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A Ship Cargo Hold Inspection Approach Using Laser Vision Systems

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Abstract

Our paper represents a vision system based on the laser measurement system (LMS) for bulk ship inspection. The LMS scanner with 2-axis servo system is installed on the ship loader to build the shape of the ship. Then, a group of real-time image processing algorithms are implemented to compute the shape of the cargo hold, the inclination angle of the ship and the relative position between the ship loader and the cargo hold. Based on those computed inspection data of the ship, the ship loader can accomplish the bulk cargo loading operation automatically. Finally, our paper describes and analyzes the experiment of the Laser Vision System in Coal Terminal of Tianjin Port.

Keywords: *Laser Measurement System, Image Processing, Vision, Ship Loader*

1. Introduction

Nowadays, more and more ports are transforming from the manned mechanized port to the unmanned intelligent port. Many engineers and researchers are now developing the intelligent control system to implement the automation for port machines. Most of those engineers and researchers used the digital video cameras as the image sensors [1], [2], [3], [4], [5], [6]. For a fast and correct image recognition, a standardize mark image should be firstly fixed on the controlled target. With the assist of the mark, it is possible to calculate the 3D position of the target by using a mono-vision system. For example, an octagon plate with six reflective circles was installed on the hoist, and then the camera could track the octagon plate mark image and calculate the real-time position of the hoist [2].

Those methods based on cameras can work for the machines themselves. However, for the automation control of bulk port machines, those methods are limited. It is because that it is not easy or possible to install standardized mark images on bulk port machines, the bulk cargo and the bulk cargo ships. The bulk ports are usually very dirty, so the pollution of cameras and standardized mark images may reduce the reliability of the digital video cameras vision systems. And the ships and the bulk cargo are also impossible to install any standardized mark images.

Therefore, some other engineers and researchers began to find a new way to implement the target position and inspection. Some used the laser to detect the 3D surface of the target while some used the frequency modulated continuous wave (FMCW) radar to detect the distance from the target to the radar [7], [8], [9], [10], [11], [12] . However, the precision of the FMCW radar is not enough to meet the requirements of the automation on ship loader [10]. The laser measurement system (LMS) is a suitable approach to solve the target-inspection problem in bulk ports. With the multi-axis servo machine, the LMS can do both single-dimension and multi-dimension scanning. Based on the images from the LMS, the shapes of the cargo and ships can be rebuilt [9]. Combined with image processing algorithms, the information of the targets can all be calculated.

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2. System Description

2.1. Laser Measurement System

Laser measurement system (LMS) is a laser-based multi-angle distance scanner. As shown in

Figure *1*, the LMS can send and receive the laser in each 0.25 degree. An optical monitor section is made by those lasers. In the optical monitoring section, any target that the laser cannot pass through will be detected. The distance and the sectional plane shape of the target can also be computed by LMS.

For a stationary LMS, only one arc section can be monitored which limits the LMS scanning performance. Usually, as shown in

Figure *2*, a multi-axis rotation servo machine is installed on the LMS that can drive the LMS to rotate into any scanning posture. With the servo machine, the LMS can scan any sectional planes of the target, and those planes scanned by LMS can rebuild the whole surface of the target.

Figure 1. the Diagram of LMS Scanning [13]

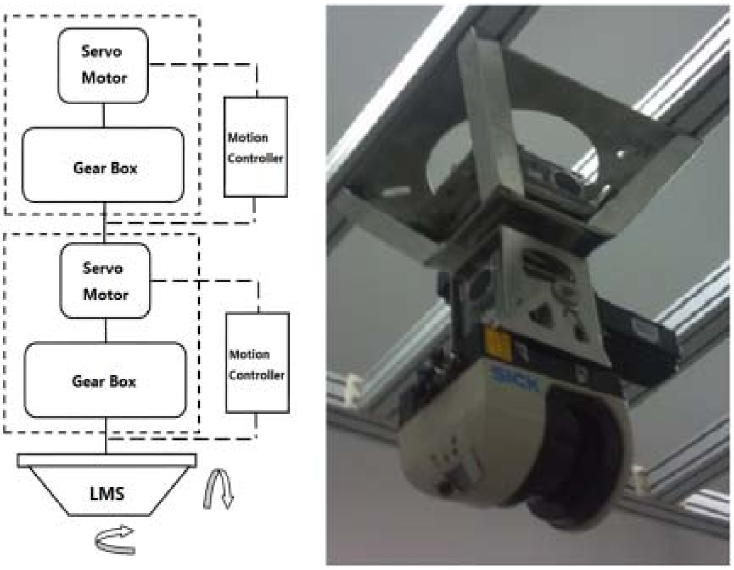

Figure 2. the Architecture and the photo of Multi-axis Servo System for LMS

2.2. Architecture of the Automatic Ship Loader

The automatic ship loader is a typical manned ship loader with a group of advanced sensors and controllers. With the assist of those sensors and controllers, the ship loader can be operated in typical manned mode and automation mode.

