Available online at http://www.ijims.com
ISSN - (Print): 2519 – 7908 ; ISSN - (Electronic): 2348 – 0343
IF:4.335; Index Copernicus (IC) Value: 60.59; UGC Recognized -UGC Journal No.: 47192. 1st July

Real-Time Laser Sensor Data Acquisition and Three-Dimensional Image Reconstruction

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Abstract

A three-dimensional object can be measured and represented as a gray scale set of points through the use of LiDAR sensor with high spatial accuracy. The ability to quickly measure and represent tree canopy profile in 3D is extremely useful in many applications in precision agriculture. In this paper, we developed a software program to characterize a tree canopy profile and to reconstruct 3D image in real time. The developed program can process 2D laser sensor raw data to reconstruct a pseudo-color 3D image in real time. The program was written in C++ and MATLAB programing languages. The software program was tested on specially designed indoor LiDAR-based canopy profile measurement platform. During the test two artificial trees (tree-1 and tree-2) were used as target objects. The reconstructed 3D image and data analysis results showed that the performance of the developed program to reconstruct 3D image in real time is relatively well at low travel speed ranged from 1.0m/s to 2m/s and detection distances ranged from 1.5m to 2.0m.

Keywords:Real Time, Laser Sensor, Data Acquisition, three dimensional image

1. Introduction

Real time display and representation of environmental parameters such as the structural characteristics of trees, crops and forests in three dimensions (3D) is a useful tool for facilitating visualization and scientific measurements. Technology has evolved to the point that a three-dimensional scene can be measured and represented as a gray scale set of points through the use of LiDAR (Light detection and ranging) [1, 2]. LiDAR allows tree orchard to be captured and represented in laser intensity as a set of 3D points (point cloud) with high spatial accuracy[3]. In most side-view monitoring activities of orchards and high row-cultivated plants, Canopy characteristics supply valuable information for tree-specific management reducing production costs and public concerns about environmental pollution. Some important agricultural tasks that can benefit from these plant-geometry characterization are the application of pesticides, irrigation, fertilization and crop training [4, 5].

In the field of pesticide application, conventional pesticide sprayers are often used. The existed conventional sprayers are not efficient and target oriented, as a result a significant amount of pesticide is wasted. According to recent statistics, only 20% to 30% of the amount is deposited on the surface of the target and the rest seriously contaminates the environment [6]. The effective method to alleviate this problem is developing a variable rate pesticide sprayer based on the geometrical characteristics of plantations. Knowledge of the geometrical characteristics of plantations will permit a better adjustment of the dose of the product applied, improving the environmental and economic impact [4, 7].

In recent years, LiDAR sensors have been widely used for the measurement of canopy structures [3, 4]. Among the LiDAR-based sensor technologies, laser scanning sensors have been extensively investigated for canopy measurement due to its high accuracy, high scan speed, and insensitivity to light sources and found good relationship between LiDAR and field measures with values typically ranging from 0.85 to 0.95 [1, 8-11]. LiDAR laser scanners have also been integrated into a prototype variable rate pesticide sprayer in many spray application research works. In [12] , *Balsari* designed a sprayer prototype able to automatically adapt spray and air distribution according the characteristics of the target, to the level of crop disease and the environmental conditions. Although numerous research works have been conducted on tree canopy characterization system in precision agriculture, it is still necessary to resolve several technological and commercial questions. The former include improving detection systems, especially with regard to developing software for the real and post-processing steps and improving the speed of calculation and decision making [4]. LIDAR provides a 3D cloud of points, which is easily visualized with Computer Aided Design software. Three-dimensional, high density data are uniquely valuable for the qualitative and quantitative study of the geometric parameters of plants.

It is therefore of vital importance to continue devoting major efforts to the development of increasingly accurate, robust and affordable systems capable of measuring the geometric characteristics of plantations, which support the development of the different areas of a sustainable and precision agriculture. In this paper, we develop real time software algorithm to compute geometrical dimensions of tree canopy profile and construction of 3D image in real time. The developed program is able to process the 2D laser sensor raw data to characterize the target tree canopy profile in real time. It is also process the data to develop a pseudo-color 3D image. The algorithm was written in C++ and MATLAB programing languages. The software program was tested on an indoor LiDAR-based canopy profile measurement platform. The laser sensor data acquisition and data process methods as well as the indoor canopy profile measurement system are presented in the subsequent sections.

