Precise Monitoring of Horizontal Displacement of Large-Scale Buildings using Low-Cost Dual Frequency GNSS Receivers

Project Proposal and Plan

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Executive Summary

Maintenance of large-scale buildings plays a major role nowadays and monitoring them is an important step to combat disasters. Nowadays, in the building process constructors and company owners ask for sub-centimeter precise monitoring at cheap prices and get triggered when they see the bill. With a considerable increase in low-cost GNSS (Global Navigation Satellite System) receiver manufacturing, the interest on their potential remarkable-accurate positioning solutions got substantial. Particularly the new released affordable dual frequency GNSS receivers can be seen as a linking bridge between high accuracy and acceptable expenses since they are labeled as centimeter accuracy bidders. This additional thesis project proposes to evaluate the capability of such a device to monitor large-scale building infrastructure. The question to be answered is if dual frequency low-cost GNSS receivers can offer sub-centimeter accuracy when combined with adequate geodetic techniques?

With a good choice on high-accurate positioning technique together with an optimal static GNSS network set-up sub-centimeter positioning accuracy is expected. Moreover, if the new gadgets prove to be efficient findings on improvement of past encountered baseline (= GNSS reference station – monitoring receiver distance) and acquisition rate limitations are anticipated. Also valuable knowledge about an effective way to mitigate multipath effect is desirable, since this type of error is predominant when using affordable GNSS antennas for monitoring purposes. Therefore, research on the accuracy limitations of these new gadgets is of great interest since it can validate the past low-cost GNSS monitoring applications research and provide more information about the technical and economical reliability of dual frequency low-cost GNSS receivers for determining large scale building deformations for ensuring a safer environment.

1. Introduction

In a world where skyscrapers, major bridges and dikes are nowadays necessity, safety should play an important role in the development and maintenance of large-scale infrastructure. Until now the traditional geodetic GNSS receiver was the only high-accurate deformation monitoring alternative. But with the release of inexpensive dual frequency GNSS receivers a door opened to affordable and accurate monitoring possibilities.
The additional research project is proposing to evaluate the capabilities of the new-released dual frequency GNSS receivers to accurately determine the infrastructure dynamic response and deformation induced by natural disruptions. To these the main challenge is to set-up and evaluate a methodology which tests the capability of the new-released gadgets in such a way that they could beat centimeter level accuracy declared by the manufacturers[1] turning it into an relevant, reliable and ultra-performant displacement monitoring gadget for the geodetic industry. In order to achieve this a valuable set of steps for determining large infrastructure deformation with minimum costs should be defined while adding up to the past and present geodetic deformation analysis techniques.

The document describes the project planning needed for achieving the research goal as it follows. In the second section the concept of low-cost GNSS technology and its use for monitoring infrastructure is described as a summary from the existing scientific literature from where know-how information is collected. Further, in the next section the main research objective and the research questions are addressed. Here many sub-questions have the role of guiding the researcher to an appropriate answer to the main research question which should proof that the new positioning gadgets are useful for monitoring large scale buildings and prevent disasters under optimal costs. Furthermore, the proposed theoretical methodology is listed. Here the subject of interest is defined followed by the procedure of designing and implementation of a GNSS network for monitoring purposes. The chosen data acquisition method, data processing methods and validation procedures are one after the other described. In a nutshell this section contains the core of the proposal an defines a detailed plan on how to achieve the research goal. In the next section the proposed experimental setup is described. Five dual frequency receivers are chosen to be set on top of EWI (Faculty of Electrical Engineering, Mathematics and Computer Science) building, to record steadily for three days in order to detect the wind induced permanent horizontal displacement along with vibration magnitudes and directions. In the sixth section the expected results and their importance to the existing source of knowledge are discussed. It is believed that within three days there should be no permanent deformation, though internal vibrations might variate depending on the power of the windstorms. According to the referred studies this should be detectable when using the appropriate geodetic technique. In the seventh section the intended work is divided in six phases with five milestones to be accomplished. The schedule is also presented in form of a Gantt chart (see Appendix 1). In the last part of the project proposal conclusions, motivation and the long-term impact of the project on the body of knowledge are drawn. Dual frequency low-cost GNSS receivers feasibility and affordability can lead to many inventions which can ensure safety worldwide. This research project proposal aims to contribute to the past single frequency GNSS monitoring applications research and further prove the importance of reliable GNSS technology for mitigating disasters. Last but not least, a list of the most important sources of information for establishing this project proposal are listed in their order of appearance.

