NTNU – Trondheim
Norwegian University of
Science and Technology

POSITION CONTROL FOR AUTOMATIC LANDING OF UAV IN A NET ON SHIP

Kjetil Hope Sørbø

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Responsible professor: Thor Inge Fossen, Tor Arne Johansen

Norwegian University of Science and Technology
Department of Engineering Cybernetics

Abstract

Automatic landing of a fixed wing Unmanned Aerial Vehicle (UAV) in a net on a ship require a accurate positioning system. To increase general availability the system must consist of low-cost components, which exclude the commercial landing system that exist today. Real Time Kinematic GPS (RTK-GPS) can provide centimeter level position accuracy with the use of low-cost Global Navigation Satellite System (GNSS) receivers. The processing time for the Real Time Kinematic GPS (RTK-GPS) system will decrease the accuracy due to its highly dynamical behaviour.

This work present two alternative software and hardware systems that are used in a navigation system which apply RTK-GPS. Two different systems, Real-Time Kinematic Library (RTKLIB) and Piksi, will be compared, including their individual performance. The RTK-GPS system is using single-frequency Global Navigation Satellite System (GNSS) receivers, the Piksi system from Swift Navigation and the open-source Real-Time Kinematic Library (RTKLIB). The RTK-GPS system is implemented in DUNE(DUNE:Unified Navigation Environment) framework running on the embedded payload computer on-board the Unmanned Aerial Vehicle (UAV). Outdoor lab tests and a flight test were used to test the performance of the navigation system.

A test of the navigation system was successfully performed, and a RTK-GPS navigation system has been prepare for integration into a automatic net landing system. The Ublox proved to have superior satellite tracing ability, and combined with RTKLIB proved the best RTK-GPS systems.

Keywords: UAV,RTK-GPS,

Contents

List of Figures

List of Tables

Acronyms

DGPS Differential GPS.

DOP Dilution Of Precision.

ECEF Earth-Centered-Earth Fixed.

ECI Earth-Centered-Inertial.

ENU East North Up.

EPO Expanded PolyOlefin.

GLONASS Global Navigation Satellite System.

GNSS Global Navigation Satellite System.

GPS Global Positioning System.

GPST GPS Time.

IMC Inter-Module Communication.

INS Inertial Navigation System.

L1 Link 1.

L2 Link 2.

L5 Link 5.

LAMBDA Least-squares AMBiguity Decorrelation Adjustment.

LSTS Underwater Systems and Technology Laboratory.

NED North East Down.

RTK-GPS Real Time Kinematic GPS.

RTKLIB Real-Time Kinematic Library.

SHF Super-High Frequency.

SIL Software In the Loop.

TOW Time Of Week.

UAV Unmanned Aerial Vehicle.

UHF Ultra-High Frequency.

UTC Coordinated Universal Time.

WGS-84 World Geodetic System, 1984.

Chapter 1

Introduction

1.1 Background and motivation

Recently development of flying UAVs have been recognized to provide an attractive alternative to work previously performed by manned operations. Typical work which has attracted attention includes inspection, aerial photography, environmental surveillance and search and rescue. Today UAVs are mostly operated over land, however in the future this will include over sea as well. This will give some challenges which must be overcome. One of these challenges is that the UAV need to be able to perform a autonomous landing.

An UAV can provide an attractive alternative for many maritime operation where today manned aircraft or satellites is the only solution. In the maritime sector UAV can be used in iceberg management, monitoring of oil spills, search and rescue and maritime traffic monitoring.

An important premise for successful and safe UAV operation, in particular at sea, is the provision of a robust system for safe landing of the UAV on a vessel following completed operations. In order to perform an automatic landing a path planner, guidance system and accurate position estimation system are required, in addition to the low level control system in the UAV. Such complete system is subject for further development. Currently only method for achieving the individual objectives has been developed, i.e. path planner and guidance system respectively.

The path planer and guidance system as basis for this work were developed as previous master thesis work in the UAVLAB by [Marcus, 2015]. A key component in the guidance system is the position estimation system, which for the guidance referenced was developed by [Amstrup, 2015]. However, this system has been concluded to be in-sufficient with respect to provide means required for automatic

landing.

Existing landing system can guide the UAV towards a net, but they are expensive and restricted to a few UAVs. A pilot can land the UAV, however a better alternative would be if the UAV could land it self by the use of a net. In order to make the UAV able to perform a automatic landing a minimum requirement is that it knows its position at any time. This will require an accurate position estimation in real time. A highly accurate position sensor is expensive, however it's possible to achieve accurate solution with low cost sensors. This can be done by combining two GNSS receivers to estimate the relative position of one of the receivers in respect of the other receiver highly accurately. This project work will test a new generation of GNSS receiver, and use Global Positioning System (GPS) to establish the relative position of the UAV. The navigation system must be accurate enough to correctly estimate if the UAV is following the generated landing path or if the deviation from the path is large enough such that an evasion manoeuvre is required. The position evasion criteria used in [Marcus, 2015] is $\pm 1m$ cross-track error and $\pm 1m$ altitude error.

This project work will continue the research done by Spockeli [Amstrup, 2015], and use a new GNSS receiver that will be used with the open source program, RTKLIB. The goal is to establish a system with accurate local position estimate, such that in the future a UAV net landing can be performed automatic.

The automatic net landing system will use RTK-GPS for position estimation. The main goal for this work is to describe the gaps of the available position system sufficient to scope further work required for closure of such gaps ultimately providing means for position estimating sufficient for completion of automatic landing.

1.2 Literature Review

Automatic landing in a net has privously been successful performed in the NTNU MSc thesis [Robert and Lie, 2014]. They managed to land a UAV in a stationary net using RTK-GPS. Unfortunately a different hardware and software setup at the Uavlab has made the code they used obsolete.

Further research on the automatic landing system at the UAVLAB at NTNU was done in the MSc thesis by [Amstrup, 2015] and [Marcus, 2015]. In the MSc thesis by Spockeli he studied a integrated RTK-GPS/Inertial Navigation System (INS) navigation system with a nonlinear observer. In the MSc thesis by Froelich he create a control and guidance system that in simulation has successfully managed to follow a landing trajectory. He also created a dynamical path generation system that allows the net to move, and re-plan the landing path. The control and guidance

system created by Froelich has yet to be integrated with the work done by Spockeli. Froelich never did a physical test of the landing system, and the position estimate used in the system was not based on Real Time Kinematic GPS (RTK-GPS).

An other successful automatic landing was done in the Stellenbosch University MSc thesis [Adriaan, 2013] using Differential GPS (DGPS). This MSc thesis gives a description on the control system required to perform an automatic landing, however the system in the thesis require a runway in order to land.

An other low-cost system that can be used for automatic landing that is vision based landing system. In the paper [Jin et al., 2013] it was proposed a vision based landing system, that would detect the recovery net, and plan a landing path. The system was successfully tested and is a valid alternative for a low-cost autonomous landing system. An other vision based landing system was proposed in [Paul and Michael, 2012]. This paper describes an intelligent vision aided landing system that can detect and generate landing waypoints for a unsurveyed airfield. The drawback with a vision based landing system is that it require much computational power. In addition the visual line of sight can quickly decrease during a operation.

Real Time Kinematic GPS (RTK-GPS) apply phase measurement of the GNSS signal for position estimation. In order to get a accurate position estimate the integer ambiguity must be resolved. An integer ambiguity resolution strategy was proposed in [Geoffrey, 1989], and demonstrated centimeter level accuracy for a baseline up to $2000km$. Further studies on integer ambiguity resolution strategies resolved in the Least-squares AMBiguity Decorrelation Adjustment (LAMBDA) strategy, which was proposed in [P.J.G., 1994], and further disused in [P.J.G., 1995, Teunissen P.J.G and C.C.J.M., 1995]. The Least-squares AMBiguity Decorrelation Adjustment (LAMBDA) has been wildly used, and has proven a quick strategy to resolve the integer ambiguity, which makes it ideal for RTK-GPS systems.

The use of RTK-GPS for accurate position estimation has been studied in [W., 2013]. The paper proposed how to create a low-cost RTK-GPS system that can accurate measure the position in 3D. They used raw GNSS data from the GNSS receiver and the program library Real-Time Kinematic Library (RTKLIB) to estimate the position of a trolley in real time.

In the paper [W. and M., 2011] it was studied high precision positioning of micro-sized UAV using RTK-GPS. The system used a GNSS receiver that used a ground based augmentation system as a base station. The use of a ground based augmentation system us advantageous if the UAV can communicate with the ground station. For UAV operations where information from a ground based augmentation system is not available a local reference station must be considered.

1.3 Scope of work

The scope of work is to validate the performance of suitable positioning systems by study and testing, and to identify gaps required to be closed for successful implementation for a integrated autonomous Guidance, Navigation and Control system which will allow for automatic landing of a UAV at sea. This will include: The scope of this work is to test the performance of ublox-LEA M8T GNSS receiver

Testing of the performance of Ublox LEA M8T
Compare the performance of RTKLIB and Piksi
Compare the real time estimate with the post processed estimate

in a real time differential Differential GPS (DGPS) configuration. The RTK-GPS 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 processed solution from RTKLIB. The result from the experiment will be used in the discussion on how to perform an automatic net landing.

1.4 Layout

This section is currently not up to date

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

Real time kinematic GPS

This chapter will explain Real Time Kinematic GPS (RTK-GPS), as well as how it is used in the automatic landing system. The first section will include a overview of the system, including a description of the current system. The next part will contain different reference frame used in the RTK-GPS module. Then the different Global Navigation Satellite System (GNSS) system will be presented as well as atributes in the Global Positioning System (GPS). Then a quick overview over the different error sources that can affect a GNSS system, before the consept Differential GPS (DGPS) is presented. Lastly the accuracy of the term RTK-GPS will be explained.