2. Materials and methods

2.1 Laser sensor

A three-dimensional object can be measured and represented as a gray scale set of points through the use of LiDAR sensor with high spatial accuracy [13]. The LiDAR sensor used in this paper was UTM-30LX Scanning Rangefinder manufactured by Hokuyo Automatic Co., Ltd. from Japan (see table 1). The sensor sends out laser pulses with a wavelength of 905nm. The pulses hit the target, are reflected and received again by the sensor. The sensor then calculates the distance of the target relative to the sensor from the travel time of the laser pulse. This principle is called time-of-flight. The sensor has an effective angular scan range of 270°. Response time for one scan over the whole range is approximately 25 milliseconds. The distance data is transferred to the host via USB connection using SCIP 2.0 protocol. Data is presented in millimeters.

2.2 Real time data acquisition and pseudo-color 3D images Reconstruction

As we discussed in Section 2.1, Hokuyo UTM-30LX Laser scanner was used to acquire the data needed to characterize tree canopy profile. A real time data acquisition and data processing programs were developed based on C++ (Microsoft Visual Studio 2005, Microsoft Corporation. USA) and MATLAB (Version 7.7.0.471, Math works, Inc. Natick, Massachusetts) programing languages respectively. The C++ development language was selected to write the data acquisition program due to its execution speed, efficiency and flexibility. However, for data processing and 3D image reconstruction algorithm we used MATLAB development platform because, it combines the ability to calculate complex equations with its graphical capabilities and interactive sessions. Though Matlab is a powerful tool in digital image processing and visualization, it does restrict users in the ability to improve its processing speed. The C++, as compiled language, offers a more versatile environment to improve the performance of the code. Though the data acquisition program was written in C++, it was implemented in Matlab IDE for real time data processing. Matlab provides a unique tool to integrate C++ code into MATLAB's platform to utilize its workspace and graphical capabilities [14]. This tool is known as a MEX-file and allows the user to program in C++ right in the Matlab user interface. Using C++ instead of Matlab for real time data acquisition program would increase the speed of computing large amounts of data with large amounts of iteration loops. We used C MEX Library API to implement C++ in Matlab. At first, the data acquisition program was written in C++ programing language and then adapted into a MEX file by using *mexFunctions and interfaces* from C MEX Library API. MEX-file is a special file format designed to take variables from the Matlab workspace and run them through precompiled C++ code located in the MEX-file [15]. After compiling the MEX file, the C++ program was called from the MATLAB command line as if they were built-in functions for real time target profile measurement and 3D image reconstruction. Figure 1 shows the real time data acquisition and data processing scheme.

2.2.1 Real time data acquisition

The data acquisition program essentially has three major functions: Initialize the laser sensor, start and stop the streaming of distance data, and transferring the data to a temporary storage area in the computer (PC). The data transaction between the laser sensor and the computer was completed through a USB port buffer at Maximum Baud rate of 12Mbps. In this operation, the measurement data is transmitted across the bus in packets. Each *packet* is a bundle of data points along with information concerning the source, destination and length of the data, and error detection information. During tree canopy profile detection, the laser sensor was driven along the slipway at a preset travel speed. As the laser sensor passed by, the tree canopy surface facing toward the sliding table was detected to form an array of distance data, and each data point represents a distance between the scanner and the point detected on the canopy surface for 0.25°angular interval. Since the laser sensor has 270° scanning range, one full scan contains1080 data points, and each data point is characterized by the distance from the scanner to the canopy surface and the angle referred to 0° of the position of the laser sensor. In this paper, one frame of data contains 1080 data points. The acquired raw data form multiple frames of distance data and each frame of distance data was stored in the temporary storage area in the form of polar coordinates. Figure 2 shows Operational principles of the laser sensor [2].

2.2.2 Real time data processing and 3D image reconstruction

The acquired raw distance data in frames were first converted from polar to Cartesian coordinates and then moved to a temporary storage area for processing. Data processing operations included: unwanted data filtering and 3D image reconstruction. Due to the environment around the target object, some characteristics of non-target objects were collected. These unwanted data were filtered out based on preset threshold detection distance values[13, 16].