2. State-of-the-art/ Literature Review

Since now low-cost GNSS receivers were able to track only on one single frequency channel and most of the research done in this field is based on monitoring deformation applications using this type of technology. Such studies were mostly based on geodetic and geotechnical positioning techniques such as:

- Static relative positioning accompanied by short baseline post-processing in Post Processing Kinematic (PPK) mode [2, 3]. This procedure involves covering the case study building with many fixed GNSS receivers capturing GNSS satellite signals in form of code and carrier phase measurements which will be turned into every second position solutions with respect to a GNSS reference station via PPK processing mode. Although the receivers are not moving the PPK mode is beneficial since it computes positions at every second. This offers a good overview over possible position deviations indicating structural deformations. However, this technique can only return solutions after some time since the position processing happens after conducting the measurements. Such a technique is preferred to be utilized in carrying out the research described in this proposal.
- Virtual Station approach together with Network Real Time Kinematic (Network RTK) and relative positioning[4]. This technique uses a network of GNSS reference stations in order to virtually create a reference station close to the study area. Cina, A. and M. Piras explain that by virtually station creation one can understand that "the virtual station is not materialized, but its data are generated by the Network RTK in a known position defined by the user"(p. 499) [4]. This new reference station is transmitting position corrections to the remaining GNSS receivers which are operating as deformation monitoring rovers. By this the distance to the remaining rovers is kept minimal.
- Real-time processing of carrier phase measurements using a wireless sensor network technology[5]. In comparison with the previous preferred deformation sensing techniques this one offers the possibility to return position solution in near real time since the data is broadcasted and processed to a central computer. Moreover, in case of major deformations area, evacuation alarms can be conducted. For this a wireless sensor network, consisting of "GNSS receivers sensor field, master station or central computer, standard WLAN for communication, solar batteries with solar panels for power supply and proofed program tools" (p. 661)[5], needs to be integrated. This technique is taken into consideration in case of an extension of this research study as a master thesis subject.

Conclusions show that the old-fashioned receivers could sense sub-centimeter displacement, when long enough position outputs are averaged out and tracking conditions are optimal, which is sufficient for satisfying construction market and safety management requirements.
In order to get remarkable results almost all of the studies relay on base station - low cost rover correction transfer principle. From many research papers a collection of the most important factors -instrument set-up, acquisition rate, base station-rover distance and antenna choice-, which are influencing the accuracy of the estimates, can be summarized. Moreover, a large majority of studies label multipath[2], which is defined by Michael S. Braasch as "the phenomenon whereby the signal from a satellite arrives at the receiver via multiple paths due to reflection and diffraction, distorting the received signal and causing errors in code and carrier phase measurements." (p. 443) [6], as one of the most disruptive effects encountered when using affordable antennas for structural monitoring purposes. In the proposal of this research study all

these disruptive factors, focusing mainly on the multipath effect, will be taken into consideration in such a way that they will be critically evaluated and mitigated. With the appearance of dual frequency tracking technique atmospheric biases and multipath can be identified and reduced by means of establishing observation linear combinations of code and carrier phase measurements and/ or double difference observations ensuring very rapid high accuracy positioning for monitoring applications[4].
Moreover, the research project is focusing mainly on the first described positioning technique applied only on carrier phase observations in order to sense the dynamic behavior of a case study building. The second technique can be take into consideration as a form of validation together with the more frequently used validation method based on utilizing expensive geodetic antennas at the same time with the affordable dual frequency receivers. When combining the existing body of knowledge with the new-released low-cost GNSS receiver trial this additional thesis project proposal is aiming on making a optimal plan on testing the actual capabilities of the new released receivers for infrastructure monitoring and proposing a stable step-by-step algorithm and mission design striving for high accuracy results. Furthermore, it is expected that besides the main goal, valuable knowledge should be accounted to past research done in this field which could be useful for the improvement and mitigation of encountered single frequency positioning limitation factors described above.