As shown in

Figure *3*, the LMSes are installed on the ship loader and can scan the ship as well as the bulk cargo. With the servo machines, the LMSes can rotate into different postures and scan the targets at any sectional planes. A 2D and 3D ship and bulk cargo image can be rebuilt by those sectional planes. The embedded computer can analyze the images based on scanning data and output the analysis results including the position of the ship, the shape of the ship cargo hold and the shape of the cargo etc. The programmable logical controller (PLC) receives the analysis results and controls the ship loader complete the loading operation automatically. For an automatic ship loader, the image processing algorithm is the key technology.

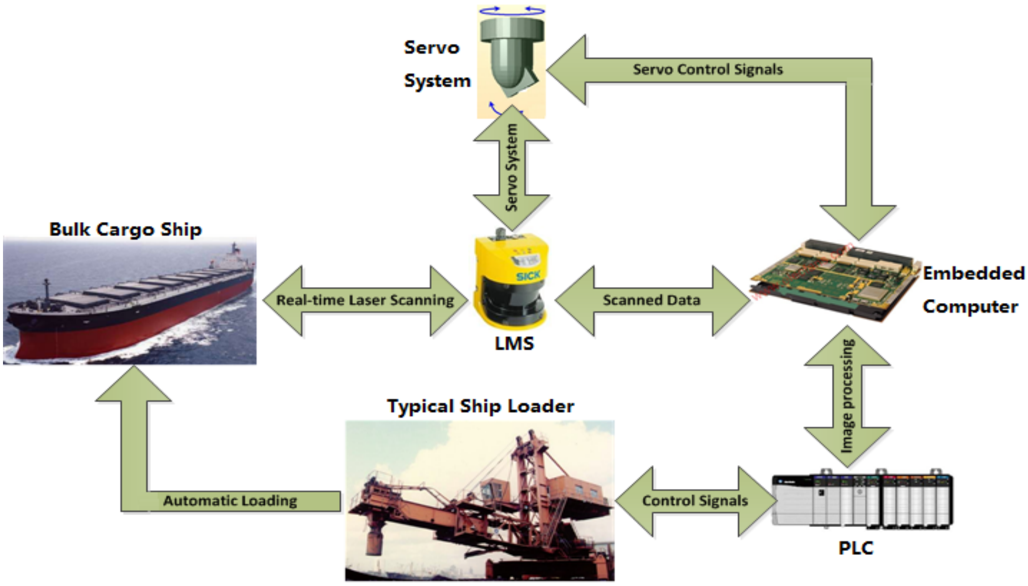

Figure 3. The Architecture of the Automatic Ship Loader

3. Image Processing Algorithm
3.1. Image Preprocessing
As shown in

Figure *4*, the LMS installed on the ship loader can scan the ship cargo hold (left part of the Figure 4) and rebuild the sectional plane image of the hold (right part of the Figure 4).

