Combination of Hand Measuring Methods and Scanning Techniques for CAFM – Data Acquisition

Andreas RIETDORF, Frank GIELSDORF and Lothar GRUENDIG, Germany

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SUMMARY

The acquisition of geometrically data for facility management applications can be very expensive. There are many on site measuring tools available for practical use, based on hand measuring methods up to various scanning techniques.

This paper deals with the combination of different methods, like hand held measurements and data collected with an automated measurement system. The prototype is based on stepping motors and DISTO hand held laser meter developed at the Technical University of Berlin. The idea of application is based on a separation of topology and geometry in the relational data model which is expressed by the parametrization by plane surface parameters presented in [3]. That data model enormously reduces the geometrical parameters which describe the entire building geometry. The determination of parameters has been done applying adjustment techniques. Thus it is especially advantageous to have the possibility for quality control.

ZUSAMMENFASSUNG

In vielen Fällen ist die Erfassung geometrischer Gebäudedaten sehr teuer. Die Erfassungsmethoden reichen dabei vom einfachen Handaufmass bis zum Einsatz von hochauflösenden Laserscannern.

Im Beitrag wird gezeigt, wie sich unterschiedliche Erfassungsmethoden miteinander verbinden lassen, um eine wirtschaftliche Datenerfassung für Facility Management - Anwendungen zu ermöglichen. Grundlage ist ein Datenmodell, welches eine strenge Trennung von geometrischen und topologischen Informationen unterstützt und auf einer Parametrisierung durch Flächenparameter basiert [3]. Das Datenmodell reduziert die Anzahl der zur Beschreibung nötigen Parameter auf ein Minimum. Die Berechnung der Geometrieparameter erfolgt durch den Einsatz von Ausgleichungsalgorithmen, dabei erlaubt die Berechnungsstrategie eine weitgehende automationsgestützte Verknüpfung von Handaufmassdaten und Daten, die mit einem kostengünstigen scannenden Messverfahren erzeugt wurden. Der Prototyp des Meßsystems beruht auf einer Kombination von Schrittmotoren und einem Laserhandentfernungsmesser.

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1. INTRODUCTION

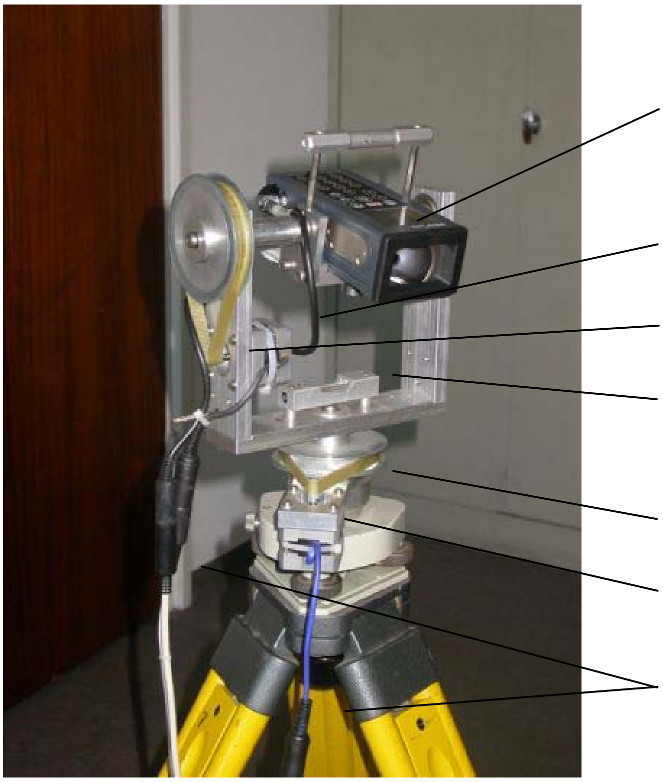
Facility Management applications are being helpful for all application around real estate. For building up and introducing these kinds of information systems the primary task is the determination of geometry, partly under consideration of some generalization techniques according to the specified task. The acquisition of geometrically data for computer aided facility management applications (CAFM) can be very expensive. There are many on site measuring methods available for practical use, like scanning from construction plans, hand measuring methods, Photogrammetry, and Tachometry. The most progressive development is done by using the techniques of laser scanning. There are many system manufacturers present on the market. These systems include efficient software and hardware. Unfortunately, most of the users are discouraged by the costs of the complete equipment and the still huge amount of effort needed for data acquisition. An additional cost factor is that the users have to be highly qualified.

