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# Design and Control Methods of a Condenser Cleaning Robot

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As the condenser has complicated indoor environment and it's difficult for the cleaning robot to complete cleaning, this paper deeply researches tele-operation system of intelligent cleaning robot, designs hardware architecture and software system at tele-operation control platform, including design of human-machine interface on the tele-operation control platform and software and hardware design of joystick force feedback controller. It designs the ontology mechanical structure, electromechanical control system, communication control program and picture processing program of intelligent cleaning robot. Industrial personal computer is used for data processing and motion control in the electromechanical control system. Test results show that the operation system herein can be used to effectively solve the problems in design and control of tele-operation system of intelligent cleaning robot and implement online high-pressure water-jetting cleaning of a condenser tube, so as to ensure efficient and safe operation of condensers in the large power plant.

## 1. Introduction

At present, there are two methods for cleaning dirt of condenser tube, i.e. online cleaning by rubber wall and manual cleaning during shutdown (Calders et al., 2017). Among them, it's temporarily unable to get ideal treatment effect for online cleaning by rubber wall due to its low recovery rate of rubber balls(Chen et al., 2017), being easy to cause blockage of cond (Fan, 2015)enser tube and unabling to completely clear all crystallisation fouling formed by chemical reaction and others; on the other hand, manual cleaning is also difficult to satisfy the large-scale production demands and requirements for safe production due to large quantity and large length of condenser tubes(Fang et al., 2015), large labour intensity, severe working environment, and requiring closing down or load-decreasing operation (Huang et al., 2017). So, it's necessary to research and develop an intelligent cleaning equipment for large condensers in a long-term and automatic way (Kelbe et al., 2015). The emergence of industrial robot brings about an industrial revolution, and it is more and more used in the industrial production process with large labour intensity (Liang et al., 2014), high technological requirements, severe working environment and short production cycle. It has great significance in improving working environment of the workers (Liang et al., 2014), reducing labour intensity, saving production materials, reducing production costs and improving product quality. But, cleaning robot can enter high altitude (Liang et al., 2015), underwater and pipeline and other inaccessible areas for cleaning dirt with large intensity and large area in replace of human (Liang et al., 2017). It has gradually become the object concerned by researchers in various countries and is listed in the high-technology research strategies of each country (Mai, 2014). In foreign countries, air duct cleaning technology is mature and has a wide market and has become the main cleaning body in the family, hotels and airports etc (Puttonen et al., 2015). Wall hanging cleaning robot firstly appeared in Japan. With increasing inventory of airplanes at present, cleaning operation also becomes heavy (Starek et al., 2013), so it's inappropriate to clean manually. Aircraft surface cleaning robot is successively designed and developed in Japan, United States and Germany etc (Sun et al., 2015).

## 2. Main tasks of tele-operation system of an intelligent cleaning robot

In order to achieve the objective of cleaning dirt at the condenser nozzle without shutdown (Wang et al., 2014), a series of subtasks should be completed through tele-operation system of an intelligent cleaning robot (Wang et al., 2014). The tasks can be divided into three classes: preparation before cleaning, seeking for cleaning objects and cleaning control (Wang et al., 2015). Among them, preparation before cleaning includes robot movement and robot navigation avoidance, which are used to achieve indoor environment positioning of condenser of a cleaning robot; seeking for cleaning objects means direct detection of condenser nozzle and condenser nozzle positioning(Wang et al., 2017), which are used to supervise degree of dirt at condenser nozzle and seek for condenser nozzles to be cleaned(Yang et al., 2017); cleaning parameter control and clean fluid ratio mean cleaning control (Zheng, 2012), which are used to adjust high-pressure water pressure parameters and online concentration ratio of cleaning liquid. The three tasks are conducted successively and relied mutually to finally complete cleaning of dirt at condenser nozzle (Zheng et al., 2013). The demand for tele-operation system of an intelligent cleaning robot is shown in Figure 1.