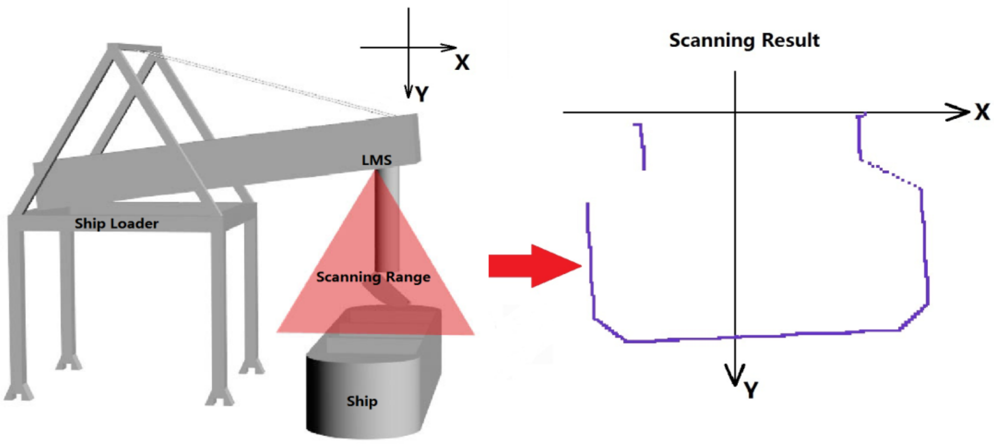

Figure 4. Diagram of LMS Scanning on Ship Loader

Based on the sectional image of the cargo hold, the width of the hold, the depth of the hold and the inclination angle of the hold can all be computed by an image processing.

The scanned point cloud should be firstly rasterized and secondly stored in a 0-1 matrix. The purpose of rasterized points is to achieve high-performance at an enough precision condition. The LMS used on the ship loader can reach 0.1cm precision which is over-accurate for automatic ship loader. For the ship loader, 1cm is enough accurate for automatic control. A rasterization formula is used to process all points into rasterized points [14], [15].

$$\begin{bmatrix} X \\ Y \end{bmatrix} = CEIL\left(\begin{bmatrix} X_0 \\ Y_0 \end{bmatrix} + \begin{bmatrix} S \\ S \end{bmatrix}\right) \times \frac{1}{S} \quad (1)$$

In Equation 1, the CEIL function is a decimal truncation function. For example, CEIL (2.6) = 2. And the S is the side length of rasterized grid. The $\begin{bmatrix} X \\ Y \end{bmatrix}$ is the rasterized points and the $\begin{bmatrix} X_0 \\ Y_0 \end{bmatrix}$ is the original points.

As shown in

Figure 5, the size of every rasterization square cell is 1cm by 1cm,inother words, S=1 in Equation 1. If there are 3 points in the original point cloud are P1 $\begin{bmatrix} 2.8 \\ 4.8 \end{bmatrix}$, P2 $\begin{bmatrix} 2.2 \\ 4.2 \end{bmatrix}$ and P3 $\begin{bmatrix} 1.6 \\ 2.7 \end{bmatrix}$ these points will be transformed into 2 points Pa $\begin{bmatrix} 3 \\ 5 \end{bmatrix}$ and Pb $\begin{bmatrix} 2 \\ 3 \end{bmatrix}$ after rasterized. The decimal part of the original points will be cut.

The benefits of the rasterization are to remove and merger the very close points to reduce the number of the points and to transform the float points into integer points to increase the computing performance in embedded computers and micro-controllers.

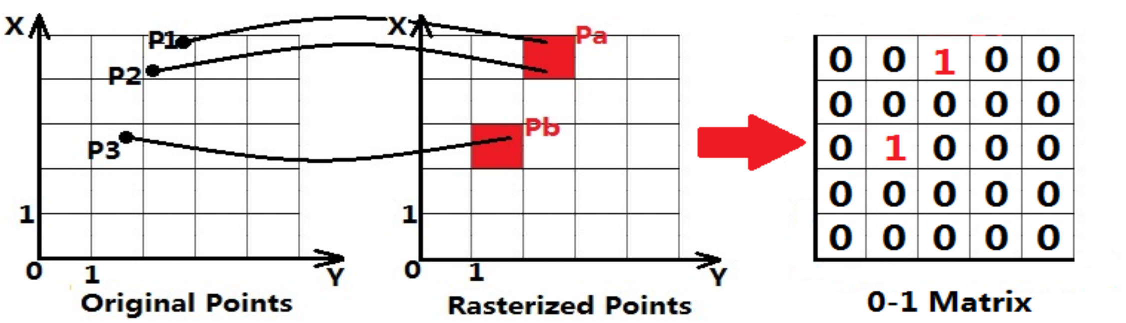

Figure 5. Transform Original Points to rasterized Points and to 0-1 Matrix

A 0-1 matrix is used to store the rasterized points for feature-extraction. The size of the matrix is equal to scanning range of LMS. The LMS used in ship loader can detect objects of less than 4000cm. Therefore, the matrix size is 4000 by 4000. Each value (0 or 1) of the element in the matrix represents whether there is a point existed at the coordinate position of the element. The steps to store the points into 0-1 matrix are shown following.

