Integrating Indoor Positioning Techniques with Mobile Laser Scanner to Create Indoor Laser Scanning Models

Yuchen YANG, (China, PR), Craig HANCOCK, (China, PR), Georgios KAPOGIANNIS, (China, PR), Ruoyu JIN, (UK), Huib de LIGT, (China, PR), Jingjing YAN, (China, PR), Chao CHEN, (China, PR), Chendong LI, (China, PR).

Keywords: Laser scanning, Indoor Positioning, 3D model, Model creation.

SUMMARY

As Built BIM models and other 3D rendering of existing buildings are becoming increasingly important for the construction industry as well as for improvement and implementation of smart and sensible cities. These models are extremely useful for things such as preconstruction planning, maintenance scheduling, urban planning and the recycling of building materials. Currently, various methods are used for creating As Built BIM and 3D models. The most widely used methods are laser scanning and photogrammetry. Laser scanning can either be used in static or kinematic (mobile) mode. The accuracy of the static laser scanning is high, compared to mobile scanning, but the costs associated can also be very high due to the time required and thus the large labor costs. Thus, mobile laser scanning could be more cost effective for some environments, where the accuracy requirements are lower. However current mobile techniques can also come at large expense, depending on the requirements of the model, an expensive system may not be necessary. This paper focuses on using a variety of indoor positioning techniques integrated with a relatively low-cost mobile laser scanner for the collection of mobile laser scanning data indoors. The aims of this paper are to analyze whether the indoor positioning techniques are able to obtain the required accuracy and precision to create suitable BIM and 3D models. Several indoor positioning methods were used in an undecorated indoor environment for these tests. The accuracy of the models created using the integrated mobile mapping techniques have been compared with static 3D scans to assess the accuracy and precision of low cost mobile scan models.

Integrating Indoor Positioning Techniques with Mobile Laser Scanner to Create Indoor Laser Scanning Models

Yuchen YANG, (China, PR), Craig HANCOCK, (UK), Georgios KAPOGIANNIS, (Greece), Ruoyu JIN, (China, PR), Huib de LIGT, (Netherlands), Jingjing YAN, (China, PR), Chao CHEN, (China, PR).

1. INTRODUCTION

The interests of utilizing 3D models of buildings grown rapidly in recent years. The 3D models of the building could be used for urban planning, spatial analysis, inventories of historical and cultural heritage, promotion of tourist places and BIM (Borkowski, A., et al. 2014). Currently, several methods are used to create 3D models, where laser scanning is one of the commonly used methods to collect data and provide 3D modeling in the architecture, engineering and construction (AEC) domain. Laser scanning could record 3D information with high accuracy and efficiency, and can also provide 3D visualization and spatial analysis of the object scanned (Huber, D., et al. 2010).

Two types of laser scanning are widely used currently, which are airborne laser scanning (ALS) and Terrestrial laser scanning (TLS). ALS is beneficial for collecting data for large areas from the sky with high accuracy and efficiently. However, the data captured by ALS causes the detail information on the ground lost. Also because of the high cost compared to other data generating methods, ALS might not be useful in several applications (Barber, D., Mills, J and Smith-Voysey, S. 2008). TLS could also generate data with high accuracy, but the data collection of the TLS would be influenced by cost, time duration, complex preparation and the scale of the site (Chen, C. et al. 2018). Thus, mobile laser scanner could create 3D models of a building with high accuracy at a relatively low cost.

In this paper, a low-cost 2D mobile laser scanner was selected to be used to create the model of the room inside of the building. By integrating the data collected by a 2D mobile laser scanner and the trajectory of the laser scanner provided by IMU, UWB, and a camera based indoor positioning system, 3D models of the room could be created. Also a mobile phone which could create 3D models automatically from images was also used as a comparison. The accuracy of the 3D model created was evaluated by comparing them with the model created by a terrestrial laser scanner in a static configuration. The conclusion of this work is that these methods can provide a low-cost and high working efficiency method of creating a 3D model of the building.

2. LITERATURE REVIEW

TLS and MLS are able to create 3D point clouds of the space selected and then create 3D models. The high accuracy of the model created by terrestrial laser scanner is widely used. However, if a large area with an irregular shape such as a shopping mall or office building is used to create a 3D model using TLS, the time used for collecting data would be too long. Furthermore, the data processing time for TLS is relatively long, especially for selecting control points from different scans, which will not only cost time, but also influence the accuracy of the final model created (Hong, S. et al. 2015). Another problem concerns people of creating model is cost. The price of a TLS is much higher than a MLS, which makes MLS a great option to create 3D models.

