Министерство науки и высшего образования Российской Федерации
НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ
ТОМСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ (НИ ТГУ)
Радиофизический факультет
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ДОПУСТИТЬ К ЗАЩИТЕ В ГЭК

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«20» сентября 2019 г.

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

РАЗРАБОТКА И ОБОСНОВАНИЕ КОНЦЕПЦИИ БЫСТРОГО ЗАПУСКА УСТРОЙСТВ СПУТНИКОВОГО СЛЕЖЕНИЯ GNSS НА ОСНОВЕ МОДУЛЕЙ U-BLOX

DEVELOPMENT AND PROOF OF FAST START CONCEPT FOR GNSS TRACKING DEVICES BASED ON U-BLOX MODULES

по основной образовательной программе подготовки магистра
направление подготовки 03.04.03 – Радиофизика

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Томск 2019

Министерство образования и науки Российской Федерации
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ЗАДАНИЕ
по подготовке ВКР магистра
студенту Вайману Евгению Витальевичу группы № 731

1. Тема ВКР: Разработка и обоснование концепции быстрого запуска устройств спутникового слежения GNSS на базе модулей u-blox.
2. Срок сдачи студентом выполненной ВКР:
а) на кафедре 20.09.2019,
б) в ГЭК 25.09.2019
3. Краткое содержание работы:
Исследование функционала ГНСС приемников на базе u-blox модулей, поиск новых технологий минимизации величины времени первого исправления.
4. Календарный график выполнения ВКР:

а) изучение литературы по теме ВКР	04.03.2019–04.04.2019
б) разработка тестирующей среды на языке Python	04.04.2019–06.06.2019
в) проведение экспериментальных исследований	06.06.2018–27.07.2019
г) обработка результатов и написание ВКР	27.07.2019–03.09.2019
д) подготовка презентации работы	03.09.2019–17.09.2019

5. Дата выдачи задания «_04_» _____02_____2019 г.

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Задание принял к исполнению _____________ Е.В. Вайман

РЕФЕРАТ

Магистерская диссертация содержит 54 страницы, 9 глав, 32 рисунка,17 таблиц, 2 формулы, 32 источника.

РАЗРАБОТКА И ОБОСНОВАНИЕ КОНЦЕПЦИИ БЫСТРОГО ЗАПУСКА УСТРОЙСТВ СПУТНИКОВОГО СЛЕЖЕНИЯ GNSS НА ОСНОВЕ МОДУЛЕЙ U-BLOX.

Объектом исследования является оценочная плата u-blox EVK-M8C.

Цель работы – анализ встроенного функционала и исследование альтернативных технологий минимизации величины времени первого исправления для оптимизации работы приемного устройства при холодном старте.

Были поставлены следующие задачи на магистерскую диссертацию

1) Аналитический обзор литературы по методам спутниковой навигации .
2) Поиск методов и технологий минимизации величины времени первого исправления
3) Разработка среды для тестирования приемного устройства при различных условиях
4) Экспериментальное исследования производительности обнаруженных методов и технологий
5) Разработка алгоритма быстрого старта устройства

Аннотация

С древних времен человечество волновал вопрос об их текущем местонахождении. Людям всегда было важно знать, где они находятся в данный момент или как добраться до определенной точки на планете. Процесс определения местоположения объектов называется навигацией. В 200 г. до н.э. в Китае был разработан первый компас, который стал первым устройством для навигации. Со временем наличие компаса стало важным и необходимым атрибутом каждого путешественника, будь то исследователь, торговец или простой странник. Для определения направления движения и текущего положения люди использовали солнце, звезды и другие объекты природы. И если в прошлом это был действительно трудоемкий процесс, то теперь технологии шагнули настолько далеко, что даже подросток способен легко узнать свое местоположение и проложить маршрут в любую точку мира. Все это стало возможным благодаря спутниковой навигации или , что то же самое, глобальных навигационных спутниковых систем (ГНСС) [1]. Под спутниковой навигацией будем подразумевать такой метод, при котором для определения местоположения объекта используются сигналы со спутников.

Идея создания спутниковой навигации зародилась еще в 1950-х годах, когда в СССР был запущен первый искусственный спутник Земли. В то время американские ученые наблюдали за сигналом, поступающим со спутника, и обнаружили, что благодаря эффекту Доплера частота принимаемого сигнала увеличивается по мере его приближения и наоборот. Так, в 1973 году была запущена программа «NavStar», которая позже была переименована в наиболее известную «GPS». Первоначально в запуске навигационной системы преобладали исключительно военные цели, в разработке которых участвовали

военные силы США. Приборы спутниковой навигации планировалось размещать на бортах кораблей, подводных лодок, танков и другой военной техники. Однако, несмотря на то, что проект GPS изначально был предназначен исключительно для военных целей, сейчас GPS широко используется в повседневной жизни. Приемники GPS продаются в магазинах, они встроены в мобильные телефоны, цифровые часы, навигаторы и многие другие устройства. Теперь модуль ГНСС встроен в каждый мобильный телефон, что позволяет ориентироваться в любое время. Кроме того, существует множество программных продуктов, с помощью которых пользователи могут видеть свое текущее местоположение, планировать маршруты, отслеживать дорожные условия, находить достопримечательности в городе и других важных местах, просматривать фотографии этих объектов и многое другое.

