Low-cost distance measuring methods and their investigation for BIM modeling

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Abstract— **The purpose of the thesis is multifaceted. On one hand, I will investigate the feasibility of producing flat shapes that serve as the basis for different purpose BIM models, depending on reliability. On the other hand, I would like to examine separately the reliability of the various low-cost total stations nowadays, for such measurements. An earlier study dealt with the use of low-cost targets for laser scanning. In connection with this, an attempt was made to measure the extent to which the used styrofoam spheres available in decoration shops can be considered as perfect spherical shapes and whether they may have flatness.**

The purpose of the thesis is multifaceted. On one hand, we investigate the possibilities of producing flat profiles (flat surface, sphere), which are the basis of various BIM models, and their reliability. On the other hand, we would like to examine separately the various low-cost, so-called, low-cost the reliability of low-cost stations for such measurements.

Distance measuring was done with traditional total stations, laser scanner. Among the total stations, low-cost, conventional and mid-range total stations were tested. Of the low-cost, I used two of the same instruments to make sure they were free from any distance measuring errors.

The measurement of short distances at low-cost total stations was also investigated in the case of prismatic and prismatic measurement. In the former case, measurements were made on the wall, the styrofoam sphere, the styrofoam plane, the metal sphere, the signboard and the marble slab, while in the case of prismatic telemetry measurements were carried out at several angles on the mini Foif and Leica prisms.

An earlier study investigated the feasibility of using low-cost interfaces for laser scanning (4). In connection with this, there was an experimental measurement to determine whether the styrofoam spheres used as an interface point in decoration shops can be considered as a perfect spherical shape, and if there is any flatness. The result was a very noisy point cloud, which could not be examined by a smoothing sphere algorithm. The probable cause is the material of the sphere.

As a follow-up to the above-mentioned study, we studied the "behavior" of the spherical surface with distance measurement. The points on the spheres were measured from the four positions of a local network. The sphere is made of styrofoam and metal. For these two materials, two total stations, low-cost and mid-range, were measured. We used the equation sphere function calculated in Matlab to determine the fit of the points.

Low-cost instrument:

I. Remote measurement errors

Distance and angle measuring instruments were developed independently of each other. Their relationship has been and continues to evolve to this day. First, two separate structural units were involved in the measurements (stand-alone distance and angle measuring instruments), then telemeters mounted on the telescope or sub-telescope of the angle measuring instruments, finally the integration of the two structural units was technically resolved and electronic tachymeters were created, and later, with the help of the solution of field calculation and data recording, the measuring stations used today.

The additive constant is one of the most important errors in distance, which loads the same for all measurement results. The origin of the error is due to the construction of both the instrument and the prism.

$$t = t_m + c_m + c_p = t_m + c \quad ; \quad c = c_m + c_p$$

The instrument's constant depends on the frequency produced by the rangefinder, so this error is often referred to as frequency error. The cause of the error is that the instrument does not produce the fine measurement frequency that was designed, but a different value. Frequency determines the wavelength from the relation $\lambda = v / f$, ie. the wavelength of the measuring wave is not a multiple of the required international meter. The nature of the error is the same as when measuring with a tape measure if its length does not match its actual value in international meters.

II. Testing the accuracy of rangefinders on prisms

First of all, low-cost prisms were the first to be investigated; traditional; mid-range; with new mid-range stations at different distances, so that the circular prism is rotated in five degrees (0°, 5°, 10°, 15°, 20°) around its stationary axis. 0° represents the measurement arrangement where the direction is perpendicular to the surface of the prism. The prisms, located 1.5 meters, were measured three times in each degree in both telescope positions.