A vehicle, a positioning technique and a camera installed on the platform forms the Mobile laser scanning (MLS) system. A laser scanner mounted at the top of a vehicle enables capturing data from built environment rapidly (Blaszczak-Bak, W. Et al. 2016). Although the data collecting range and the resolution of the data captured by MLS was not as good as terrestrial laser scanner(TLS), the high efficiency of data generating and low cost make MLS achieve a quick data collection than TLS (Nikoohemat, S., et al. 2018). Because of its flexibility, mobile laser scanning system are widely used in both outdoor and indoor environments (Thomson, C. et al., 2013).

Indoor positioning systems (IPS) are system which could determine the position of a person or an object continuously in real-time in indoor environments (Gu,Y., Lo, A. Niemegeers,I. 2009). Because of the lack of GNSS signals and the signal propagation in the indoor environment, different IPS are widely used in human life (Mautz, R. 2012).

Ultra-wideband (UWB) is a type of indoor positioning system which needs infrastructure installed. Because the high band width and high frequency of UWB system, UWB could transmit a large amount of data in a short time period, usually TOA or TDOA method are used for UWB positioning (Svalastog, M.S. 2007). High accuracy, low power consumption and large bandwidth are the main advantages of UWB positioning system, and the accuracy provided by UWB system could achieve centimeter accuracy (Gao, Y. et al. 2014). However, because the line-of-sight technical issues, UWB positioning system could not achieve 100% of coverage for the area tested (Wang, J. et al. 2016).

IMU is another way of positioning an object both indoors and outdoors. The position of the object could be generated by knowing the position of the starting point and using the principles of dead reckoning to calculate future positions by measuring angles and accelerations. Several algorithms have been developed for processing the positions of an object by using the data collected by IMU (Beauregard, S., Haas, H. 2006). No-infrastructure is needed, no signal transition and high accuracy are benefits of using IMU for positioning. However, the error in IMU accumulates for each time data recording due to the error provided by accelerator and gyroscopes, which cause large error in a long distance without the aid of other positioning systems. The accuracy of IMU by using PDR could reach decimeter accuracy (Foxlin, E. 2005).

3. METHODOLOGY

The aim of the experiment is to test the quality of the model created by using different indoor positioning techniques to position a mobile laser scanner in low cost ways. The basic method is to link the points created by the laser scanner and the trajectory created by different indoor positioning techniques in a loosely coupled way.

The laser scanner selected was the SICK LMS5xx LiDAR sensor, which uses a 905nm infrared laser as a light source. The scanner was designed for acquiring data in both outdoor and indoor environment. The working range is up to 80m and the aperture angle is 190 degree, from -5 degrees to 185 degrees (SICK. 2019). Figure 1 is the photo of the SICK scanner and the middle black part is the viewing window of the scanner. The operation of the scanner is simpler than a TLS and the cost of the SICK scanner is also cheaper than a TLS.

Figure 1. SICK LMS5xx LiDAR sensor

As the scanner is used to collect 2D information of a room, the scanner should be inverted by 90 degrees, meaning that the viewing window should be parallel to the ceiling of the room and perpendicular to the trajectory of recording data. Thus, the X and Z coordinate data will be recorded and Y should be provided by the indoor positioning systems.

The first trajectory should be provided by the IMU, the IMU selected was Xsens MTi-G-700 IMU. MTi-G-700 contains two units, the IMU unit and GPS unit. A three-axial accelerometer, a three-axial gyroscopes and a magnetometer are contained in the IMU units of MTi-G-700 (Xsens. 2019). Accelerometer measures the linear acceleration (m/s^2) in the x, y and z axes. The gyroscopes record the angular velocity (deg/s) in the x, y and z axes. A magnetometer is used to record the magnetic field of the earth in three orthogonal axes (Stanford University. 2018). The IMU unit was set to collect data at 100Hz. The GPS unit that is integrated with the IMU is used to provide an accurate time. By using the IMU, a precise trajectory can be calculated which could be further used as the y axes of the 3D model, then the 3D model could be created using the scan lines from the 2D scanner.


Figure 2 and 3. IMU unit and GPS Unit of Xsens-MTi-G-700

The second trajectory was created by using the UWB. The UWB device used is KUNCHEN UWB. The transmitter range is 30m and the tag needs at least three transmitters to receive the signal to be able to calculate a position. The transmitter was facing down to ensure the coverage of the area. The frequency of the tag is 300 Hz and the device will provide the x, y and z coordinate of the point collected (Kunchen. 2019). Once the laser scanner position is known then the point cloud can be created.