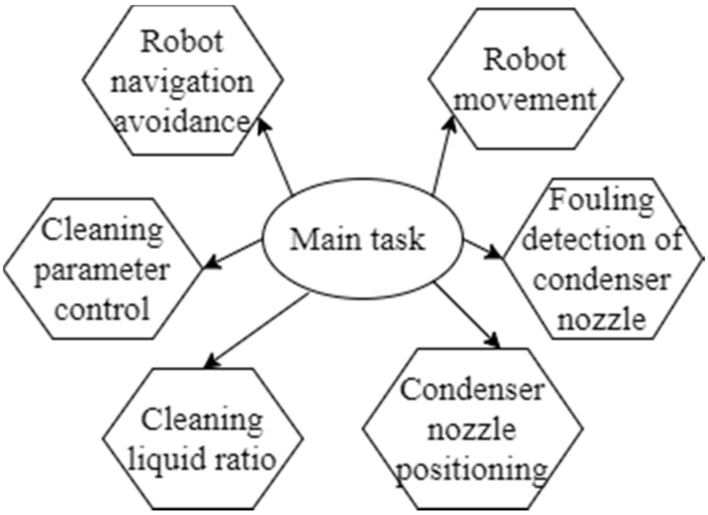


*Figure 1: Demand for Tele-Operation System of an Intelligent Cleaning Robot*

## 3. Composition of hardware in the tele-operation control platform

According to requirements for hardware of tele-operation system of an intelligent cleaning robot, tele-operation control platform can be functionally divided into graphic display module (Zheng et al., 2016), image processing module, operation control module, cleaning control module, communication control module and data management module (Zhou et al., 2016). According to functional module division of tele-operation hardware system, the designed diagram for hardware structure of tele-operation control platform is shown in Figure 2.

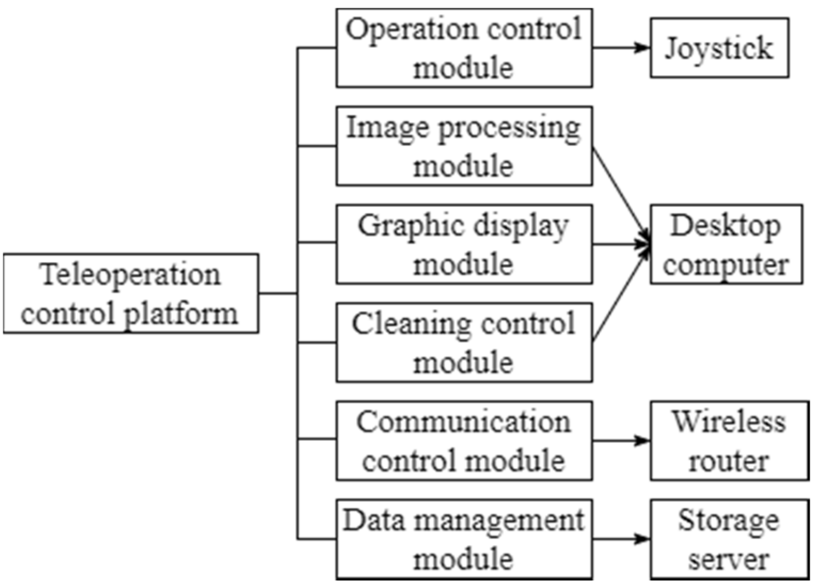


*Figure 2: Functional Diagram for Hardware Modules on the Tele-operation Control Platform of Tele-operation System of an Intelligent Cleaning Robot*

## 4. Design of main manipulator joystick

As a main manipulator of tele-operation system, the joystick is closely related with tele-operation control accuracy and it sense of immediacy and plays an important role in tele-operation system. So, a joystick should be used to realize positioning control of three-dimensional space (Mai, 2014), feedback force of tele-operation system, and highlight handleability, accuracy and quickness for control. Block diagram for measuring system of a joystick is shown in Figure 3.

