The Use of Multiple Methods to Map the Old City of Jerusalem and it's Use as a Foundation for a Smart City (12730)

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Key words: Total Station, VRS Network, Mobile Mapper, Smart City

SUMMARY

The municipality of Jerusalem ordered our services to map the old city for planning purposes at 1cm accuracy demand.
In this article we discuss different methods of mapping with different obstacles and how each methods pros and cons, as well as time and cost factors of each approach.
The final product had many benefits including a foundation for smart cities and digital twins thanks to some of the advanced methods that gave extra value.

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1. INTRODUCTION

The city of Jerusalem is one of the most challenging cities in the world to map due to many variants of hazards. The municipality of Jerusalem ordered our services to map the old city for planning purposes at 1cm accuracy demand.
With many challenges ahead, some of these hazards are: the terrain, the scale of the project, the density of high buildings with narrow streets, the hard accessibility, crowded touristic areas and restricted areas.

2. PLANNING STRATEGY

Planning the mapping area, we divided the methods to of mapping in to two main categories: 1. Satellite based methods 2. Laser based-non satellite methods this will help emphasize the tradeoff between reducing many factors on the first method, but add cost and time on the other.

2.1 Satellite based methods

2.1.1 CORS network solution:

In the region, currently there are three providers of approved fixed stations, and all three face many daily difficulties in the old city regarding accuracy.
Some of those reasons are:

A common reason is constant connectivity problems; some of the problems are high old buildings blocking sky view, narrow long streets also create difficult connection and far bases, cellular connection getting lost frequently for VRS users; thus makes the use of CORS very limited.

While establishing that the use of CORS network should go under supervision, it is still recommended to use for a self-check on easy data collectors that aren't as affected from the previous mentioned problems.

The shift in the terrain due to mountain area can give false projected values due to inaccurate datum.

2.1.2 Adjustment networks and Static GNSS solution:

If we could avoid the mentioned hazards by using static measurements, we do need to note that it can be very time costly and needs more resources.

2.2 Laser based – non satellite methods

The use of these methods gives us the ability to avoid any need of any connection to outer world and make measurements only with the use of reference known points; thus

giving us the opportunity of committing very accurate measurements in relevance to the project itself unrelated to outer world factors.

2.2.1 Total Stations

We mentioned adjustment network with static measurements that can be checked and improved with laser unrelated measurements.

2.2.2 Digital Levels

A way to precisely adjust and measure the delta between a known height and other heights of stations and measured points, while also not being connected to anything but the reference points.

2.3 Can be used both ways

2.3.1 Big data collectors

Some methods that work both ways are the big data collectors such as:

- photogrammetry (UAV or Plane)
- Mobile Mappers
- Slam

Their added value is incredible time and cost efficiency while capturing much more detailed amount of data, if the hazards of the satellites are an issue, they can be used with connectivity only to the reference stations and thus keep the quality of the trajectory high while tackling the mentioned factors.

3 METHOD

3.1 Creating a work strategy

3.1.1 Determining the size of the project and creating time schedules for each task

3.1.2 Analyzing the hazards expected

3.1.3 Listed the pros and cons of each method and it’s need

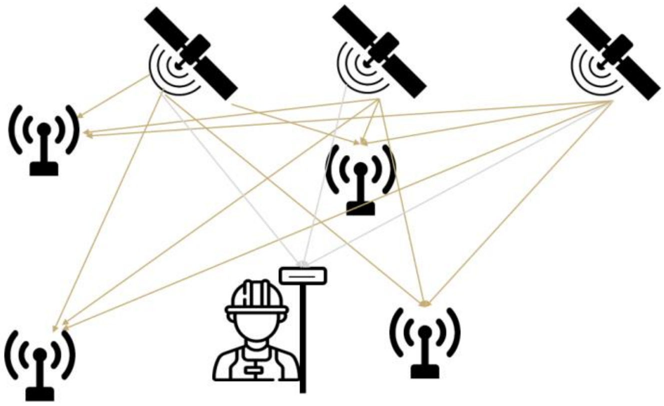
3.1.4 Executing missions according to Gant schedules in order to keep smooth workflow

3.2 Creating the base for the project

3.2.1 Creating an adjustment network

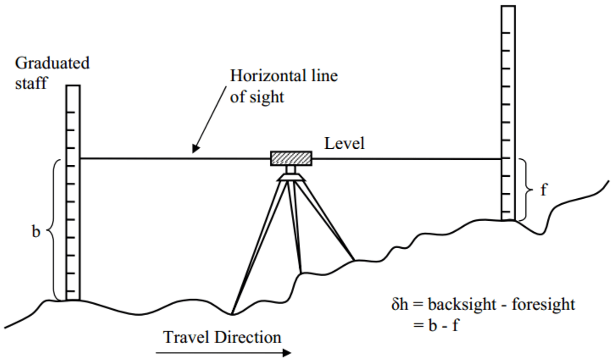
3.2.1.1 Choosing an efficient allocation between the stations includes sight between the stations for TS measurements as well as a distance long enough to cover a big part and short enough to conduct accurate measurement; also creating well allocated equal triangulations for smooth work.