3. Research Question, Aim/Objectives and Sub-goals

Summing up, the research objective of the additional thesis project is to design and apply a low-cost GNSS building deformation mission in order to test the actual accuracy capabilities of the new released receivers to sense the structural influence of natural disruptive factors (s.a wind) on a tall building by establishing an optimal network emplacement of the GNSS receivers, acquiring dual frequency code and carrier phase observations and computing relative horizontal positions and accuracy estimates (using only on carrier phase data) based on statistical approaches.

In order to achieve this a set of guiding sub-questions and a general question is addressed. The general question to be answered in this research project is:

- What is the accuracy potential offered by a dual frequency GNSS receiver for monitoring large-scale building dynamic behavior and permanent deformation?

In order to come up with an answer several sub-questions are to be taken into consideration. These are the following:

- Why is it important to monitor the behavior of a building?
- What are the most influential deformation factors?
- To what type of deformations are we looking at?
- What are the main steps in determining the deformation of a building by means of using low-cost GNSS technology?
- How to identify periodic effects and natural disrupting factors influencing the GNSS position estimates?
- How can the empirical accuracy of the estimates be determined?
- What is the reference (“ground truth”) of the estimated position residuals?
- What is the accuracy limitation to strive for when studying large scale infrastructure deformation?

- How significant is multipath effect for the horizontal position estimates and how can it be mitigated?
- Are the results enough accurate?
- What is the optimal positioning method and instrument set-up to be implemented?

By answering all the addressed questions the research project aims to provide information about the technical reliability of dual frequency low-cost GNSS receivers for determining large scale building static deformations and dynamic vibrations.

The provided knowledge can also bring economic benefits to private company owners and survey conductors since with successful implementation the execution cost of the survey and instrument cost should considerably decrease. Moreover, GNSS receiver manufacturers will get to know the limitations of their product. A possible positive correlation between economic and technical reliability (positioning accuracy) of the new released gadgets can lead also to many other inventions since receivers will become handy to a large mass of users. But most important is that the usefulness of the gained knowledge can be exploited in order to ensure safety on large scale buildings.

To sum up, the motivation in pursuing this research is to contribute to the past single frequency GNSS monitoring applications research and further prove the relevance of affordable GNSS instruments in maintaining a safety environment. Since the new dual frequency receivers are affordable, positive results might give access to qualified people to contribute to a safer world.

4. Theoretical Content/ Methodology

The framework to be followed bases on a study of the existing GNSS positioning techniques, mass-market GNSS receiver offers and recent research in the field of building deformation monitoring using low-cost GNSS equipment. These yields an optimal experiment set-up and deformation analysis by means of which the accuracy capability of the new released affordable dual frequency GNSS receivers can be tested. The results should conclude on the accuracy potential of the new mass-market GNSS receivers on sensing infrastructure static and dynamic behavior leading to temporarily or even permanent deformation.

In order to answer all the questions listed in the previous section and achieve the research objective a set of steps need to be implemented. First of all, it is known that tall building structural behavior is mostly influenced by windstorms. Therefore, one needs to define the deformation types of interest in this research project. Since wind causes internal vibrations to tall structures, the dynamic behavior of tall buildings during windstorms is set to be subject of interest. Furthermore, any provisory and/or permanent horizontal displacements caused by wind together with their order of magnitude and direction are subject of interest.