In the following the behaviour of a receiver is denoted using terms rover and base station. The term base station means a receiver that has a known position by the other receivers. The term rover means a receiver that is allowed to move, and this is the main focus for position estimation.

2.1 System layout

An integrated system required for automatic landing will typically consist of four main sub-systems as shown in figure 2.1. Today these systems are individually available or in development; however not integrated into a proven working system allowing for automatic landing of UAVs. The four main systems comprises of the navigation part, guidance part, control part and the user interface, where further validation and development of the first is the main topic for this work.

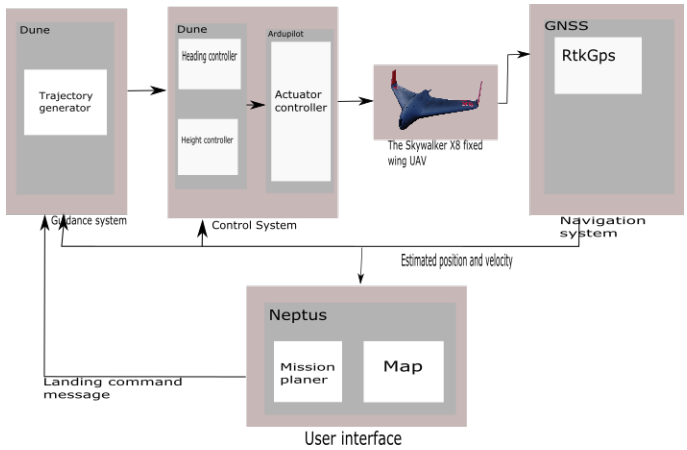


Figure 2.1: The structure of the autonomos landing system

The navigation system will apply RTK-GPS to estimate the relative position of the UAV. More details of the RTK-GPS will be further described in 2.6.4.

The control and guidance system has currently only been tested in Software In the Loop (SIL) simulations with Ardupilot, which shows promising result likely to be sufficient for automatic landing applications. However this module has not yet been implemented to support the use of RTK-GPS as required for performing automatic landing.

This work will identify and describe the navigation system necessary to allow for automatic landing of UAVs. The RTK-GPS solution will be compute by two different system ,which will be compared against each other. The first system is called Piksi, and is developed by Swift navigation. The second system will is called Rtklib, and is developed by T. Takasu. The latter is indepente on the type of receiver, and thus will be the main focus of this work. More detail about Piksi and Rtklib will be given in 3.1.3 and 3.2.2.

The comparison test will be used to summarize further work required for complete identification of technology gaps and work required for closure of these gaps such that a control system including provision for automatic landing. This system must be UAV in a control system. The UAV that will be used in the test is a Skywalker X8 Fixed Wing UAV. More details about the X8 will be given in 3.1.1

This work will identify and describe the gaps which will need to be closed in order to find a solution which will allow for automatic landing of UAVs. Two different system that will be compared against each other. The current state of the system is

that it consist of two parts that has not yet been integrated with each other. The main focus of this project work is the positioning part. The plan is to use RTK-GPS for positioning estimation. The second part is the guidance and control. Currently there has only been done simulation of the guidance system. It shows promising results, but is yet to be integrated with RTK-GPS. Figure 2.1 gives a overview of the different modules in the system.

2.2 Reference frames

A GNSS system calculate an estimated position estimated on the Earth where the receiver is. For the position to have any meaning a reference system has to be defined where a frame can be consider as an inertial frame. Based on this a reference frame can be fixed to the Earth rotation, but for local navigation it must be referred to surface of the Earth. This section will present the different reference frame used in global navigation systems.

2.2.1 ECI

Earth-Centered-Inertial (ECI) frame is considered a inertial frame for terrestrial navigation. The origin is fixed in the center of the Earth, and the axis is fixed in space. This frame can be considered as an non-accelerating where Newton's laws of motion applies.

2.2.2 ECEF

The Earth-Centered-Earth Fixed (ECEF) coordinate system is defined with the origin 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). The ECEF frame rotate relative to the ECI frame at an angular velocity of $\omega_e = 7.2921 \times 10^{-5} rad/s$, where ω_e is the Earth rotation. Due to the relatively low rotation speed some system can consider the ECEF frame as inertial.

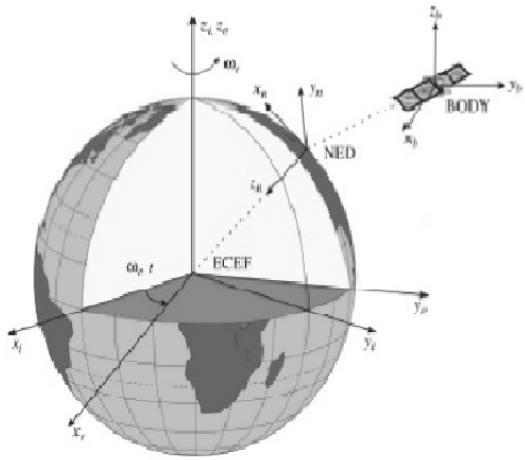


Figure 2.2: The ECEF frame. Picture from [I, 2011]

2.2.3 Local reference frame

The North East Down (NED) and East North Up (ENU) frame is defined as relative to the Earth reference ellipsoid (World Geodetic System, 1984 (WGS-84)). For the NED frame the x axis points in the direction to the true North, y axis towards East while the z axis points downward to completed the right handed orthogonal coordinate system. The ENU has the x and y axis exchange place with respect to the NED frame, and the z axis point upwards instead of downwards.

2.3 GPS

A quick overview of the gps and other gnss systems.

2.3.1 GNSS constellations

There are currently two operational GNSS constellations with global coverage, American GPS and Russian Global Navigation Satellite System (GLONASS). Other GNSS constellations that will be operational in the near future is the Chinese BeiDou and European Galileo.

2.3.2 GPS attributes

The GPS satellites transmits continuously using two radio frequencies in the L-band referred to as Link 1 (L1) and Link 2 (L2). The L-band covers frequencies between 1 GHz and 2GHz, and is a subset of the Ultra-High Frequency (UHF) band.

Previously only the L1 signal was intended from civil users, but in the future a new l2 signal as well as the Link 5 (L5) signal will be available for civil users.

Coordinated Universal Time (UTC) is standard time on the Earth of which all clock are referred to. UTC time is defined with the use of atomic clocks, which is also used in GPS. However the GPS apply an other time standard namely the GPS Time (GPST). The GPST is also based on atomic clock in the satellites. Due to the distance from the Earth the GPST deviates from the UTC time. To correct this the GPS keeps track of the offset between GPST and UTC. The offset is included in the GPS message as leap seconds to be added to the GPST. GPST can be given as Time Of Week (TOW), which include the number of weeks since 1980-01-06T00:00Z. TOW is given in seconds, and is reset each week when the week number is incremented. More information about the GPS can be found in [Bjørnar, 2014, Pratap and Per, 2011]

There are two basic ways to measure the GPS signal to estimate a position, which is code and phase measurement. Of the two phase measurment is the most accurate, however also the least reliable due to the integer ambiguities. In code measurement the information in signal is used to calculate the psudorange between the receiver and the satellite. The psudorange is the geometric range from the receiver to the satellite in addition to the delay introduce from various error sources. In phase measurement the receiver measures the phase of the GNSS satellite and compares it against a receiver generated signal. Then by knowing the phase and the frequency function, as well at the start and end epoch time the geometric range between the receiver and satellite can be estimated. It's phase measurement that is mostly used in RTK-GPS. In phase measurement it's advantageous to know the unknown number of cycles

between the satellite and the receiver, referred to as integer ambiguity. Estimation of integer ambiguity is called integer ambiguity resolution and will be more explained in 2.6.1.

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 is used to calculate the receiver clock bias. The position is calculated in the ECEF reference frame.

2.4 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 most significant error sources that can affect the GPS signal, and how to remove or mitigate them in the estimation.

2.4.1 Clock error

There is drift in both the satellite clock and the receiver clock. The atomic clock in the satellites makes the clock drift negligible 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 error given in the satellite message.

2.4.2 Ionospheric and Trophospheric Delays

When the GPS signals travel though the atmosphere there will be a delay caused by the different atmospheric layers, as further explained in this section.

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, however by including 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. This will be further explain in 2.6.3.

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. This will be further explain in 2.6.3.

2.4.3 Ephemeris Errors

A satellite is not able to perfectly follow a given orbit, therefore there will be a deviation between satellite position given to the receiver and the true position of the satellite. This is called the ephemeris error. The true position of a satellite is monitored and corrected by the owner of the GNSS constellation, but error between each correction can be expected.

2.4.4 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 GNSS 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 no tall structures nearby.

2.5 Dilution of Precision

The geometry of the GNSS constellation affect the accuracy of the position solution. Pore geometry will also enhance the effect that different error sources has on the position solution.

2.6 Differential GPS

Differential GPS (DGPS) 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. Figure 2.3 gives an example on DGPS. The base station has a known position, and the rover estimate the baseline from itself to the base station.

In this project work only phase measurements will be considered for position estimation method. The problem with precise relative positioning with phase measurement is problem of estimation of integer ambiguities.