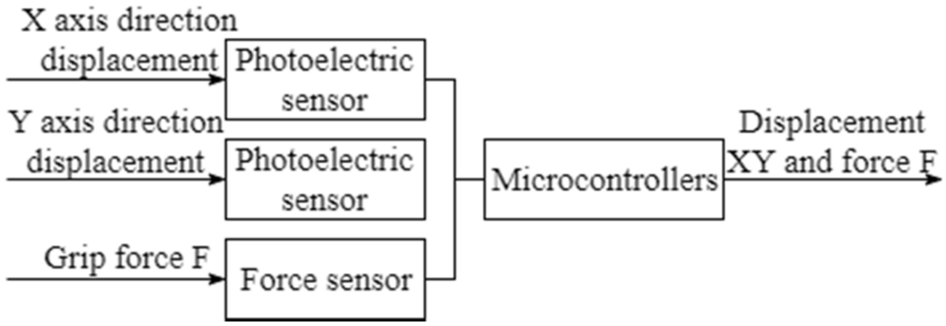


*Figure 3: Block Diagram for Measuring System of a Joystick*

## 5. Ontology structure of an intelligent cleaning robot

In order to achieve the objective of continuous online cleaning of condenser tubes by an intelligent cleaning robot(Zheng, 2012), according to the principle of safe, stable, efficient, and energy-saving and consumption-reducing, realize efficient and rapid cleaning of condenser tubes, follow the standard system development process and consider the effects brought about by system modularization, an intelligent cleaning robot can be divided into six modules: graphic display module, image processing module, motion control module, cleaning control module, communication control module and status monitoring module, as shown in Figure 4.

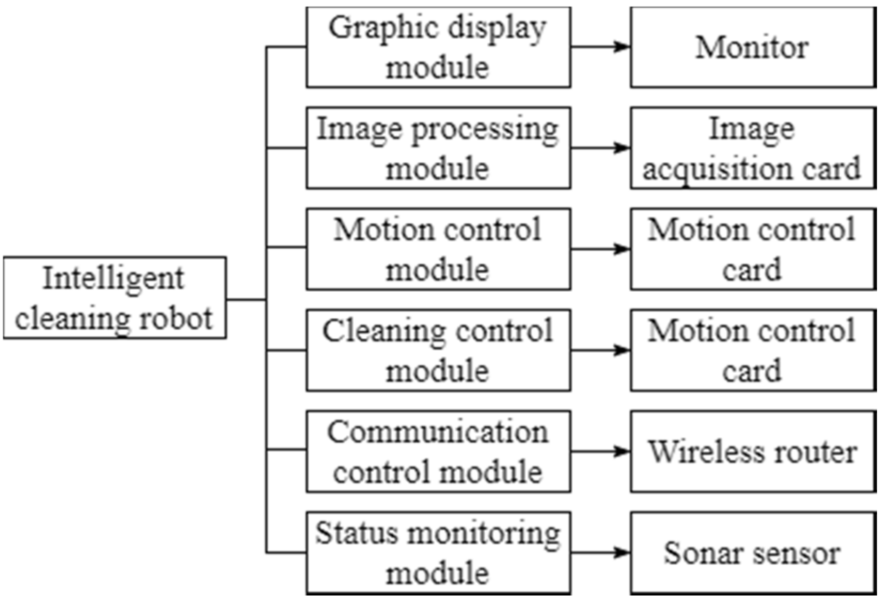


*Figure 4: Functional Diagram for Hardware System Module of Intelligent Cleaning Robot*

## 6. Motor control system of a spray gun

After visually positioning the nozzle to be cleaned, it’s necessary to rotate the mechanical arm and move the spray gun to align the nozzle to be cleaned. So, it’s very important to accurately move the spray gun in the alignment of the nozzle to be cleaned. Specific control structure diagram is shown in Figure 5.

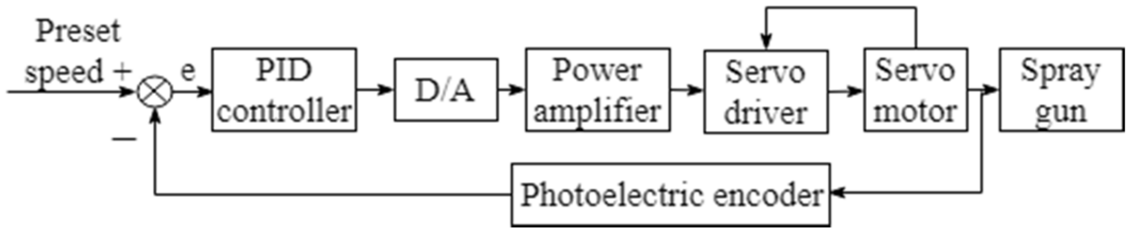


*Figure 5: Structure Diagram for Motor Control System of a Spray Gun*

Hereon, a PID controller is used to control movement of a spray gun. After visually positioning the nozzle to be cleaned, it's only necessary to provide moving motor of a spray gun with a rotating speed, which is converted from expected coordinates in the space of a spray gun, so as to complete alignment of nozzle to be cleaned. Motor servo control system of a spray gun is composed of PID controller (motion control card), power amplifier, servo driver, servo motor and photoelectric encoder to realize rapid and accurate motor control of a spray gun. Its working process is that after the control system has the preset rotating speed, PID analog control signals are output by motion control card and input into servo driver after function of power amplifier. Then, the servo driver can drive the motor to drive. Then, the servo motor is used to drive the loaded driving pulley for rotation. In this way, feedback signals of the driving pulley are fed back to motion control card for controlling, so as to achieve PID closed-loop control of the motor of a spray gun.