The real time 3D image of the target tree was reconstructed from the measured raw data in the following procedure. Each frame of raw data was first concentrated into a raw distance data matrix according to adjacent time order. Then, a horizontal distance data matrix and a vertical distance data matrix which represent the vertical and horizontal distances between the target and the laser scanner were derived from each data point Cartesian ordinate system. The horizontal distance data matrix was converted into a normalized gray scale data matrix and made an affine transformation in the horizontal direction to compensate differences caused by travel speed variations. Then the horizontal distance data matrix was interpolated in the vertical direction to compensate the height differences caused by detection distances and scanning angles. Finally, the normalized gray scale matrix was transformed into a pseudo color data matrix that mapped 3-D object surface images [17-20].The overall program development flow chart is illustrated step by step in Figure 3.

2.3 Program validity test

The validity of the real time target profile acquisition and 3D image reconstruction were verified by conducting an indoor target profile measurement experiment on a specially designed and constructed Lidar-based target profile measurement platform. The measurement platform is based on a 2-D LiDAR range finder. Figure 1 shows the structure and main components of the System. The system is composed of two parts: Target detection unit and sliding motion control unit. The target detection unit included a high speed Hokuyo UTM-30LX (Japan) 2D laser rangefinder and a personal computer for real time data acquisition and data process. The laser sensor was mounted on a sliding block of a long sliding table platform at a height of 1.85m above the ground surface such a way that its 90° blind surface faced downward the ground. The sliding table has 6.4 m length and 8 cm width. The sliding motion controller was designed and implemented to control the laser sensor movement along the slipway by specifying a position and a speed as a set point. The laser sensor was positioned in such a direction that its 1080 detection points were on the same fan-shaped plane perpendicular to the sky, which could provide a 2-dimensional grid of line-of-sight distances between the sensor and the object when the sensor was stationary. When the sensor traveled horizontally, it could provide a matrix of distances to form a 3-D surface with proper algorithms.

In this experiment, two artificial trees with different size and shape were used as target objects. During the experiment, each of these trees was positioned on the ground in such a way that its centerline was in the same straight line which was parallel to the laser sensor travel direction. The maximum distance between the tree and the laser sensor set to be 2.5m by considering raw distances in most orchard tree plantations. The photograph and actual physical dimensions of the artificial trees are listed in Table 2.

Throughout the experiment, Data collation and data processing were performed sequentially for each target tree. In data collection, each target tree was continuously scanned at different laser sensor travel speeds (1.0, 1.5, 2.0, 2.5, 3.0, 3.5and 4.0 m/s) and detection distances (1.5, 2.0 and 2.5m). At first, the laser sensor was driven along the slipway at 1.0 m/s travel speed to scan artificial tree-1 positioned at 1.5m from the laser sensor. Then, the travel speed was increased by 0.5m/s until the travel speed reached at 4.0 m/s. During the next round, the detection distance was set to 2.0m and the travel speed was increased from 1.0 m/s to 4.0m/s in 0.5 intervals. The artificial tree-1 was scanned continually by changing the travel speed and detection distance in the above manner. Artificial tree-2 was scanned in the same fashion with artificial tree-1 to evaluate the performance of the developed algorithm. Real time measurement data was acquired and processed in the on-board computer by the developed program in MATLAB IDE. The program processed each complete scanning data to reconstruct a pseudo-color 3D image in real time. The output images and measurement data were saved in the computer for post data processing. The entire experiment procedure and operation are given in the following sequence:

1. Initialize the canopy profile measurement platform
2. Set the laser sensor travel speed and travel distance via the host controller
3. Set the detection distance
4. Start scanning the target tree
5. Acquire the laser sensor data (1080 points per frame) from a scanning cycles in real time
6. Process the scanner raw data based on the developed algorithm in real time
7. Display the reconstructed 3D image in real time
8. Repeat the sequence four times for each detection distances to consider the repeatability of the results

After the experiment completed, all results obtained from the operation was processed and analyzed for the developed algorithm verification. The results and conclusions are presented in the subsequent section.

