Height Estimation of Gondola-typed Facade Robot

Dong Yeop Kim [1]*, Hwadong Sun [1], Jong Su Yoon [1], and Chang-Woo Park [1]

[1] *Intelligent Robotics Research Center, Korea Electronics Technology Institute, Bucheon-si, Gyeonggido, Republic of Korea*
** Corresponding author (sword32@keti.re.kr)*

Purpose We researched an automated and robotic facade maintenance robot. This robot can protect people against safety hazards, and save labour cost for building facade maintenance. Our platform is gondola type. Accurate and robust height estimation is necessary for automation. We propose a methodology for height estimation. **Method** Even though there are many sensor systems for height estimation, a new design for a gondola-typed robot was needed. Our goal was to make this sensor for the gondola accurate, robust, and cheap. We used a dome camera mechanism with tilt sensors. A range sensor always points vertically to the ground. An estimation algorithm then simulated various situations. **Results & Discussion** We will present our results in a graph and/or table (*Figure 2*) and describe and discuss them briefly. We used a Kalman-filter frame to estimate the height of gondola. The concept of monoSLAM was then applied1. There is a control update phase and measurement update phase. For control update, the velocity of the gondola cage was also estimated. During the measurement update, there are branches for any obstacles under the sensor. For example, a worker can go under the gondola, construction materials can be laid, and the terrain under the gondola fluctuates.

***Keywords**: robotics, gondola, facade, maintenance, height estimation*

INTRODUCTION

The robotic system for building façade is a good example of a robot substituted for human workers in dangerous and poor working places[1]. Many human workers have fallen from building façade, and their stress from the fear of high place in the air is very severe. The robot with intelligent system is free from these threats.

The system in this paper is a gondola typed robot. The strong point of this type is that it can be installed at building without intension about robots[2]. The built-in type robot needs special guide rails on the building walls.

For automation of the robot system on the building façade, sensors for pose and localization is required. Many application of the robot needs the pose and localization information. For example, paint should be spread evenly. If human worker paints, the person recognizes the state of the wall, and adjusts the amount of the paint. Similarly, the robot also controls the amount of the paint spread on the wall. The pose and location of the gondola cage is an important factor for the control.

In this paper, we proposed the methodology of height estimation as a component of the pose and localization sensor system. A range sensor points the direction perpendicular to the ground. The direction is defined by an attitude reference system (ARS). The ARS is a sensor system providing the roll and pitch values.

Additionally, a Kalman filter is applied to estimate the height. The filter define has a scenario that such an object come under the sensor temporary.

POSE AND LOCALIZATION OF GONDOLA ROBOT

The gondola robot executes intelligent jobs using pose and localization information. We have proposed sensor systems for pose estimation[2, 3]. The pose means the roll, pitch, and yaw of the gondola cage relative to the building façade. However, the gondola robot keeps the contact to the building façade. If the contact is lost, the gondola will pause the operation until the abnormal status is finished. Two suction fans are installed at the lower part of the gondola cage, and keep the contact. Therefore, the rolling is critical pose.

Height of the gondola is the distance from the ground to the gondola cage. The movement of the gondola depends on this height information. The main operations are executed while the gondola moves from top to bottom on the building façade. Therefore, moving the gondola cage to the top of the façade is important. At near the bottom of the building façade, deceleration for safe landing of the gondola should be guaranteed. Especially, landscaping works around the building are protected from the gondola robot operations. Additionally, color change in accordance with building height can be expected.

In our scenarios, the gondola robot on the building façade is supplied only with power and communications. A paint tank is equipped the lower part of the gondola cage. Therefore, consumption of the paint varies the mass distribution of the gondola. Therefore, intelligent and online sensing and control of the pose and localization of the gondola is important.

