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Abstract

Preface

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Chapter 1

Introduction

This chapter the background and motivation to why this project thesis has been written. Also reference to privios work, the goal of the thesis and the layout.

1.1 Background and motivation

Why is the project thesis relevant: Installing better GPS to enable better hight estimation

What have I done? Integrated new GPS with DUNE

What is next? Land the UAV. Test algorthm to Frølich, better state estimation

Unmanned aerial vehicles have in seen an increase usage in the civilian sector on land, where they can be used at a cheaper price then manned aircraft. However this has not yet been the case in the civil maritime sector, due to a harsher environment and smaller landing areas.

A UAV can increase performance in many maritime operation where today only other manned aircraft or satellites are the only solution. In the maritime sector they can be used in iceberg management, monitoring of oil spills, search and rescue and maritime traffic monitoring. To enable a safe UAV operation at sea there must be a system in place to ensure a safe landing.

There exist landing system that can guide the UAV towards a net, but they are expensive and restricted to a few UAVs. A pilot could always land the UAV, but it would be better if the UAV could hit the net by it self. In order to make the UAV able to perform a automatic landing the minimum requirement is that it know where it is at all time. This put a requirement of the position sensor. The position system need to combine low cost with high position accuracy. This thesis will test a new generation of GNSS receiver, and use GPS to find the position to the UAV. The demand on the accuracy is that the error must be in decimetres to ensure safe landing in the net.

A automatic landing system must include a path planner, guidance system and a accurate position estimation system, in addition to the low level control system in the UAV. A path planner and guidance system were created in a master thesis at the uavlab by Marcus Frølich. The gudiance system is currently under further development in two project thesis. A position system was created by Bjørn Spockeli, but it concluded that the GNSS receiver used were insufficient to perform automatic landing. This thesis will continue the research done by Spockeli, and introduce a new GNSS receiver that will be used with the open source program, rtklib. The motivation is to have a system with accurate local position estimate, such that in the future a landing can be performed automatic. The automatic landing system will use RTK GPS for position estimation. Motivation for work: Autonomos landing. Required accurate posisioning system, a feasable path, tuned guidence system, robust lav nivå kontroll. Include a system figure can give the reader information on how the autolanding system should work, and why this thesis is relevant.

1.2 Previous work

Citation checking [Frølich, 2015, Spockeli, 2015] or Frølich [2015], Spockeli [2015] or Frølich [2015], Spockeli [2015]

GNSS navigation has been

The uavlab at NTNU has in the last year studied how to perform a autonomous landing with a fixed wing UAV. Automatic landing of a UAV in a net using low-cost single frequency gps is described in [Skulstad and Syversen, 2014], and a path generation system that is integraded with neptus is described in [Frølich, 2015]. Research on RTK GPS intergration in Dune is described in [Spockeli, 2015].

Work done on ambiguity Blewitt [1989], P.J.G Teunissen and Tiberius [1995], Teunissen [1994, 1995] Work done with rtk gps [Stempfhuber and Buchholz, 2011] [Stempfhuber, 2013]

Work done in the UAVLab on automatic landing. The other master thesis on landing using visual assist. Other method that has been applied.

Work done in the rtk gps field conserning automatic systems.

Previous work in the field of ambiguity resolution, rtk gnss, auto landing with fixed wing drone without ground assist.

The work done by Frølich on simulation of a net landing. Work done by Spockeli. Need other research field. GPS navigation is a well researched field. Relevant to this task is landing with gps, or high accurate position estimation.

Other master thesis, paper on visual aid landing system. Frølich did the same research, using reasearch from Spocli.

1.3 Goal of thesis

The goal of this thesis is to test the ublox-LEA M8T GNSS receiver in a real time differential GNSS setting. The RTK GNSS solution will be calculated with the open source program rtklib, which will communicate with a task in DUNE. The solution from rtklib will be compared against the solution from Piksi, and a post prosesed solution from rtklib. The result from the experiment will be used in the discusion on how to perform a autonomous landing.

Table 1.3 summaries the goal with this project thesis.