Figure 4 and 5. Kunchen UWB tag and transmitter

The last trajectory was created by a method of positioning a people by a camera and a mobile phone. Mobile phone and Camera are two base components of the system. The IMU unit in mobile phone will record the acceleration and orientation during the movement. Then when camera tracks people, the position would be estimated by depth information in the frame. Absolute positioning will be provided by vision-based positioning with the help of map, then the features of the absolute position could be used as constraints to INS for drift calibration, and the position information could be collected (Yan, J. He, Gen., Hancock, C. 2018). The camera was used for correcting the position data provided by the phone. The trajectory provided could be calculated by using the trajectory and the 2D information collected by laser scanner.

Another individual 3D model would be created using images collected on mobile phone. The 3D model would be created by turning the device 360 degrees through the center of the mobile phone for one cycle. During this process images are collected and processed using photogrammetry to create a 3D model.

4. EXPERIMENT

The site selected for the experiment was a meeting room. The size of the room is about 50m^2. A trolley is used to carry the equipment. Figure 6 shows clearly how the equipment is attached to the trolley. A large box was settled on the top of the trolley to ensure the laser scanner is high enough and the IMU will not be influenced by the metal part of the trolley. The laser scanner was settled at the top of the box, and connects the power supply at the bottom level of the trolley. The laptop was placed at the second level of the trolley. Beside the laser scanner is the IMU unit (see Figure 6.right). A wooden box was placed between the laser scanner and the IMU unit to make sure the laser scanner will not influence the IMU unit. The phone was placed on the trolley directly during the experiment procedures. Furthermore, the height of the laser scanner was about 0.8m above the ground surface, so the scanner will only collect data 0.8m above the floor.

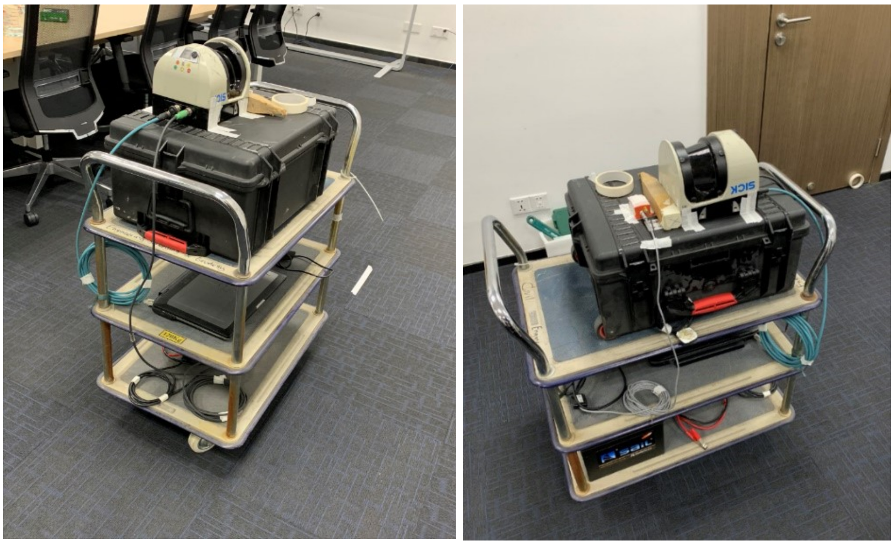

Figure 6 left and right. Two views of trolley of carrying equipment

The UWB unit was placed besides the laser scanner during the experiment. As shown in figure 7, four transmitters of the UWB were settled above four tripods at about 1.8m high at the corners of the room. The positions of the transmitter were measured by a total station after setting the rotation and zero coordinates. Then the UWB tag could receive and transmit the data as (x, y, z) coordinates, then the laptop will collect the time and coordinate information. All data were collected based on the laptop clock, which was to ensure the later data combination correctly.