## 7. Experiment preparation for tele-operation system of an intelligent cleaning robot

Inspection tasks before experiment include that inspecting whether equipment of cleaning robot and tele-operation control platform is intact, whether connection wires are used to power a cleaning robot and tele-operation control platform, whether control software of a cleaning robot and tele-operation control platform is enabled, whether the motor is operated normally, whether it can be connected through wireless local area network, whether network communication is normal, whether joystick controlling robot is moved normally, whether video images collected by the robot can be correctly displayed, and whether driving force emergency stop button of a robot can be operated normally etc. Specific preparation process is shown in Figure 6.

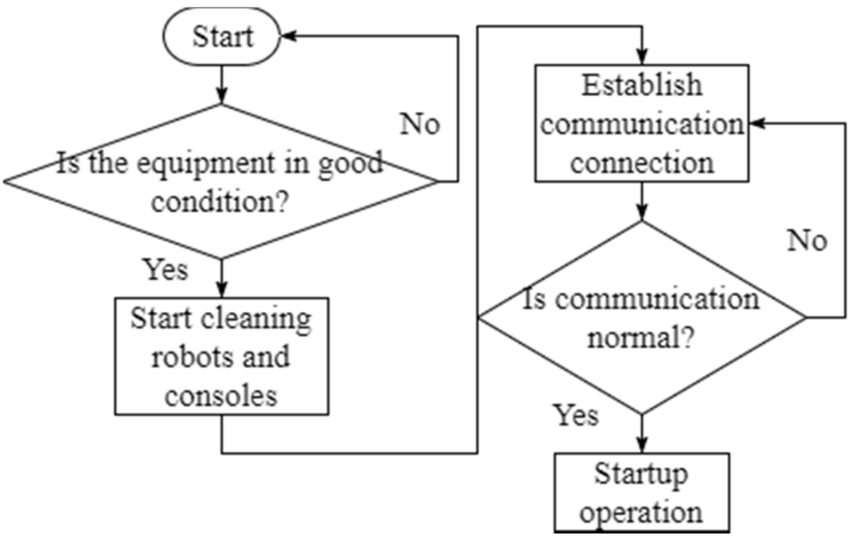


*Figure 6: Experimental Preparation Process for Tele-operation System of an Intelligent Cleaning Robot*

After completion of experiment preparation, operators can proceed to the next, i.e. completing mobile positioning of condenser indoor environment of a cleaning robot under guidance of remote video images and sonar data analysis, rotary positioning of mechanical arm and positioning of condenser nozzle. After positioning, the cleaning robot enters the mode, which means that under the condition of high-pressure water cleaning, the motor is operated to offset impact force of high pressure water, so as to fix the base of robot. Finally, operators complete proportioning of cleaning liquid according to dirt condensation etc., and then start the high-pressure water for cleaning to complete the dirt cleaning at condenser nozzle. As it's only necessary to check whether three sub-tasks can be smoothly completed to determine the effectiveness and reliability for tele-operation system of an intelligent cleaning robot, consideration in this paper is only given to that whether mobile positioning of an intelligent cleaning robot can be achieved by the tele-operation system. Other following operations are not within the scope of this paper.