Таким образом, технологии спутниковой навигации находят применение в таких областях, как:

- Геодезия и тектоника плит
- Картография
- Навигация
- Спутниковый мониторинг транспорта
- Сотовая связь
- Геометки и Активный отдых

Современные ГНСС-приемники способны определять свое местоположение за короткое время и с высокой точностью. Швейцарская компания u-blox производит высококачественные приемники, которые используются во всем мире. Согласно данным исследованиям [2] за 2018 г. считается, что продукты u-blox обеспечивают кратчайшее время для первой фиксации (TTFF) при холодном запуске. Значение этой величины характеризует время, в течение которого приемник может определить первые координаты собственного местоположения. Значение TTFF имеет большое значение, и большинство пользователей, включая компанию IBH-IMPEX, задаются вопросом, каким образом и на какую величину значение TTFF может быть уменьшено, используя доступные функции. Большинство устройств имеют огромное количество встроенных опций, разработанных для особых ситуаций. Поэтому важно выяснить, использование каких конфигураций устройства позволяет максимально быстро рассчитать местоположение. Данная работа предназначена для разрешения этой неопределенности. В качестве изучаемого устройства была выбрана оценочная плата u-blox EVK-M8C. Данное устройство разработано на основе ГНСС приемника MAX-M8C, размеры которого подходят для изделий компании IBH-IMPEX. Основная проблема заключается в том, что при плохих условиях определение позиции может занять десятки минут. Большое значение TTFF неприемлемо для устройств в области слежения. В виду того, что размер устройств слежения очень сильно ограничен, а антенна в большинстве случаев не может быть расположена в месте, легко доступном для спутниковых сигналов, необходимо использовать встроенный функционал. Таким образом, основной целью данной работы является анализ встроенных функций и выявление наиболее продуктивных при холодном запуске устройства. Предполагается провести анализ альтернативных путей с целью их дальнейшей реализации. В качестве основных критериев были выбраны самый короткий TTFF и хорошая точность (менее 10 м). Задача предполагает разработку собственного алгоритма и среды для тестирования устройства. Важно, чтобы найденные решения и методы соответствовали продуктам компании IBH-IMPEX. Кроме того, он должен быть широко доступным и простым в реализации.

В результате проделанной работы были сформулированы 2 научных положения:

1. При движении оценочной платы u-blox EVK-M8C использование трех спутников системы ГЛОНАСС для вычисления местоположения обеспечивают среднюю точность позиционирования свыше 100 метров, при этом ее величина с течением времени итерационно увеличивается на 1-3 метра
2. При нахождении оценочной платы u-blox EVK-M8C в неактивном состоянии более 2 часов после предварительной загрузки действительных навигационных данных реализация теплого старта устройства позволяет сократить время первого исправления в 7.07 раз при уровне несущей не превышающей 25 дБГц

Информация о компании

Company Logo	
Company Name	IBH-IMPEX Elektronik GmbH
Department	Research and Development Department
Name of Supervisor	Dr. Alexander Burggraf

Контактная информация

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Оглавление

Перечень сокращений

ACK	Acknowledge
AGPS	Assited GPS
BOC	Binary Offset Carrier
BPSK	Bipolar Phase-Shift Keying
C/A Code	Civilian Access Code
CEP	Circular Error Probabilty
CN0	Carrier-to-Noise Density
COM Port	Communication Port
CR	Carriage Return
DI	Digital Information
DNSS	Defense Navigation Satellite System
DOP	Dilution Of Precision
DRMS	Distance Root Mean Square
GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
I2C	Inter-Integrated Circuit
LF	Line Feed
NACK	Negative Acknowledge
NMEA	National Marine Electronics Association
NTRIP	The Networked Transport of RTCM via Internet Protocol
P Code	Precise Code
PC	Personal Computer
PZ-90	Parametry Zemli 1990 goda
QZSS	Quasi-Zenith Satellite System
RAM	Random Access Memory
RF	Radio Frequency
RS232	Recommended Standard 232
SBAS	Satellite Based Augmentation System
SCPI	Standard Commands for Programmable Instruments
SEP	Spherical Error Probable
SPI	Serial Peripheral Interface
SV	Space Vehicle
TTFF	Time To First Fix
UART	Universal Asynchronous Receiver-Transmitter
UERE	User Equivalent Range Error
URE	User Range Error
USB	Universal Serial Bus
USNO	United States Marine Observatory
UTC	Coordinated Universal Time
WGS-84	World Geodetic System 1984