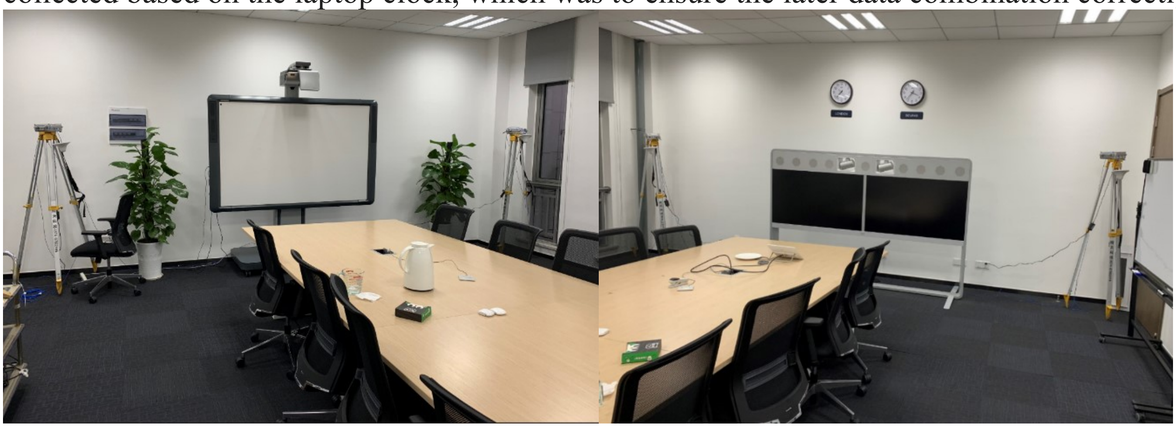

Figure 7 left and right. The position of the UWB transmitter and the room

The data collection route follows an anti-clockwise rectangular shaped trajectory, for each side of the trajectory, the speed of the trolley was as uniform as possible, also the line of trajectory was as linear as possible. The relative position of the laser scanner, the IMU, the UWB and the phone was recorded for later calculation.

5. DATA PROCESSING AND RESULT

5.1 Terrestrial laser scanner

The data collected by Terrestrial laser scanner was processed by Recap, and the final 3D point cloud was selected as the reference model for comparison. The 3D model created is shown in figure 8. After all 3D models were collected, the software used for comparison was CloudCompare. By comparing the distance between points from the control point cloud and the various test point clouds the quality of the different point clouds is assessed.

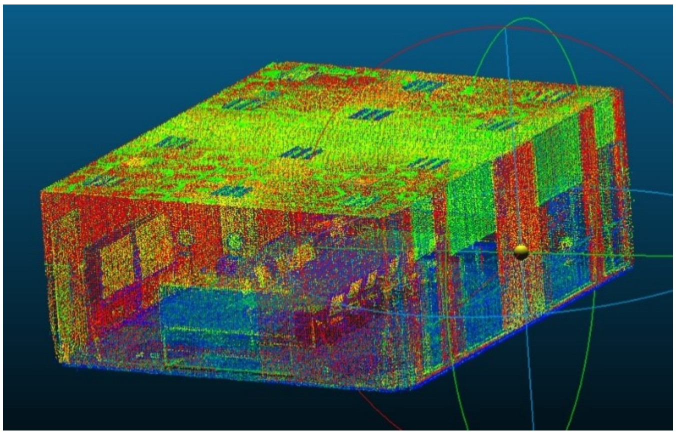

Figure 8. 3D model of the room made by TLS

5.2 Laser scanner and IMU

The 2D data collected using the mobile laser scanner contains the X and Z coordinate and the time information of the point. The acceleration and angular velocity provided by IMU could be used for create the trajectory of the movement. The algorithm used was Pedestrian Dead Reckoning, which could provide relatively accurate coordinate information of each point (Foxlin, E. 2005). By combining the coordinates of the laser scanner points and IMU points from the same time, the 3D point cloud could be created.

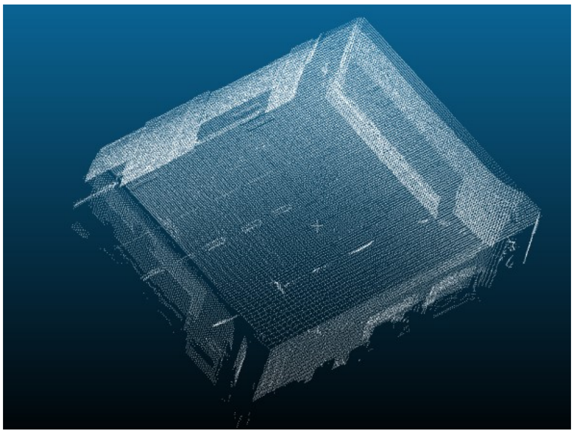

Figure 9. Model created by IMU trajectory+MLS

Figure 9 shows the 3D point cloud created by IMU and Mobile laser scanner. Figure 10 shows the comparison of the 3D point cloud created by TLS and MLS+IMU.

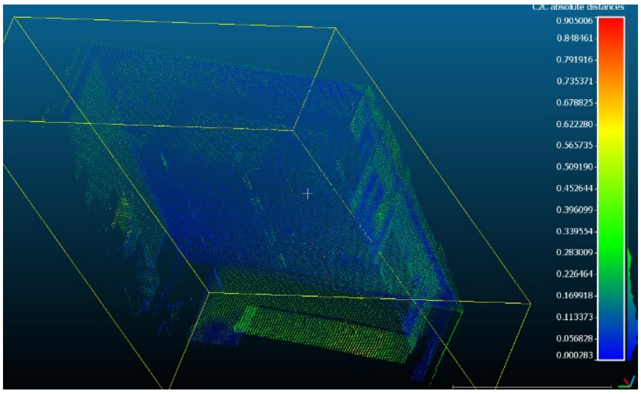

Figure 10. Compared 3D model created by MLS+IMU

As shown in the figure 10, most of the points have distance error are distributed in the interval of 0-0.3m. All points colored red are from the interference points at the middle of the room.