3. Result and Discussion

As we mentioned in the above section, the canopy profile of the artificial trees was measured according to the experiment procedure. The experiment results are given in Figure 6 and Figure 7 .Figure 6 shows images of the artificial tree-1 obtained from the digital camera and the laser sensor correspondingly. The pseudo color images from the laser sensor were reconstructed in real time from the dataset acquired at 2.0 m detection distance and various laser sensor travel speed (1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 m/s). The colors in the image represent distances from the target tree surface to the laser sensor. As depicted in Figure 6, pseudo color images from the laser sensor raw data obtained at 1.0m/s,1.5m/s, and 2.0m/s sensor travel speeds are comparatively matched with the original pictures of the target tree taken by the digital camera. In most side-view monitoring activities of orchards and high row-cultivated plants, a vehicle forward speed is ranged from 1.5m/s to 2.5m/s. In light of this fact, the performance of the developed algorithm to reconstruct 3D image of the target tree at these specific travel speeds could be considered well. However, for images reconstructed from the raw data obtained at 3.0m/s,3.5m/s, and 4.0m/s are relatively less matched with the true color image of the target tree. This is because the data acquisition program acquired less amount of measurement data at high forward travel speed compared to measurement data acquired at low forwarded travel speed. As the laser sensor traveled at the speed of 4m/s on the sliding table, the number of data frames received during a complete target scan was lower than data frames received at 1.0, 1.5, and 2.0m/s laser sensor travel speed for the same spatial distance. As a result, the quality of the reconstructed pseudo color images at this specific travel speed was affected. Although the reconstructed image at 4m/s travel speed is not well matched with the true color image of the target, number of key points in the image is good enough to represent the original target. Figure 7 shows images of the artificial tree-

2 obtained from the digital camera and the laser sensor respectively. The pseudo color images in the Figure were reconstructed from the sensor raw data obtained at 2m/s sensor travel speed and different target detection distances (1.5,2.0 and 2.5m) in real time. The colors in the image represent distances from the target tree surface to the laser sensor. As shown in the figure, the shape and color of the reconstructed 3D image of target tree was changed as the detection distance increased from near to far. This indicates that the accuracy of the laser sensor to characterize tree canopy structure could be affected by the detection distance.

Generally, the performance of the developed algorithm to measure tree canopy profile and to reconstruct 3D image in real time depended on both the sensor travel speed and detection distance. Under the specified travel speed and detection distances, the developed real time algorithm perform well.

4. Conclusion

As part of major efforts devoting to the development of accurate and robust tree canopy detection systems, real time software algorithm to characterize tree canopy structure was developed. The program algorithm was developed based on C++ and MATLAB programing languages. The C++ program was integrated on the MATLAB environment by using C MEX Library API for real time data acquisition. The MATLAB program was able to reconstruct 3D image in real time from the real time laser sensor raw data. Hokuyo UTM-30LX Light Detection And Ranging (LIDAR) unit was used to acquire raw distance data points from a target object. The performance of the algorithm was evaluated on a specially designed indoor target profile measurement platform. During the performance test experiment, two artificial trees were used and continuously scanned by the laser sensor at different travel speed and detection distances. Obtained laser sensor raw data was processed in real time to reconstruct the pseudo color 3D images of the target tree. The reconstructed 3D image showed that the performance of the developed algorithm to reconstruct 3D image in real time depended on both the sensor travel speed and detection distance. The algorithm perform well at low travel speed ranged from 1.0m/s to 2m/s and detection distances ranged from 1.5m to 2.0m. Although the program performed relatively well at mentioned parameter ranges it has some limitations when it comes to high laser sensor travel speed. At high travel speed the laser sensor acquired less number of data frames for the same spatial distance due to the resolution of the laser sensor .This leads to a blurred pseudo color images. For a real filed application, this research work should be improved in several aspects including generating real time control signals for controlling and monitoring processes in orchard and crop management.

Acknowledgements

The Authors gratefully acknowledge the funds provided by National Natural Science Foundation of China (Grant No.51505195) and the Priority Academic Program Development (PAPD) of Jiangsu Higher Education Institutions (China).

References

[1] C. J. Houldcroft, C. L. Campbell, I. J. Davenport, R. J. Gurney, and N. Holden, "Measurement of canopy geometry characteristics using LiDAR laser altimetry: A feasibility study," *Ieee Transactions on Geoscience and Remote Sensing,* vol. 43, pp. 2270-2282, Oct 2005.