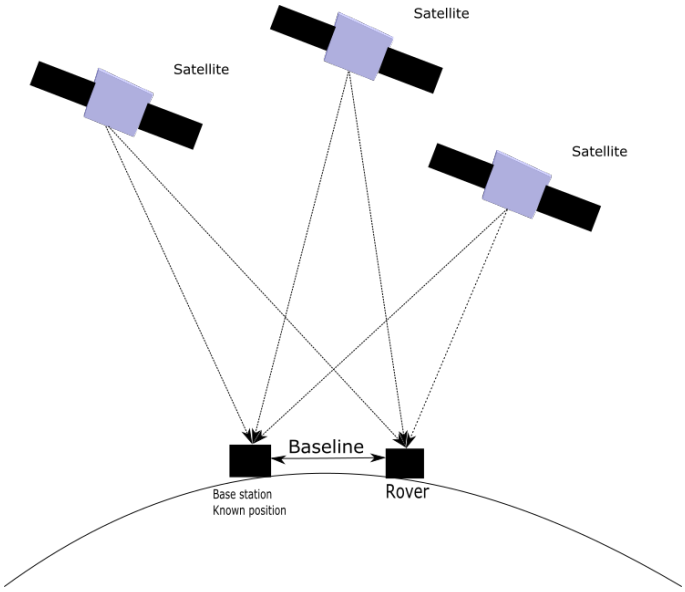


Figure 2.3: Concept figure of DGPS

2.6.1 Integer Ambiguity Resolution Strategy

A well used strategy is the LAMBDA method. LAMBDA starts by reducing the integer search space by decorrelation adjustment. The LAMBDA method has two types of outputs. One is called the fixed solution, and the other is called the float solution. The float solution is the first solution given by the LAMBDA method and is used to find the fixed solution. When the right fixed solution is reached the position estimation in from a DGPS can be considered highly accurate. The solution program can calculate the wrong fixed solution, or experience a cycle slip. In order to reduce the possibility of letting a wrong solution become the fixed solution the program need a integer ambiguity validation strategy. One validation strategy is to check if the ratio between the best ambiguity estimate and the second best estimate in greater then a certain threshold. High Dilution Of Precision (DOP) will effect the time the LAMBDA method needs to find a fixed solution.

2.6.2 Cycle slip

When the integer number of cycles experience a sudden jump in value due to loss of lock of a receiver phase lock it's called cycle slip. The effect of cycle slip is a bias in

the measurement large enough to make navigation difficult. The effect of cycle slip will appear as seen in figure 2.4.

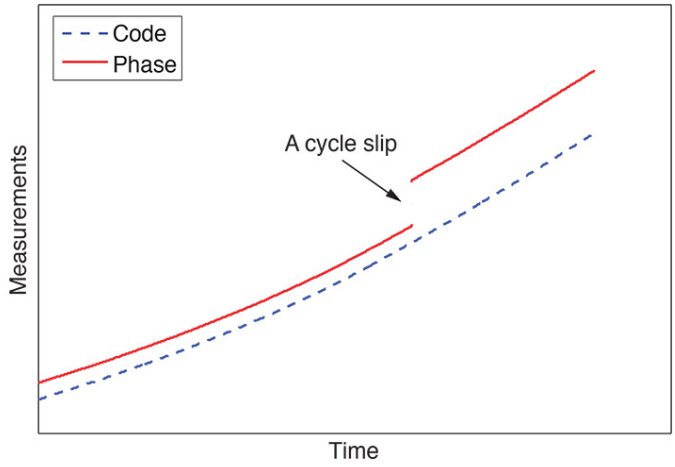


Figure 2.4: The ECEF frame. Picture from http://gpsworld.com/wp-content/uploads/2014/01/I-Fig1.jpg

2.6.3 Error mitigation in DGPS

In DGPS the rover considers that both the rover and base station receive GPS signal that has experienced the same delay. Thus the rover can remove all error sources that is correlated with the base station. This assumption holds given that the baseline is not to long. For longer baseline other methods must be applied to correct for atmospheric delay. DGPS error mitigation do not include multipath. Multipath is an uncorrelated error, and thus must be corrected locally by both the rover and base station.

2.6.4 RTK GPS

RTK-GPS provide accurate baseline position estimation in real time. RTK-GPS can either have a kinematic setting or a moving baseline setting. The difference between the two is that in kinematic the base station has a known stationary position, while in moving baseline the base station position is unknown and allowed to move. The advantage with the moving baseline configuration is that RTK-GPS can be used to find the relative position between two dynamical system using GNSS in real time. This will be the case in automatic ship landing system, where the base station is on a ship thus must be allowed to move. The advantage with kinematic mode is that it can give a more accurate position estimate. The relative position of the rover can be given in either the NED or enu frame.

RTK-GPS systems needs to calculate the position estimate quicker then a standard system. This is done by sacrificing the correctness of the solution, however in the resent time efficient software and hardware has reduced the this factor.

Chapter 3

System Components and implementation

This chapter will present the different software and hardware components used in this work, in addition to how they are implemented and connected to each other. The two first sections in this chapter will present the hardware and software components respectfully. This is followed by a overview over the components in the UAV and base station that is used to create the RTK-GPS system. The two last chapters will explain how the software and hardware implementation respectfully.

3.1 Hardware

The different hardware used in this work is a UAV, payload computer, GNSS receiver and antenna.

3.1.1 UAV

The Skywalker X8, see 3.1, is a fixed wing UAV that is moulded out of Expanded PolyOlefin (EPO), which makes it a cheap and robust platform for prototype testing. The large space within the fuselage makes it ideal for experimental payload and projects with modest requirements.

Figure 3.1: X8 Skywalker from Skywalker Technologies, Picture from www.campilot.tv/blog/win-x8

The X8 has a wingspan of 2120mm which allow for a Maximum Take-Off Wight of 4.2kg, including 1kg for the payload. The X8 used in this work is outfitted in according to the specification given in [Zolich A. P. and K., 2015]. The components that is used in the X8 at the UAVLAB is given in table 3.1.

Sensors	3DR ublox GPS with Compass Kit
	Pixhawk Airspeed Sensor Kit
Servo	Hitec HS-5125MG
Motor	Hacker A40
ECU	Jeti Master Spin 66 Pro
Main Battery	1 Zippy Compact 4S 5000 mAh
Autopilot	3DR Pixhawk
Primary digital data link	Ubiquiti Rocket M5

Table 3.1: Components in the X8 at the UAVLAB

3.1.2 Embedded Computer

The embedded computer chosen as payload in the X8 is a Beaglebone Black, shown in figure 3.2. The Beaglebone was chosen because of its sufficient computation power, low energy consumption and variety of communication interfaces. For ease interface access the the Uavlab at NTNU has developed an extension board called "CAPE".

Figure 3.2: BeagleBone Black element 14, Picture from http://www.element14.com

The Beaglebone black supports linux operation systems, and is compatiable with the Underwater Systems and Technology Laboratory (LSTS) toolchain, which will be return to in 3.2.

3.1.3 GNSS receiver

The system will use two types of GNSS receivers, namely the Ublox LEA M8T and the Piksi system.

Ublox LEA M8T

The Ublox LEA M8T is a new generation of low-cost GNSS receiver from ublox. The receiver support sending out raw GNSS data from both GPS and GLONASS in the same configuration. The receiver have great performance in acquisition and tracking sensitivity of GNSS satellites. More technical detalise can be found in [Ubl, a,b]. 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.

Figure 3.3: Ublox LEA M8T, Picture from http://www.csgshop.com

Piksi

Piksi, see figure 3.4, is a low cost, high performance GPS receiver with RTK-GPS functionality with capability for centimeter level relative positioning accuracy developed by Swift Navigation. Piksi is ideal for autonomous vehicles because of its small form factor, fast position solution update rate and low power consumption. More detailed information about Piksi can be found in [Pik]

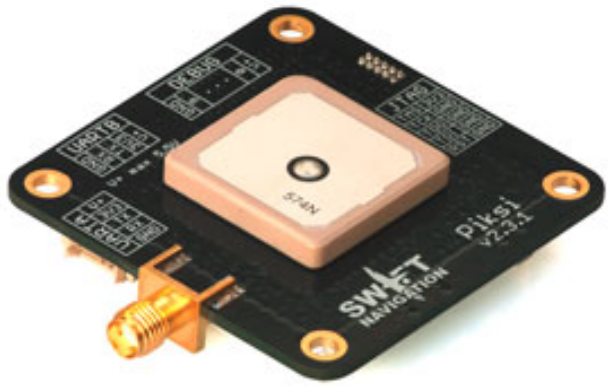


Figure 3.4: Piksi, Picture from www.swiftnav.com

3.1.4 GNSS Antenna

The navigation system will use two GNSS antenna, one for the UAV and the other for the base station. The main criteria for the UAV antenna is that it's small,compact and have a light weight.

The M1227HTC-A-SMA, seen in figure 3.5 has been used in other UAV setups at the UAVLAB with good results. The antenna is small, compact and with an light weight of $17g$. It's design for L1/L2 gps/glonass bands. Further information or specification can be found in [max]

The base station do not have any restriction on size, weight or aerodynamic. The important factor for a base station antenna is that it has good multipath rejection. Also the base station position should be calculated as accurate as possible which impose further restriction on interference handling, phase center stability and noise rejection.

The Novatel GPS-701-GG, seen i figure 3.6, was chosen as the base station antenna. The antenna has excellent multipath rejection whit a highly stable phase center. It has reception for both GPS and GLONASS L1 signals..Further information or specification can be found in [nov].

Figure 3.5: Piksi, Picture from http://sigma.octopart.com/21411362/image/Maxtena-M1227HCT-A-SMA.jpg

Figure 3.6: Piksi, Picture from http://www.novatel.com/assets/Web-Phase-2-2012/Product-Page-Images/Product-Images-Banner-and-Thumbnail/Antennas/702-L.png

3.2 Software

This section contain the different software that is used in the x8 system. The following sections contain the operating system that runs on the base station and rover, the middleware used to connect the different tasks, the messages protocol, the missionplaner program and rtklib which will have the main focus.