Once the subject of interest is set, based on a thorough literature study a set of useful tools and steps for estimating high accurate GNSS positions need to be defined. A static GNSS receiver network of five u-blox ZED-F9P[1] dual frequency low-cost GNSS receivers is set to be mounted on the roof of a tall building which will acquire 10 Hz code and carrier phase double frequency measurements for at least three days. Stable weather for at least one day is mandatory in order to define the "ground truth" deformation reference for the desired horizontal position and residual

[1] https://www.u-blox.com/en/product/zed-f9p-module

estimates. During the remaining days severe weather conditions are expected in order to estimate the actual influence of wind on the tall structure. Moreover, for setting-up an optimal network in order to sense the maximum amplitude of the wind signal, past meteorological data such as wind speed (magnitude) and wind direction can be used for decision making. Such data should be also gathered during the measurement campaign and used for identifying any correlation patterns between building response and windstorms.

In the vicinity of the new established GNSS network, a permanent GNSS station is needed in order to transfer corrections to the receivers for mitigating atmospheric errors and improving the accuracy of the position estimates of the low-cost receivers. The network will be linked to the permanent station in the post-processing phase by means of Post Processing Kinematic (PPK) measurement processing mode. But before post-processing the observations, a filtering step needs to be carried out. Since the measurements can be affected by, ionosphere (caused by ions in the atmosphere) and troposphere delays (caused by dry gases and water vapor in the atmosphere, appears also for a large height difference between permanent station and GNSS monitoring network), multipath effect (caused by nearby obstacles) or cycle slips (caused by signal interruptions), these need to be identified and mitigated. For these time series, carrier phase double differencing and linear combinations of different types of observations can be used. With a clear view over the actual accuracy of the raw data and a filtered version of it, the carrier phase dataset can be post-processed in order to retrieve accurate 2D relative positions of the receivers every 1/10 of a second. The resulting position estimates will be further analyzed using time series analysis in order to identify and label the displacement induced by windstorms.

The estimated 2D positions can be verified by mounting a geodetic antenna to one of the low-cost receivers and determine the position at the same time with the rest of the low-cost GNSS network. Another validation possibility of the 2D relative position estimates is to use the virtual station approach described in Literature Review section. By this a close virtual reference station can be created and used for determining 2D relative positions of the dual frequency receivers. Due to lack of time the validation procedure will not be implemented in this additional thesis project but could be considered in the future as part of the graduation project.

From the literature study, there are several techniques to identify the periodic effects induced by wind to the building position. Harmonic analysis or least squares harmonic estimation are two possibilities to identify periodic effects in the GNSS position time series[2]. These also need to be quantified in terms of maximal amplitude and occurring frequency. These results can be verified by looking at the power spectra plots of each receiver during the same epoch and by identifying the same harmonic pattern. Also the building vibration analysis will be considered only if time allows. But for sure it will be considered as primary research step in case of implementing a real-time alarm triggering GNSS deformation monitoring system as part of the graduation project.

In order to get close to answer the main research question, the empirical accuracy of the 2D positions need to be estimated in order to prove the deformation sensing capability of the dual frequency low-cost GNSS receivers. This will be done using the least squares estimation theory on behalf of which the relative position estimation was also done. The position accuracy estimates are compared with the proposed campaign accuracy limitation to check if the results are within declared tolerance.

In the end, since for such accuracy-pretentious applications sub-centimeter positioning accuracy is needed, a conclusion on the positioning accuracy potential of the dual frequency low-cost GNSS receivers can be drawn. Based on the resulting conclusions a step-by-step high accuracy dual frequency low-cost GNSS receiver positioning algorithm together with further recommendations on future possibility of designing and implementing a real-time alarm triggering GNSS deformation monitoring system can be proposed.