5.3 Laser scanner and UWB

The coordinate information was collected by the UWB directly. Because only x, y coordinate are necessary in this experiment, z coordinate information would be not important. By also combining the coordinates of the points of UWB and laser scanner from the same time to create the 3D point cloud. The created 3D point cloud is shown in figure 11.

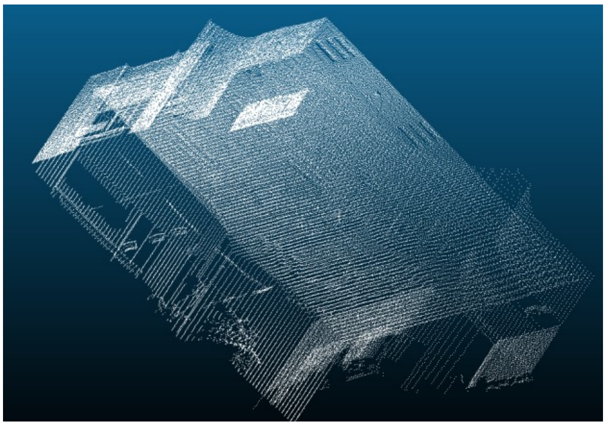

Figure 11. 3D point created by MLS+UWB

Also the point cloud created by MLS+UWB was compared with the TLS was compared by CloudCompare. As shown in figure 12, most of the distance error between points are less than 0.7m.

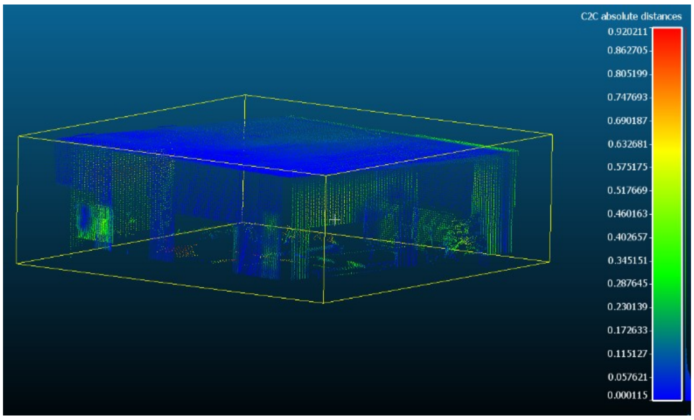

Figure 12. Comparison of the model created by UWB+MLS and TLS

5.4 Laser scanner and Phone IMU+camera correction

The phone IMU+Camera correction method is similar to the IMU method, which also uses Pedestrian Dead Reckoning to calculate the trajectory of the movement. However, this method uses the IMU by mobile phone which could be carried by a human, and the camera was used for correcting the position and the trajectory. The data-merging method of IMU+Camera correction method+MLS is similar to the merging process of IMU+MLS. By merging the y coordinates of the point provided by IPS and x, z coordinate of the points provide by mobile laser scanner at the same time to create a 3D point cloud of the room.

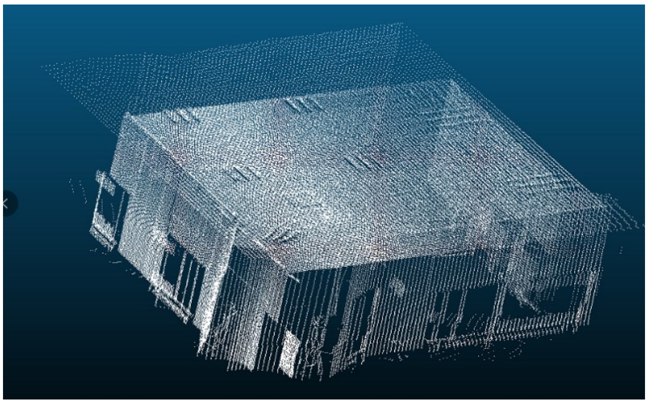

Figure 13. Model created by Phone IMU+Camera correction+MLS

Figure 13 shows the 3D point cloud created by such IPS+MLS. Figure 14 shows the comparison result of the model created by IPS+MLS and the model created by TLS. The distance error between points of two models are from 0-0.8m evenly.