Перечень рисунков

Перечень таблиц

1. INTRODUCTION AND GOALS

Since ancient times, mankind has been concerned about their current location. It was always important for people to know where they are at the moment or how to get to a certain point on the planet. The process of determination location of objects called *navigation*. In 200 BC in China the first compass was developed and it was the first device for navigation. Over time it has become an important and necessary attribute of every traveler, be it a researcher, trader or simple wanderer. To determine the direction or current position people used the Sun, stars and other objects of nature. If in the past it was really complicated process, then now the technologies have gone so far, that even teenager able to easily know his location and build a route to anywhere in a world. It all became possible by *satellite navigation* or what the same *Global Navigation Satellite Systems (GNSS)* [1]. By *satellite navigation* we mean such method in which the signals from satellites are used to determine the location of object.

The idea of creating satellite navigation appeared in 1950s, when the USSR launched the first artificial satellite of the Earth. At that time American scientists observed for the signal coming from satellite and found that due to Doppler effect the frequency of receiving signal increases as it approaches and vice versa. Thus in 1973 was launched “NavStar” program, which was renamed to most famous “GPS” later. Initially, the launch of the navigation system was dominated exclusively by military goals, development of which was involved the three main US forces: Navy, Air Force and Army. Devices of satellite navigation were planned to be placed on boards of ships, submarines, tanks and other military equipment. Despite the fact that the GPS project was originally exclusively for military purposes, now GPS is widely used in civilian life. GPS receivers are sold in stores, they are embedded in mobile phones, digital watches, navigators and many other devices. Now the GNSS module is built in absolutely every mobile phone which allows navigate in every time. In addition, there are many software products with which you can see your current location, plan routes, track road conditions, find sights in the city and other significant places, see photos of these objects and much more.

Thus, the satellite navigation technologies are using in such areas as:

- Surveying
- Cartography
- Navigation
- Satellite monitoring of transport
- Cellular communication
- Tectonics plin
- Geotagging
- Active rest

And over time this list will only increase, because satellite navigation is a permanent attribute of modern human life.

Modern GNSS receivers are able to determine their location for short time and with high accuracy. The Swiss u-blox company produces the receivers which are used over the world. According to the research [2] for 2018 considered that the u-blox products provide the shortest time to first fix (TTFF) at a cold start. This value characterizes the time during which receiver can determine its first location. The value of TTFF has a great importance and most of users, including IBH-IMPEX, are wondering how else they can reduce this value using available features. Most devices have huge amount of built-in options designed for particular situations. Therefore, it is important to find out usage of which configurations of the device allows fastest position calculation. This work is intended to solve this uncertainty. As the studied device EVK-M8C evaluation board was selected. It is developed on basis of MAX-M8C GNSS receiver, sizes of which are suitable for IBH-IMPEX products. The main problem is that under poor conditions, position determination could take several minutes. However the large value of TTFF is not acceptable for tracking devices. The problem is very common especially for tracking devices. Due to the fact that the size of tracking devices is very limited, and the antenna in most cases cannot be located at a place that is easily accessible for satellite signals, it is necessary to operate with the built-in functionality. Thus the main objective of this work is to analyze built-in features and to reveal the most productive at the cold start of the device. It is supposed to conduct an analysis of alternative ways with a view to their further implementation. As main criteria the shortest TTFF and good accuracy (less than 10 m) were selected. The task involves the development of own algorithm and environment for device testing. It is important, that solutions and techniques found are consistent with the IBH-IMPEX company’s products. Besides, it should be widely available and easy to implement.

Thus, the assigned task includes the following steps:

- Familiarity with the principles of satellite navigation
- Studying the protocols used information transmission
- Management and communication with used equipment
- Search for fast start acceleration techniques
- Development of a test environment
- Performance analysis of different configurations
- Processing results and making conclusions

2. GNSS OVERVIEW

If until 2000 the positioning of the whole world was carried out by GPS and GLONASS, then by now several satellite systems have already been launched and are functional. Nowadays, the development of navigation technologies is also carried out by India, China, Japan and Europe and each of them develop own systems. Thus, to date there are 6 active navigation systems: GPS, GLONASS, BeiDou, Galileo, QZSS and NavIC. The satellite navigation systems which have a global coverage over the world are called global navigation satellite system. Now there are only two fully operated global systems: American GPS and Russian GLONASS. Other navigation systems are either regional or do not have enough apparatus to provide full coverage. Even so, Chinese BeiDou and Europian Galileo scheduled to be fully operational by 2020. This chapter describes the structure of two main navigation systems: GPS and GLONASS.