5. Experimental Set-up

From the practical point of view the project is set-up to take place over two and a half months. It is plausible that the GNSS network, measurements and analysis can be done within the time set by taking into consideration only a limited amount of measurements epochs (s.a at least three days with extremely bad meteorological conditions). Necessary materials (s.a five u-blox ZED-F9P dual frequency low-cost GNSS receivers, five low-cost external antennas, 1 permanent GNSS station, data logging equipment, power supply, waterproof housing, wind speed and wind direction measurements etc..) and knowledge to carry out this study are provided by professors of the Geoscience and Remote Sensing department of TU Delft and by the student who is pursuing this research.

More in detail, a thorough discussion with professors of the structural engineering TU Delft department and meteorological datasets can be used in order to create an emplacement plan and optimally set-up a low-cost static dual frequency GNSS network on the roof of EWI building situated in Delft, the Netherlands. The network will be continuously plugged in for at least three days and acquire code and carrier phase measurements every 1/10 of a second. The carrier phase data will be later post-processed using PPK mode in order to estimate the relative position of the GNSS receivers with respect to a relatively close (approximatively 2 km away) permanent reference GNSS station (GNSS observatory of Delft University of Technology). Active natural disruptive factors are necessary during the measuring campaign.

Since most of the commercial softwares work as black boxes, not showing if they take into account on multipath, ionosphere and troposphere delay effects, the accuracy estimation cannot be entirely trusted. Therefore, in order to offer the most accurate results, the quality of the raw carrier phase GNSS measurements need to be manually checked[2]. If such disruptive effects are identified they need to be eliminated or mitigated before using any commercial software package. In this case study multipath effect is expected to influence and harm the GNSS signal. This vicious effect will be identified and mitigated from both captured GNSS frequencies using the carrier phase double difference residuals method described by P. F de Bakker, H. v.d Marel and C. C. J. M. Tiberius. This method proposes to form double difference carrier phase (DD) observations and fit a low-order polynomial through them which needs to be subtracted from the DD observations in order to eliminate the low frequency erroneous behavior and the geometric part of both captured GNSS signals remaining with the carrier phase random noise and multipath. [7] By these the carrier phase multipath can be estimated and reduced when subtracted from the DD observations. The preprocessing will be done using Matlab software and Matlab functions provided by professors of Geoscience and Remote Sensing Department. Linear combination, double differencing, time series and harmonic analyses are pre-processing techniques which need to be taken into consideration. After obtaining a filtered dataset, the post-processing step will be done using a commercial GNSS processing software, RTKLIB, to fix the phase ambiguities[8] and estimate the most accurate position of the building and its linked accuracy.

Furthermore, a timeseries analysis will be performed in order to detect possible permanent horizontal displacements of the building induced by wind. Subject of interest is also the order of magnitude and direction of the possible permanent displacements. If time allows spectral domain analysis will be used for quantifying wind induced vibrations which can cause severe deformation to the case study building. If any deformation is found it will be quantified and labeled on how critical it could be for the structural integrity of the building and how accurate it was estimated. In the end a step-by-step algorithm will be presented and a conclusion on the accuracy potential of the new mass-market GNSS receivers will be drawn.

6. Results, Outcome and Relevance

The primary data used for conducting this study are 10 Hz carrier phase measurements which need to be processed in order to compute 2D relative positions of the GNSS receivers along wind affected building facades. To be mentioned is that the carrier phase measurements are ambiguous. Therefore, for obtaining sub-centimeter accurate positions an important parameter to be resolved are the ambiguities. This step takes place during the relative position estimation procedure. After this a time series of filtered 2D positions and a spectral domain analysis will be conducted in order detect wind induced permanent displacements and vibrations which can cause severe deformation to the case study building.