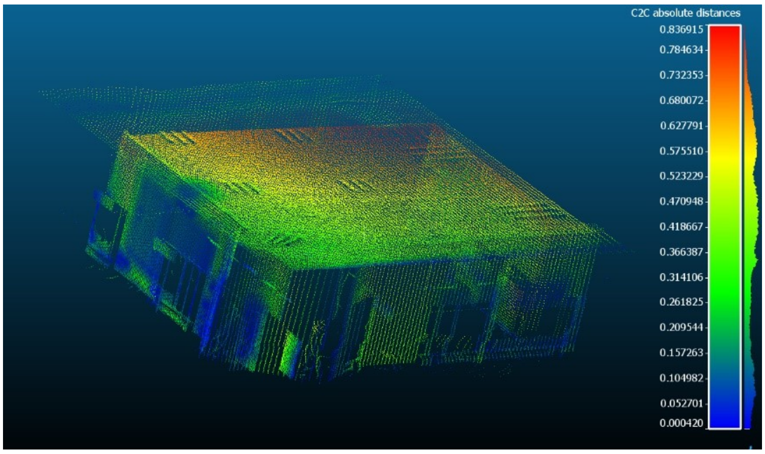

Figure 14 Comparison model of MLS+PhoneIMU+Camera

5.5 3D point cloud created by a phone

The 3D model created by the phone was obtained directly without adding any trajectory. The 3D point cloud be created easily after a simple data process. Figure 15 shows the model created by the phone, and figure 16 shows the comparison model.

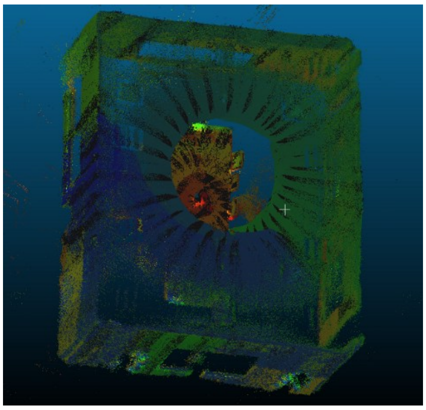

Figure 15. Model created by a phone

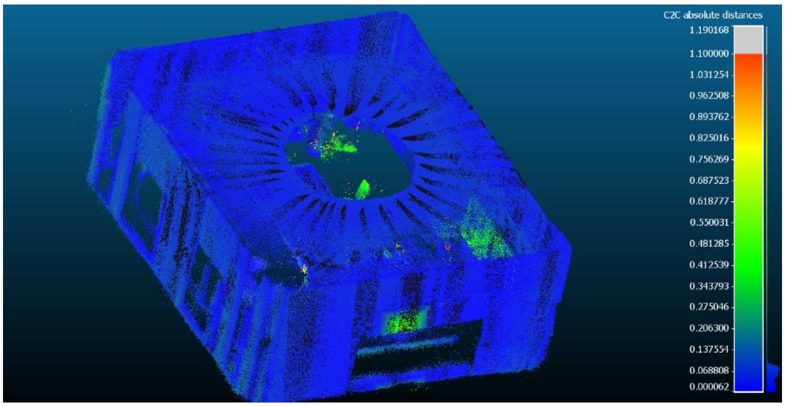

Figure 16. Comparison model of the phone model and TLS model

As shown in the figure 18, all points in the main part of the model (extract middle influences) are all have the error below 0.15m.

5.6 Analysis and result

Method	Error distribution
IMU only	<0.3
UWB	<0.7
Phone IMU+Camera	<0.83
Phone	<0.15

Table1. The comparison of result of comparison between models and TLS model

From Table 1 it can be seen that the model created by the phone is the model with smallest overall error. The shape of the model created by the Phone is also the best comparing to the other models. Not only because of the density of the point cloud of the model created by phone+camera positioning system is the highest, but also the model created is in good shape in visual aspect. Thus, the best model would be created by a mobile phone with 360-degree twisted scan. However, there are some limitations of using this method. Firstly, the phone should be as stable as possible when comparing to the ground, which is difficult to satisfy because of the human errors. Secondly, different scans are difficult to be merged together precisely because of the model have too many points. Due to the coordinate system of the models created by the phone not being the same, therefore the difficulty of picking the same point from scan to scan can be a problem. Thus, the mobile phone should be good enough for creating a 3D model for a small sized less decoration room.

The model created by the Phone IMU corrected by Camera+MLS has the lowest accuracy among all the methods. However, the result would be different from theoretical aspect, the accuracy of the model created by Phone IMU+Camera should be better than IMU its own. Because of the camera is used for correcting the trajectory by the human, so the trajectory provided by this method should be better than IMU its own. The reason of this might because the problem of the quality of the IMU on the Phone. Furthermore, the GPS unit of the IMU was not used in this experiment, which will lead some error of creating model by using IMU. For this sets of experiment, the movement of the trolley was as straight as possible, which might automatically reduce the error resource and then increase the accuracy.

For UWB, the accuracy is less than 0.7m, but the shape of the model is not consistently with the TLS model. The reason of this might because that the time information provided by the laser scanner and the UWB unit have some difference. The temporal resolution of the laser scanner and the UWB are not the same, which might cause some time offset errors when connecting the points from the same time, then further influence the accuracy.