		0°		5°		10°		15°		20°	
		I.	II.	II.	I.	I.	II.	I.	II.	I.	II.
prism	1	1,590	1,500	1,499	1,545	1,588	1,598	1,588	1,579	1,498	1,498
	2	1,590	1,500	1,500	1,537	1,588	1,598	1,593	1,579	1,498	1,500
	3	1,590	1,500	1,498	1,535	1,589	1,598	1,588	1,578	1,499	1,498

Mid-range new instrument:

		0°		5°		10°		15°		20°	
		I.	II.	II.	I.	I.	II.	II.	I.	I.	II.
prism	1	1,499	1,501	1,500	1,499	1,499	1,500	1,499	1,499	1,499	1,499
	2	1,500	1,500	1,500	1,499	1,499	1,499	1,500	1,499	1,499	1,499
	3	1,499	1,499	1,499	1,499	1,499	1,500	1,500	1,499	1,499	1,499

Mid-range new instrument 2:

		0°		5°		10°		15°		20°	
		I.	II.	II.	I.	I.	II.	II.	I.	I.	II.
prism	1	1,499	1,499	1,499	1,499	1,499	1,499	1,499	1,499	1,499	1,499
	2	1,499	1,499	1,499	1,500	1,499	1,499	1,499	1,499	1,499	1,499
	3	1,499	1,499	1,500	1,499	1,499	1,499	1,499	1,499	1,499	1,499

It can be seen from the tables that for prism positions between 5° and 10°, the measurement is subject to a significant error of regularity, whereas it increases with the incidence angle and disappears.

For the low-cost instrument, it is striking that there was a large difference between measurements at one and a half meters. Therefore, we placed the III. five, six, eight and ten meters apart. The effect of the error decreased surprisingly as the distance traveled increased and then disappeared.

III. EXAMINATION OF PRISMATIC DISTANCE MEASUREMENT

The total station's distance meter was also tested on other surfaces after the prisms. First we measured the signboard, the flat styrofoam, and then the dark marble slab and wall. For these measurements we used a low-cost, traditional mid-range station.

The signal board was measured 1.5 and 30 meters from the low-cost total station. Similar to the prism measurement, it was measured by rotation in increments of 0° from 40° to 5° with ten repetitions and telemetry.

The results of the measurements obtained in tabular form are as follows:

		0°		5°		10°		15°		20°		25°		40°	
		I.	II.	II.	I.	I.	II.	II.	I.	I.	II.	II.	I.	I.	II.
geodetic target	1	1,517	1,517	1,521	1,523	1,527	1,529	1,535	1,535	1,541	1,538	1,543	1,546	1,556	1,570
	2	1,517	1,517	1,521	1,524	1,530	1,530	1,535	1,535	1,540	1,540	1,543	1,544	1,559	1,564
	3	1,517	1,517	1,521	1,523	1,529	1,530	1,535	1,535	1,539	1,537	1,543	1,545	1,557	1,566
	4	1,517	1,516	1,521	1,522	1,528	1,530	1,535	1,536	1,538	1,538	1,543	1,543	1,559	1,564
	5	1,517	1,517	1,521	1,522	1,529	1,530	1,535	1,535	1,538	1,538	1,543	1,543	1,559	1,564
	6	1,517	1,517	1,521	1,522	1,529	1,530	1,535	1,535	1,538	1,541	1,543	1,543	1,557	1,567
	7	1,517	1,517	1,521	1,521	1,529	1,531	1,535	1,536	1,538	1,541	1,543	1,544	1,557	1,564
	8	1,517	1,517	1,521	1,522	1,529	1,529	1,535	1,536	1,538	1,538	1,543	1,543	1,559	1,565
	9	1,517	1,517	1,521	1,522	1,529	1,530	1,534	1,536	1,538	1,538	1,543	1,544	1,557	1,566
	10	1,517	1,517	1,521	1,522	1,529	1,530	1,535	1,536	1,539	1,539	1,543	1,544	1,558	1,565

		0°		5°		10°		15°		20°		25°		40°	
		I.	II.	II.	I.	I.	II.	II.	I.	I.	II.	II.	I.	I.	II.
geodetic target	1	30,005	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,029
	2	30,005	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,029
	3	30,006	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,026
	4	30,006	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,026
	5	30,005	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,025
	6	30,005	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,025
	7	30,005	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,026
	8	30,005	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,026
	9	30,005	30,004	30,003	30,008	30,009	30,006	30,009	30,009	30,009	30,011	30,015	30,009	30,009	30,026
	10	30,005	30,004	30,004	30,008	30,009	30,006	30,009	30,009	30,009	30,012	30,014	30,009	30,009	30,026