## 8. Conclusions

With research object of tele-operation system of an intelligent cleaning robot, this paper deeply researches the system structure of tele-operation system, impedance control method for sliding-mode variable structure of tele-operation system, sliding-mode control stability and transparency of tele-operation system, function module design of tele-operation control platform and cleaning robot ontology, functional partitioning and programming at ends of tele-operation control platform and cleaning robot ontology. One task is dispersed to two ends and each end is used to implement different tasks, so as to scientifically and reasonably solve the task planning and information transfer in the tele-operation system of an intelligent cleaning robot. Software and hardware at ends of tele-operation control platform and cleaning robot are designed to serve as the basis for standard management of project development process, which also provides convenience for later developers, shortens development time and improves the development efficiency. For research on vision localization system of condenser cleaning robot, this paper obtains certain theoretical results. But, there are still many problems to be further researched in the future, such as research on effectiveness and feasibility of transmitting the underwater images and control commands in a lossless and real-time way in the condenser hydroecium environment through underwater sound wireless communication.

### Reference

Calders K., Disney M.I., Armston J., Burt A., Brede B., Origo N., Muir J., Nightingale J., 2017, Evaluation of the Range Accuracy and the Radiometric Calibration of Multiple Terrestrial Laser Scanning Instruments for Data Interoperability, IEEE Transactions on Geoscience and Remote Sensing, 55, 2716-2724, DOI: 10.1109/TGRS.2017.2652721

Chen X., Yu K., Wu H., 2017, Determination of Minimum Detectable Deformation of Terrestrial Laser Scanning Based on Error Entropy Model, IEEE Transactions on Geoscience and Remote Sensing, 1-12, DOI: 10.1109/TGRS.2017.2737471

Fan L., Atkinson P.M., 2015, Accuracy of Digital Elevation Models Derived from Terrestrial Laser Scanning Data, IEEE Geoscience and Remote Sensing Letters, 12, 1923-1927, DOI: 10.1109/LGRS.2015.2438394

Fang W., Huang X., Zhang F., Li D., 2015, Intensity Correction of Terrestrial Laser Scanning Data by Estimating Laser Transmission Function, IEEE Transactions on Geoscience and Remote Sensing, 53, 942-951, DOI: 10.1109/TGRS.2014.2330852

Huang P., Cheng M., Chen Y., Zai D., Wang C., Li J., 2017, Solar Potential Analysis Method Using Terrestrial Laser Scanning Point Clouds, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10, 1221-1233, DOI: 10.1109/JSTARS.2016.2636300

Kelbe D., van Aardt J., Romanczyk P., van Leeuwen M., Cawse-Nicholson K., 2015, Single-Scan Stem Reconstruction Using Low-Resolution Terrestrial Laser Scanner Data, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 8, 3414-3427, DOI: 10.1109/JSTARS.2015.2416001

Liang X., Kankare V., Yu X., Hyyppä J., Holopainen M., 2014, Automated Stem Curve Measurement Using Terrestrial Laser Scanning, IEEE Transactions on Geoscience and Remote Sensing, 52, 1739-1748, DOI: 10.1109/TGRS.2013.2253783

Liang Y.B., Zhan Q.M., Che E.Z., Chen M.W., Zhang D.L., 2014, Automatic Registration of Terrestrial Laser Scanning Data Using Precisely Located Artificial Planar Targets, IEEE Geoscience and Remote Sensing Letters, 11, 69-73, DOI: 10.1109/LGRS.2013.2246134

Liang X., Wang Y., Jaakkola A., Kukko A., Kaartinen H., Hyyppä J., Honkavaara E., Liu J., 2015, Forest Data Collection Using Terrestrial Image-Based Point Clouds from a Handheld Camera Compared to Terrestrial and Personal Laser Scanning, IEEE Transactions on Geoscience and Remote Sensing, 53, 5117-5132, DOI: 10.1109/TGRS.2015.2417316

Liang Y.B., Qiu Y., Cui T.J., 2017, Semiautomatic Registration of Terrestrial Laser Scanning Data Using Perspective Intensity Images, IEEE Geoscience and Remote Sensing Letters, 14, 28-32, DOI: 10.1109/LGRS.2016.2624268

Mai T., Wang Y., 2014, Adaptive Force/Motion Control System Based on Recurrent Fuzzy Wavelet CMAC Neural Networks for Condenser Cleaning Crawler-Type Mobile Manipulator Robot, IEEE Transactions on Control Systems Technology, 22, 1973-1982, DOI: 10.1109/TCST.2013.2297405

Puttonen E., Krooks A., Kaartinen H., Kaasalainen S., 2015, Ground Level Determination in Forested Environment with Utilization of a Scanner-Centered Terrestrial Laser Scanning Configuration, IEEE Geoscience and Remote Sensing Letters, 12, 616-620, DOI: 10.1109/LGRS.2014.2353414