6 CONCLUSION

The result shows that IMU positioning method integrates with the mobile laser scanner data could provide 30cm level accuracy 3D point cloud, and the Phone scanning 3D could achieve 15cm level accuracy. Although the accuracy of the model created still stay at decimeter accuracy, the result shows that these two methods are good enough for further model-creation. The experiment also have some aspects could be improved, which means that the centimeter level accuracy could be tried to achieve. The two main problem currently influences the accuracy of the model are the accuracy of the trajectory provided by indoor positioning systems, and the data connection by time. If a better solution exists to solve two problems above, the accuracy of the model created by mobile laser scanner could be further improved.

REFERENCES

Alarifi, A., Al-Salman, A., et al. 2016. Ultra Wideband Indoor Positioning Technologies:Analysis an Recent Advances. Sensors. Vol.16. Issue.5. pp:707-743.

Barber, D., Mills, J. & Smith-Voysey, S. 2008. Geoometric validation of a grounf-based mobile laser scanning system. ISPRS Journal of Photogrammetry and Remote Sensing. Vol.63. pp:128-141.

Beauregard, S.; Haas, H. Pedestrian dead reckoning: A basis for personal positioning. In Proceedings of the 3rd Workshop on Positioning, Navigation and Communication, Hannover, Germany, 16 March 2006; pp. 27–35.

Blaszczak-Bak, W. Et al. 2016. High performance filtering for big datasets from Airborne Laser Scanning with CUDA technology,Survey Review, vol.50:360, pp: 262-269.

Blaszczak-Bak, W. Et al. 2018. Reduction Method for Mobile Laser Scanning Data. ISPRS. International Journal of Geo-Information. Vol.7. pp: 285-298.

Chen, C., Yang, L., Tang, L & Jiang, H., 2017, BIM-based Design Coordination for China's Architecture, Engineering and Construction Industry. 2nd International Conference on Building Information Modelling (BIM) in Design, Construction and Operations. Alicante, Spain, May 10-12.

Chen, C. et al. 2018. 2D-based Indoor Mobile Laser Scanning for Construction Digital Mapping Application. FIG Congress 2018. Istanbul, Turkey, May 6-11, 2018.

Foxlin, E. 2005. Pedestrian tracking with shoe-mounted inertial sensors, *IEEE Computer Graphics and Applications*, vol. 25, no. 6, pp. 38-46, Nov.-Dec. 2005. doi: 10.1109/MCG.2005.140

Gao, Y., Meng, X., Hancock, C. M., Stephenson, S. & Zhang, Q. UWB/GNSS-based Cooperative Positioning Method for V2X Applications. 27th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS+ 2014), Tampa, Florida, 2014.

Gu, Y., Lo, A., Niemegeers, I. 2009. A survey of Indoor Positioning Systems for Wireless Personal Networks. IEEE Communications Surveys & Tutorials. Vol.11. Issue.1. pp:13-32.

He, S. et al. 2016. Wi-Fi Fingerprint-Based Indoor Positioning: Recent Advances and Comparisons. IEEE Communications Surveys & Tutorials, Vol.18. No.1.pp:466-490.

Huber, D., Akinci, B., Tang, P., Adan, A., Okorn, B., Xiong, X. Using Laser scanners for modeling and analysis in architecture, engineering, and construction. 2010 44th Annua Conference on nformation Sciences and Systems(CISS*)* . Princeton, NJ, 2010. PP: 1-6. Doi: 10.1109/CISS.2010.5464818

Kunchen. Positioning for Jail Aspect. View at: http://www.kunchen.cc/surveillance.htm. Last Access:[31/01/2019].

Mautz, R. 2012. Indoor Positioning Technologies. Department of Civil, Environmenal and Geomatic Engineering, Institute of Geodesy and Photogrammetry, ETH Zurich.

Nikoohemat, S., et al. 2018. Semantic Interpretation of Mobile Laser Scanner Point Clouds in Indoor Scenes using Trajectories. Remote Sending. Vol. 10. Issue.11.

Svalastog, M.S. 2007.Indoor Positioning – Technologies, Services and Architechtures. University of OSLO. Department of Informatics.

SICK. 2D LiDAR sensors LMS5xx-Reliable and precise, even over long distances. View at: https://www.sick.com/us/en/detection-and-ranging-solutions/2d-lidar-sensors/lms5xx/c/g179651?q=:Def_Type:Product. Last Access:[30/01/2019].

Thomson, C. Et al. 2013.Mobile Laser Scanning for Indoor Modelling. ISPRS Annuals of the Photogrammetry, Remote Sensing and Spatial Information Sciences. II-5/W2.