[2] J. Llorens, E. Gil, J. Llop, and A. Escola, "Ultrasonic and LIDAR Sensors for Electronic Canopy Characterization in Vineyards: Advances to Improve Pesticide Application Methods," *Sensors,* vol. 11, pp. 2177-2194, Feb 2011.

[3] J. R. R. Polo, R. Sanz, J. Llorens, J. Arno, A. Escola, P. Ribes-Dasi, *et al.*, "A tractor-mounted scanning LIDAR for the non-destructive measurement of vegetative volume and surface area of tree-row plantations: A comparison with conventional destructive measurements," *Biosystems Engineering,* vol. 102, pp. 128-134, Feb 2009.

[4] J. R. Rosell and R. Sanz, "A review of methods and applications of the geometric characterization of tree crops in agricultural activities," *Computers and Electronics in Agriculture,* vol. 81, pp. 124-141, Feb 2012.

[5] D. Andujar, A. Escola, J. R. Rosell-Polo, R. Sanz, V. Rueda-Ayala, C. Fernandez-Quintanilla, *et al.*, "A LiDAR-Based System to Assess Poplar Biomass," *Gesunde Pflanzen,* vol. 68, pp. 155-162, Sep 2016.

[6] H. Zhu, M. Salyani, and R. D. Fox, "A portable scanning system for evaluation of spray deposit distribution," *Computers and Electronics in Agriculture,* vol. 76, pp. 38-43, Mar 2011.

[7] D. K. Giles, P. Klassen, F. J. A. Niederholzer, and D. Downey, ""Smart" sprayer technology provides environmental and economic benefits in California orchards," *California Agriculture,* vol. 65, pp. 85-89, Apr-Jun 2011.

[8] M. Bietresato, G. Carabin, R. Vidoni, A. Gasparetto, and F. Mazzetto, "Evaluation of a LiDAR-based 3D-stereoscopic vision system for crop-monitoring applications," *Computers and Electronics in Agriculture,* vol. 124, pp. 1-13, Jun 2016.

[9] E. Naesset and K. O. Bjerknes, "Estimating tree heights and number of stems in young forest stands using airborne laser scanner data," *Remote Sensing of Environment,* vol. 78, pp. 328-340, Dec 2001.

[10] E. Naesset and T. Okland, "Estimating tree height and tree crown properties using airborne scanning laser in a boreal nature reserve," *Remote Sensing of Environment,* vol. 79, pp. 105-115, Jan 2002.

[11] J. O. Sexton, T. Bax, P. Siqueira, J. J. Swenson, and S. Hensley, "A comparison of lidar, radar, and field measurements of canopy height in pine and hardwood forests of southeastern North America," *Forest Ecology and Management,* vol. 257, pp. 1136-1147, Feb 10 2009.

[12] M. Grella, P. Marucco, M. Manzone, M. Gallart, and P. Balsari, "Effect of sprayer settings on spray drift during pesticide application in poplar plantations (Populus spp.)," *Science of the Total Environment,* vol. 578, pp. 427-439, Feb 1 2017.

[13] H. Z. Hui Liu "Evaluation of a laser scanning sensor in detectionof complex-saped targets for variable-rate sprayer development," *Transaction of the ASABE,* vol. 5, p. 59, 2016.

[14] S. Nuratch and Ieee, *Firmware Design and Development of MCU and Matlab-Simulink Interfacing for Real-time Measurement, Analysis and Control Applications*. New York: Ieee, 2016.

[15] M. Bucurica, R. Dogaru, and I. Dogaru, "A Comparison of Extreme Learning Machine and Support Vector Machine Classifiers," in *2015 Ieee 11th International Conference on Intelligent Computer Communication and Processing,* R. Potolea, Ed., ed New York: Ieee, 2015, pp. 471-474.

[16] J. Wei and M. Salyani, "Development of a laser scanner for measuring tree canopy characteristics: Phase 1. Prototype development," *Transactions of the Asae,* vol. 47, pp. 2101-2107, Nov-Dec 2004.

[17] A. Sud and D. Manocha, "Fast distance field computation using graphics hardware," *Tech. Rep.,* 2003.

