USE OF STATIONARY RECEIVERS LOCATED BY MULTILATERATION FOR THE IMPROVEMENT OF THE METROLOGICAL PERFOMANCE OF INDOOR-GPS SYSTEMS

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Abstract: In this article a methodology for locating stationary receivers of an Indoor-GPS system by sequential multilateration with a Laser Tracer is described. Simulation-based optimization of the measurement strategy and experimental validation are presented.

Key words: indoor-GPS, large volume metrology, industrial geodesy, multilateration, Laser Tracer.

1. INTRODUCTION

Increasing requirements for manufacturing and assembling processes of large parts and structures, mainly in the fields of aircraft and shipbuilding industries, have been pushing forward the development and improvement of measurement technologies, especially those designed for flexible tridimensional metrology with low measuring uncertainty [1]. One of these recently developed systems is the Indoor-GPS (iGPS).

The iGPS features a flexible measuring range and allows the performance of measurement and positioning tasks with uncertainties of about 1 mm [2]. However, its metrological performance depends on several influencing factors, especially on those related with the setup process. The setup using stationary receivers – also called monuments – located by sequential multilateration technique using a Laser Tracer as reference length measurement system is presented as a way to improve the metrological reliability of iGPS measurements.

2. THE INDOOR-GPS SYSTEM

The iGPS is a modular and distributed coordinate measurement system. Distributed because a set of measuring stations is needed to perform the measurement; and modular because its measuring range can be increased by the addition of such stations.

The system is comprised of at least two transmitters and one receiver. The actual amount of each of these components depends on the application. Transmitter and receiver are illustrated in Figure 1.

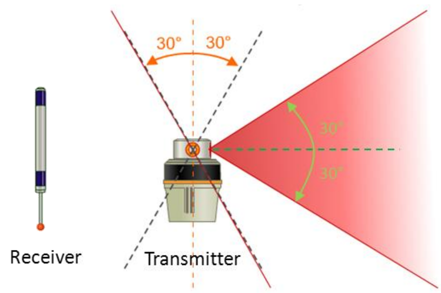

Figure 1: Receiver and Transmitter of the iGPS
[Source: www.nikonmetrology.com]

Each transmitter generates two rotating fanned infrared laser beams and one LED strobe with a particular rotating frequency (around 50 Hz). The receivers comprise two or more photo detectors. Based on the geometry of the laser beams, detection time of the light signals, and the rotation frequency of the transmitters, it is possible to calculate the horizontal and vertical angles (azimuth and elevation, respectively) between a transmitter and a detector of a receiver. The triangulation of the information from two or more transmitters allows for the calculation of x, y and z coordinates of each detector of a receiver in a coordinate system that is defined during the setup.

2.1. System setup

The setup consists in calculating the position and orientation of the transmitters in a global coordinate system. This can be achieved by two different methods: using a reference bar (scale bar) and an iterative mathematical algorithm (bundle adjustment) or using stationary receivers located with a reference measurement system.

The scale bar is a receiver with two detectors separated by a known distance. During the setup the scale bar is positioned in several locations within the measurement volume. The position and orientation of the transmitters is determined iteratively by minimizing the intersection errors between the detector-transmitter vectors (bundle adjustment). Due to environmental conditions, it may be necessary to repeat this process more than once a day.

The other method consists of measuring the position and orientation of stationary receivers with a reference measurement system. This information will then be the used in the setup process. This technique is potentially capable of improving the metrological performance of the iGPS, due to the low measurement uncertainty of the reference measurement system and the robustness of the mathematical model.

The stationary receivers are commonly mounted on the tripods (or other fixture) of the transmitters (Figure 2). The detectors of a stationary receiver are separated by a known distance. Figure 3 shows the stationary receivers (monuments) in detail. Five conic nests for 1/2" spherical mounted reflectors (SMR) are available for the determination of the position and the orientation of the receiver.

Figure 2: Transmitter with stationary receivers
[Source: www.nikonmetrology.com]

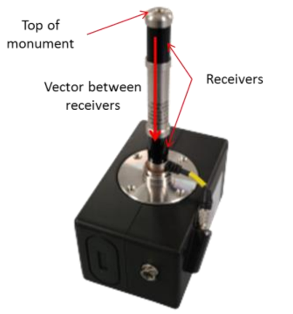

Figure 3: Detail of stationary receivers
[Source: www.nikonmetrology.com]

3. USING A LASER TRACER AS REFERENCE MEASUREMENT SYSTEM

Laser Trackers are most commonly used as reference system to locate the monuments. These systems allow determining the position of an automatically tracked reflector in a spherical coordinate system. The distance to the reflector is determined by a laser interferometer and the horizontal and vertical angles by angular encoders. The metrological performance of a Laser Tracker is limited by the accuracy of the encoders and of the rotating mechanism.