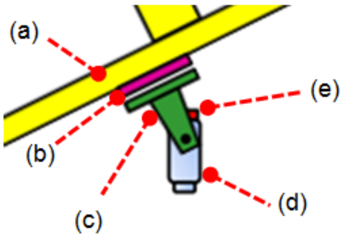
Range Sensor Based Height Estimation

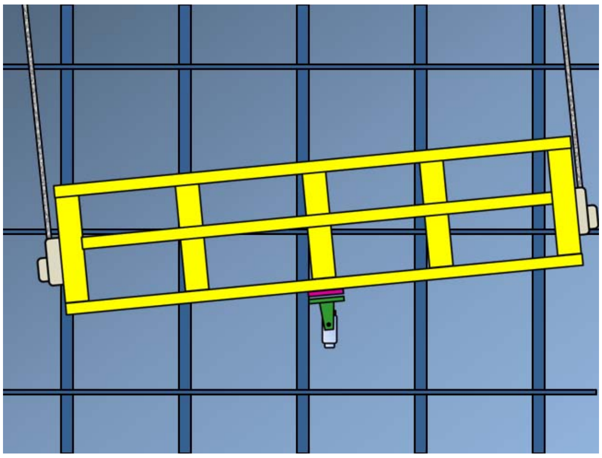
There are some kinds of height estimation method used in many areas. Air plane systems uses two approaches. At higher flight altitude, barometer based system measures it. Its degree of precision is one meter. It is suitable for the airplane, and mountaineers and mountain bike riders use this system. However, the height of barometer is the distance from the standard datum of leveling. In other words, a huge mountain under the airplane cannot be recognized with barometer. Therefore, at lower flight altitude, radio altimeter is used. It measures the time of radio echo. This device measures the distance between the object and the ground. However, this device is military or aerospace product. It is not suitable for the gondola robot system.

In this paper, we proposed a sensor system using a range sensor. It can measure about 100 meter maximum, and the precision is about one centimeter. Because the height of building floor is generally less than three meter, this sensor can cover at least 30 floors.

The problem of this range sensor is that the pose of gondola fluctuates. If the range sensor is installed under the bottom of the gondola cage in direction of the vertical column of the cage, the direction of the range sensor is changed as the pose of gondola rotates. The returned distance of the range sensor is not the height of the gondola cage. It is the distance to the off-site ground from the foot of perpendicular of gondola cage.

To solve this problem, we design a pan-tilt module to support the range sensor as shown in figure 1. Figure 1 (d) is the range sensor. It always points the ground in direction of the gravity. The direction is defined by feedback control from the ARS sensor (figure 1 (e)). The ARS sensor measures the roll and pitch. Panning and tilting modules conduct feedback control to maintain zero roll and zero pitch. Because of this sensor system, the range sensor can always measures the exact height between the gondola cage and the ground.





(f)

Fig.1. Range sensor with pan-tilt module. (a) The gondola cage. (b) Panning module. (c) Tilting module. (d) Range sensor. (e) Attitude reference system (ARS). (f) An example of the sensor system installation.

Kalman Filter Design

The measured height of proposed sensor system can be used as deterministic height of the gondola cage. However, this approach has two week points. First, the raw data from range sensor can contain sensor noise. Second, some objects can go under the sensor system. For example, a worker may put construction materials such as pipes and bricks. Many vehicles move in sites. If the range sensor value decrease one meter rapidly, we can guess the reason such as a forklift under the gondola cage. However, the robot system may recognize it as the gondola height decrease one meter below. Landscaping works is another good cause for this rapid height change. If the point of the range sensor system goes from the ground to the top of a tree, it is not change of the gondola cage height.

Basically, we adopt basic design of the Kalman filter[4]. There is control update (prediction) phase, and measurement update (correction) phase. Before the measurement update, current sensor data is compared with former sensor data as shown in figure 2. If the change of the sensor data is bigger than threshold, the Kalman filter recognizes the sensor data gap as an obstacle height. From next filtering, the obstacle height is added to returned sensor data. This state is released when the sensor data is changed rapidly about the obstacle height. It means the obstacles are moved, and the sensor system begins to point the ground again. Note that from first recognition of the obstacle, the gondola cage can move. The release threshold needs margin in comparison to the obstacle height threshold. We use 70% as a ratio to the obstacle height threshold.