3.2.1 LSTS toolchain

The Underwater Systems and Technology Laboratory (LSTS) toolchain is a flexible, scalable, open-source software that supports integration and control of various types of unmanned vehicles [Pinto et al., 2013]. The toolchain includes a operating system, runtime environment, message protocol and a command and control for operations. The following program is included in the toolchain

GLUED

Glued is a minimal Linux distribution, 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.

Dune

Dune (DUNE Uniform Navigation Environment) is a runtime environment for unmanned systems. DUNE is operating system independent and can run on-board the embedded computer. It can interact with the sensors, actuators and payload. It can also be used for tasks like communication, navigation, control, manoeuvring, plan execution and supervision.

Dune works by setting up individual task that can dispatch and subscribe to different IMC messages. The IMC messages will be explained in 3.2.1.

IMC

The Inter-Module Communication (IMC) protocol is build to interconnect systems of vehicles,sensors and human operators. The protocol is a messages-oriented protocol that enable exchange of real-time information about the environment and updated objectives, such that the participant in the communication can pursue a common goal cooperatively. IMC has a standard way of dispatching and consuming messages, which abstracts hardware configuration from the software.

Neptus

Neptus is an open source command and control software that can be used for a single or fleet of unmanned vehicles with different types of sensors. The operator can observe real time data from a vehicle, review previous missions and plan future mission. In this work Neptus has been used to extract data logged by Dune during a defined mission, and to monitor the integer ambiguity solution from rtklib and piksi.

3.2.2 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 3.7 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].

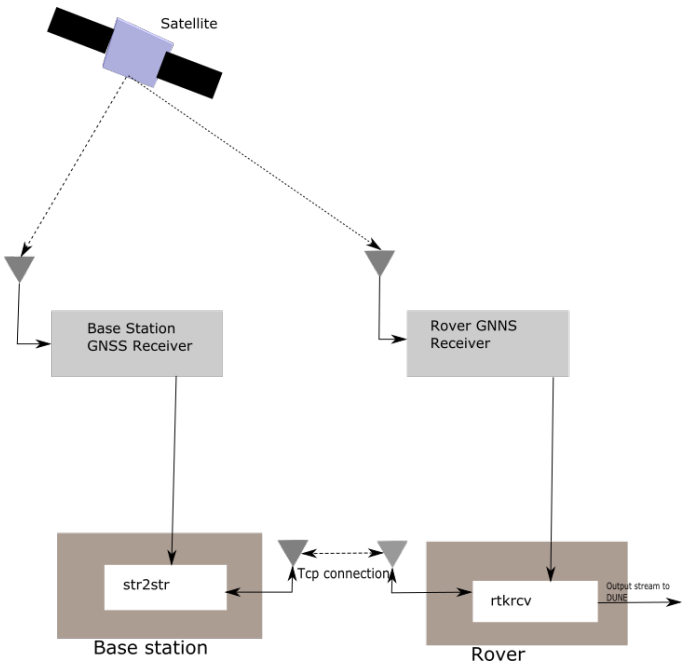


Figure 3.7: The communication structure of rtklib

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 automatic 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. The format of the output is given in table 3.2.

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 format

Table 3.2: Rtklib output solution 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 position solution is calculated with a Extended Kalman Filter, that can have different structure depending on how rtkrcv is configured

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.

3.3 Implementation

This section explain how the implementation was done for the RTK-GPS navigation system. Figure 3.8 gives an overview on how the system is connected. The implementation includes both a software and a hardware part.

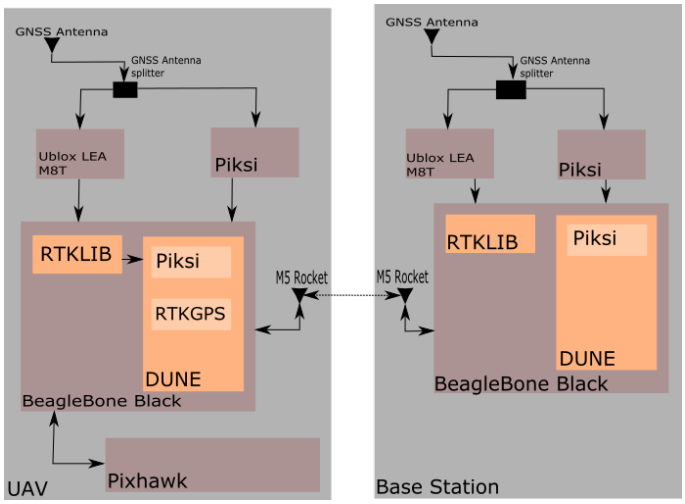


Figure 3.8: Hardware Software

3.3.1 Software implementation

The software implementation consist mainly of rtklib and dune. Piksi is also used in the experiment, however it's rtklib and the Dune task RTKGPS that will be discussed thoroughly. It should the noted that the rtklib that is used is an altered version from the latest stable version. The alteration was done in the ENU output setting where the ENU velocity variables was included. The new structure is given in 3.2

Rtkgps

The RTK-GPS module in the navigation system consist of three parts. That is rtklib, and the two Dune tasks RTKGPS and Piksi. The RTKGPS task is connected to rtklib though a virtual connection, and the Piksi task has a physical connection to the Piksi receiver.

Rtklib is separated into the base station and the rover. The base station implementation runs the str2str program were it communicate with the Ublox over a uart cable, and start up a tcp server.

The rover uses the rtkrcv program from rtklib to estimate the position of the rover. Rtkrcv connect itself as a tcp client to the tcp server that str2str create. Rtkrcv is configured in a moving baseline configuration to simulate the behaviour that is expected during a landing on a ship. The configuration file is included in A

The output from the Dune tasks is a IMC message called RtkFix, see table 3.3, which include the relative position of the UAV as well as the velocity, type of integer solution and the GPS TOW.

Header	**Content**
tow	Gps time of Week
n	Baseline North coordinate
e	Baseline East coordinate
d	Baseline Down coordinate
v_n	Velocity North coordinate
v_e	Velocity East coordinate
v_d	Velocity Down coordinate
iar_hyp	Number of hypotheses in the Integer Ambiguity Resolution
iar_ratio	Quality ratio of Integer Ambiguity Resolution
type	Type of fix: None = No solution, but RTK task is running Obs = No solution, but receiving observations Float = Floating point solution of Integer Ambiguity Resolution Fix = Fixed(single) solution of Integer Ambiguity Resolution

Table 3.3: The IMC message RtkFix

3.3.2 Hardware implementation

The base station configuration was already finish by the time this work began. The only hardware that was included was the Ublox and the GPS antenna splitter. On the UAV a the payload computer had to be prepared.

The embedded computer uses GLUED as its operating system, and on it runs both Dune and rtklib. The Piksi and Ublox is connected to the BeagleBone over uart cables.

The primary data-link to the UAV is done with shf Ubiquiti AirMax radios, that is based on a Ubiquity Rocket M5

The two RTK-GPS system is connected to a antenna splitter , figure 3.9, such that both system receive the same GNSS signals. This is done to easy the comparison of the two RTK-GPS system, and to remove the antenna as a source of error.

More information on the hardware setup used in the X8 and the Base station is given in [Zolich A. P. and K., 2015]

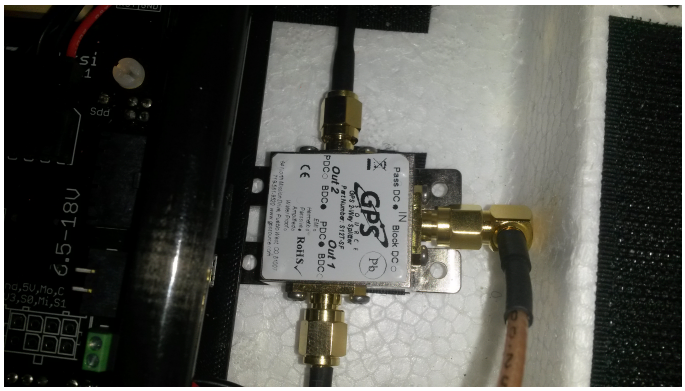


Figure 3.9: Antenna splitter

Chapter 4

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. All position and velocity data is given in the NED frame.

4.1 Performance testing of UAV Position System

The experimental test was split in two independent test, one where the X8 UAV was carried around on a open field to test the performance of the RTK-GPS system in a more controlled environment. The goal of the first was to log data from both RTK-GPS system in optimal condition for the navigation system. The second test was perform in a more realistic environment for a navigation system.

4.1.1 Test 1: Test of the RTK-GPS navigation system

In this part two test of navigation data will be presented. Both tests were performed on the same day, which was cloudless and at a time with low DOP. The raw data from the Ublox receiver was post processed with rtklib, and is should be more accurate than it's real time counter part. Therefore a estimate of error was defined as:

$$e(t) = p_r(t) - p_p(t) \tag{4.1}$$

where $p_r(t)$ and $p_p(t)$ is defined as the position solution from the real time system and the position solution from the post processed solution respectfully. $e(t)$ is used as a measure on the performance of the position estimate relative to the assumed

more accurate post-processed estimate. It should be noted that in order to compare the different time-series the position data was synchronized with each other. From the error the cumulative standard deviation for the error was calculated using the matlab function "std".

First test

In the first session of the test the UAV was carried around on a open field, and latter placed exactly on the same place where it started. As expected both systems provided a position estimate with fixed integer solution that followed the true path, and further confirms that both system performed in a similar manner. Therefore both systems are suitable for further comparison of position estimation in a flying test. Figure 4.1 shows a North East plot of how the walk was. The plot contain only the fixed solution from both the piksi and rtklib.

