. by using the sensor systems. To put it briefly, if machine guidance is performed greatly, the achievement of dozer machine control system could be better. For this reason, machine guidance is also significant part, and the sensor system should be installed well too.

This paper will describe the method about pose and position estimation of blade by integration of IMU with two RTK GPSs. And then proposed algorithm is verified by experimental results.

2 Well Used Sensor Fusion Method Examples about Pose Estimation

Many researcher have worked about sensor fusion method for estimating the pose and position of vehicle. The UAV(Unmanned Aerial Vehicle), ship and flight has to install the navigation system for driving as well.

Keong, [3], proposed the method about determining heading and pitch by using a single difference GPS. Kumar, [4], used the extended Kalman filter for doing integration of inertial navigation system and global positioning system. Godha, [5], suggested the integrated GPS and INS system for pedestrian navigation in a single degrade environment. This paper has a novelty value in approach to non-vehicle system. In domestic, Ko, [6], performed the indoor localization of a mobile robot by using external sensor. Yeom, [7], used the GPS and accelerometer for estimating the position of moving object.

To implement the dozer machine control, Xue, [8], analyzed the kinematics of dozer by simulation, and Sun, [9], me, studied on sensor fusion algorithm for estimating the attitude of dozer blade.

3 Estimating the Position and Pose of Dozer Blade

3.1 System configuration and coordinates

In machine guidance of dozer, sensor system may have to be installed to dozer. Firstly, two IMU are used to get the pose, namely, roll, pitch and yaw of blade and cabin at period of 100Hz. Secondly, GPS antennas are used to get the position. The one is base antenna that will be installed on the outside of dozer, the others are attached on the blade. The rover will be in the cabin. Figure 2 illustrates a system configuration in detail.

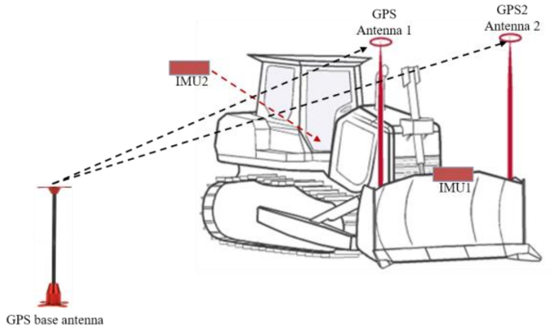


Figure 2. System configuration: IMU and GPS

To generate the Cartesian coordinates system, instead of GPS which has longitude, latitude and height, UTM (Universal Transverse Mercator) coordinates is used. Based on this, the frame of dozer, sensor and reference frame can be formed. Reference frame is naturally set to be the origin of UTM coordinate system. And then frame with respect to cabin of dozer and blade are set by convention, i.e., roll is defined by rotation about axis that pointing forward and yaw is rotation that done by upward axis. Pitch is done by right hand rule.

We installed the GPS and IMU for receiving the pose and position of blade and cabin. Especially, pose of blade is estimated by calculation of GPS data for compensating the unstable in IMU device, which is expressed with respect to origin of frame in UTM coordinates system. This is why frame of sensor system is necessary.

3.2 Pose Estimation

The process of linear Kalman filter is used for estimating the pose of blade reliably. Figure 3 is algorithm about linear Kalman filter that is used in.

$$(N \le k \le 2N-1)\ \hat{x}_k^- = A\hat{x}_{k-1} + u_k$$

$$\hat{x}_N^- = A\hat{x}_{N-[\,]}\ ,\ [\,] = \left[\frac{IMU\_data\_sampling\_frequency}{GPS\_data\_sampling\_frequency}\right]$$

$$P_N^- = AP_{N-[\,]}A^T + Q$$

$$K_N = P_N^- H^T(HP_N^- H^T + R)^{-1}$$

$$\hat{x}_N = \hat{x}_N^- + K_N(Z_N - H\hat{x}_N^-)$$

$$P_N = (I - K_N H)P_N^-$$

$$u_N \sim u_{2N-1} = K_N(Z_N - H\hat{x}_N^-)$$

Figure 3. Modified Kalman filter algorithm for estimating the pose

3.2.1 Prediction and Measurement Modeling

There are two process modellings in the linear Kalman filter. One is prediction and another is measurement. Prediction modelling is defined as follows, equation (1).

$$x_{k+1} = Ax_k, \tag{1}$$

where

$$x = \begin{bmatrix} 1 \\ Roll_{IMU} \\ Pitch_{IMU} \\ yaw_{IMU} \end{bmatrix}, A(N) = \begin{bmatrix} 1 & \\ Roll_{IMU} & \\ Pitch_{IMU} & 0_{4\times3} \\ Yaw_{IMU} & \end{bmatrix}$$

N is the step parameter for GPS data, and state of x will be compared with pose derived from measurement modelling.