2.1. GPS Structure

GPS is one of the leading and most widely used navigation systems. The history of GPS starts with launching “DNSS” (Defense Navigation Satellite System) project in 1973. At the same year it got two names: NavStar and later GPS. It was initiated by U.S. Department of Defense and at the beginning it followed only military goals. It was fast developed and already in 1995 it was fully operational. Now the most part of modern devices support GPS.

In general the GPS consists of three main segments: space, control and user (Figure 2.1). Space segment is a number of satellites which are moving in concert along specially selected orbits. Satellites broadcast a signal from space and all GPS receivers use this signal for determination of their location in real time. Moreover to determine the exact location of the signal from only one satellite will not be enough. Therefore, the tracking devices receive signals from each of the available satellites. Such method of navigation allows serving an unlimited number of users. This principle applies to all existing GNSS.

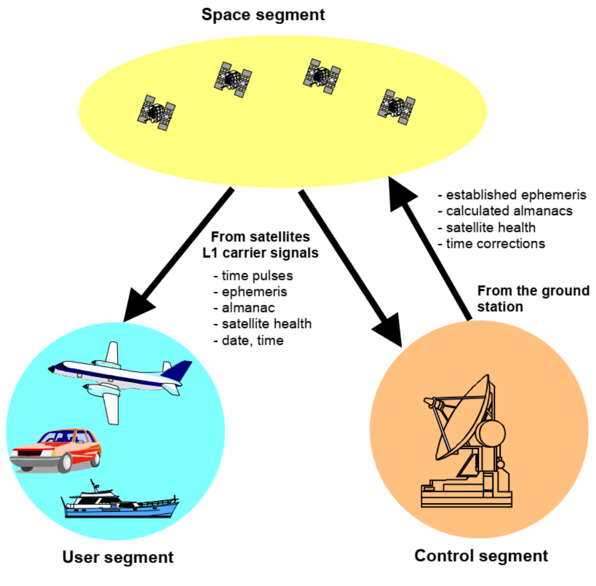


Figure 2.1 – Structure of GPS [3]

For GPS space segment consists of 31 operational satellites orbiting the Earth on the 6 different orbital planes. On each of apparatuses the atomic clocks (cesium or rubidium or combination of them) are installed, which are synchronized with clocks on the central synchronizer of system. Synchronized doesn’t mean that they go in phase. It means that the difference of the clock is known. It is the central synchronizer stores the so-called system time scale. GPS satellites orbit at a height of 20,200 km above the Earth’s surface. The tilt angle is 55° to the equator. Important feature is that the orbit completes in around 12 hours, but during to rotation of the Earth satellite will be at initial point after 24 hours (23 hours, 56 minutes to be precise). Such position of satellites ensures communication with at least 4 satellites at all times anywhere in the world [4].

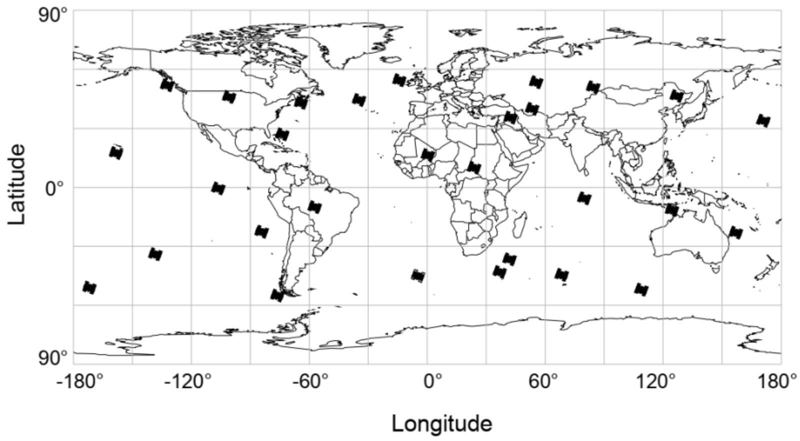


Figure 2.2 – Position of the GPS satellites at 12:00 hrs UTC on 14th April 2001 [3]

Each of these satellites broadcasts carrier oscillation in two frequency bands: L1 and L2. Satellites transmit on frequencies of 1575.42 and 1227.6 for L1 and L2 respectively. The carrier oscillation is modulated by a special code in sequence in such way that the phase of code signal coincides with the readings of the satellite clock. In the GPS system each device has a unique code sequence that allows distinguishing their signals, despite the common frequency.