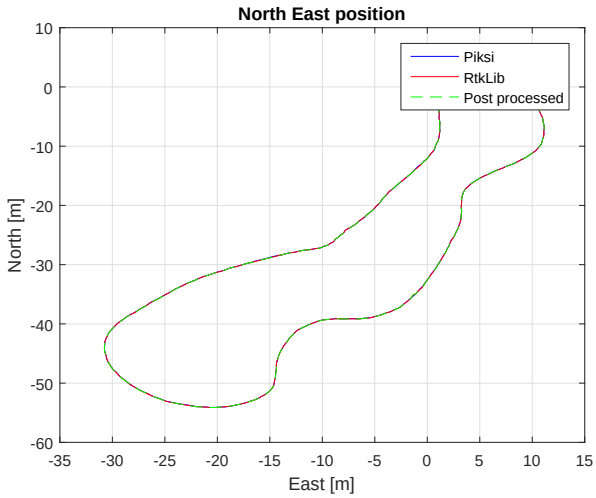


Figure 4.1: A xy plot of the piksi,rtklib real time solution and the rtklib post processed solution

Figure 4.2 shows the down position, as well as how the integer ambiguity solution was during the experiment. As seen in the figure both the Piksi and Rtklib manage to keep there fixed solution. The position solution from both the Piksi and Rtklib agrees with the post processed solution.

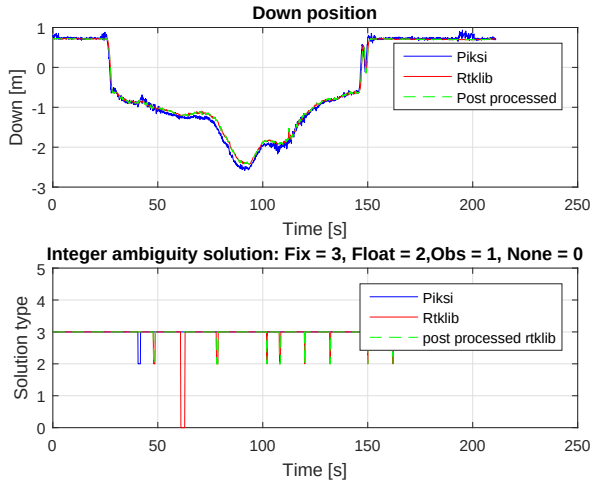


Figure 4.2: The communication structure of rtklib

As seen in figure 4.1 the difference between the different solution appear to be small, which is comfirmed in the error plot shown in figure 4.3 and 4.4

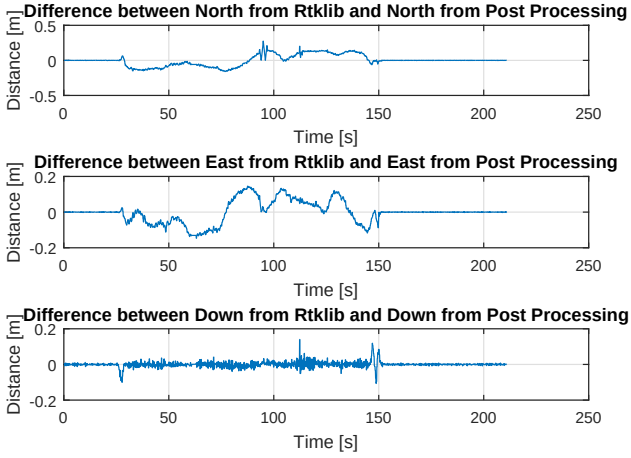


Figure 4.3: The difference between rtklib real time and post processed solution

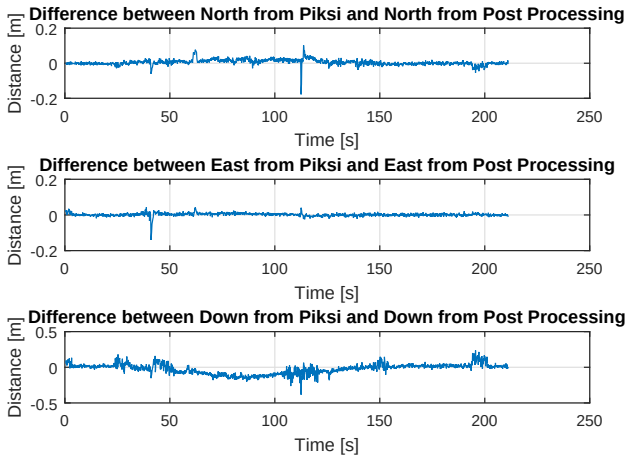


Figure 4.4: The communication structure of rtklib

The small variasion in the position error can be seen in figure 4.6 and 4.5.

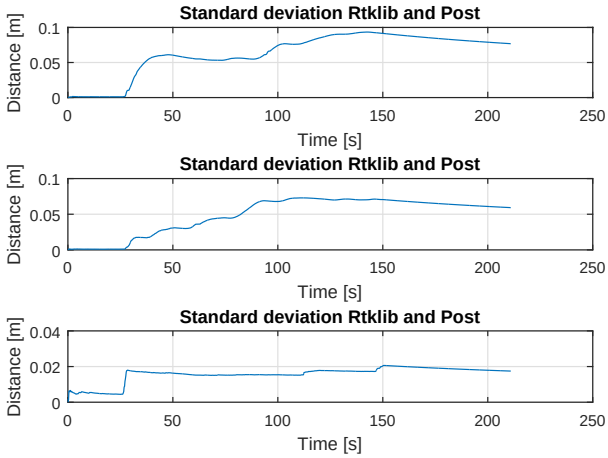


Figure 4.5: Standard deviation of the difference between rtklib real time and post processed solution

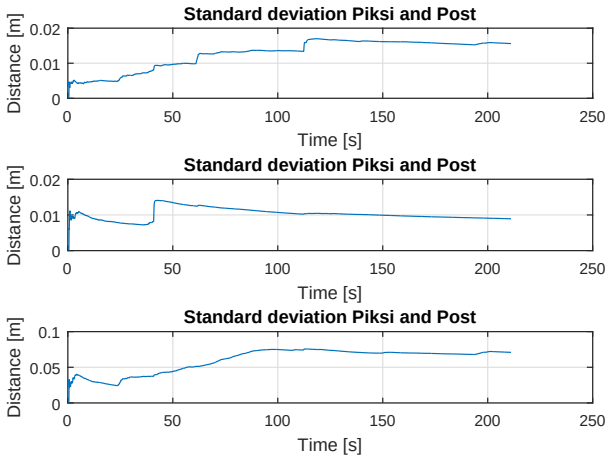


Figure 4.6: Standard deviation of the difference between piksi real time and rtklib post processed solution

Both the Piksi and RTKLIB appear to be able to correctly estimate the North and East velocity, as seen in figure 4.7. However the Down velocity from RTKLIB is more noisy then the Piksi.

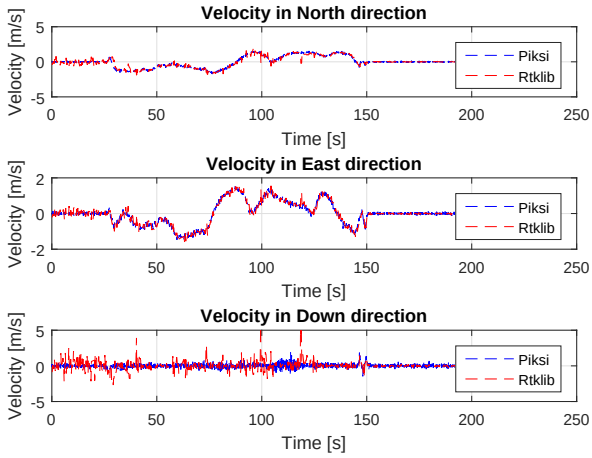


Figure 4.7: Velocity data from the piksi and rtklib real time solution

The different receiver used in Rtklib and Piksi was not able to track the same

satellites at all time. Figure 4.8 shows that the Ublox LEA M8T receiver connected to Rtklib managed to track more satellite then the receiver used in Piksi. Figure

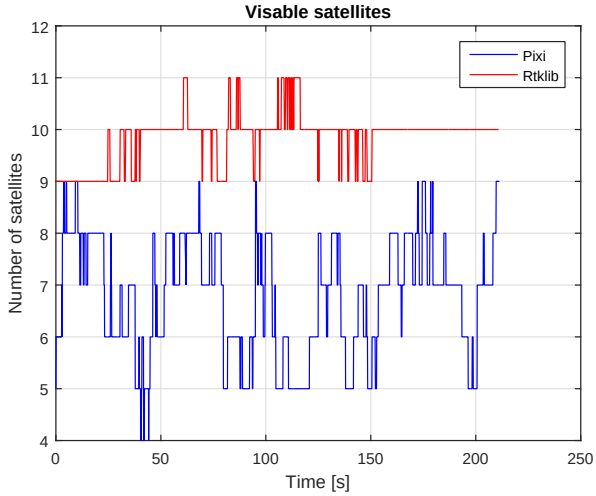


Figure 4.8: Visable statellite for the piksi and rtklib

The position estimate of the rover is a relative position in reference to the base station. Due to the fact that the position of the base station is calculated with a single receiver with one frequency, there will be introduced a bias in the position estimate. Figure 4.9 shows the North, East position of the the first walk. The true position is exactly the same, but in the figure it appear that the distance is approximately $5cm$. The distance from the base station to the estimated start and stop position was calculated to be $3.29m$ and 3.26 respectfully. The measured distance was approximately $3.3m$. That gives an initial error off $0.04m$. This gives an accuracy level at centimeter level at stationary condition.