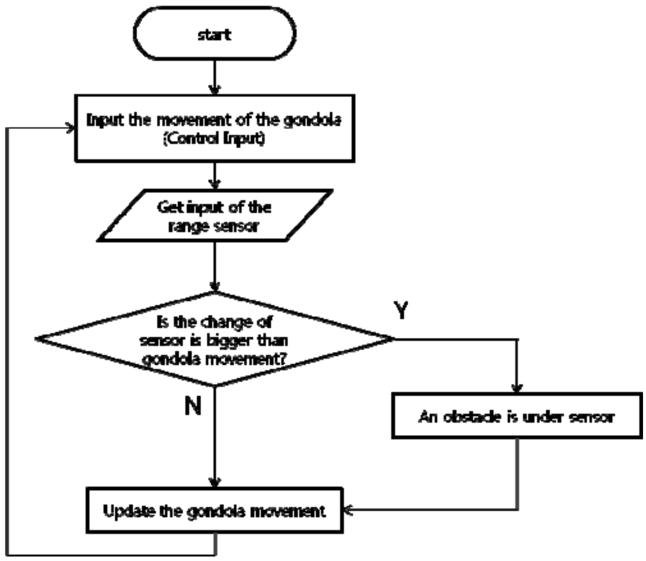


Fig.2. Flow chart for modification of Kalman filter. Before the measurement update, there is a comparison of current and former sensor data.

As Kalman filter state, the tracked component is the gondola cage height x_t and velocity v_t.

$$\mathbf{X}_t = \begin{bmatrix} x_t \\ v_t \end{bmatrix} \quad (1)$$

The reason for including velocity v_t to state $\mathbf{X}_t$ is that the gondola is expected to keep the equal speed movement downward. The exact velocity should be measured with high accuracy.

The equation from $\mathbf{X}_{t-1}$ to $\mathbf{X}_t$ is

$$\begin{bmatrix} x_t \\ v_t \end{bmatrix} = \begin{bmatrix} x_{t-1} + u_t^v \Delta t \\ u_t^v \end{bmatrix} \quad (2)$$

u_t^v is the velocity control input. Δt is the sampling time for the Kalman filter. As mentioned before, the movement control of the gondola cage is based on the velocity. The control input is also a target velocity. u_t^v is measured by encoders on wire ropes of the gondola system.

$$u_t^v = \frac{e_t - e_{t-1}}{\Delta t} \quad (3)$$

e_t is current encoder value, and e_{t-1} is former encoder value. As shown in mobile robot research, encoder system noise is accumulated[4]. Therefore, the encoder value is converted to velocity information, not distance information.

Figure 3 is Gondola vertical localization sensor on wire rope. This sensor system has an encoder on the wire rope, and mechanical jig to support the contact of encoder to the wire rope. The attribute of the wire rope varies to every direction. The linear guide and two shafts provide this plexiblity.

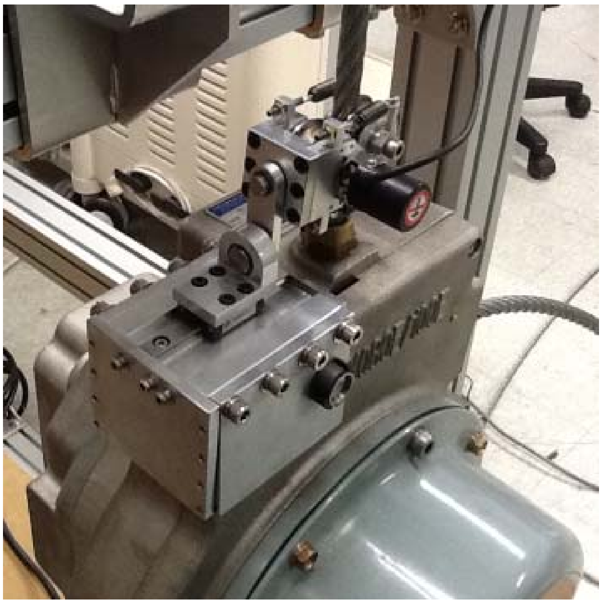


Fig.3. Gondola vertical localization sensor on wire rope. It is an encode with supporting links.

The measurement $\mathbf{z}_t$ is

$$\mathbf{z}_t = \begin{bmatrix} z_t^x \\ z_t^v \end{bmatrix} = \begin{bmatrix} x_t \\ v_t \end{bmatrix} \quad (4)$$

The sensor data from the range sensor is changed to gondola height information z_t^x and velocity information z_t^v.