Measurement modelling is defined as follows, equation (2), (3), (4) and (5).

$$z_N = \begin{bmatrix} Roll_{GPS}(N) \\ Pitch_{GPS}(N) \\ Yaw_{GPS}(N) \end{bmatrix} \tag{2}$$

$$Roll_{GPS} = \arcsin((z_1 - z_2)/Baseline) \tag{3}$$

where z_1 and z_2 is height data of GPS

$$Yaw_{GPS} = \arctan((y_1 - y_2)/(x_1 - x_2)) + \pi/2 \tag{4}$$

Where, $x_1 > x_2$, $\pi/2 \leq \arctan((y_1 - y_2)/(x_1 - x_2)) \leq \pi/2$

$$Yaw_{GPS} = \arctan((y_1 - y_2)/(x_1 - x_2)) - \pi/2 \tag{5}$$

Where, $x_1 < x_2$, $\pi/2 \leq \arctan((y_1 - y_2)/(x_1 - x_2)) \leq \pi/2$

Each function is used in linear Kalman filter so that the attitude of blade can be estimated more precisely.

3.3 Estimation of Edge Position

Most important things in dozer machine guidance in construction working is to know the bottom position of blade, namely edge. Because, landform have a considerable effect on working process. However, edge position cannot be estimated directly because of sensor installation on the top of the blade. Therefore, in order to estimate the edge position by using the sensor system, kinematics has to be used as alternative solution. Figure 4 is explaining overall frame of body, link and joint. Each Table 1 and 2 is Denavit-Hartenberg parameters table about figure 4.

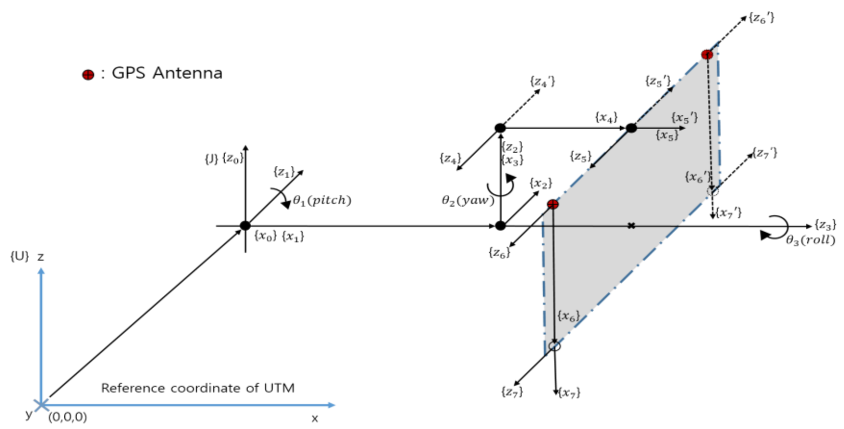


Figure 4. The assignment of link frames in dozer blade having 3 degrees of freedom

Table 1. D-H parameters table concerned with antenna 1

i	α_{i-1}(deg)	$a_{i-1}(m)$	$d_i(m)$	θ_i(deg)
1	-90	0	0	θ_1
2	90	a_1	0	$90+\theta_2$
3	90	0	0	$90+\theta_3$
4’	**90**	a_3	**0**	**90**
5’	**0**	a_4	**0**	**0**
6’	**0**	**0**	**Baseline/2**	**90**
7’	**0**	a_6	**0**	**0**

Table 2. D-H parameters table concerned with antenna 2

i	α_{i-1}(deg)	$a_{i-1}(m)$	$d_i(m)$	θ_i(deg)
4	**-90**	a_3	**0**	**-90**
5	**0**	a_4	**0**	**0**
6	**0**	**0**	**Baseline/2**	**-90**
7	**0**	a_6	**0**	**0**

The reference frame is denoted by {U}. {J} or {0} is frame of pitch joint and origin of this is on the middle of two pitch joint. Frame 7 is end effector and 6 is used for estimating the origin position of {0}. Theta 1, 2 and 3 is angle of pitch, yaw and roll. The transformation matrix of body expressed with respect to UTM coordinates system can be derived by IMU data which is installed in cabin. By doing the forward kinematics overall, edge position of blade will be estimated.

4 Experiment and Evaluation

4.1 Experimental Setup

Figure 5 is showing the dozer and sensor system and where experiment was done.