1. Build a D by D zero matrix, where D is equal to the LMS scanning range.

2. Traversal all points $\begin{bmatrix} X \\ Y \end{bmatrix}$ and make $\text{Element}_{X,Y} = 1$.

As shown in

Figure 5, for instance, there are Pa and Pb in $\begin{bmatrix} 3 \\ 5 \end{bmatrix}$ and $\begin{bmatrix} 2 \\ 3 \end{bmatrix}$, so $\text{Element}_{3,5} = 1$ and $\text{Element}_{2,3} = 1$.

Based on the 0-1 matrix, the feature-extraction can be easily executed.

3.2. Feature Extraction

For an automatic ship loader, the features including the width of the cargo hold, the depth of the hold and the inclination angle of the hold should be extracted.

Based on the 0-1 matrix, a dynamic projection approach is used to detect the edge of the cargo hold and then determine the width and depth of the hold.

As shown in Equation 2, all the elements in 0-1 matrix are projected to X axis and a one-dimensional projection array $[P_0 \quad \ldots \quad P_m]$ is acquired.

$$[P_0 \quad \ldots \quad P_m] = Projection(\begin{bmatrix} M_{0,0} & \cdots & M_{0,n} \\ \vdots & \ddots & \vdots \\ M_{n,0} & \cdots & M_{n,n} \end{bmatrix}, Interval) \qquad (2)$$

In Equation 2, the projection function has two input parameters which are the 0-1 matrix $\begin{bmatrix} M_{0,0} & \cdots & M_{0,n} \\ \vdots & \ddots & \vdots \\ M_{n,0} & \cdots & M_{n,n} \end{bmatrix}$ and the projection interval size $Interval$.

The each element of the projection array is determined by Equation 3.

$$\mathrm{P_t} = \sum_{x<(t+1)\times Interval}^{x=t\times Interval} \mathrm{M_{x,y}} \qquad (3)$$

The purpose of the projection is to reduce the dimension and size of the matrix and to search for the edge by sorting the projection array. It is because that the edge of the hold is nearly perpendicular to the X axis. By projection, the big element in the projection array is usually the edge in the image scanned by LMS.

As shown in

Figure *6*, for an instance, a projection interval is selected. In the 0-1 matrix, these elements which are within the same interval are accumulated, and the sum is store in an element of projection array P. The right part of the

Figure *6* is the accumulated results stored in projection array P. The big accumulated results (big Ps) and the edges are all corresponded.

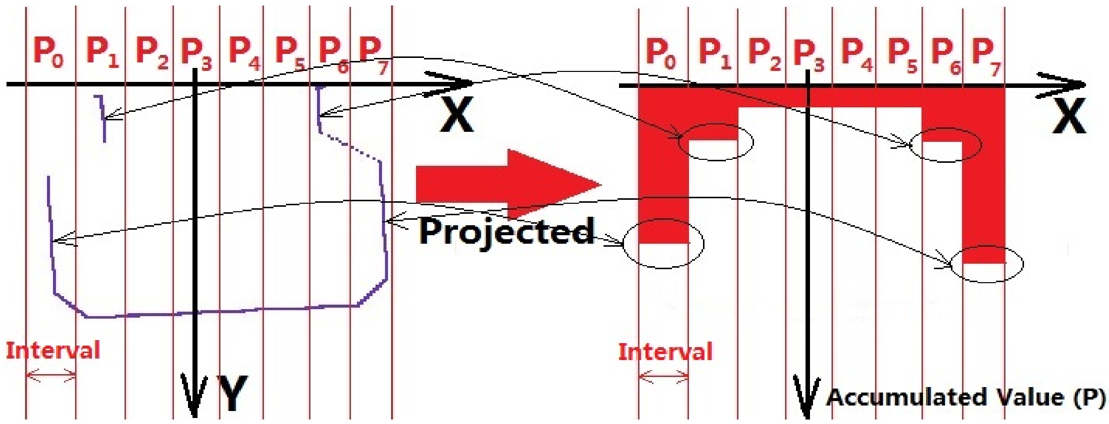

Figure 6. Diagram of Dynamic Projection Approach

For this approach, the parameter “projection interval” should be correctly selected. If the interval is too big, the edge can be found approximately and may not be accurate enough to operate the ship loader automatically. For an instance, in Figure 6, the interval is almost 500cm which is too big. Although the edges can be found, but the minimum accuracy is equal to the interval 500cm, in other words, the edge is known inside a 500cm-length space but the accurate position of edge in the space is unknown. In Figure 6, selecting so big interval is just for readers to realize how the projection approach works visually.