The control segment is the main control station (located in the state of Colorado) and several additional stations, as well as ground antennas and monitoring stations, some of the resources mentioned are shared with other projects. The current Operational Control Segment includes a master control station, an alternate master control station, 11 command and control antennas, and 16 monitoring sites (Figure 2.3)

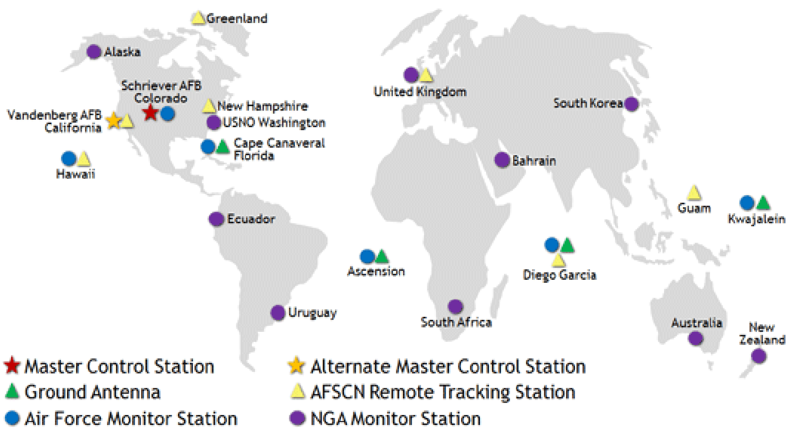


Figure 2.3 – Control segment of GPS [4]

Monitor stations tracks GPS satellites and collects navigation signals and feed the observations data to the master control station. In turn master control station provides command and control of the GPS constellation. It computes the precise location of satellites and generates navigation messages.

The user segment is represented by GPS receivers administered by state institutions and hundreds of millions of receivers owned by ordinary users. Receivers can be categorized by their type in different ways, and under different criteria. For instance, receivers can be stand-alone, or may benefit from corrections or measurements. Moreover receivers might be generic or can be specifically having the application.

GPS uses the World Geodetic System 1984 (World Geodetic System - WGS-84) and own time system. WGS 84 determines the coordinates relative to the center of mass of the Earth, so the error is less than 2 cm. The GPS system time is associated with coordinated universal time (UTC) in accordance with observations of the United States Marine Observatory. Nominally, the GPS time scale has a constant 18 s discrepancy with the international atomic time. The time is counted in GPS weeks and seconds within the current week from 06.01.1980 at 00:00:00. In the GPS system, the week number is recorded using a 10-bit binary number. The zero week number was repeated at midnight from August 21 to August 22, 1999.

2.2. GLONASS overview

For the first time on the use of satellites for navigation was made by Prof. Shebshaevich V.S. in 1957. The opportunity was opened by him in the study of applications of radio astronomy methods in navigation. These studies were used in 1963 during the development work on the first domestic low-orbit satellite system “Cicada”. In 1967 the first Russian satellite Kosmos-192 was launched into orbit. The “Cicada” system was commissioned as part of 4 satellites in 1979. After 2008 the consumers of the space navigation systems “Cicada” and “Cicada –M” were transferred to the GLONASS service, and the operation of these systems was discontinued [5].

Subsequently, the function for detecting objects in distress was implemented in “Cicada” satellites. First of all it concerned various ships and aircrafts. Due to this, quite a few lives were saved, which later drew attention to satellite navigation. Based on the research it was decided to use the GLONASS orbital constellation. Now GLONASS is a main competitor to GPS and it was developed by Russian Federation.

The first tests of the GLONASS system were started in October off 1982. In the same year the first GLONASS navigation spacecraft was launched. And in 1993 the experimental exploration began. At that time there was no civilian segment of consumers, which was a significant drawback. In 1995 the full-capacity orbital grouping was deployed and the system was fully operational.

Like GPS GLONASS also consists of space, control and users segments. Nevertheless it is two totally different navigation systems. Currently GLONASS includes 27 satellites, 22 of which is active and 3 reserve satellites. They are located in medium-altitude near-circular orbits at an altitude of 19,100 km. Instead of 6 orbital levels GLONASS has only 3 with an angle of 64.8° from the equator with the orbital period was 11 hours 15 minutes and 44 seconds, what totally differs from GPS technology. Such period of circulation allowed creating a stable orbital system that does not require the maintenance of corrective impulses, which was one of the main differences from GPS. Also the inclination angle provides 100% availability of satellites in the territory of the Russian Federation. In addition, two problems which important for satellite navigation were solved. The first is the mutual synchronization of satellite time scales with nanosecond accuracy. The second is highly accurate determination and prediction of orbital parameters of satellites. This became possible due to the inclusion of values of second order of smallness such as light pressure, uneven rotation of the Earth, etc [5].