With a mid-range total station for 1.5, 5, 30 meters:

		0°		25°		40°	
		I.	II.	II.	I.	I.	II.
geodetic target	1	1,505	1,505	1,509	1,509	1,509	1,509
	2	1,505	1,505	1,509	1,509	1,510	1,510
	3	1,505	1,505	1,509	1,510	1,511	1,510
	4	1,505	1,505	1,510	1,510	1,509	1,510
	5	1,505	1,506	1,510	1,509	1,509	1,510
	6	1,505	1,505	1,509	1,510	1,509	1,510
	7	1,505	1,506	1,510	1,510	1,510	1,509
	8	1,506	1,505	1,510	1,509	1,510	1,510
	9	1,505	1,505	1,510	1,510	1,510	1,510
	10	1,505	1,506	1,509	1,509	1,510	1,511

		0°		5°		10°		40°	
		I.	II.	II.	I.	I.	II.	II.	I.
geodetic target	1	5,001	5,001	5,002	5,002	5,004	5,004	5,005	5,005
	2	5,001	5,001	5,003	5,003	5,004	5,004	5,005	5,005
	3	5,001	5,001	5,003	5,003	5,004	5,004	5,005	5,005
	4	5,001	5,001	5,003	5,002	5,004	5,004	5,005	5,005
	5	5,002	5,001	5,003	5,003	5,004	5,004	5,005	5,006
	6	5,002	5,002	5,003	5,002	5,004	5,004	5,005	5,005
	7	5,001	5,001	5,003	5,002	5,004	5,004	5,005	5,006
	8	5,001	5,001	5,003	5,003	5,004	5,004	5,005	5,005
	9	5,001	5,001	5,002	5,003	5,004	5,004	5,005	5,005
	10	5,002	5,001	5,003	5,003	5,004	5,004	5,006	5,005

		0°		5°		10°		15°		20°		25°		40°	
		I.	II.	II.	I.	I.	II.	II.	I.	I.	II.	II.	I.	II.	I.
geodetic target	1	30,004	30,004	30,005	30,006	30,007	30,006	30,006	30,007	30,008	30,006	30,007	30,008	30,007	30,007
	2	30,004	30,004	30,004	30,005	30,006	30,005	30,006	30,007	30,007	30,006	30,007	30,008	30,007	30,007
	3	30,004	30,004	30,004	30,006	30,007	30,006	30,007	30,008	30,007	30,006	30,007	30,008	30,007	30,008
	4	30,004	30,004	30,005	30,006	30,007	30,006	30,007	30,007	30,007	30,007	30,007	30,008	30,008	30,008
	5	30,003	30,004	30,004	30,006	30,007	30,006	30,007	30,008	30,008	30,007	30,007	30,008	30,008	30,007
	6	30,004	30,004	30,005	30,006	30,007	30,006	30,007	30,008	30,008	30,006	30,007	30,008	30,008	30,008
	7	30,004	30,004	30,005	30,006	30,007	30,006	30,006	30,007	30,008	30,006	30,007	30,008	30,008	30,008
	8	30,004	30,004	30,005	30,006	30,007	30,006	30,007	30,007	30,008	30,007	30,007	30,008	30,007	30,008
	9	30,004	30,004	30,005	30,006	30,007	30,006	30,007	30,007	30,008	30,006	30,007	30,008	30,007	30,008
	10	30,004	30,004	30,004	30,005	30,007	30,005	30,007	30,007	30,008	30,007	30,007	30,008	30,007	30,008

It can be seen from the table that the difference in the distance between the two face and the angle of incidence is smaller than in the previous case.