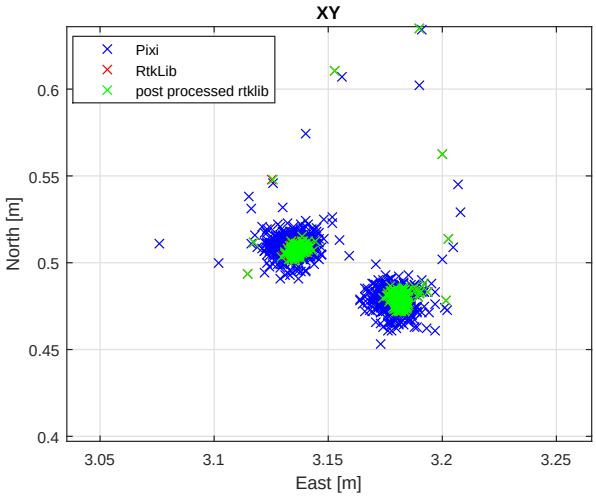


Figure 4.9: Visable statellite for the piksi and rtklib

The position estimate from RTKLIB appear to be delay in comparison to the solution from the Piksi. Figure 4.10 shows that both the post processed solution and the real time solution is delay by 0.5 secounds compared to the Piksi. This could be how RTKLIB resolve the millisecond in Time Of Week (TOW), and will not be seen as an extra delay seen from the control systems perspective.

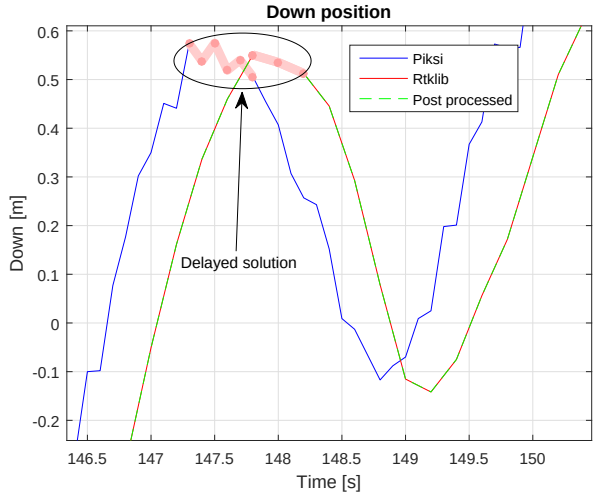
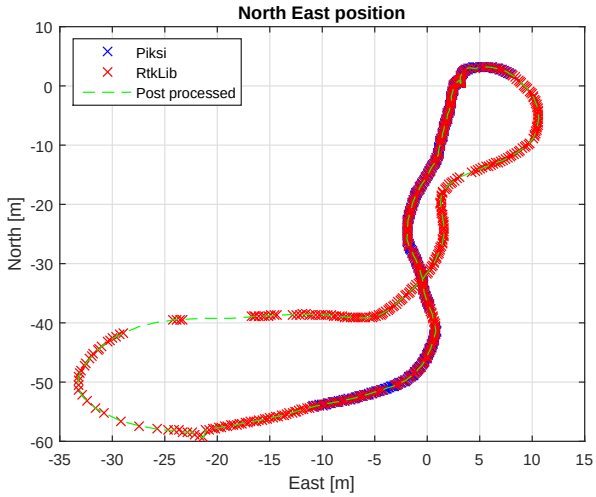


Figure 4.10: Velocity data from the piksi and rtklib real time solution

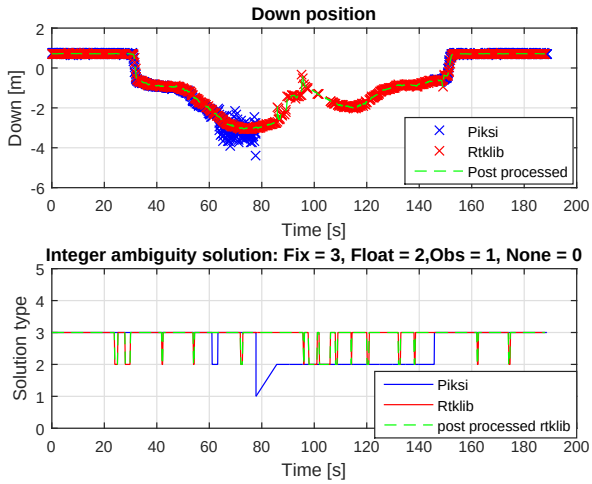
Given that the error given in figure 4.4 and 4.3 is never has a greater absolute value then $0.2m$ it's possible to assume that the true error will be bellow $1m$ which was given as an evasion criterion in the MSc thesis by [Marcus, 2015], if the RTK-GPS system has a fixed integer solution.

Second test

The second session was perform few minutes after the first, whit the same weather condition. During the second session the Piksi lost its fixed integer solution, while Rtklib managed to keep its fixed integer solution as seen in figure 4.11a and 4.11b.



(a) Visable statellite for the piksi and rtklib



(b) Visable statellite for the piksi and rtklib

The reason for why the Piksi lost its fixed solution might be because it lost track of several satellite, as seen in figure 4.12. Since both receive share the same antenna it can be concluded that the satellite tracing performance in the Ublox is superior to the Piksi. Even when the Piksi managed to regain track of the satellite it lost, it took 60 seconds before it regain a fixed integer solution.

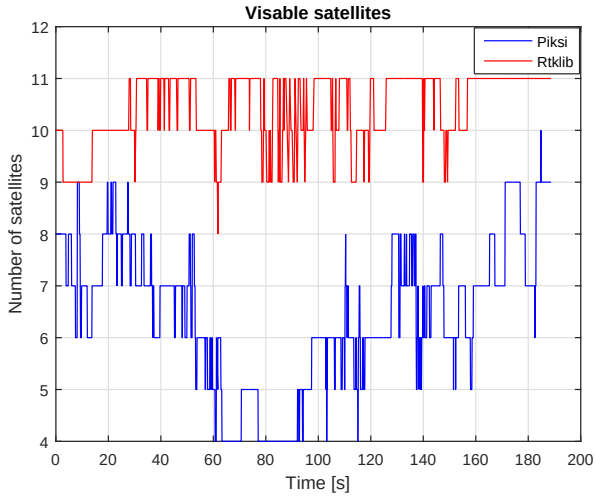


Figure 4.12: Visable statellite for the piksi and rtklib

4.1.2 In-flight test

A flight test with the UAV was performed at Udduvoll. Because of bad weather the were only performed one flight, and before the flight started only the Rtklib had a fixed solution. That is why in this part only performance from the Rtklib is considered, as a fixed solution is a must for a automatic landing system.

During the flight test the integer ambiguity solution were more float then fixed as seen in figure 4.14 and 4.13, which affected the measurement. The same behavior will be seen during the landing, however if the float solution is accurate enough the system should be able to perform a automatic landing.

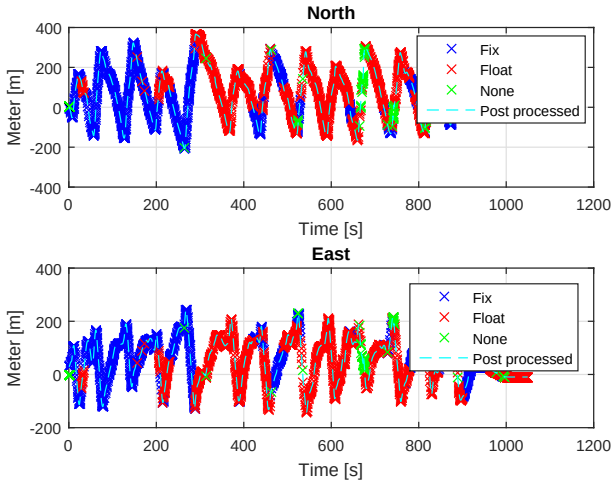


Figure 4.13: Velocity data from the piksi and rtklib real time solution

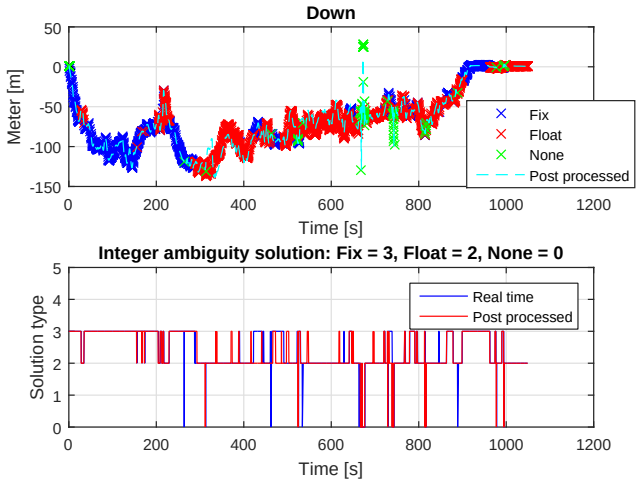


Figure 4.14: Velocity data from the piksi and rtklib real time solution

The main reason for this behaviour is because of the number of valid satellite the receiver can track experience large variation, as seen i figure 4.15. A problem that was experienced during the flight is that the dynamic behaviour of the UAV blocks the antennas view of different satellites. That is a problem that can be solved by setting restricion on the dynamical behavior of the UAV expesially befor and during landing.