WANG, J., GAO, Y., LI, Z., MENG, X. & HANCOCK, C. M. 2016. A tightly-coupled GPS/INS/UWB cooperative positioning sensors system supported by V2I communication. *Sensors,* 16**,** 944.

Wetzstein, G. 2018. Inertial Measurement Units I. View at: http://stanford.edu/class/ee267/lectures/lecture9.pdf. Last Access:[30/01/2019].
Xsens. MTi-G-710 page. View at: https://www.xsens.com/products/mti-g-710/. Last Access: [30/01/2019].

YAN, J., HE, G. & HANCOCK, C. Low-Cost Vision-Based Positioning System. Adjunct Proceedings of the 14th International Conference on Location Based Services, 2018. ETH Zurich, 44-49.

YAN, J., HE, G., BASIRI, A. & HANCOCK, C. Vision-aided indoor pedestrian dead reckoning. 2018 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), 2018. IEEE, 1-6.

YAN, J., HE, G., BASIRI, A. & HANCOCK, C. Indoor Pedestrian Dead Reckoning Calibration by Visual Tracking and Map Information. IEEE Ubiquitous Positioning, Indoor Navigation and Location-Based Services (UPINLBS), 2018. IEEE.

BIOGRAPHICAL NOTES

Yuchen YANG (1st author)
Academic Experience:
Bachelor of Civil Engineering, University of Nottingham Ningbo China (2013-2015);
Bachelor of Civil Engineering, University of Nottingham, UK (2015-2017);
Master of Geospatial Engineering with Building Information Modelling (BIM), University of Nottingham Ningbo China (2017-2018);
PhD in Surveying and BIM, University of Nottingham Ningbo China(2018-now).

Craig HANCOCK (corresponding author)
Academic Experience:
BSc Hons Surveying and Mapping Science, Newcastle University, UK;
PhD Space Geodesy, Newcastle University, UK;
Associate Professor in Geodesy and Surveying Engineering, University of Nottingham Ningbo China.
Publication:
Hancock, C.M., Roberts, G. W., Bisby, L., Cullen, M. & Arbuckle, J., 2012, Detecting Fire Damaged Concrete Using Laser Scanning. FIG Working Week 2012. Rome, Italy, Detecting Fire Damage Concrete Using Laser Scanning.

Georgios KAPOGIANNIS (co-author)
Academic Experience:
Assistant Professor in Building Information Modelling, Marketing and Recruitment Coordiantor, University of Nottingham.
Publication:
Kapogiannis, G., Sherratt, F. 2018. Impact of integrated collaborative technologies to form a collaborative culture in construction projects. Built Environment Project and Asset Management, Vol.8. Issue.1. pp24-38.

Ruoyu JIN (co-author)
Academic Experience:
PhD. The Ohio State University.
Senior Lecturer, School of Environment and Technology. University of Brighton.
Publication:
Jin, R., Yang, T., Piroozfar, P., Kang, B. G., Wanatowski, D., Hancock, C. M. 2018. Project-based pedagogy in interdisciplinary building design adopting BIMM. Engineering, Construction and Architectural Management.

Huib de LIGT (co-author)
Academic Experience:
Senior Laboratory and Field Work Teacher (Engineering Surveying/GNSS), Department of Civil Engineering, University of Nottingham Ningbo China.
Publications:
Roberts, G. W., Montillet, J-P., Huib de Ligt. Et al. 2007 The Nottingham Locatalite Network. International Global Navigation Satellite System Society-IGNSS Symposium 2007.

JingJing YAN (co-author)
Academic Experience:
PhD in Digital Economy, University of Nottingham Ningbo China (2015-now).
Publications:
Yan, J., He, G., & Hancock, C., 2018, Low-Cost Vision-Based Positioning System. Adjunct Proceedings of the 14th International Conference on Location Based Services, 2018. ETH Zurich, 44-49.

Chao Chen (co-author)
Academic Experience:
PhD in GIS and BIM integration, University of Nottingham Ningbo China (2015-2019).
Publication:
Chen, C., Yang, L., Tang, L & Jiang, H., 2017, BIM-based Design Coordination for China's Architecture, Engineering and Construction Industry. 2nd International Conference on Building Information Modelling (BIM) in Design, Construction and Operations. Alicante, Spain, May 10-12.

Chendong LI (co-author)
Academic Experience:
PhD in Satellite positioning. University of Nottingham Ningbo China (2017-now).

CONTACTS

Yuchen YANG,
University of Nottingham Ningbo China
199 Taikang East Road, Yinzhou District.
Ningbo, Zhejiang province
China
Tel. +86 0574-88180000
Email: slxyy1@nottingham.edu.cn