Figure 5. Experimental setup: Dozer, sensors and location that is Hanyang Univ. at Ansan

The sampling rate of GPS and IMU are set to be different. GPS is 20Hz and IMU is 100Hz. Link parameters and joint parameters of D-H parameter were measured. Baseline is 2.78m, a_1 is 1.69m, a_3 is 0.51m, a_4 is 0.23m, a_6 is 0.85m and d_6 is Baseline/2. Each parameter Q, R, H and P_0 of sensor integration part are given by equation (6).

$$Q = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, R = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{6}$$

$$H = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, P(0) = O_{4\times 4}$$

4.2 Result and Evaluation

Experiment was done in roll, pitch and yaw motion of blade with non-driving. In this paper, experimental result will be mentioned about roll motion with non-driving representatively.

The results of estimating the pose in roll motion at period of 100Hz through the sensor integration are in Figure 6. The results of graph which represent the estimated edge position with regard to x, y and z axis in roll motion can be founded in Figure 7, 8, and 9.

In Figure 6, pose, in other words, rotation data from IMU and estimations derived from sensor integration are matched well. If more anti-vibration system to sensor is applied well, the result will be better. Additionally, Figure 7, 8 and 9 are modified little for analysing the proposed method. In the figure, UTM zone position value is removed. Consequently, edge position of blade is estimated as expected.

5 Conclusion

In this paper, estimation method about pose and position of dozer blade was proposed for machine control. To do that, IMU and RTK GPS were installed in dozer system.

The estimation results about edge position were done as expected. However, sensor error such as black out, satellite factor and inaccurate measurement of link parameter were existed. This is a problem awaiting to be solved with software and hardware.

The estimated position was not compared with real edge position. Therefore, more reliable evaluation is needed and should be done later.

Pose and position of dozer, not blade, was not handled. But for doing machine control, guidance system about cabin and blade of dozer are necessary. So, this will have to be done later also.

As mentioned in introduction, machine guidance is necessary part in implementation of machine control. Final goal of this research is to do the machine control. When machine guidance is completed, machine control of dozer will be progressed based on this research.

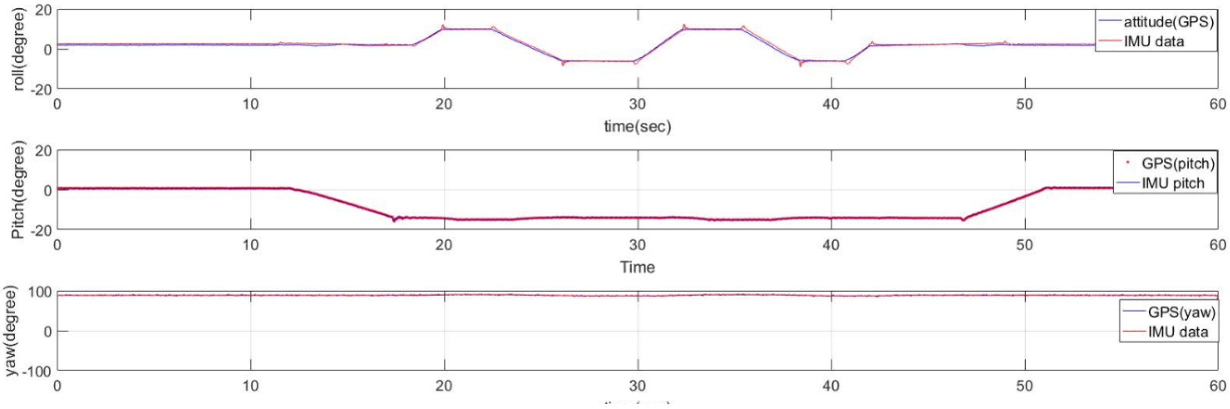


Figure 6. The graph of test results about estimated pose of blade in roll motion: IMU data is compensated by GPS