Every GLONASS satellite transmits two codes (C/A and P-Code) on two frequencies. Every satellite transmits the same code, but at different frequencies in the vicinity of 1602MHz (L1 Band) and 1246 MHz (L2 Band). The frequencies can be determined through the following equation, where k (k = -7, -6, -5 … 6) is the frequency channel of the satellite under consideration:

- Frequency in L1 Band: f1 = 1602 MHz + k • (9/16) MHz
- Frequency in L2 Band: f2 = 1246 MHz + k • (7/16) MHz

If at the beginning of 2000 accuracy provided by GLONASS was significantly below GPS accuracy, then now both navigation systems determine the position of object with error less than 10 meters (Figure 2.4). Some sources claim that the accuracy of GLONASS exceeds the accuracy of GPS [6].

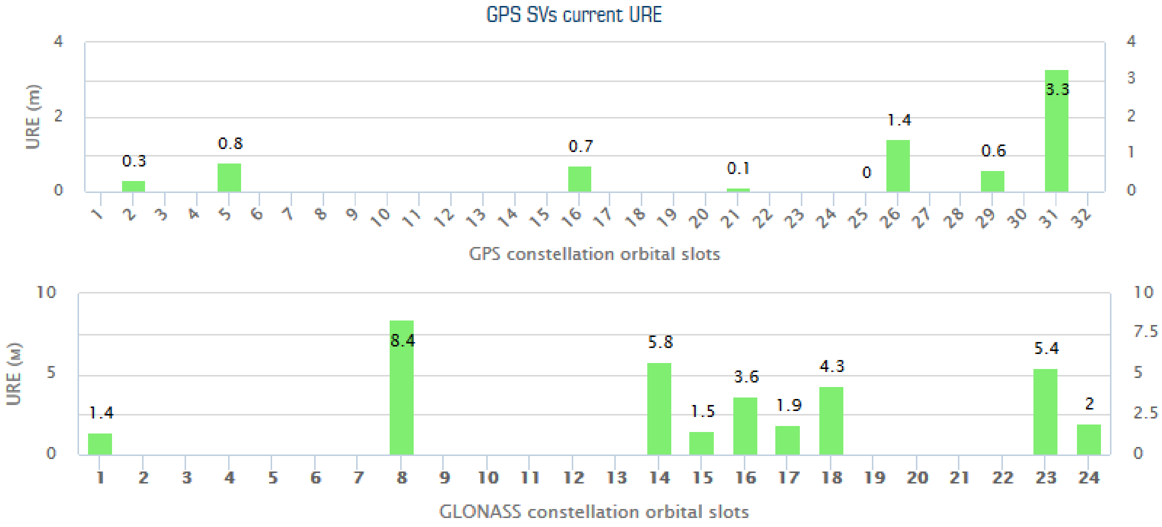


Figure 2.4 – GPS and GLONASS User Range Error on 25.07.2019 [7]

GLONASS uses a coordinate system called “PZ-90” in which the precise location of the North Pole is given as an average of its position from 1990 to 1995. GLONASS time corresponds to UTC time in Moscow.

3. GENERAL PRINCIPLES OF SATELLITE NAVIGATION

The chapter describes the basic principles of satellite navigation. It tells what data the satellites broadcast and how the receiving device uses it to determine its own location. The protocols used to provide the results of calculations and their structure are described. Also, it provides information about frequency bands that are used for the satellite navigation.

3.1. Position determination

The satellite navigation allows using the satellites to determine the location of an object. The satellites are located on orbit in space and spinning around the Earth. Each of orbiting satellites transmits information about its exact position. Each satellite equipped with onboard clocks. When tracking device receives the signal from satellite, first of all it needs to determine the delay time required for propagation the signal from satellite to the receiver. So, each satellite has an own time and it transmits it as well as satellite location data. After receiving this signal, receiver is able to calculate the signal travel time (Figure 3.1). To determine the distance it is assumed that the radio waves from satellite propagate with a constant speed equal speed of light c in vacuum ($3 \cdot 10^8$ m/s). Thus, we will get the distance from the receiver directly to the satellite by multiplying the speed by travel time. However this value is true, if clocks in receiver and satellites are very good synchronized. If it is not, then there can be discrepancy between the calculated and actual distance. In navigation this observed distance referenced to the local clock is referred to as *pseudorange*. For example travel time of one microsecond generates a pseudorange of 300 meters [3]. To solve this ambiguity it is needed to use the second synchronized time signal. In other words, when an unsynchronized onboard clock is employed in calculating position, it is necessary that the number of time signal transmitters exceed the number of unknown dimensions by a value of one.