It is expected that over a short time period (three days only) the horizontal position of the building would not be permanently affected by wind induced vibrations. Therefore, no major horizontal deformation is expected. On the other hand, powerful wind vibrations are subject of detection. Since it is known that single frequency receivers are capable of returning positions with sub-centimeter accuracy there is no doubt that the new dual frequency receivers would not perform similar or even better than their predecessors. In such case powerful windstorm effects on tall buildings should be easily detectable with mass marked dual frequency receivers. Moreover, the price to pay for the affordability of the new gadgets is that, because of their components design, they are hardly affected by a multitude of factors. Since the case study building is mainly build out of glass and metal signal refraction is expected. Therefore, the multipath effect is expected to be substantial knowing that low-cost GNSS systems do not contain choke ring antennas which are ideally designed to mitigate multipath effect.

In order to prove the reliability of the method rigorous validation needs to be conducted. This can be done in two ways. Firstly, by linking a precise geodetic antenna to one of the five receivers. In this way the deformation analysis results of the remaining four GNSS receivers with low-cost antennas can be compared to the results obtained with the expensive and precise antenna. The second option is by implementing a virtual station as described in Section 2 and 4. This step will not be considered part during the additional thesis project but should be taken into consideration in case of extending this research topic as a graduation project.

If one is correcting for all disruptive factors presented in Section 4 there are high chances to accurately sense intensive vibrations of the case study building and come up with the conclusion that the accuracy potential of the new mass-market GNSS receivers is sufficient for conducting a deformation study and monitor the dynamic response of tall buildings caused by natural disruptive factors.

7. Project Planning and Gantt Chart

The project planning is summarized in the Gantt chart displayed in Appendix 1. Each phase (see Appendix 1 - horizontal dark grey arrow) and milestone (see Appendix 1 - dark flag) is presented below:

- *Literature & Instruments Manual study*: 12 days are allocated for gaining the necessary knowledge for pursuing the project. This comprises of thorough literature study to understand the current state of research in this activity domain. In addition, during this period the instrument manipulation and installation procedure will be presented. Right after four days are allocated for conducting some simple 10 Hz GNSS data gathering tests in TU Delft's campus. Although this phase is presented in the Gantt chart it is not officially taken into consideration as part of the additional thesis project and will be accomplished before the Kick-off meeting. During this period it is necessary to keep track on time since the literature study will take place during first quarter of the academic year together with other subjects.
- *Measurements & Data*: This phase starts with the Kick-off meeting where the project plan is discussed in order to validate and improve it. 6 days are scheduled for terrain inspection, software acquisition & installation, measuring campaign and data management. After collecting the data it is mandatory to convert it to an universal format called RINEX (Receiver Independent Exchange Format) which is needed to load the raw measurements in the used softwares (RTKLib, Matlab).
  At the end of this phase a first discussion, Data Management Discussion Meeting, is planed where the current progress and future data handling procedure is discussed.
- *Data Processing & Results*: This is the longest (15 days) phase of the project where raw data needs to be cleaned from possible perturbing effects. After eliminating these effects from the raw data, results need to be discussed and approved by the coordinator before every 1/10 of a second 2D coordinates will be computed via PPK. Last but not least, the accuracy and the horizontal coordinates are computed and inventoried in a table and as time series plots.
- *Deformation Analysis*: For the most important part of the project 14 days are scheduled. A time series and spectral domain analysis (if time allows) on the resulting horizontal coordinates is needed to identify and monitor the possible response of the tall building to windstorms (for a detailed description see Section 4 and 5). Since this phase is seen as the most complicated part of the project a Questions meeting is planed where the followed analysis procedure will be discussed. At the end of this phase a conclusion on the possible movement of the building and the capability of the low-cost dual frequency GNSS receivers to sense it need to be drawn.
- *Winter Break*: Winter vacation is also taken into consideration. For 12 days the work will be temporarily on hold until 6th of January 2020.
- *Developing Theory*: During the last phase of the project a scientific report containing the used theoretical knowledge, literature review, practical experience, deformation analysis and accuracy results will be drafted. Based on the results in the report a step-by-step algorithm for efficiently monitoring tall structures using low-cost dual frequency GNSS receivers will be proposed. Recommendations on how to deploy such a geodetic campaign will also be presented at the end of the report which needs to be hand in and

graded by the project supervisor and an additional professor as form of completion of the additional thesis project.