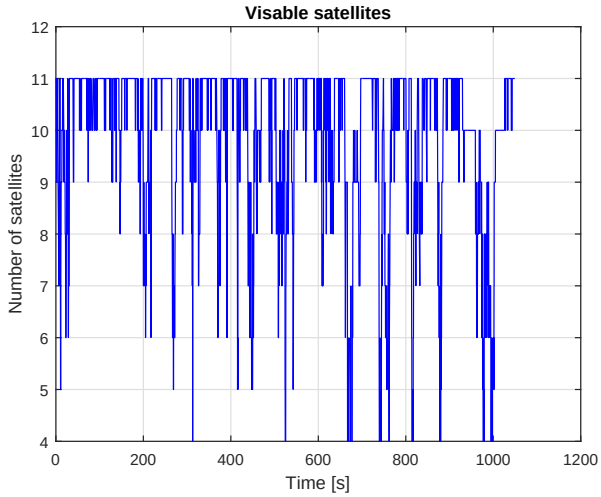


Figure 4.15: Velocity data from the piksi and rtklib real time solution

Landing

As expected the RTK-GPS system had problem with keeping it's fixed integer solution. The RTK-GPS position estimate of the landing path is shown in figure 4.16. The system kept changing between float and fixed solution during the landing phase. Figure 4.17 shown the North East position during the landing with the type of solution. The Down position as well as the integer ambiguity solution is for the landing phase is seen in 4.18. The RTK-GPS system was unable to maintain a fixed solution, however it did maintain a float solution. Further test with a control system is required in order to test if also the float solution is accurate enough to perform a automatic landing.

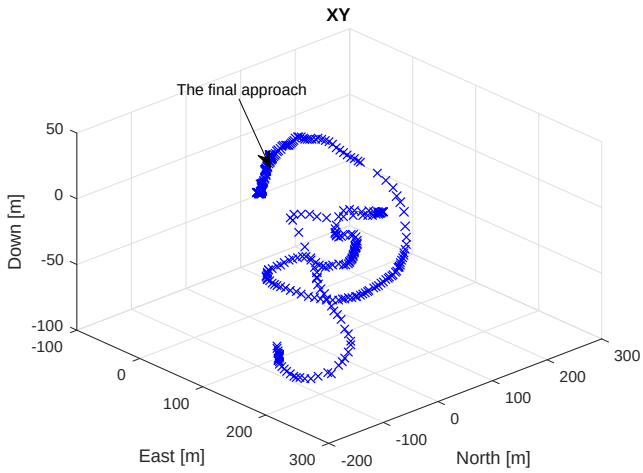


Figure 4.16: Velocity data from the piksi and rtklib real time solution

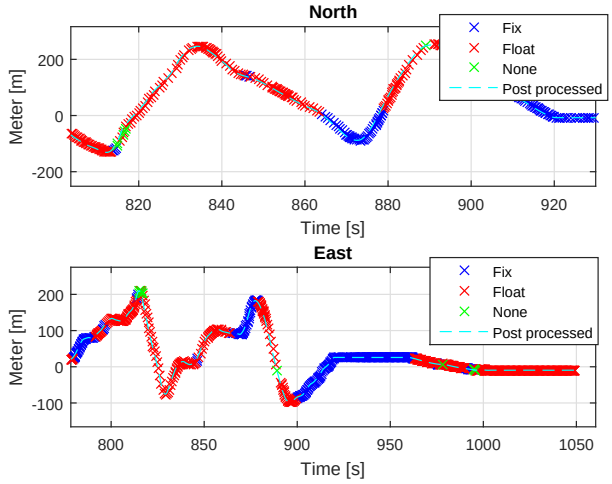


Figure 4.17: Velocity data from the piksi and rtklib real time solution

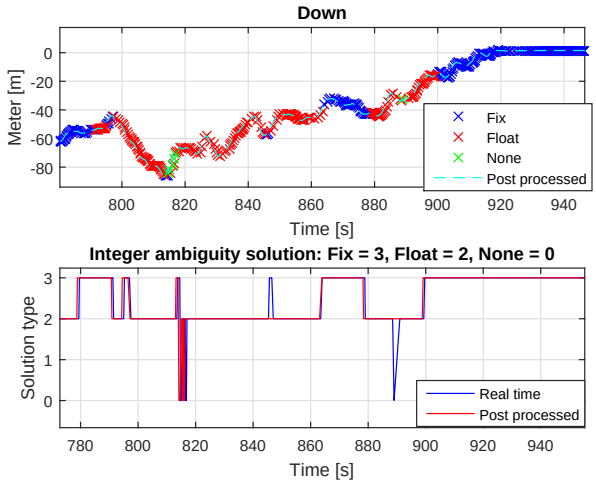


Figure 4.18: Velocity data from the piksi and rtklib real time solution

From the error plot seen in figure 4.19 it appear that to be able to estimate it's own position with an error bellow 1 meter most of the time. However this is compared to the post processed estimate, which also will diverge from the true value.

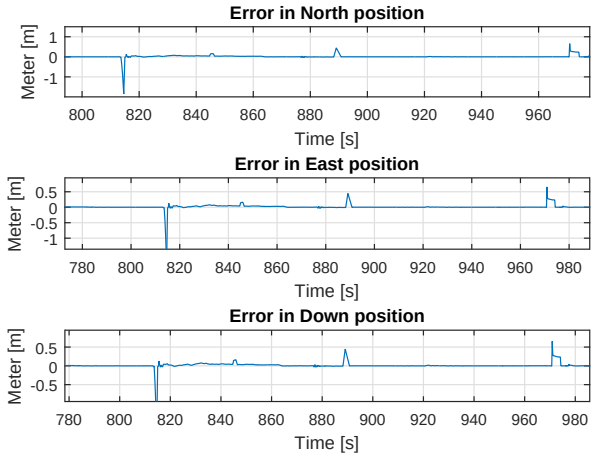


Figure 4.19: Velocity data from the piksi and rtklib real time solution

The landing velocity seen in 4.20 confirms the trend see in the first session. The North and East velocity seams to get a nice estimate, however that is not the case

with the Down velocity. The Down velocity estimate appear noisy, and not suited for input into a control system.

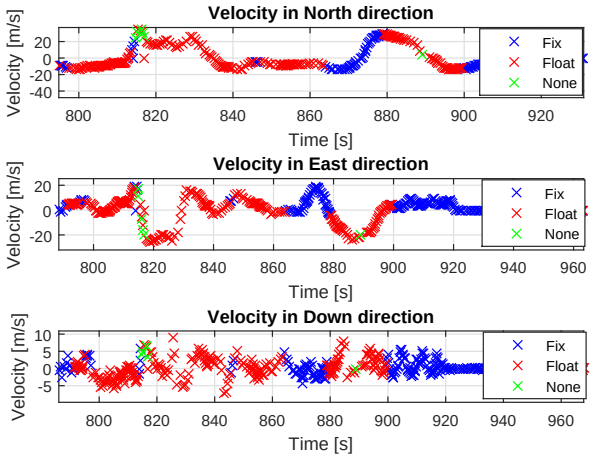


Figure 4.20: Velocity data from the piksi and rtklib real time solution

Chapter 5

Conclusion and recommendation for further work

This chapter will discus the result from the field tests, which will be used to conclude the performance of the individual RTK-GPS system. The last part of this chapter will include suggestion for further work regarding the design of a automatic landing system.

5.1 RTK-GPS lab testing

It was seen in the lab testing that both the Piksi and RTKLIB was able to get a fixed solution, although the RTKLIB was faster. In the first test were the UAV was carried both system gave similar result during the first session UAV, however during the second the Piksi lost its fixed solution. Rtklib had also problem during this session, but unlike the Piksi managed to find a fixed solution again. The ability for the navigation system to quickly recover its integer solution is critical in a automatic landing system.

The estimated position is accurate when the UAV isn't moving down to centimeter level accuracy. When the UAV is in motion this will decrease down to decimeter accuracy, and due to the precision in the position estimate it could be concluded that the accuracy is not worse then decimeter level accuracy. That should be good enough in a navigation system for a automatic landing system.

The velocity estimate from Piksi and RTKLIB have similar estimate for the North and East component, but differ in the Down component. The velocity output from RTKLIB appear to affect by to much noise to be at any use for a control system. It could be used if sent through a low-pass filter.

The tracking performance from the two receiver type indicate that the Ublox is superior to the Piksi. It always manage to track more satellites, and did not easily loose track of them.

5.2 RTK-GPS in-flight test

The flight test showed that keeping the fixed integer solution during a flight is difficult, most likely because of the dynamic behaviour of the UAV. The landing phase of the UAV operation should be kept independent from the rest of the operation. Therefore landing specific constraint cannot be imposed on the UAV behaviour. In order to then get a best relative position estimate the RTK-GPS must be able to recover it's fixed integer solution as quickly as possible while the UAV is in flight.

Before the take-off the piksi had yet solved its integer ambiguity, while RTKLIB had. That might be because of it kept track of fever satellites. However the navigation system must be able to resolve its integer ambiguity quickly to increase the probability of performing a safe and successfully automatic landing.

During the flight the Ublox lost track of more satellite then during the GPS lab tests. The antenna follows the orientation of the UAV and therefore some satellite will be blocked by the fuselage. This must be consider when designing a guidance system for automatic landing. To ensure that the antenna has a clear view of the sky, the UAV should try to have a maximum roll when the automatic landing system is engaged.

DO NOT INCLUDE WHAT IS BELLOW BEFORE FURTHER WORK

It might be that the float position estimate is good enough to perform a automatic landing. Further test are required.

Rtklib managed to keep float/fixed solution during the landing.

The rtklib was the only system able to get a fixed solution. Discus the performance of rtklib, whit the ublox receiver.

What can be concluded:

Rtklib is able to faster find a fixed solution. Can be because of better receiver, better integer ambiguity resolution strategy, poorer validation of ambiguity, more efficient algorithm. Based on how many satellites the ublox receiver manage to track I will say that the receiver had a large part in shortening the time.

When fixed there is not a large deviation between the two solutions. One difference that might cause problem in a guidance system is that it appear that the solution

from rtklib is delayed. The TOW that's given with the solution do not include the millisecond value.

The Piksi is faster to calculate the position, but slower to resolve the integer ambiguity.

The conclusion of the different system. Piksi has better and more efficient solution software, however rtklib can use a superior GNSS receiver.