- Install the Ublox Lea M8T on the base station and x8
- Configure rtklib to calculate the relative position of the x8 in relation to the base station
- Make Dune able to receive the output stream from rtklib, and support a new imc message that contain the relative position of the x8
- Test and compare the Ublox receiver against the pixi(TRENGER MODEL NAVN) receiver

Install new GPS receiver on the x8 and base station. Test and compare to the pixi gps that is the standard solution i the uavlab. Evaluate if the new gps is good enough to enable automatic landing Install new GPS reciver with higher accuracy to enable automatic landing

1.4 System layout

How the landing can be performed. A operator send a landing request from Neptus to dune. The path generation task generate waypoints in both local and global frame. The global waypoints are return to Neptus to show the operator were the planed path is. The local waypoints are given to a guidance system. The guidance system only requrier the local position, which it will receive from a rtk GNSS task. The rtk GNSS task is required to send both the local position and the global. The global position will be calculated as an offset from the base station location. The local position is the relative position of the UAV with respect to the base station.

Include a figure that show how the full system will look like

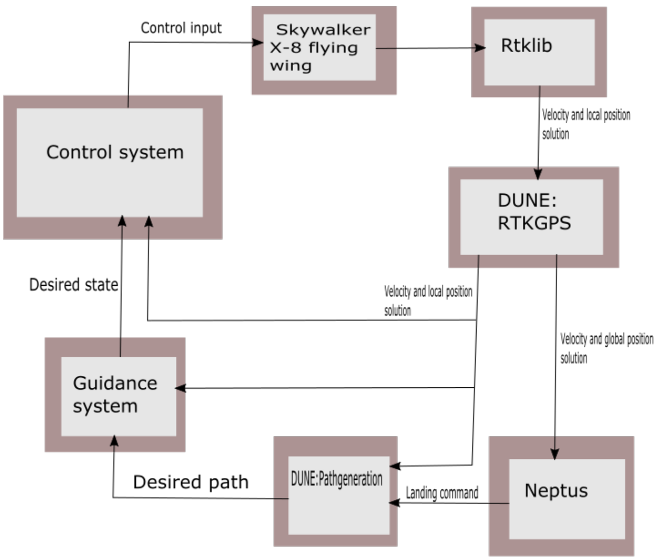

Figure 1.1: The structure of the autonomos landing system

The current state of the system is that there has been done research on all of the module in different master and project thesis. However there has not been done a physical experiment with the DUNE version of the system.

1.5 Layout of thesis

Chapter 1 Intro Chapter 2 Theory about coordinate system Chapter 3 Theory about GNSS system with focus on the GPS Chapter 4 Hardware and software Chapter 5 Test and result Chapter 6 Conclusion, discussion and further work

Chapter 2

Coordinate systems

This chapter will give an overview over different coordinate system and the relationship between them. A coordinate system is used to define a position relative to a origin. The choice of coordinate system is critical when describing the equation of motion. Newtons first law only apply when the origin is viewed as an inertial frame. When navigating on/or close to the surface there are two convension used; ENU and NED. Both the ENU and NED system is defines relative to the center of the Earth.

Write about the long lat system and the WGS 84, the ellipsoid and geosomething

2.1 ECEF

The Earth Centered, Earth Fixed coordinate system is defined in the center of the Earth with it's x-axis point toward the intersection between the Greenwich meridian and Equator (0 deg longitude, 0 deg latitude). The z-axis points along the Earth's rotational axis, and the y-axis complete the right handed orthogonal coordinate system. The ECEF system can be represented in either Cartesian coordinates (xyz) or ellipsoidal coordinates (longitude, latitude and height).

2.2 Ellipsoid

How the the Earth ellipsoid defined. Advantages and disadvantages. What most be considered when estimating altitude. The difference between the ellipsoid and geoid. The geoid follows the curvature of the Earth. When flying perpenticular to the geoid there will be an angle between the normal from the geoid and the normal from the ellipsoid.

2.3 NED and ENU

The North East Down frame and East North Up frame. See at lab assignment in gps. Defined tangential to the Earth ellipsoid. The ellipsoid that is currently used is the WGS-84 ellipsoid. The WGS-84 ellipsoid ... how it's defined, why used then refer Different orientation

Chapter 3

Real time kinematic GNSS

This chapter outline the basic of the GPS signal. how RTKGPS works. It's assumed that the reader is familiar with how a single GPS receiver works. The first section give a brief summary on what differential GPS is, and how that principle is applied in RTK-GPS. The two following sections is directly used in RKT-GPS(maybe write some more). The last section give a quick overview over the error sources that effect the measurement.