Starek M.J., Mitasova H., Wegmann K.W., Lyons N., 2013, Space-Time Cube Representation of Stream Bank Evolution Mapped by Terrestrial Laser Scanning, IEEE Geoscience and Remote Sensing Letters, 10, 1369-1373, DOI: 10.1109/LGRS.2013.2241730

Sun H., Wang G., Lin H., Li J., Zhang H., Ju H., 2015, Retrieval and Accuracy Assessment of Tree and Stand Parameters for Chinese Fir Plantation Using Terrestrial Laser Scanning, IEEE Geoscience and Remote Sensing Letters, 12, 1993-1997, DOI: 10.1109/LGRS.2015.2443553

Wang H., Wang C., Luo H., Li P., Cheng M., Wen C., Li J., 2014, Object Detection in Terrestrial Laser Scanning Point Clouds Based on Hough Forest, IEEE Geoscience and Remote Sensing Letters, 11, 1807-1811, DOI: 10.1109/LGRS.2014.2309965

Wang Z., Zhang L., Fang T., Mathiopoulos P.T., Qu H., Chen D., Wang Y., 2014, A Structure-Aware Global Optimization Method for Reconstructing 3-D Tree Models from Terrestrial Laser Scanning Data, IEEE Transactions on Geoscience and Remote Sensing, 52, 5653-5669, DOI: 10.1109/TGRS.2013.2291815

Wang Z., Zhang L., Fang T., Mathiopoulos P.T., Tong X., Qu H., Xiao Z., Li F., Chen D., 2015, A Multiscale and Hierarchical Feature Extraction Method for Terrestrial Laser Scanning Point Cloud Classification, IEEE Transactions on Geoscience and Remote Sensing, 53, 2409-2425, DOI: 10.1109/TGRS.2014.2359951

Wang D., Kankare V., Puttonen E., Hollaus M., Pfeifer N., 2017, Reconstructing Stem Cross Section Shapes from Terrestrial Laser Scanning, IEEE Geoscience and Remote Sensing Letters, 14, 272-276, DOI: 10.1109/LGRS.2016.2638738

Yang H., Xu X., Xu W., Neumann I., 2017, Terrestrial Laser Scanning-Based Deformation Analysis for Arch and Beam Structures, IEEE Sensors Journal, 17, 4605-4611, DOI: 10.1109/JSEN.2017.2709908

Zheng G., Moskal L.M., 2012, Leaf Orientation Retrieval from Terrestrial Laser Scanning (TLS) Data, IEEE Transactions on Geoscience and Remote Sensing, 50, 3970-3979, DOI: 10.1109/TGRS.2012.2188533

Zheng G., Moskal L.M., Kim S.H., 2013, Retrieval of Effective Leaf Area Index in Heterogeneous Forests with Terrestrial Laser Scanning, IEEE Transactions on Geoscience and Remote Sensing, 51, 777-786, DOI: 10.1109/TGRS.2012.2205003

Zheng G., Ma L., He W., Eitel J.U.H., Moskal L.M., Zhang Z., 2016, Assessing the Contribution of Woody Materials to Forest Angular Gap Fraction and Effective Leaf Area Index Using Terrestrial Laser Scanning Data, IEEE Transactions on Geoscience and Remote Sensing, 54, 1475-1487, DOI: 10.1109/TGRS.2015.2481492

Zhou G., Cao S., Zhou J., 2016, Planar Segmentation Using Range Images from Terrestrial Laser Scanning, IEEE Geoscience and Remote Sensing Letters, 13, 257-261, DOI: 10.1109/LGRS.2015.2508505

Mai T., Wang Y., 2014, Adaptive Force/Motion Control System Based on Recurrent Fuzzy Wavelet CMAC Neural Networks for Condenser Cleaning Crawler-Type Mobile Manipulator Robot, IEEE Transactions on Control Systems Technology, 22, 1973-1982, DOI: 10.1109/TCST.2013.2297405

Zheng G., Moskal L.M., 2012, Leaf Orientation Retrieval from Terrestrial Laser Scanning (TLS) Data, IEEE Transactions on Geoscience and Remote Sensing, 50, 3970-3979, DOI: 10.1109/TGRS.2012.2188533