An economic solution to the task of geometrical data acquisition of buildings can be achieved by improving the data processing procedure rather than the data acquisition methods applied on site. The objective of this paper is to illustrate the development of an easy to use system for the mapping of building geometry with the help of standard components and intelligent software tools. This paper describes the development of a self-controlled and low-priced measuring system built on the basis of standard components, like stepping motors, hand-held distance meter and moreover the strategy of analysis and interpretation in combination with hand measurement techniques. An overview of the accuracy for the prototype is given and the determination of structured object qualities with the assistance of adjustment techniques is outlined.

2. SYSTEM DESCRIPTION

The self-controlled and low-priced measuring system was built on the basis of standard components. The system is based on stepping motors and hand-held distance meter. First development was done in 2000 and is described in [1]. After reconstruction it has been based on two stepping motors and Leica DISTO™ pro4a. The main axes (tilting axis and vertical axis) have been built in deep groove ball bearings in combination with an aluminium profile frame. The construction and fitting was done by technical staff at the Department of Geodesy and Geomatics at Technical University of Berlin. An overview of the present prototype can be seen in Figure 1.

The Leica DISTO™ pro 4a Laser distance meter allows for a still higher precision of ±1.5 mm at a range of 0.3 m to over 300 m. Points to be measured are visible on the object itself. For the automatic rotation of the measuring system with respect to two axes the prototype is prepared with stepping motors. The operating voltage takes 12 V whereas the amperage is defined to be 400 mA [4]. One step of the multiphase motors leads to the alteration of tech driving axle by 2 grades. Consequently a half step (minimum operating performance) leads to alteration of tech driving axle of 1 grade. Using gearing mechanism it is possible to produce minimally increments of 0.1 grade for horizontal and vertical directions. The control of the stepping motors is realized by a stepping motor interface. This Interface can be connected to the parallel port of a personal computer or laptop. The control software was developed in C++ and allows the operator to have supervision of the measurement procedure starting from parameter input over single point measurement to automated area scanning.



Components:

Hand-held distance meter Leica DISTO™ pro 4a

Stepping motor vertical circle

Gearing mechanism vertical circle

Plate level

Gearing mechanism horizontal circle

Stepping motor horizontal circle

Connecting cables

Costs:
approx. 750,- €

Figure 1 Prototype of the measurement system

3. CALIBRATION AND ACCURACY

The determination of axis errors has been very challenging because it isn’t possible to collimate points in both, face left and face right, due to the minimal rotation increments of 0.1 grades. We solved this problem for the horizontal collimation error, vertical collimation error and dislevelment of the trunnion axis by realizing appropriate calibration methods. Additionally the additive constant of the Hand-held distance meter Leica DISTO™ pro 4a has still to be found. That can be done by the usual approach.

The relationship between the axis errors of the system and their effects on angular measurements is described in [2]. The axis errors are correlated and should be determined in an interconnected way.

In order to evaluate the accuracy of the calibrated system a calibration field was established consisting of approximately 50 points. These points were measured with both, a total station providing high precision results and the scanner prototype.

Applying the transformation approach

$$\vec{X} = \vec{X}_S + m\mathbf{R}\vec{x}$$

$\vec{X}$: global coordinate system
$\vec{X}_S$: translation
m : scale factor
$\mathbf{R}$: rotation matrix
$\vec{x}$: local coordinate system

the local measurement data from scanner can be transformed into the global reference frame which is represented by the total station coordinate system. In the adjustment model it has to be postulated that the rotation matrix will be orthogonal. Due to the high precision of the total station measurements the residuals after the transformation can be interpreted as errors of the scanning. The standard deviation achieved resulted in 1 cm. Hence the measurement system presented fulfils the requirements for standard applications, like office buildings and tenements.