In the alternative way of locating the stationary receivers presented here a length measurement system commercially known as Laser Tracer (Figure 4) is used as reference. Although being similar to the Laser Tracker, the Laser Tracer is optimized for lengths measurement. It has a precision sphere in its rotating center, which acts as the stationary reflector of the interferometer. The center of the sphere is then the reference for the length measurements, which become independent of the mechanical precision of the rotating mechanism. This allows achieving spatial length measurements with uncertainties about 10 times lower than using a Laser Tracker.

Figure 4: ***Laser Tracer***
[Source: www.etalon-ag.com]

Even though the Laser Tracer is only capable of measuring lengths, by using the multilateration technique it becomes possible perform tridimensional measurements, taking advantage of the low measurement uncertainty to locate the monuments.

4. MEASUREMENT PROCEDURE AND MATHEMATICAL MODEL

The sequential multilateration technique has already been successfully used in the determination of geometrical errors of large coordinate measuring machines and machine tools [3].

The measurement procedure for locating the stationary receivers consists in placing the Laser Tracer within the iGPS measuring volume and taking distance measurements to each point of interest. This procedure is then repeated for other positions (stations) of the Laser Tracer. The amount and position of measurement stations influence the uncertainty of the results of the multilateration process. At least four stations are needed. For the equation system to be solved, the first three positions usually define a plane and the fourth must be, necessarily, out of this plane [4].

By using the measured distances as input, an overdetermined system of non-linear equations is solved in order to define the positions of the target points as well as the positions of the Laser Tracer stations.

The system is solved by the minimization of the sum of the squared residuals, as described in Eq. 1, with appropriate initial and boundary conditions:

(1)

Onde:
i target point number
j Laser Tracer station number
n amount of target points
m amount of Laser Tracer stations
measured length from station j to point i
Laser Tracer dead-length at station j
position of target point i
position of station j
residual

5. SIMULATION FOR OPTIMIZING THE POSITION OF THE STATIONS AND ESTIMATING THE MEASUREMENT UNCERTAINTY

Numerical simulations have been carried out using an algorithm developed in Matlab® in order to define the best geometrical arrangement of the stations in relation to the stationary receivers. The simulation is based on a reference data set, which contains target points with known coordinates simulating the position of the receivers. For a given position of the stations the distances between stations and the target points are calculated. In the sequence, the distances are contaminated with normally distributed random deviations, simulating the measurement uncertainty of the Laser Tracer. The contaminated distances are then the input to the multilateration algorithm, and the coordinates of the target points are calculated. The difference between the positions of the target points in the reference data-set and the positions calculated by multilateration is defined as the residual. The root mean square (RMS) value of the residuals in the x-, y- and z-directions is used as criterion for evaluating the quality of each tested geometrical configuration.

The tests led to the conclusion that the best configuration consists in positioning the stations in the middle of the lines connecting the monuments of the iGPS. In fact, this configuration produces greater length variation, contributing to the convergence of the optimization algorithm. Figure 5 illustrates this configuration. Additionally, it is important to have significant height variations (in z-directions) between stations and target points.