The term rover and base station will be used when referencing two or more receivers. The term base station means a receiver that is assumed to have a known position by the other receivers. The term rover means a receiver that is allowed to move, is the main focus for position estimation.

A short description of GPS signals and error sources. How to find the Ambiguity resolution and why it's important. What is differential gps, and why use RTK-GPS.

3.1 GNSS constelations

The two main GNSS constelation is operation today is GPS and Glonass.

3.2 GPS signals

GPS uses the signals L1 and L2 to calculate the receiver position, with the L5 signal soon fully available. More detailed information about the GPS signals can be found in Misra and Enge [2011]

The position is calculated from the pseudorange to each satellite that the receiver is tracking. The two basic ways to measure the psedurange is code and phase measurement. Phase measurement is the most accurate of the two, bu also least reliable.

The receiver needs at least four satellite to be able to estimate the receiver position. Three of the satellite is used for the position, and the fourth if used to calculate the receiver clock bias.

What is needed:

Carrier frequencies?

Code and phase measurements: Phase measurement is a must due to the ambiguity resolution

For position estimation purpose there are two signals mainly available, $L1$ and $L2$. A third signal,$L5$, has recently been introduce, but since the service is not fully operational it will not be covered in this thesis. The signal structure form GPS is written:

$$\begin{aligned}
L_1(t) &= A_1 p(t) d(t) \cos(f_1 t) + A_1 c(t) d(t) \sin(f_1 t) \\
L_2(t) &= A_2 p(t) d(t) \cos(f_2 t)
\end{aligned}$$

The carrier frequencies for the L_1 and L_2 signal are

$$\begin{aligned}
f_1 &= 1575.42 MHz \\
f_2 &= 1227.60 MHz
\end{aligned}$$

A_1 and A_2 are the signal amplitude, and $c(t)$ and $p(t)$ are the Pseudo Random Noise, where $c(t)$ is sequences modulated into the L_1 signal and $p(t)$ into both the L_1 and L_2 signals.

Could tell what c(t) and p(t) is, and what is known about them. Also the strength of A1 and A2. How the psudorange is not important for this thesis.

What is important:

Have done: Setting up the new GPS in the base station and in x8. Need to explain how rtklib work, and what is RTKGPS. Also need to talk about Ublox LEA M8T. It's here the talk about L1 becomes relevant. Maybe talk about the coordinate frame. Why use NED/ENU with base-station as fixed frame. The configuration of the GPS (elvation mask, kalman filter, search algortihm). Think I must remove the path theory chapter. Insert a theory chapter about coordinate frames. Maybe a chapter about Kalman filtering.

3.3 Error sources

In order to get high accuracy in the position estimation the different error sources must be identified and removed if possible. This section will identify some of the larger error souces that can affect the gps signal, and how to remove them in the estimation. Link the error source to where they originate

3.3.1 Clock error

There is drift in both the satellite clock and the receiver clock. The atomic in the satellites makes the clock drift neglable from the user perspective. The receiver clock tend to drift, and if not taken into account will cause large deviations in the position estimate from the true position. This error is remove by including a fourth satellite in the position computation. The satellite clock drift is smaller, because the clock is an atomic clock. The receiver clock error can be relative large. The satellite clock error given in the satellite message.

Relative time different

3.3.2 Ionospheric and Trophospheric Delays

Effect of signals travelling through the atmosphere. Free electrons from ultraviolet rays ionize a portion of gas molecules. These influence electromagnetic wave propagation.

Ionospheric delay

Gas molecules in the ionosphere becomes ionized by the ultraviolet rays that is emitted by the sun, which release free electrons. These electron can influence electromagnetic wave propagation, such as GNSS signals. The delay that the single get from the ionosphere may cause a error the the order of $1 - 10 meters$. The error can be mitigated by using a double frequency receiver, or by applying a mathematical model to estimate the delay. Both those cases is with a single receiver, but by having a second receiver the GNSS solution system can assume that both receiver receive signal in the same epoch, which means that the signals have experienced the same delay. More on this in section 3.4.2.