In order to input (2) and (4) to Kalman filter, they can be rewrite as

$$\begin{bmatrix} x_t \\ v_t \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} x_{t-1} \\ v_{t-1} \end{bmatrix} + \begin{bmatrix} \Delta t \\ 1 \end{bmatrix} \begin{bmatrix} u_t^v \end{bmatrix}$$
$$\begin{bmatrix} z_t^x \\ z_t^v \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_t \\ v_t \end{bmatrix} \quad (5)$$

EXPERIMENT

MATLAB simulation was designed to verify the proposed Kalman filter modification. The scenario is that the gondola moved from 300 cm high to 60 cm high. 20 cm obstacle and 30 cm obstacle was placed under the gondola one by one. Figure 4 is the height and sensor value graph for this scenario. The sensor data is adjusted to height value to compare with the true gondola height. The red dashed line at bottom part of the graph is the obstacle height. From 7 sec to 13 sec, there was a 20 cm obstacle, and from 23 sec to 27 sec, it is a 30 cm obstacle. The range sensor value mirrors these obstacle heights, so the blue solid line has hollow sections which coincide with the obstacles. However, the real gondola height does not have such hollow sections as shown with the black dash-dot line of figure 4.

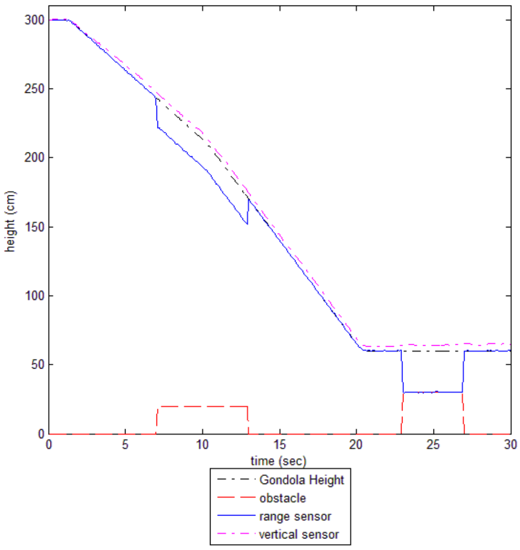
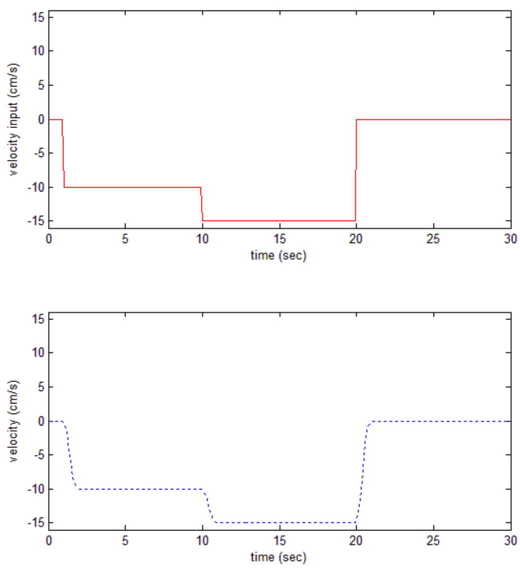
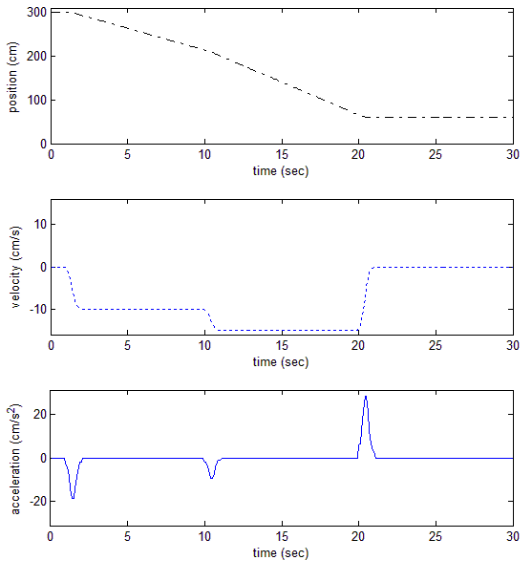


Fig.4. Simulation Environment

The velocity input from user or upper controller is shown in figure 5 (a). Because the input is described with number, the velocity input graph is trapezoidal. This input (red solid line) is converted with sigmoid function in order to change to real velocity of the gondola system (blue dashed line). Figure 5 (b) is the corresponding position, velocity and acceleration graph about this converting.