4. FUNCTION MODEL

The original observational data of a scan are 3D polar coordinates - horizontal directions, vertical directions and distances. In a first processing step these polar coordinates can be transformed into cartesian coordinates with a simple approach:

$$\begin{aligned} x_i &= \cos\alpha_i \cdot d_i \\ y_i &= \sin\alpha_i \cdot d_i \\ z_i &= \cos\zeta_i \cdot d_i \end{aligned}$$

It should be taken into account that these cartesian coordinates are stochastically correlated. The local reference frame is defined by the temporary position and orientation of the scanner. Just the orientation of the z-axis can be seen as identical with the global reference frame.

The second processing step is the plane detection. The objective is to represent related objects by their surfaces and not by a multitude of discrete points. The object can be described by a number of intersecting surfaces. For the approximation of the objects, surfaces of first order (planes) or also of second order (cylinder, cone, sphere, ellipsoid) are used.

The task of plane detection is to aggregate points to subsets which represent a parameterized surface and to estimate their corresponding parameters. In the following only planes will be considered. The planes are described by a vector polynomial of first degree.

$$\vec{n}_j \vec{x}_i - d_j = 0$$

$\vec{n}_j$: normal vector of the plane

$\vec{x}_i$: position vector of a plain point

d_j : orthogonal distance between plane and origin

The result of plane detection are first the assignment of points to planes and second the plane parameters $\boldsymbol{n}_j$ and d_j. The plane parameters as well as the point coordinates are now referenced to the local frame of the scanner station.

Required are plane parameters in a global reference frame. For that reason it is necessary to transform the local plane parameters. The common transformation approach is based on identical points in both coordinate systems. In the present case those points are not available. Point coordinates could be calculated by intersection of planes but here a more elegant way is proposed.

The transformation can be approached using identical planes. If an object, consisting of at least three non parallel planes, were surveyed from two stations, then both station frames can be transformed into each other. One could try to solve the problem step by step but this would lead to a very unfavourable error propagation. In addition it would be difficult to locate blunders in the observation data.

However the transformation can be performed using quaternions [5]. It can be formulated as an indirect adjustment problem with constraints between the unknowns. The residual equations for the rotation parameters are:

$$\overset{o}{n}_{i\,local} + \overset{o}{v} = \overset{o}{q}_j \cdot \overset{o}{n}_{i\,global} \cdot \overset{o}{q}{}_j^{-1}$$

$\overset{o}{n}_{i\,local}$: quaternion of the local normal vector

$\overset{o}{n}_{i\,global}$: quaternion of the global normal vector

$\overset{o}{q}_j$: quaternion of rotation

i : index of plane

j : index of local system

and for the translation parameters:

$$d_{i\,local} + v = d_{i\,global} - \mathbf{n}_{i\,global} \cdot \mathbf{t}_{j\,global}$$

It has to be enforced that the norm of the global normal vectors respectively of the rotation quaternions has to be 1:

$$\left|\mathbf{n}_{i\,global}\right| = 1$$

$$\left|\overset{o}{q}_j\right| = 1$$

The vector of observations contains the local plane parameters:

$$\mathbf{l}^{\mathrm{T}} = \left(\mathbf{n}_{i\,local},\, d_{i\,local}\right)$$

Unknowns are the global parameters of each plane and the transformation parameters of each local station frame:

$$\mathbf{x}^{\mathrm{T}} = \left(\mathbf{n}_{i\,global},\, d_{i\,global},\, \overset{o}{q}_j,\, \mathbf{t}_{j\,global}\right)$$

The final adjustment calculation requires proximity values of the unknowns. Those proximity values can be calculated in an interconnected way by formulating of linear substitution problems and bi-linear ones.

The approach presented here allows for an interconnected transformation in which all local frames will be transformed simultaneously into the global reference frame. Process automation, favourable error propagation and efficient blunder detection are its main characteristics.

The procedure is shown in Figure 2 below as a process chain.