Tropospheric delay

The tropospheric delay is a function of the local temperature, pressure and relative humidity. The delay can vary from 2.4meters to 25 meters depending on the elevation angle of the satellites. The error can be mitigated by applying a mathematical model to estimate the tropospheric delay, and by using a elevation mask can remove all satellites with a elevation angle bellow a certain threshold. Error caused by tropospheric delay can be removed in the same manners as ionospheric delay when using two or more receivers. More on this in section 3.4.2.

3.3.3 Ephemeris Errors

Error from satellites out of position. Cannot be corrected locally, but are maintained by someone.

3.3.4 Multipath

One of the primary source of error in in a GNSS receiver is multipath. Multipath happens when the satellite signal is reflected by a nearby surface before if reach the antenna. The delay introduced in the signal can make the receiver believe that its position is several meters away form its true position. The easiest way to mitigated multipath is to place the antenna at a location with open skies, and not tall structures nearby.

3.4 Differential GPS

Differential GPS consist of at least two receivers, where one is called a base station and the rest rovers. The two receivers are within range of a communication channel over which they are communicating. There are two basic ways to implement DGPS. There is the position-space method and the range-space method. Only the latter will be covered in this thesis.

3.4.1 Interger Ambiguity Resolution

The integer ambiguity is the uncertainty of phase cycles between the receiver and the satellites.

There are several strategies on how to resolve the integer ambiguity. A well used strategy is the LAMBDA method. LAMBDA starts by reducing the integer search space by decorrelation adjustment. Fixed and Float Interger Amiguity is used to calculate the carrier phase

$$\phi(t) = \phi_u(t) - \phi^s(t - \tau) + N \tag{3.1}$$

Counting the periods from

Write about how the different strategies work

3.4.2 Error mitigation in DGPS

The advantage with DGPS is that two or more receivers can share the same error sources. This enable the solution system almost completely remove them. In the case of a moving baseline situation the GNSS system assumes that the rover is close enough to the base station such that they shear the same atmospheric conditions. If this assumption holds the system should be able to almost remove the error caused by atmospheric delay.

3.4.3 RTK GPS

RTK GPS scarifies correctness in order to give a position estimate in real-time. ADD HERE RESEARCH IN THE RTK FIELD. Real time position is critical for a autonomous system to navigate to a given position.

PASS PÅ FOR Å GÅ INNOM SYSTEM SPEC. KUN TEORI OM RTK GPS Dynamic system can be solved in kinematic mode, or with a moving baseline. In kinematic mode the rover is allowed to move, but the base station is assumed stationary with a known position. In the case of a moving baseline both the rover and base station is allowed to move. The position of the base station is calculated in single mode. Without a known position of the base station the global position of the rover can never be better then if calculated in single mode. However the relative position of the rover from the base station is calculate accurately. There for from a local control systems per Need to write about baseline restrictions. In the case of this thesis is a moving baseline relevant.

Trade off between getting the position fast, and getting it right

Moving baseline restrictions. The base stations position is calculated with in single mode. The error in position to the base station is inherit by the rover. Source of error.

3.5 Interger Ambiguity Resolution

3.5.1 Search space minimization strategies

There are several search techniques that can be applied to resolve the integer ambiguity, but this section will only cover the "Least Square Ambiguity Decorrelation Adjustment" (LAMBDA) method which is the technique used in rtklib.

Chapter 4

System Components

This chapter contains a brief description of the system that has been used.

4.1 Software

This section contain the different software that is used in the x8 system. The control and guidance system is runs on Dune, and the missionplaner on Neptus. The x8 operation system is GLUED. The system is connected to the rtklib which is in communication with DUNE. The internal communication in DUNE is based on IMC messages

4.1.1 GLUED

Glued is a minimal Linux distribution developed by LSTS, and design with embedded system in mind. It is platform independent, easy to configure and contain only the necessary packages to run on a embedded system. This makes GLUED a light and fast distribution. GLUED is configured through a single configuration file that which can be created for a specific system.

4.1.2 Dune

Dune is a runtime environment for unmanned systems on-board software created by LSTS (Underwater Systems and Technology Laboratory) in Porto, Portugal. The environment type is called a middleware, which is seeing increase usage in unmanned systems. Can refer to ROS or MOOS middleware.

Dune works by setting up individual task that can dispatch and subscribe to different IMC messages. The IMC messages will be explained in 4.1.3 A type of middleware. write how to link rtklib with dune Refer to the dune wiki page

4.1.3 IMC

Write about the message structure and how it's connected to DUNE. Include how to make new messages.