[18] J. W. Zhang, G. Q. Han, and Y. Wo, "Image registration method based on mutual information about distance field of image edges," *Journal on Communications,* vol. 27, pp. 87-93, 2006.

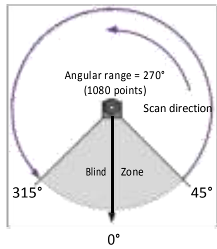
[19] W. Xuehua, W. Yongguo, and Z. Jun, "Tree crown volume calculation based on 3-D laser scanning point clouds data," *Transactions of the Chinese Society for Agricultural Machinery,* vol. 44, pp. 235-240, 2013.

[20] Y. Mao and M. Wu, "Security evaluation for communication-friendly encryption of multimedia," in *Image Processing, 2004. ICIP'04. 2004 International Conference on*, 2004, pp. 569-572.

Table 1

Characteristics of Hokuyo UTM-30LX Laser range scanner

Hokuyo UTM-30LX Laser scanner
www.robotshop.com



Scanning range

Model/Name	UTM-30LX
Manufacturer	Hokuyo
Detection range	0.1-30m
Field of view	270°
Angular resolution	0.25°
Scanning frequency	40Hz
Interface	USB 2.0
Protective Structure	IP64
Dimensions (mm)	60*60*85

Table 2:

Artificial tree and its physical dimension

Artificial tree -1

Target object name	Artificial tree - 1
Height	0.82m
Width	0.90m
Depth	0.78m

Artificial tree-2

Target object name	Artificial tree - 2
Height	1.68m
Width	1.14m
Depth	0.65m

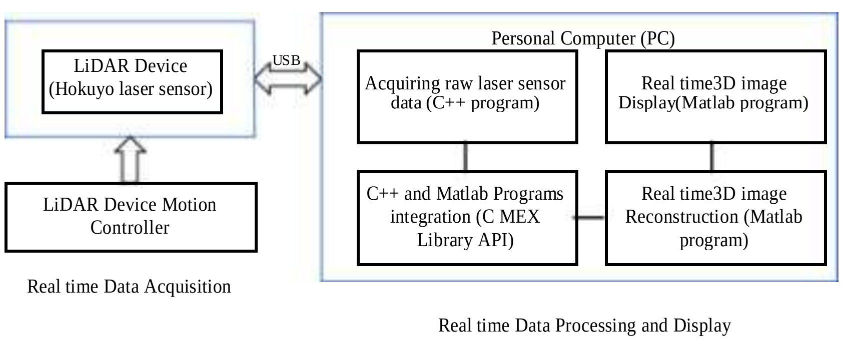


Figure 1. Real time data acquisition and data processing scheme.

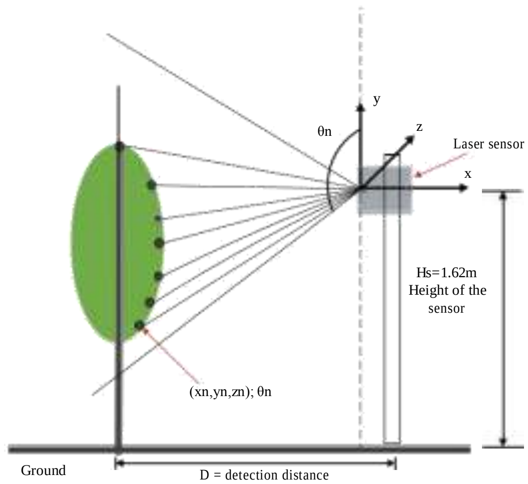


Figure 2 Operational principles of the laser sensor: Each laser beam return is characterized by the distance and angle referred to 0° of the position of the laser sensor.