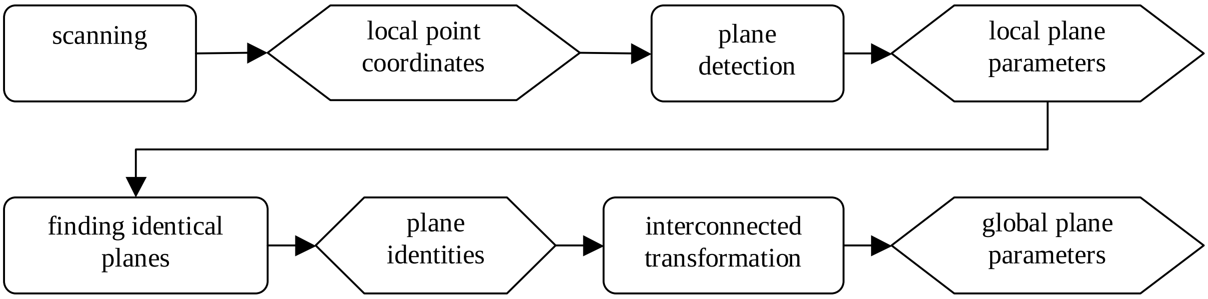


Figure 2 Transformation procedure

The procedure of data acquisition can be combined with observational data like hand held measurements from tapes in order to be integrated in the data model presented in [3].

5. CONCLUSION

It has been shown, that the measurements to be made on site can be achieved in a very efficient way. For ordinary buildings, robust and easy to use measurement tools, like measurement tapes or hand hold laser distance measurement instruments, can be applied. Such observations can be collected by technician level workers.

The task of the surveying engineer, applying the automated process shown above, will be to find a consistent result, exploiting the redundancy of the measurements to remove errors while transforming the data into a unique spatial reference frame. This task is a typical application of geodetic adjustment techniques which surveying engineers are used to.

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BIOGRAPHICAL NOTES

Andreas Rietdorf, born 1971. Graduated in 1998 as Dipl.-Ing. in Surveying from University of Hanover. Since 1998 Assistant at the Department of Geodesy and Geomatics, Technical University of Berlin.

Dr. Frank Gielsdorf, born 1960. Graduated in 1987 as Dipl.-Ing. in Surveying from Technical University of Dresden. Obtaining doctorate degree in 1997 from Technical University of Berlin. Since 1995 Assistant Professor at the Department of Geodesy and Geomatics, Technical University of Berlin.

Prof. Dr. Lothar Gründig, born in 1944. Graduated in 1970 as Dipl.-Ing. in Surveying and obtaining doctorate degree in 1975, both from University of Stuttgart. From 1970 to 1977, work as Assistant Professor and until 1987 senior research assistant at University of Stuttgart. Scientist at Scientific Center of IBM in Heidelberg on data bases 1984-1982 and guest scientist at Calgary University for 4 months in 1983. Since 1988 Professor of Geodesy and Adjustment Techniques at the Department of Geodesy and Geomatics, Technical University of Berlin.

CONTACTS

Dipl.-Ing. Andreas Rietdorf
Technische Universität Berlin, Sekretariat H20
Strasse des 17. Juni 135
10623 Berlin
GERMANY
Tel. + 49 30 3142 2374
Fax + 49 30 3142 1119
email: rietdorf@fga.tu-berlin.de
Web site: www.survey.tu-berlin.de

Dr.-Ing. Frank Gielsdorf
Technische Universität Berlin, Sekretariat H20
Strasse des 17. Juni 135
10623 Berlin
GERMANY
Tel. + 49 30 3142 2374
Fax + 49 30 3142 1119
Email: gielsdorf@fga.tu-berlin.de
Web site: www.survey.tu-berlin.de

Prof. Lothar Gruendig
Technische Universität Berlin, Sekretariat H20
Strasse des 17. Juni 135
10623 Berlin
GERMANY
Tel. + 49 30 3142 2375
Fax + 49 30 3142 1119
Email: gruendig@fga.tu-berlin.de
Web site: www.survey.tu-berlin.de