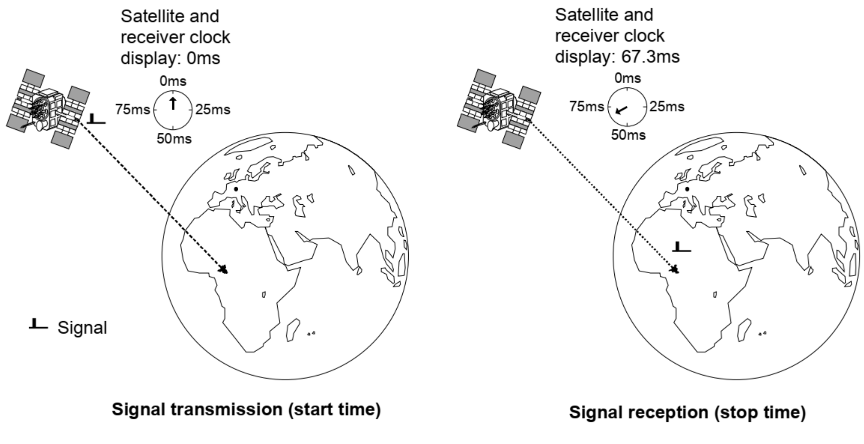


Figure 3.1 – Travel time determination [3]

In this manner the receiver determines the distance to each satellite. Knowing the distance to one satellite the receiver can be located at any point of a circle of radius equal the distance. In other words, using one satellite is impossible to determine the location of the object. Two satellites will give us the two circles, which are intersect in 2 points. If we have a third satellite, then these 3 circles intersects in one point. Exactly this point is a location of our object. So for determination position of device needed to estimate distance at least to three satellites with known positions. Such method in geolocation called *trilateration*. In this case we speak about 2D positioning since we don't consider a third coordinate.

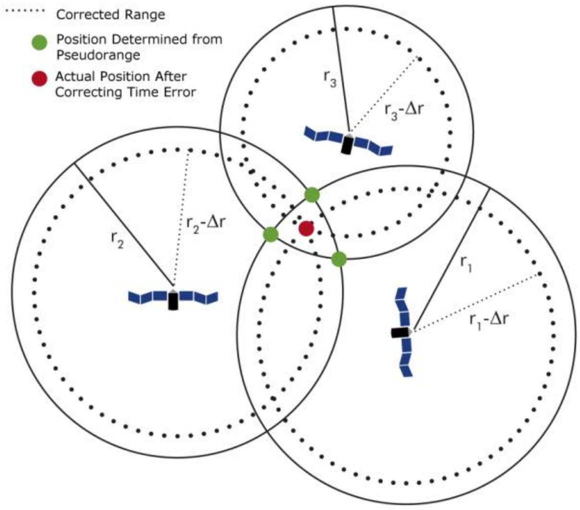


Figure 3.2 – Two -dimensional trilateration with three satellites [8]

Thus geometry plays an important role in this process. If receivers and satellites clock are not synchronized then we get a distance with error. To obtain the value of this error we should multiply the speed of the light *c* on difference between time of satellite and time of the receiver Δt:

$$\Delta r = c \bullet \Delta t \tag{1}$$

This error leads to inaccurate position calculation. To eliminate this inaccuracy, the receiver needs another satellite firstly to adjust the time, and then this correction will correct the pseudorange error. Therefore, for determining 3D position at least 4 satellites are required: 3 of them are used for 3 dimensions coordinates determination and 1 is for time synchronization.

3.2. Navigation radio signals

When choosing the types and parameters of signals used in satellite radio navigation systems, a whole set of requirements and conditions are taken into account. The signals should provide high accuracy of measurement of the time of arrival (delay) of a signal and its Doppler frequency and a high probability of correct decoding of the navigation message. Also, the signals must have a low level of mutual correlation in order for the signals of different navigation spacecraft to be reliably distinguished by the navigation equipment of consumers. In addition, GNSS signals should use the allocated frequency band as efficiently as possible with a low level of out-of-band emission, and have high noise immunity.

Almost all existing navigation satellite systems, with the exception of the Indian NavIC system, use the L-band (1-2 GHz) for transmitting signals. Instead of this the NavIC system will also emit signals in the S-band (2-4 GHz).