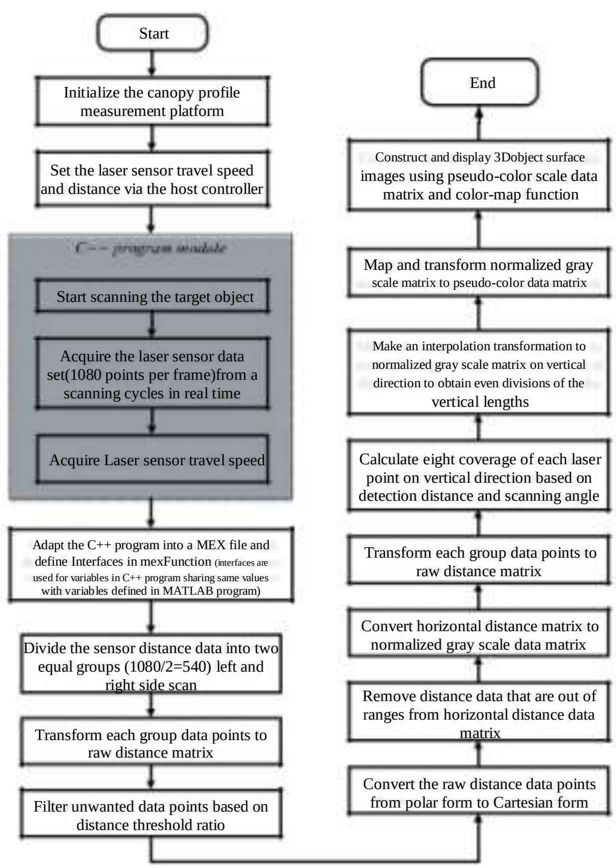


Figure 3 Flow chart for the MATLAB algorithm program complied with the C++ program module for detecting and constructing 3-dimensional object surfaces.