With a conventional total station 1.5 meters:

		0°		5°		10°		15°		20°		25°		40°	
		I.	II.	II.	I.	I.	II.	II.	I.	I.	II.	II.	I.	I.	II.
geodetic target	1	1,504	1,503	1,506	1,507	1,507	1,508	1,510	1,509	1,510	1,511	1,511	1,513	1,514	1,514
	2	1,504	1,504	1,506	1,506	1,507	1,508	1,511	1,510	1,510	1,511	1,511	1,512	1,516	1,515
	3	1,503	1,503	1,506	1,506	1,506	1,507	1,511	1,509	1,510	1,510	1,511	1,512	1,515	1,514
	4	1,505	1,504	1,505	1,505	1,507	1,508	1,510	1,509	1,511	1,511	1,510	1,511	1,514	1,515
	5	1,504	1,504	1,505	1,505	1,507	1,507	1,510	1,509	1,510	1,510	1,511	1,511	1,515	1,514
	6	1,504	1,504	1,505	1,506	1,507	1,507	1,509	1,509	1,510	1,511	1,512	1,512	1,517	1,518
	7	1,504	1,504	1,505	1,506	1,507	1,507	1,509	1,509	1,511	1,510	1,511	1,512	1,515	1,514
	8	1,504	1,505	1,505	1,506	1,507	1,507	1,509	1,509	1,510	1,511	1,512	1,512	1,515	1,514
	9	1,504	1,505	1,505	1,505	1,508	1,507	1,509	1,509	1,510	1,510	1,512	1,511	1,517	1,516
	10	1,504	1,505	1,505	1,506	1,507	1,508	1,509	1,510	1,510	1,511	1,511	1,511	1,516	1,515

Dark marble surface 5, 10, 15, 20, 25, 30 meters I and II. telescope measurements were made with low cost and conventional total stations.

		II.	I.	I.	II.	II.	I.	I.	II.	II.	I.	II.	I.
marble	1	5,107	5,075	10,219	10,035	15,189	15,254	19,886	20,066	25,117	24,870	29,797	30,182
	2	5,108	5,075	10,219	10,035	15,189	15,154	19,885	20,066	25,117	27,870	29,797	30,182
	3	5,116	5,076	10,219	10,035	15,189	15,255	19,887	20,065	25,117	30,870	29,798	30,183
	4	5,109	5,078	10,219	10,036	15,189	15,255	19,886	20,065	25,117	33,870	29,796	30,183
	5	5,107	5,079	10,219	10,034	15,189	15,254	19,886	20,065	25,117	36,870	29,798	30,182
	6	5,109	5,076	10,219	10,034	15,189	15,254	19,886	20,065	25,117	39,870	29,797	30,182
	7	5,108	5,078	10,219	10,033	15,189	15,255	19,886	20,065	25,117	42,870	29,797	30,183
	8	5,109	5,079	10,219	10,034	15,189	15,255	19,886	20,065	25,117	45,870	29,797	30,183
	9	5,110	5,079	10,219	10,034	15,189	15,254	19,886	20,065	25,117	48,870	29,797	30,182
	10	5,110	5,077	10,219	10,034	15,189	15,254	19,886	20,065	25,117	51,870	29,797	30,182

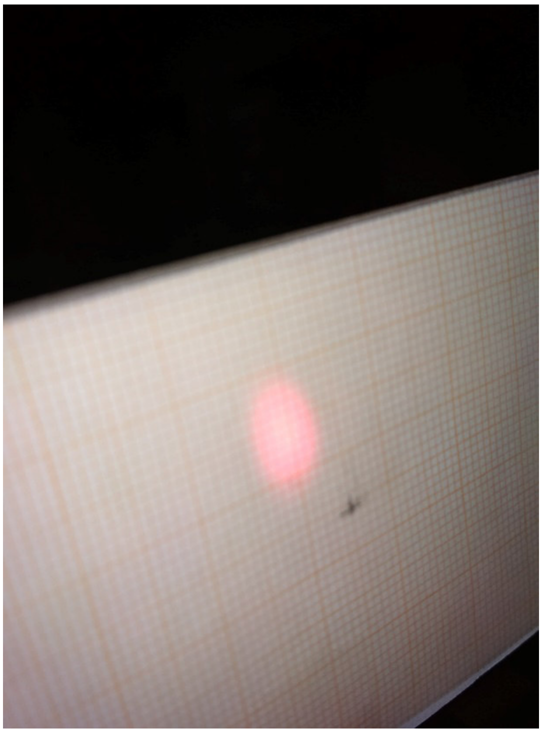
The wall surface was measured with a low cost and conventional measuring station at distances of about 4, 10, 15, 20, 25, 30 and 35 meters.