And if the interval is too small, the tolerance of the inclined cargo hold would be reduced. It is because the inclined edge may be separated into 2 parts by the dividing line of projection interval. It is possible that 2 edges are found while there is only a separated edge by too small projection interval.

Therefore, a dynamic method is applied to search for a suitable projection interval. This method is a search algorithm. The discriminat formula of the suitable interval is shown below.

$$PS_0 - \overline{\mathrm{PS}} > T_d \text{ and } PS_1 - \overline{\mathrm{PS}} > T_d \text{ and } PS_2 - \overline{\mathrm{PS}} > T_d \text{ and } PS_3 - \overline{\mathrm{PS}} > T_d \text{ and } PS_4 - \overline{\mathrm{PS}} \le T_d \quad (4)$$

In discriminant formula 4, T_d is the threshold of the edge accumulated value and the non-edge accumulated value. PS is the sorted projection array P and the PS_0 is the biggest value. For the cargo hold, there are 4 edges in which the 2 edges of the hatch and 2 edges of the underdeck cargo hold. Therefore, if there are more than 4 edges found, it means the interval is too small and one of the edges is separated into 2 parts by the dividing line of projection interval.

The interval parameter can be searched from a small value until the discriminant formula is satisfied. With the suitable interval, the edges of the cargo hold can be determined.

By projecting the 0-1 matrix into X axis, the edges are found. And the 0-1 matrix is also projected to Y axis, and then the bottom of the cargo hold is also easily found. Detailed steps are similar with the previous projection algorithm.

The edges are found, and then an accurate line fitting should be done inside those edges. The least square method is a typical line fitting approach.

Set points $\begin{bmatrix} X_0 \\ Y_0 \end{bmatrix} \ldots \begin{bmatrix} X_n \\ Y_n \end{bmatrix}$ are n points which are inside an edge found by projection approach. According to the least square method, the slope of the line “k” and the intercept “b” can be determined by the equations shown below.

$$k = \frac{\overline{XY} - \overline{X}\,\overline{Y}}{\overline{X^2} - \left(\overline{X}\right)^2} \quad (5)$$

$$b = \overline{Y} - k\overline{X} \quad (6)$$

The edge line is determined by least square method and the inclination angle of the cargo hold can be calculated by slope “k” of the edge line. The inclination angle of the cargo hold is equal to “arctan (k)”.

By the dynamic projection approach with a suitable interval parameter, the edges and the bottom of the cargo hold are found. The edge lines are all fit by the least square method, and then the inclination angle of the hold is also calculated by the slope of the edge line. At this point, the key features of the LMS sectional plane scanning are all extracted.

As shown in

Figure *4*, the LMS scans the ship from one side to the other side, and the width, depth and the skew inclination angle of the cargo hold are computed by the sectional plane scanning image. With the servo machine, the LMS can turns 90 degrees in the horizontal plane and scans the ship from the bow side to the poop side. It is similar that the length, depth and the pitch inclination angle of the cargo hold are also computed. Thus, a whole shape of the cargo hold is determined. With the shape data, the ship loader can automatically load the hold.

4. Experiment

The LMS (Model: SICK LMS-511-10100) with a servo machine was installed on the 2# ship loader in Coal Terminal of Tianjin Port. LMS Scanning & Image Processing software was also developed and transplanted into an embedded computer (Model: GE IP VME-SBC V7768).

Figure 7. the Photo of LMS and the Software of LMS Scanning & Image Processing

As shown in

Figure 7, these hardware and software are all prepared and being tested. According to the requirements of the ship loader automation, the precision of the LMS measurement and image processing should be 100cm in length and 1 degree in angle. The experimental test results are shown in Table 1.

Table 1. Experimental Results of Ship Cargo Hold Inspection using LMS

Date		Length (cm)	Width (cm)	Depth (cm)	Skew inclination angle (Degree)
2012-07-09	Real Value	2060	1370	1120	0.0
	Computed Value	2000	1350	1100	0.2
2012-07-10	Real Value	2040	1380	1150	0.0
	Computed Value	1950	1350	1100	0.7
2012-07-11	Real Value	2020	1400	1130	0.0
	Computed Value	1950	1350	1100	0.1

As shown in Table 1, the computed sizes of the cargo hold are close to the real sizes. The experimental results show that the ship cargo hold inspection approach described by this paper is enough precise to meet the requirements of automatic ship loader.