Both system has a good estimation of the North and East velocity, however it appear that rtklib has problem estimating the vertical velocity.

5.3 Further work

The Ublox receiver and the GNSS antennas are able to receive both GPS and GLONASS L1 signals, which should be exploited to increase the number of valid satellite available for the RTK-GPS system. This could also give better constellation geometry, and help the system resolve its integer ambiguity faster.

The RTK-GPS system must be integrated with the existing control and guidance system, and a test landing in a stationary net must be performed.

A RTK-GPS system can use both the Piksi and Rtklib such that the automatic landing system has redundancy in position, and velocity estimation. A validation task must then be design to choose which of the system should send the rtkfix IMC message to the rest of the system.

A RTK-GPS/glsins integration navigation system can be implemented in the automatic landing system. A RTK-GPS/glsins integration was proposed in [Amstrup, 2015], which can be used.

A position estimation system that can accurately predict were the UAV will be a few seconds ahead of time, such that the UAV can better know were it is instead of were if was.

Setting constraints on the path such that the antenna has a clear view of the satellites at all time during the landing phase.

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Appendix A

Rtklib Configuration

A.1 str2str

Need start commando and rate configuration of the ublox

A.2 rtkrcv

Configuration given bellow. Summarize the important parts of the configuration.

```
# RTKNAVI options (2015/10/30 13:05:07, v.2.4.2)

pos1-posmode       =movingbase # (0:single,1:dgps,2:kinematic,3:static,4:movingbas
pos1-frequency     =l1         # (1:l1,2:l1+l2,3:l1+l2+l5,4:l1+l2+l5+l6,5:l1+l2+l5
pos1-soltype       =forward    # (0:forward,1:backward,2:combined)
pos1-elmask        =10         # (deg)
pos1-snrmask_r     =off        # (0:off,1:on)
pos1-snrmask_b     =off        # (0:off,1:on)
pos1-snrmask_L1    =0,0,0,0,0,0,0,0,0
pos1-snrmask_L2    =0,0,0,0,0,0,0,0,0
pos1-snrmask_L5    =0,0,0,0,0,0,0,0,0
pos1-dynamics      =on        # (0:off,1:on)
pos1-tidecorr      =off        # (0:off,1:on,2:otl)
pos1-ionoopt       =brdc       # (0:off,1:brdc,2:sbas,3:dual-freq,4:est-stec,5:ion
pos1-tropopt       =saas       # (0:off,1:saas,2:sbas,3:est-ztd,4:est-ztdgrad)
pos1-sateph        =brdc       # (0:brdc,1:precise,2:brdc+sbas,3:brdc+ssrapc,4:brd
pos1-posopt1       =off        # (0:off,1:on)
pos1-posopt2       =off        # (0:off,1:on)
pos1-posopt3       =off        # (0:off,1:on)
```

```
pos1-posopt4       =off        # (0:off,1:on)
pos1-posopt5       =off        # (0:off,1:on)
pos1-exclsats      =           # (prn ...)
pos1-navsys        =1          # (1:gps+2:sbas+4:glo+8:gal+16:qzs+32:comp)
pos2-armode        =fix-and-hold # (0:off,1:continuous,2:instantaneous,3:fix-and-ho
pos2-gloarmode     =off        # (0:off,1:on,2:autocal)
pos2-bdsarmode     =off        # (0:off,1:on)
pos2-arthres       =3
pos2-arlockcnt     =0
pos2-arelmask      =0          # (deg)
pos2-arminfix      =10
pos2-elmaskhold    =0          # (deg)
pos2-aroutcnt      =5
pos2-maxage        =30         # (s)
pos2-syncsol       =on        # (0:off,1:on)
pos2-slipthres     =0.05       # (m)
pos2-rejionno      =30         # (m)
pos2-rejgdop       =30
pos2-niter         =1
pos2-baselen       =0          # (m)
pos2-basesig       =0          # (m)
out-solformat      =llh        # (0:llh,1:xyz,2:enu,3:nmea)
out-outhead        =off        # (0:off,1:on)
out-outopt         =off        # (0:off,1:on)
out-timesys        =gpst       # (0:gpst,1:utc,2:jst)
out-timeform       =tow        # (0:tow,1:hms)
out-timendec       =3
out-degform        =deg        # (0:deg,1:dms)
out-fieldsep       =
out-height         =ellipsoidal # (0:ellipsoidal,1:geodetic)
out-geoid          =internal   # (0:internal,1:egm96,2:egm08_2.5,3:egm08_1,4:gsi200
out-solstatic      =all        # (0:all,1:single)
out-nmeaintv1      =0          # (s)
out-nmeaintv2      =0          # (s)
out-outstat        =state        # (0:off,1:state,2:residual)
stats-eratio1      =100
stats-eratio2      =100
stats-errphase     =0.003      # (m)
stats-errphaseel   =0.003      # (m)
stats-errphasebl   =0          # (m/10km)
stats-errdoppler   =1          # (Hz)
```

```
stats-stdbias      =30         # (m)
stats-stdiono      =0.03       # (m)
stats-stdtrop      =0.3        # (m)
stats-prnaccelh    =10         # (m/s^2)
stats-prnaccelv    =10         # (m/s^2)
stats-prnbias      =0.0001     # (m)
stats-prniono      =0.001      # (m)
stats-prntrop      =0.0001     # (m)
stats-clkstab      =5e-12      # (s/s)
ant1-postype       =llh        # (0:llh,1:xyz,2:single,3:posfile,4:rinexhead,5:rtc
ant1-pos1          =90         # (deg|m)
ant1-pos2          =0          # (deg|m)
ant1-pos3          =-6335367.6285 # (m|m)
ant1-anttype       =
ant1-antdele       =0          # (m)
ant1-antdeln       =0          # (m)
ant1-antdelu       =0          # (m)
ant2-postype       =llh        # (0:llh,1:xyz,2:single,3:posfile,4:rinexhead,5:rtc
ant2-pos1          =90         # (deg|m)
ant2-pos2          =0          # (deg|m)
ant2-pos3          =-6335367.6285 # (m|m)
ant2-anttype       =
ant2-antdele       =0          # (m)
ant2-antdeln       =0          # (m)
ant2-antdelu       =0          # (m)
misc-timeinterp    =off        # (0:off,1:on)
misc-sbasatsel     =0          # (0:all)
misc-rnxopt1       =
misc-rnxopt2       =
file-satantfile    =
file-rcvantfile    =
file-staposfile    =
file-geoidfile     =
file-ionofile      =
file-dcbfile       =
file-eopfile       =
file-blqfile       =
file-tempdir       =/tmp/
file-geexefile     =
file-solstatfile   =
file-tracefile     =
```

```
#

inpstr1-type       =serial     # (0:off,1:serial,2:file,3:tcpsvr,4:tcpcli,7:ntripcl
inpstr2-type       =tcpcli     # (0:off,1:serial,2:file,3:tcpsvr,4:tcpcli,7:ntripcl
inpstr3-type       =off        # (0:off,1:serial,2:file,3:tcpsvr,4:tcpcli,7:ntripcl
inpstr1-path       =uart/2:115200:8:n:1:off
inpstr2-path       =:@10.0.60.51:50022/:
inpstr3-path       =
inpstr1-format     =ubx        # (0:rtcm2,1:rtcm3,2:oem4,3:oem3,4:ubx,5:ss2,6:hemis
inpstr2-format     =ubx        # (0:rtcm2,1:rtcm3,2:oem4,3:oem3,4:ubx,5:ss2,6:hemis
inpstr3-format     =rtcm2      # (0:rtcm2,1:rtcm3,2:oem4,3:oem3,4:ubx,5:ss2,6:hemis
inpstr2-nmeareq    =off        # (0:off,1:latlon,2:single)
inpstr2-nmealat    =0          # (deg)
inpstr2-nmealon    =0          # (deg)
outstr1-type       =serial        # (0:off,1:serial,2:file,3:tcpsvr,4:tcpcli,6:ntri
outstr2-type       =file       # (0:off,1:serial,2:file,3:tcpsvr,4:tcpcli,6:ntrips
outstr1-path       =../tmp/ttyV0:115200:8:n:1:off
outstr2-path       =/opt/lsts/rtklib/log/rtklib_output%Y%m%d%h%M.pos
outstr1-format     =enu        # (0:llh,1:xyz,2:enu,3:nmea)
outstr2-format     =enu        # (0:llh,1:xyz,2:enu,3:nmea)
logstr1-type       =file       # (0:off,1:serial,2:file,3:tcpsvr,4:tcpcli,6:ntrips
logstr2-type       =file       # (0:off,1:serial,2:file,3:tcpsvr,4:tcpcli,6:ntrips
logstr3-type       =off        # (0:off,1:serial,2:file,3:tcpsvr,4:tcpcli,6:ntripsv
logstr1-path       =/opt/lsts/rtklib/log/rtklib_ubxstream_x8_log%Y%m%d%h%M.ubx
logstr2-path       =/opt/lsts/rtklib/log/rtklib_ubxstream_base_log%Y%m%d%h%M.ubx
logstr3-path       =
misc-svrcycle      =50         # (ms)
misc-timeout       =30000      # (ms)
misc-reconnect     =30000      # (ms)
misc-nmeacycle     =5000       # (ms)
misc-buffsize      =32768      # (bytes)
misc-navmsgsel     =all        # (0:all,1:rover,2:base,3:corr)
misc-proxyaddr     =
misc-fswapmargin   =30         # (s)
#misc-startcmd =./rtkstart.sh
#misc.startcmd =./rtkshut.sh
file-cmdfile1 =/etc/rtklib/data/ubx_raw_10hz.cmd
file-cmdfile2 =/etc/rtklib/data/ubx_raw_10hz.cmd
```