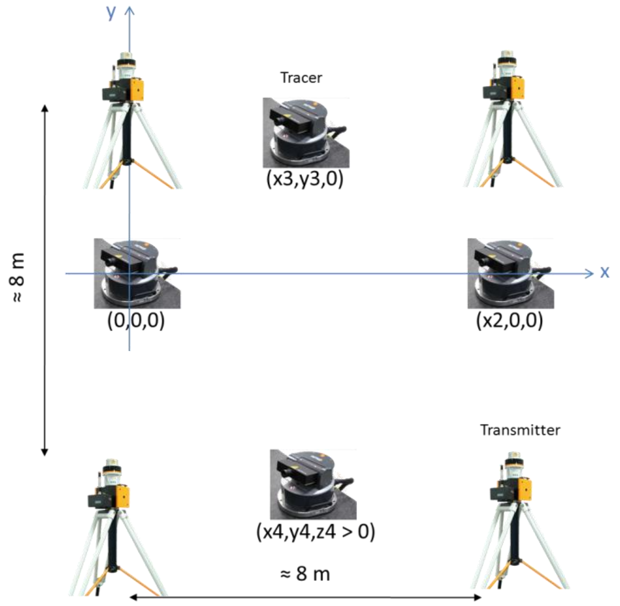

Figure 5: Geometrical configuration of receivers and measurement stations

6. EXPERIMENTAL VALIDATION

The measurement of the position of the 1/2" nests with a SMR proved to be impracticable, for the laser beam was easily broken. In order to make the Laser Tracer measurements possible, an adapter has been built, allowing the use of a cat-eye reflector, which has a wider acceptance angle. Hence, a new – but not less accurate – measuring strategy has been defined. Two points are measured for each monument. Being approximately collinear to the detectors, they define the origin and the vector direction of the monument (Figure 6).

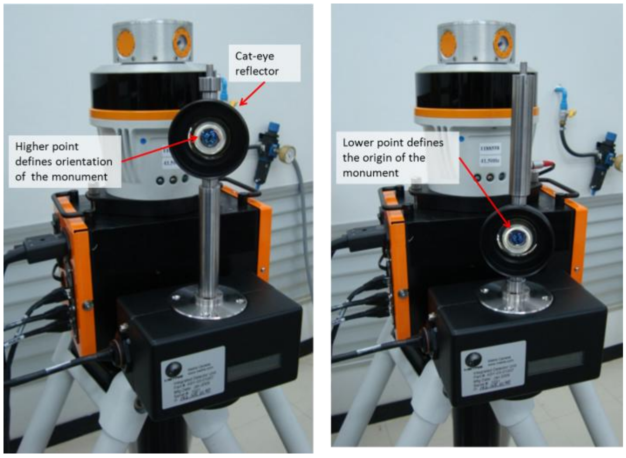

Figure 6: Points measured on each monument

Since each transmitter needs to have line of sight to at least four monuments, a total of five monuments were used. Intending to increase the number of equations to be solved, measurements have been taken from five different Laser Tracer positions (Figure 7). Approximately one hour was needed to perform the 40 length measurements of this configuration.

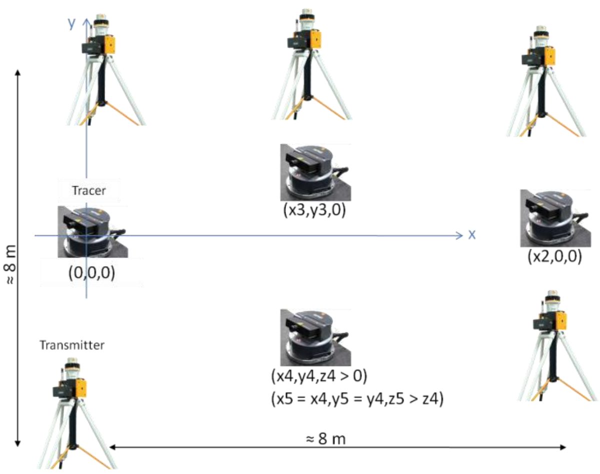

Figure 7: Experiment configuration

Calculations resulted in a maximum residual of δ_{max} = 0,05 mm (see Eq.1) which are consistent with the mechanical manufacturing accuracy of the cat-eye adapter.

7. CONCLUSION

The Indoor-GPS is a scalable and versatile industrial geodesy system of potential application in the naval and aircraft industries. Its metrological performance depends on many influencing factors, especially on those related to the setup. The iGPS setup using stationary receivers located by multilateration is a method for reducing the uncertainty of the setup process, increasing the metrological reliability of the system.

Based on numerical simulations and recommendations from the literature, a strategy for this sequential multilateration measurement has been developed, which aims at the best geometrical arrangement of the Laser Tracer measurement stations in relation to the stationary receivers.

Through the experience gained with the first experiments the measurement technique has been developed and improved. First results indicate the applicability of the technique. Next steps are the further improvement of the geometrical arrangement of the measurement stations as well as the enhancement of the mechanical precision of the cat-eye adapter and the comparison of the performance of the iGPS after each setup method (bundle adjustment with scale bar x stationary receivers located by multilateration).

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