4.1.4 Netpus

4.1.5 RTKLIB

Rtklib is a open source program package for standard and precise positioning with GNSS developed by T. Takasu. Rtklib can use raw GNSS data to estimate the position of the rover. Rtklib can be configured to give a position solution in real time in differential mode. Figure 4.1 shows how rtklib can be used in a RTKGNSS mode. The two main moduels here is str2str and rtkrcv. Both will be explalined more closely in the following sections. More information about rtklib can be found in [Rtk].

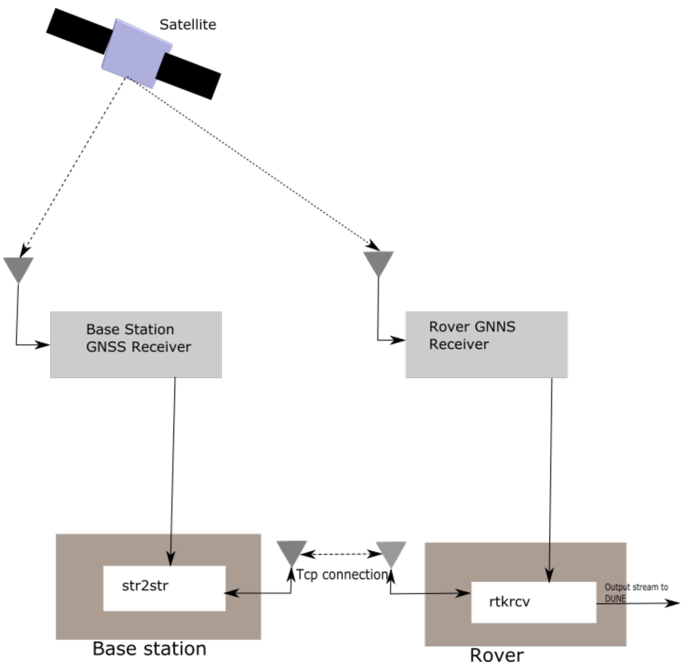

Figure 4.1: The communication structure of rtklib

rtkrcv

Rtkrcv is the app program that calculate the position of the rover. Rtkrcv can be configured to have two output streams. The structure of the output stream is given the rtklib manual, however there has been done some alteration in the structure of the output. It's desired in a autonumos landing system that have that velocity solution. This is was not provided in the newest version of rtklib, and therefore the source code was altered to send out the velocity data. A quick note here is that it is only available in the output solution is in a enu format.

When set configured as a differential GPS rtkrcv uses the LAMBDA method to resolve the integer ambiguity. The solution is considered fixed if the ration between the best estimate and the second best estimate is above a certain threshold. The solution body is given is table

Header	**Content**
1 Time	The epoch time of the solution indicate the true receiver signal reception time. Can have the following format: yyyy/mm/dd HH:MM:SS.SSS: Calender time in GPST, UTC or JST. WWWW SSSSSSS.SSS: GPS week and TOW in seconds
2 Receiver Position	The rover receive antenna position
3 Quality flag (Q)	The flag which indicates the solution quality. 1:Fixed 2:Float 5:Single
4 Number of valid satellites (ns)	The number of valid satellites for solution estimation.
5 Standard deviation	The estimated standard deviation of the solution assuming a priori error model and error parameters by the positioning options
6 Age of differential	The time difference between the observation data epochs of the rover receiver and base station in second.
7 Ratio factor	The ratio factor of "ratio-test" for standard integer ambiguity validation strategy
8 Receiver velocity	The velocity of the rover. Given only when output is in enu fo

Table 4.1: Table 1.

str2str

Str2str is the app program that retrieve the ublox signal from the gps and sends over tcp to the rtkrcv app. The str2str is setup to either send RMTC 3 messages, or whatever is send in from the GPS. Since the str2str do not support to send ublox signal directly. How to write that the user should not specify the input format or the output format.

4.2 Physical system

This section outline the physical components in the x8 and the base station.

4.2.1 Beaglebone

The system runs on a Beaglebone. A beaglebone were prepared for mounting in a x8

4.2.2 The GPS receiver

Write about the Ublox LEA M8T gnss receiver. Also include that it support sending GPS and GLONASS data at the same time. Need to be configured. A receiver were prepare and mounted in the x8.