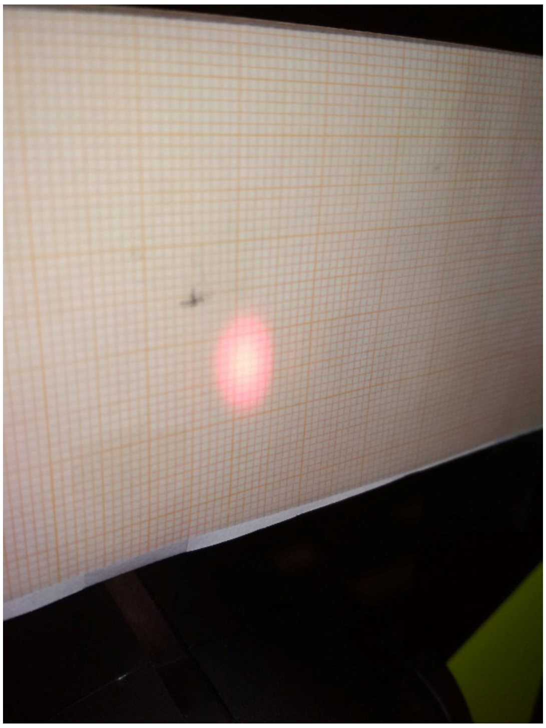
		I.	II.	II.	I.	I.	II.	I.	II.	II.	I.	I.	II.	II.	I.
wall	1	3.844	3.845	9.773	9.775	15.284	15.275	19.837	19.834	24.973	24.980	29.772	29.687	34.099	34.113
	2	3.844	3.843	9.773	9.780	15.285	15.275	19.837	19.835	24.974	24.974	29.698	29.689	34.085	34.111

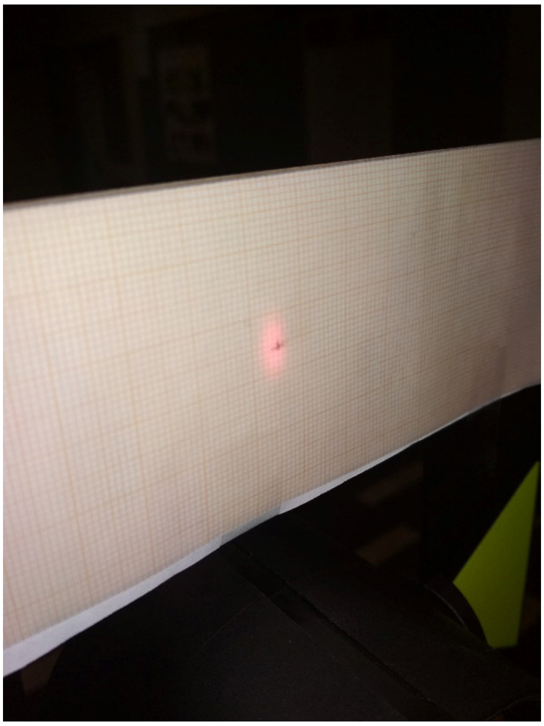
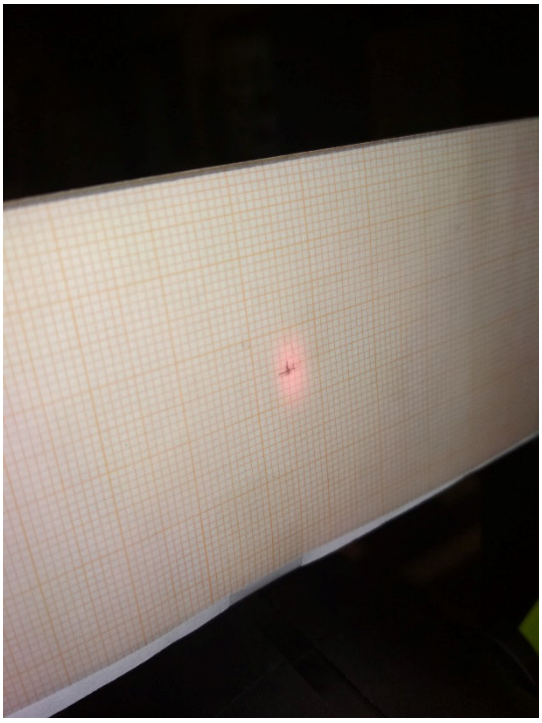
		II.	I.	I.	II.	II.	I.	I.	II.
wall	1	3.843	3.842	9.776	9.779	15.289	15.269	19.825	19.867
	2	3.844	3.844	9.769	9.789	15.288	15.270	19.809	19.874