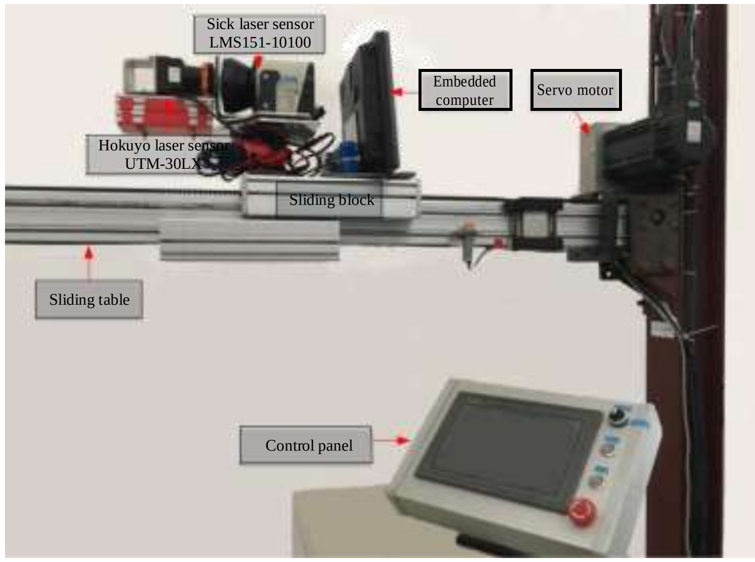


Figure 4 Lidar-based indoor target detection system

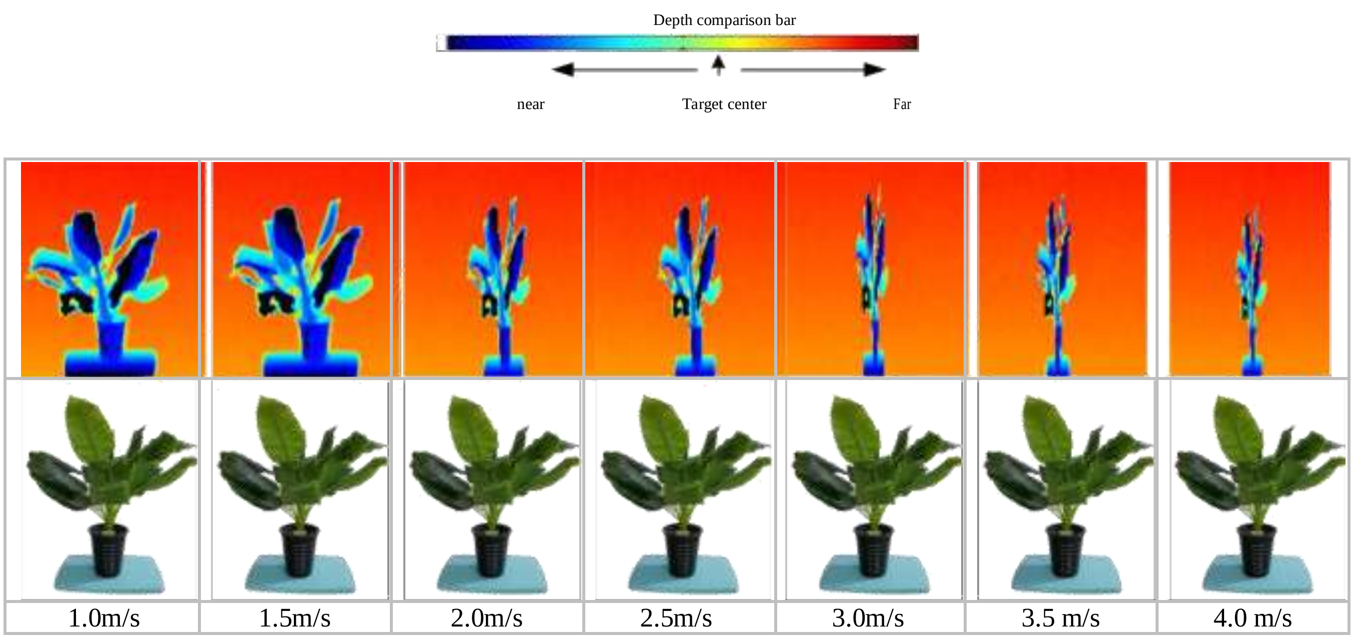


Figure 6. Paired images of the artificial tree-1 obtained from the digital camera and the laser sensor. The pseudo color images from the laser sensor were reconstructed in real time from the dataset acquired at 2.0 m detection distance and various laser sensor travel speed (1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 m/s).

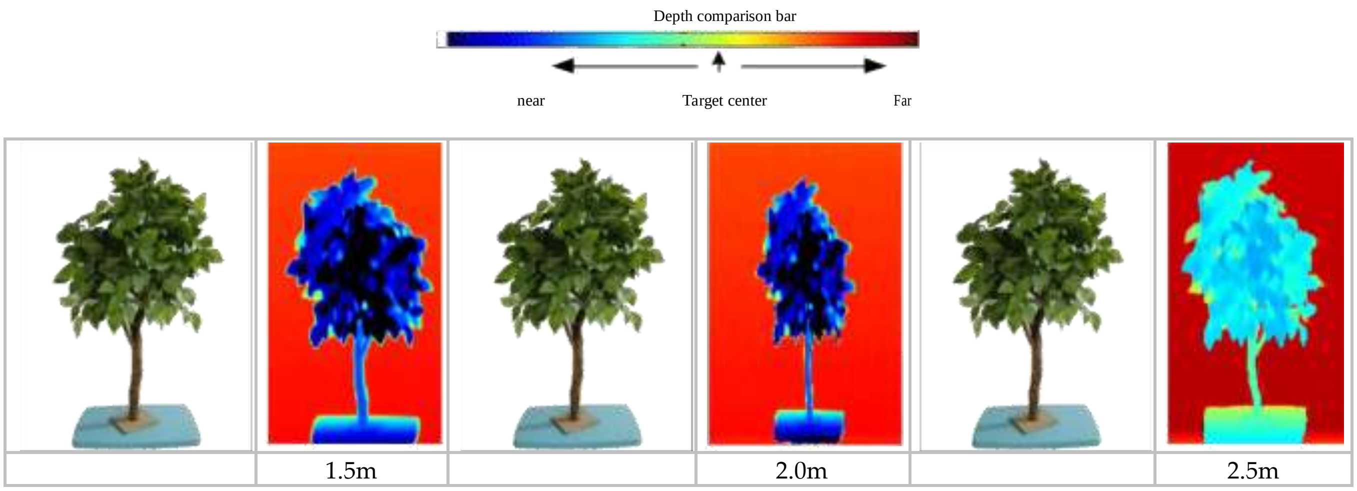


Figure 7. Paired Images of the artificial tree-2 obtained from the digital camera and the laser sensor. The pseudo color images were reconstructed from the sensor raw data obtained at 2m/s sensor travel speed and different target detection distances(1.5,2.0 and 2.5m) in real time.