Chapter 5

Implementation

5.1 Software implementation

5.1.1 Rtklib

PLASSERES I APPENDIX

str2str configuration

The system has to instances of rtklib. The base station uses the str2str and the x8 uses rtkrcv. str2str is configured to receive raw data from the ublox at a frequency of 10 Hz. The connection between str2str and the GNSS receiver is a uart cable that is configured with a baudrate at 115200. The program starts a tcp serve were rtkrcv becommes a client.

Very short about how Glued is used: Start up,

About rtklib: What does rtklib do in the system, were do it run, what instances is used, how do it connect to dune, what is the output message

About dune: What task are used to communicate with rtklib, how do they communicate, what is the output of the given task

About Neptus: What do neptus do, how is it used in the system, how will it be used in a automatic landing senario.

About Ardupilot: Very short on what Ardupilot do in the system

All in one section unless something need more space. Write here how rtklib is configured and how the system is connected Write here how Dune receive data from rtklib and what task is used. Include also what imc message is involeved in the task

Write here how neptus is configured for the test, and how it is used How Glued is configured to run rtklib and Dune

5.2 Hardware implementation

This section contain how all the physical components are connected at both the rover and the base station. Include also how everything was prepared.

About Beaglebone: What runs on the beaglebone, connections, devices, what is it place in the system

About Ublox: Explain the ublox from a system perspective, how it's connected

Pixhawk: What do it do in the system:

Piksi: Same as ublox

The X8: How do it fit in the system

The base station: Same as x8

Antennas:

Wifi router

Chapter 6

Experimental testing

This chapter contain the result from the test that were performed. The goal with these test was to evaulate the ublox receiver againgst the pixi receiver, and to get a impresion on the accuracy to the rtklib solution with ublox. The comparison test was performed with the pixi and ublox connected to the same antenna at both the rover and the base station. Then the deviation in the position estimate can only come from the receivers. The accuracy test of the ublox was tested by performing the same manoeuvre several times.

6.1 Physical testing

The physical experiment were done in two parts. During the first part the x8 was carried around on a open field. The goal with this experiment was to log data from rtklib and piksi, and then compare how they deviated from each other. The second part of the physical experiment was flying (SKRIV NÅR FLYVING ER GJENNNOMFØRT)

6.1.1 Fly test

6.1.2 GPS test

The experiment started when both rtklib and piksi would signal that they had a fixed integer solution.

Chapter 7

Conclusion and Discussion

7.1 Further work

Setup the reciver to use both gps and glonass raw data.

References

RTKLIB ver. 2.4.2 Manual.

Geoffrey Blewitt. Carrier phase ambiguity resolution for the global positioning system applied to geodetic baselines uo to 2000 km. *Journal of Geophysical Research*, 94(B8):10,187–10,203, 1989.

Marcus Frølich. Automatic ship landing system for fixed-wing uav. Master's thesis, Norwegian University of Science and Technology, NTNU, 2015.

Pratap Misra and Per Enge. *Global Positioning System Signals, Measurements and Performance Revised Second Edition.* Ganga-Jamuna Press, 2011.

P.J. de Jonge P.J.G Teunissen and C.C.J.M. Tiberius. The lambda-method for fast gps surveying. Presented at the International Symposium "GPS Technology Applications" Bucharest,Romania, 1995.

Robert Skulstad and Christoffer Lie Syversen. Low-cost instrumentation system for recovery of fixed-wing uav in a net. Master's thesis, Norwegian University of Science and Technology, NTNU, 2014.

Bjørn Amstrup Spockeli. Integration of rtk gps and imu for accurate uav positioning. Master's thesis, Norwegian University of Science and Technology, NTNU, 2015.

W. Stempfhuber. 3d-rtk capability of single gnss receivers. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2013.

W. Stempfhuber and M. Buchholz. A precise, low-cost rtk gnss system for uav applications. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 2011.

P.J.G. Teunissen. A new method for fast carrier phase ambiguity estimation. *IEEE*, pages 562–573, 1994.

P.J.G. Teunissen. The least-squares ambiguity decorrelation adjustment: a method for fast gps integer ambiguity estimation. *Journal of Geodesy*, 70:65–82, 1995.