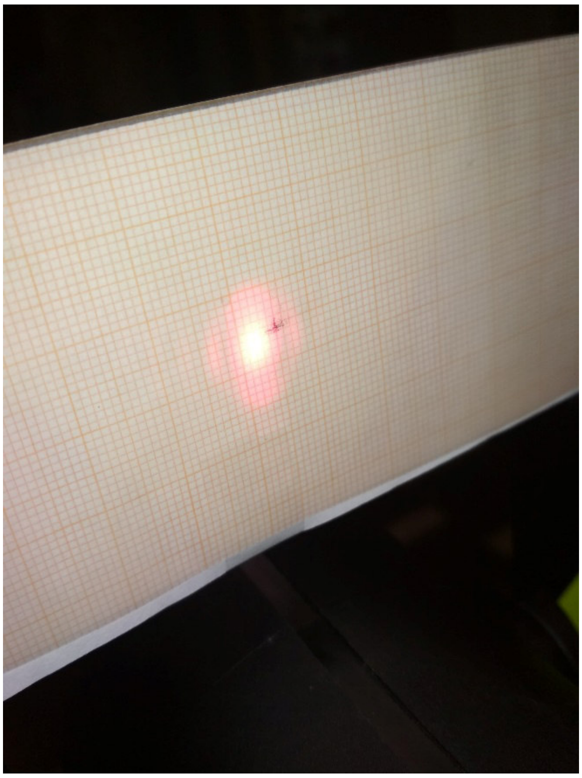
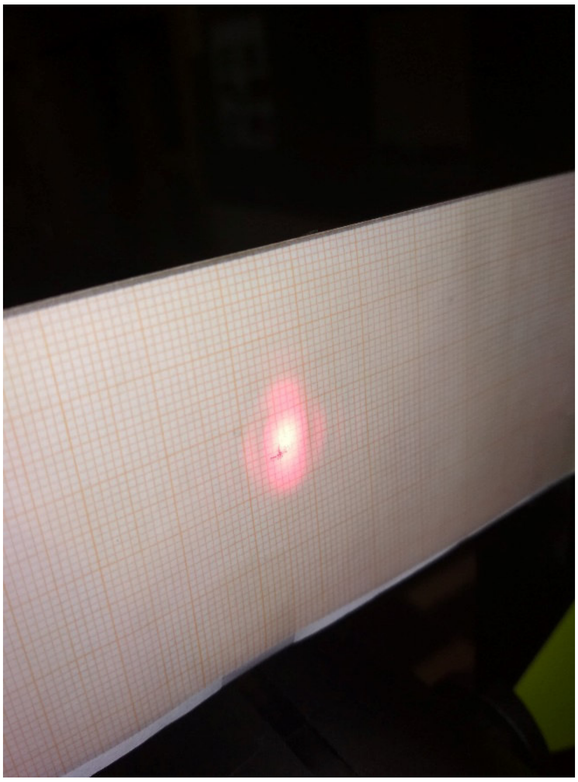
Examining the significant differences between the first and second telescope positions, we concluded that the telescope's orientation diverges from the laser. To test this, we measured on millimeter paper on two face at thirty meters distance, and the result can be seen in the following figures for the various instruments:

Low-cost total stations





Convetional total stations	
	

Mid-range total stations	
	

It can be seen from the diagrams that for some instruments the bearing and distance measurement are not centered, with a rough error. The effect of this is especially significant when measuring non-flat surfaces. Such is the measurement of the spherical surface described below.