Without taking into consideration the winter break the project is set to last 63 days, approximatively two and a half months, over the last part of the first academic quarter and the entire second quarter.

8. Conclusions

To sum up, this additional thesis project proposal aims to come up with a conclusion on the accuracy capability of new released low-cost dual frequency GNSS receivers to monitor large-scale building infrastructure. Next to this, the project proposal offers a clear and detailed strategy on how to design and deploy a low-cost GNSS receiver deformation monitoring mission, asking for a step-by-step precise monitoring algorithm. For this the main challenge is to evaluate a methodology for testing the accuracy of the low-cost dual frequency GNSS receivers to determine the dynamic response of tall buildings on natural perturbators.

If the accuracy limitations of these new gadgets turn to be under centimeter level the impact of the concluded knowledge can validate the past low-cost GNSS monitoring applications research and provide more information about the technical and economical reliability of dual frequency low-cost GNSS receivers for determining large scale building deformations. Furthermore, if these gadgets turn to be economically and technically feasible this can lead also to many other inventions since receivers will become handy to a large mass of users. Therefore, the usefulness of the gained knowledge is essential and can be exploited in order to ensure structural integrity of large scale buildings worldwide.

In conclusion, there is a high motivation in pursuing this project in order to prove the importance of reliable GNSS instruments for maintaining a safety environment.

9. References

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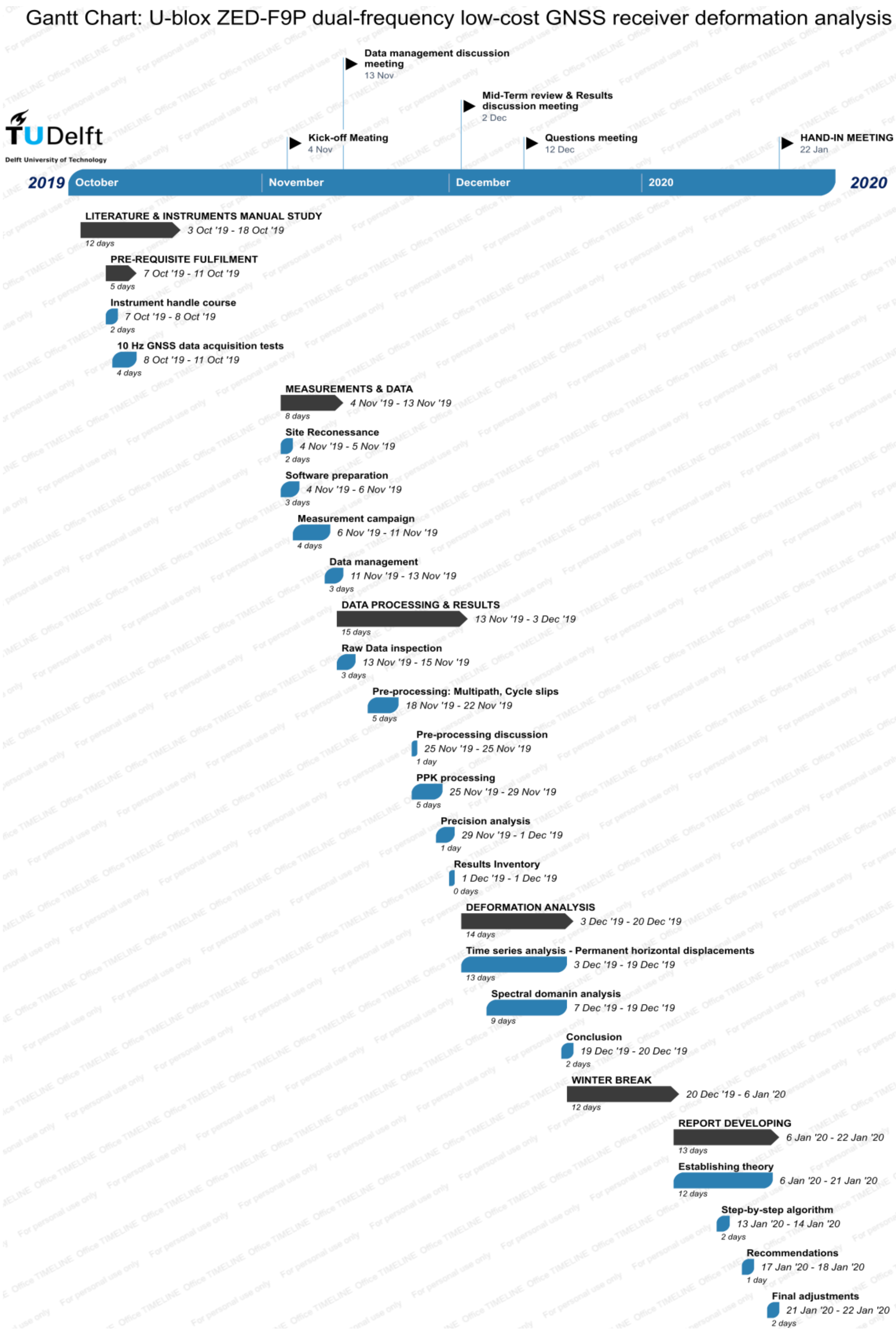
Appendix 1