3.2.1.2 Static measurements using GNSS:



3.2.1.3 Since mentioned that we can run into areas with no sky view Measuring angles and distances with the TS for quality control and improving the network is mandatory.

3.2.1.4 Using digital level to check height difference accuracy:



3.2.1.5 Using the **least square** method to calculate the adjusted TS values while giving as much as possible known coordinates from the static measurements as initial values to improve the calculation.

3.2.1.6 The matrix calculation method of Least Squares:

$$ {}_{m}A^{n}\,{}_{n}X^{1} = {}_{m}L^{1} + {}_{m}V^{1} $$

$$ {}_{m}A^{n} = \begin{bmatrix} a_{11} & a_{21} & a_{13} & \cdots & a_{1n} \\ a_{21} & a_{22} & a_{23} & \cdots & a_{2n} \\ a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ a_{41} & a_{42} & a_{43} & \cdots & a_{4n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{m1} & a_{m2} & a_{m3} & \cdots & a_{mn} \end{bmatrix} \qquad {}_{n}X^{1} = \begin{bmatrix} X_1 \\ X_2 \\ X_3 \\ \vdots \\ X_n \end{bmatrix} $$

$$ {}_{m}L^{1} = \begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \\ \vdots \\ L_m \end{bmatrix} \qquad {}_{m}V^{1} = \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \\ \vdots \\ V_m \end{bmatrix} $$

$$ (A^TA)X = A^TL $$

$$ (A^TA)^{-1}\,(A^TA)X = (A^TA)^{-1}(A^TL) $$

$$ IX = (A^TA)^{-1}(A^TL) $$

$$ X = (A^TA)^{-1}(A^TL) $$

3.2.1.7 While the standard deviation is:

$$ S_0 = \sqrt{\frac{V^TWV}{r}} $$

3.3 After creating the adjustment network, we can use big data collectors to map the area

3.3.1 Mobile mapper:

3.3.1.1 By driving with the Pegasus mobile mapper system, we managed in one day to collect data of all the accessible streets in the project area, covering most needed data, which can be used in two ways to self-check, with the GNSS data or only by looking for the adjusted network stations and import them as control point; thus, transforming the entire 3d point cloud to the adjusted network's system.

3.3.1.2 Comparing the adjusted controlled point cloud with the non-adjusted VRS made point cloud for self-check

3.3.1.3 Comparing the Data with check points created with the TS for accuracy validation.

3.3.2 Static laser scanner:

3.3.2.1 The mobile mapper won't cover everything, some spots we will need to go back and scan or measure; allies, crowded areas and restricted car access areas which is the most common.

3.3.2.2 It will need to be connected to some control points since it does not have a GNSS

3.3.2.3 A tradeoff could be used would be a Slam or mobile scanner.

3.3.3 Photogrammetry (Drone):

3.3.3.1 get clarified to fly above the city in very few areas.

3.3.3.2 Since drones fly higher than objects and buildings, we didn't have problems with VRS network connectivity

3.3.3.3 used the same method of the mobile mapper creating two calculated alignments; one using the adjusted control points and the second using GNSS.

4 RESULTS & DISCUSSION

4.1 Adjustment network accuracies:

4.1.1 The accuracy received at the second iteration of the least squares calculation indicated accuracy of 5mm at the XY Value.