5. Conclusion

This paper describes an approach to inspect the cargo hold of bulk ship using a laser based scanner LMS. The LMS is a novel sensor to accurately measure distances of the target in an arc section. The dynamic projection approach described in the paper is an effective method to work out the edge and angle features from the sectional plane image built by LMS. The experimental results show those methods are all valid and enough precise for automation.

Based on those features computed by image processing algorithm, the ship loader can acknowledge the cargo hold shape real-timely and unmannedly. Thus, the ship loader can be operated automatically.

Acknowledgements

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References

[1] Yunsub Jung, In Gwun Jang, Byung Man Kwak etc. Advanced sensing system of crane spreader motion (for Mobile Harbor). Proceeding of the Systems Conference (SysCon), *IEEE International*. 2012: 59-63.
[2] Kelvin Chen, Chih Peng, William Singhose. Crane Control Using Machine Vision and Wand Following. Proceeding of the *2009 IEEE International Conference on Mechatronics*. 2009.
[3] Chikura Takashi, Yamamoto Motoji, Monzen Tadaaki etc. Development of automated transfer crane in a port container yard. Nihon Kikai Gakkai Ronbunshu C. 2005; 71(2): 567-572.
[4] Kawai H, Choi Y, Kim YB etc. Position measurement of container crane spreader using an image sensor system for anti-sway controllers. Proceeding of *2008 International Conference on Control, Automation and Systems, ICCAS*. 2008: 683-686.
[5] Budiharto Widodo, Santoso Ari, Purwanto Djoko, Jazidie Achmad. Multiple moving obstacles avoidance of service robot using stereo vision. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2011; 9(3): 433-444.
[6] Permana Gayuh Titis, Abdurohman Maman, Khairudin Mohammad, Lutfi Mohammad. Automated Navigation System based on Weapon-Target assignment. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2011; 9(3): 445-452.
[7] Zhou Hong, Zou Xianglin, Wu Bangchun. Design and development of port crane crash-preventing system based on FMCW radar. *Journal of Scientific Instrument*. 2007; 28(9): 1689-1694.
[8] Brooker Graham, Hennessey Ross, Bishop Mark, Lobsey Craig, Durrant-Whyte Hugh, Birch David. High-resolution millimeter-wave radar systems for visualization of unstructured outdoor environments. *Journal of Field Robotics*. 2006; 23(10): 891-912.
[9] Ricci R, De Dominicis L, De Collibus MF, Fornetti G, Guarneri M, Nuvoli M, Francucci M. U-ITR: A 3D laser scanner prototype aimed at underwater archaeology applications. Proceeding of *International Conference on Lasers in Conservation of Artworks, LACONA VIII*. 2011: 221-226.
[10] Goshi DS, Liu Y, Mai K, Bui L, Shih Y. Recent advances in 94 GHz FMCW imaging radar development. Proceeding of *2009 IEEE MTT-S International Microwave Symposium, IMS 2009*. 2009: 77-80.
[11] Harter Marlene1, Schipper Tom, Zwirello Lukasz, Ziroff Andreas, Zwick Thomas. 24GHz digital beamforming radar with T-shaped antenna array for three-dimensional object detection. *International Journal of Microwave and Wireless Technologies*. 2012; 4(3): 327-334.
[12] Testar Miquel, Stirling-Gallacher Richard. New super-resolution ranging technique for FMCW radar systems. *Proceeding of Millimetre Wave and Terahertz Sensors and Technology IV*. 2011.
[13] SICK Group. Operating Instructions for Laser Measurement Sensors of the LMS5xx Product Family. 2011.
[14] Liao Zicheng, Hoppe Hugues, Forsyth David, Yu Yizhou1. A subdivision-based representation for vector image editing. *IEEE Transactions on Visualization and Computer Graphics*. 2012; 18(11): 1858-1867.
[15] Takaya Kunio, Qian Zheng. FPGA based stereo vision system to display disparity map in realtime. *Proceeding of 2012 International Conference on Information Science and Applications*, ICISA 2012. 2012.