Gantt Chart: U-blox ZED-F9P dual-frequency low-cost GNSS receiver deformation analysis
Data management discussion meeting
13 Nov
Mid-Term review & Results discussion meeting
2 Dec
TUDelft
Delft University of Technology
Kick-off Meating
4 Nov
Questions meeting
12 Dec
HAND-IN MEETING
22 Jan
2019
October
November
December
2020
2020
LITERATURE & INSTRUMENTS MANUAL STUDY
3 Oct '19 - 18 Oct '19
12 days
PRE-REQUISITE FULFILMENT
7 Oct '19 - 11 Oct '19
5 days
Instrument handle course
7 Oct '19 - 8 Oct '19
2 days
10 Hz GNSS data acquisition tests
8 Oct '19 - 11 Oct '19
4 days
MEASUREMENTS & DATA
4 Nov '19 - 13 Nov '19
8 days
Site Reconessance
4 Nov '19 - 5 Nov '19
2 days
Software preparation
4 Nov '19 - 6 Nov '19
3 days
Measurement campaign
6 Nov '19 - 11 Nov '19
4 days
Data management
11 Nov '19 - 13 Nov '19
3 days
DATA PROCESSING & RESULTS
13 Nov '19 - 3 Dec '19
15 days
Raw Data inspection
13 Nov '19 - 15 Nov '19
3 days
Pre-processing: Multipath, Cycle slips
18 Nov '19 - 22 Nov '19
5 days
Pre-processing discussion
25 Nov '19 - 25 Nov '19
1 day
PPK processing
25 Nov '19 - 29 Nov '19
5 days
Precision analysis
29 Nov '19 - 1 Dec '19
1 day
Results Inventory
1 Dec '19 - 1 Dec '19
0 days
DEFORMATION ANALYSIS
3 Dec '19 - 20 Dec '19
14 days
Time series analysis - Permanent horizontal displacements
3 Dec '19 - 19 Dec '19
13 days
Spectral domanin analysis
7 Dec '19 - 19 Dec '19
9 days
Conclusion
19 Dec '19 - 20 Dec '19
2 days
WINTER BREAK
20 Dec '19 - 6 Jan '20
12 days
REPORT DEVELOPING
6 Jan '20 - 22 Jan '20
13 days
Establishing theory
6 Jan '20 - 21 Jan '20
12 days
Step-by-step algorithm
13 Jan '20 - 14 Jan '20
2 days
Recommendations
17 Jan '20 - 18 Jan '20
1 day
Final adjustments
21 Jan '20 - 22 Jan '20
2 days