(a)



(b)

Fig.5. (a) Velocity input from user or upper controller. (b) Corresponding position, velocity and acceleration to velocity input.

With sensor data of figure 4 and velocity input of figure 5, the Kalman filter estimated the gondola height. Figure 6 is its output. The top graph of figure 6 is the true gondola height. The middle graph has blue and red graph. The blue solid line is unfiltered height that range sensor data is converted. If the sensor data is 300 cm, the height is confirmed as 300 cm straightforwardly. However, the red dotted line is the output of Kalman filter proposed in this paper. The obstacle is recognized by rigid change of the range sensor value. Therefore there is no hollow section. The bottom graph is the error. The error is calculated by subtracting the true height (top graph) from sensed and filtered height (middle graph). Note that the hollow sections become large error sections. Statistically, the mean and the standard deviation of straightforward height sensing is -7.94 cm and 11.67 cm, respectively. On the other hand, the proposed Kalman filter reduce them to 1.74 cm and 0.91 cm.

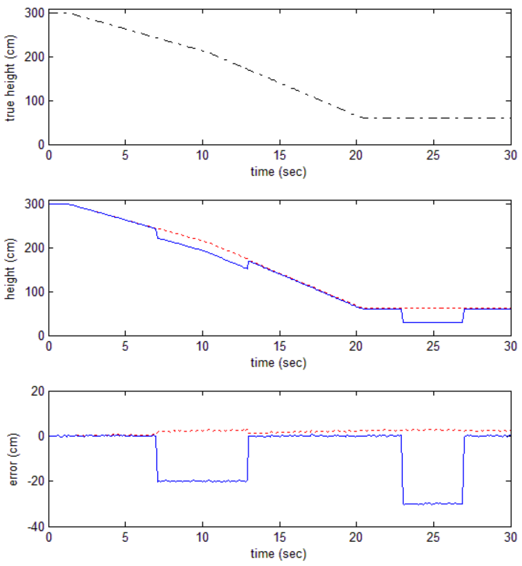


Fig.6. True height of the gondola cage (top). Range sensor value (blue solid line) and Kalman filter estimation (red dotted line) (middle). The error of the unfiltered range sensor data (blue solid line) and Kalman filter error (red dotted line) (bottom).

CONCLUSION

The proposed sensor system is for the gondola height estimation. Pan-tilt module with ARS makes the range sensor point to direction perpendicular to ground (gravity direction). Sometimes, some objects such as vehicles and trees may corrupt this sensor value. Therefore, we suggest modified Kalman filter to estimate the height.

As future work, we will apply this sensor system to the gondola, and test at 20 meter or higher building.

ACKNOWLEDGEMENTS

The work presented in this paper was funded by BMRC(Building-Façade Maintenance Robot Research Center), supported by Korea Institute of Construction and Transportation Technology Evaluation

References

1. Gambao, E., Hernando, M., “System for a semi-automatic façade cleaning robot”, in *Proc. of the 2006 International Symposium on Automation and Robotics in Construction (ISARC 2006)*, pp.407-41, 2006.
2. Sun, H., Kim, D.Y., Kwon, J.H., Kim, B-S., and Park, C.-W., “The position and orientation measurement of gondola using a visual camera”, in *Proc. of the 2011 International Symposium on Automation and Robotics in Construction (ISARC 2011)*, pp. 693-697, 2011.
3. Kim, D.Y., Kwon, J.H., Sun, H., Kim, B-S., and Park, C-W., “Rope attribute measurement system for gondola type facade robot”, in *Proc. of the 2011 2nd International Conference on Construction and Project Management (ICCPM 2011)*, pp. 103-106, 2011.
4. Thrun, S., Burgard, W., and Fox, D., *Probabilistic Robotics (Intelligent Robotics and Autonomous Agents)*: The MIT Press, 2005.