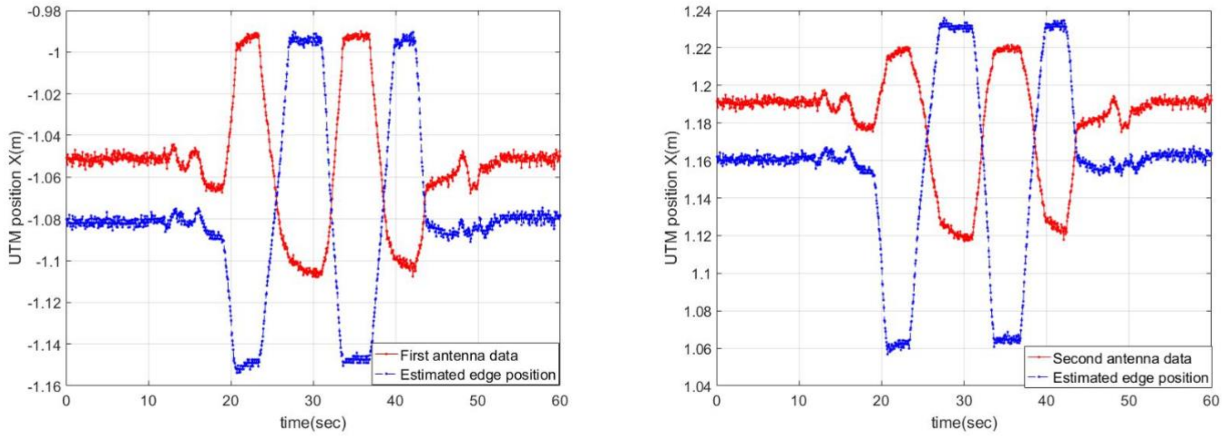


Figure 7. The result graph of test about estimating the edge position with regard to x axis in roll motion

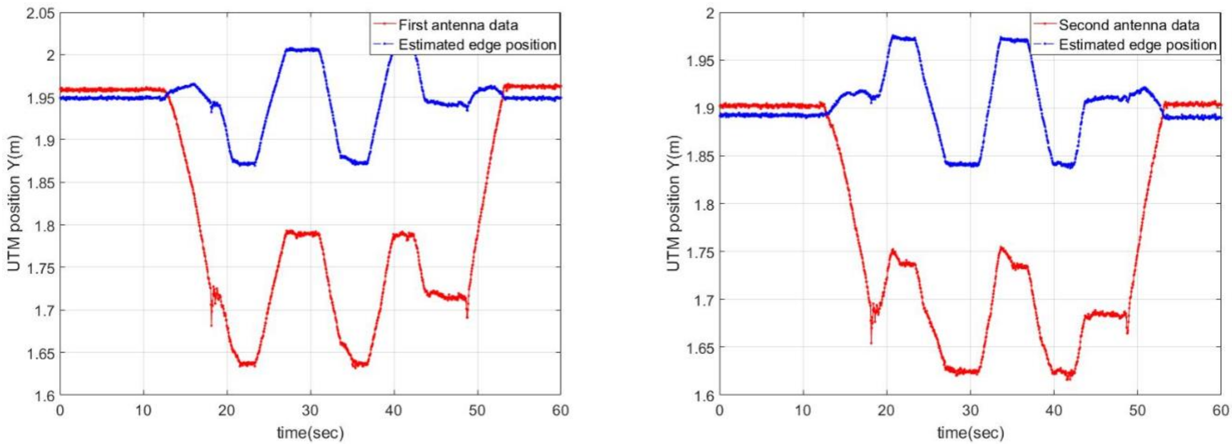


Figure 8. The result graph of test about estimating the edge position with regard to y axis in roll motion

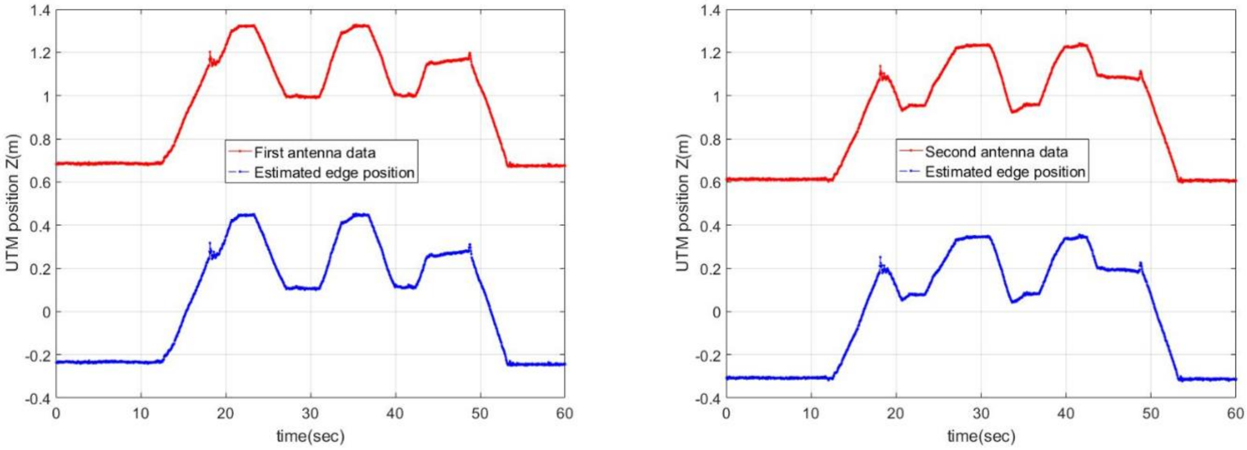


Figure 9. The result graph of test about estimating the edge position with regard to z axis in roll motion

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