4.1.2 The accuracy received at the precise digital level calculation indicated accuracy of 3mm at the Z value.

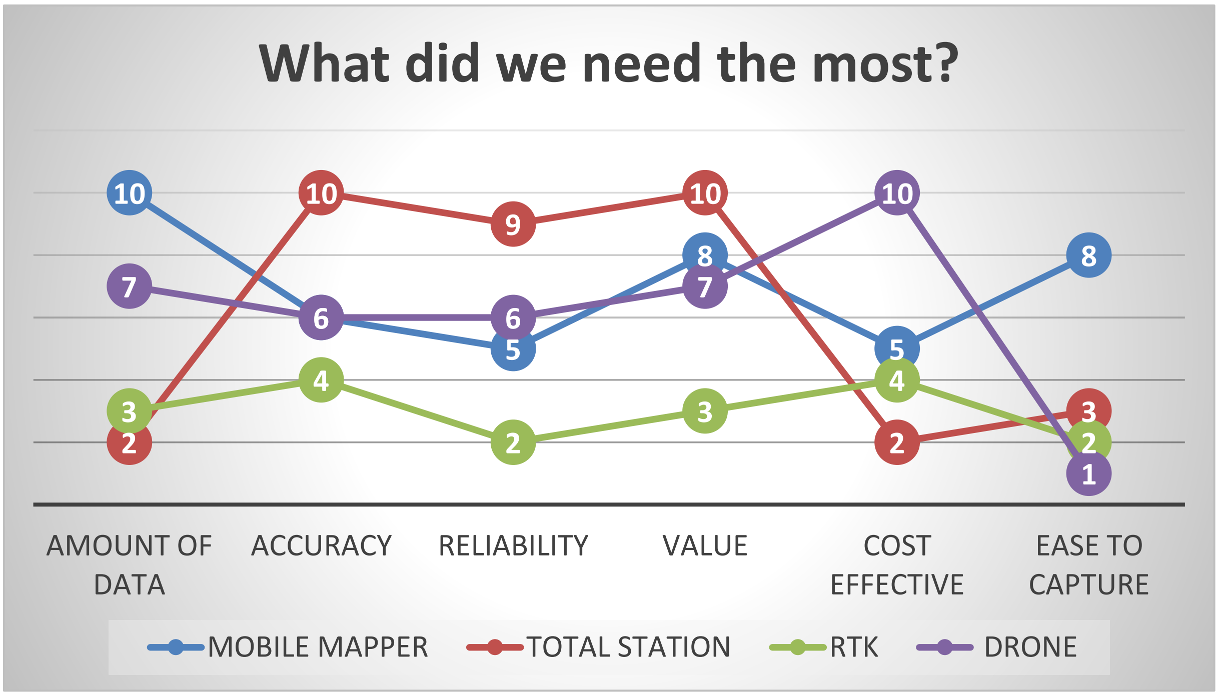
4.2 High data collectors accuracy:

4.2.1 We calculated the accuracy by the accuracy of the control points and measurements made to check points from the mobile mapper and laser

scanner and compared them with the data we collected using the TS from the control points.

4.2.2 We received a general accuracy of 8mm.

4.3 Cost efficiency report:



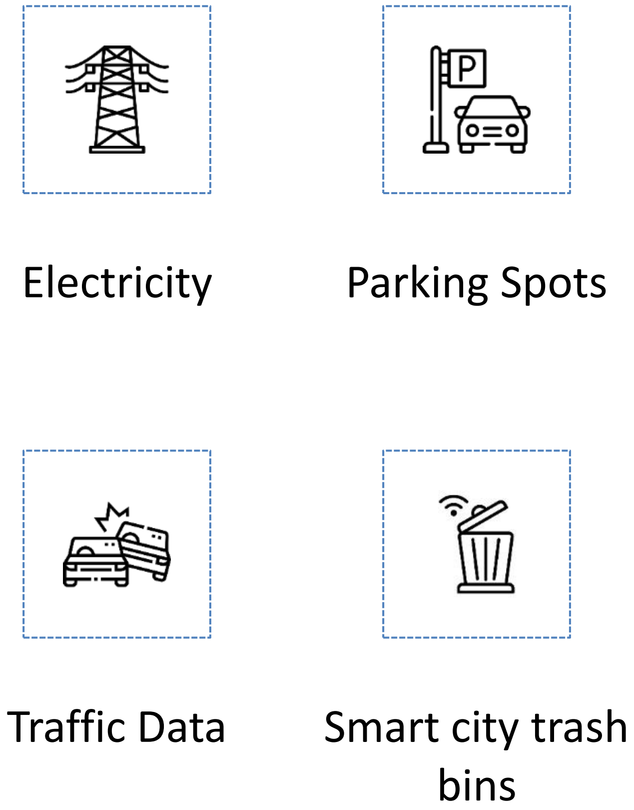
5 CONCLUSION

As expected all of the methods were used in this project while some were needed more than others; it can be seen that the need in strong foundation while keeping

the cost efficiency high using big data collectors was the optimal method of mapping at this scale

6 USE CASE FOR SMART CITIES

with the big amount of data collected the city used the maps and 3d mesh created models to install live sensors of the following utilities:



with this data and the 3d data of buildings, traffic lights streets and many more collected and analyzed by our engineers, the data manages to anticipate and act based on a real time feed of a 3d detailed 3d model.

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