IV. Examining the Sphere as a Simple Geometrical Target

As one of the simplest target, the sphere has proven to be useful for connecting laser scanned point clouds. (4) However, if you want to use it as an interface, it is essential for larger networks to be able to define it as an interface. An example of such a network is the survey of the temple of Taransetmaria, which used factory sphere interfaces (3). However, if we want to include spherical targets in the measurement of the local area network, we need to be able to perform measurements similar to those of the scanners, sometimes with non-ideal measurement arrangements. Such tests were performed on styrofoam and metal spheres. The test measurement was performed with a low-cost and mid-range station. The spheres were placed in the center of the room, which was measured from the four points of the local area network. The points to be measured on the spheres are numbered for unambiguous identification. Only points that were clearly identifiable from the given position were measured when the angle of incidence was favorable. The network was adjusted, although we did not have classical superfluous measurements for the test points, since they could only be determined from one or maximum of two stations.

The reliability of the spherical points was ~ 2mm.

There are many references in the literature to fitting the regression sphere (1). We performed our calculations in a Matlab environment. We used a least-squares sphere fitting based on Alan Jennings's (2011) source for detail points (2). The algorithm minimizes the square sum of the radial deviations during the sphere fitting.

$$\sum((x-xk)^2+(y-yk)^2+(z-zk)^2-r^2)^2 \rightarrow min$$

Where xk, yk, zk is the center of the smoothing sphere, while r ^ 2ann has the radius.

After fitting the sphere, we investigated the residual radial inconsistencies and calculated the distance of the measured points from the surface of the smoothing sphere, thus qualifying the reliability of the measurement and the fitting of the regression sphere.

The result of the calculation for a silver-plated sphere is: the mean of the absolute values of the differences is 7mm, while the standard deviation is larger, about 9mm. The radius of the adjusted sphere is 60 mm.

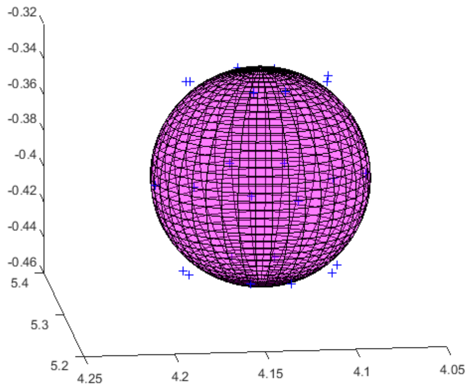


Figure 1. Measurements on the silver sphere and the balancing sphere

During the measurement on the styrofoam, we also found a point with a gross error, presumably due to the error of the telemetry, which was omitted from the calculation. For this type of anchor point, the mean of the absolute values of the deviations is 5 mm and the standard deviation is 6 mm. The radius of the adjusted sphere is 71mm.

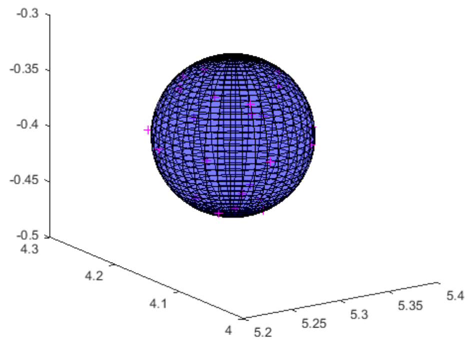


Figure 2. Styrofoam sphere measurements and balancing sphere

Overall, for both interfaces, the definition is significantly higher than the expected values for the interface. At the same time, measurements were not made with an ideal measurement layout.

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