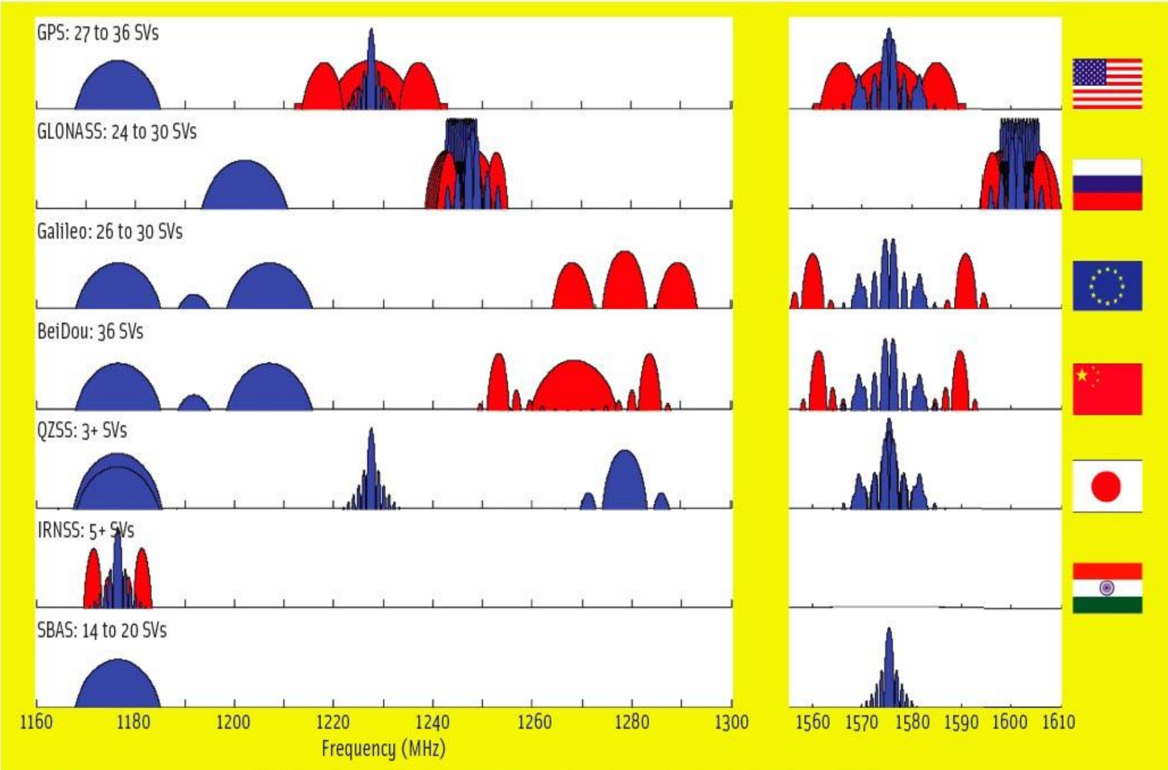


Figure 3.3 – Frequency bands occupied by various navigation satellite systems [9]

As satellite navigation systems developed, the types of modulation of radio signals used were changing. Most navigation systems used signals with binary phase shift-keying (BPSK) modulation. Now satellite navigation has begun a transition to a new class of modulating functions, called BOC (Binary Offset Carrier) signals. The use of signals with BOC modulation increases potential measurement accuracy and delay resolution. At the same time, the level of mutual interference in the joint operation of navigation systems using traditional and new signals is reduced.

3.3. Types of navigation message information

As it was said earlier, each of the satellites transmits information about its position and time from the onboard atomic clocks. However, this is not the only information that allows determining the exact location of the object. The most important are *ephemeris* and *almanac* data. The concept of *ephemeris* appeared in astronomy. It is a table of the celestial coordinates of the Sun, the Moon, planets and other astronomical objects. In navigation, this table consists of the coordinates of the transmitting satellite, as well as its current health. In turn the *almanac* contains information about each satellite of the constellation. In addition, the almanac contains data for time calibration, as well as ionosphere parameters, etc. Thus, the following information is transmitted in the navigation messages.

- Ephemeris information, which required for calculation of coordinates with sufficient accuracy
- Deviation error of the onboard time scale relative to the system time scale for taking into account the time shift of the spacecraft during navigation measurements
- The discrepancy between the time scale of the navigation system and the national time scale for solving the problem of synchronization of consumers
- Signs of fitness with satellite status information for prompt exclusion of satellites with identified failures from the navigation solution
- Almanac with information on orbits and the status of all devices in the grouping for a long-term rough forecast of satellite motion and measurement planning
- Ionosphere model parameters required by single-frequency receivers to compensate for navigation measurement errors associated with the propagation delay of signals in the ionosphere
- Earth rotation parameters for accurate recalculation of the coordinates of the consumer in different coordinate systems

Signs of fitness are updated within a few seconds, when a failure is detected. The parameters of ephemeris and time, as a rule, are updated no more than once every half hour. At the same time, the update period for several systems is very different and can reach four hours, while the almanac is updated no more than once a day.

According to its content, the navigation message is divided into operational and non-operational information and is transmitted as a stream of digital information. Initially, all navigation satellite systems used a frame / sub-frame / word structure. With this structure, the flow of digital information is formed in the form of continuously repeating frames, a frame consists of several sub-frames, and a sub-frame consists of several words and so on (Figure 3.4).

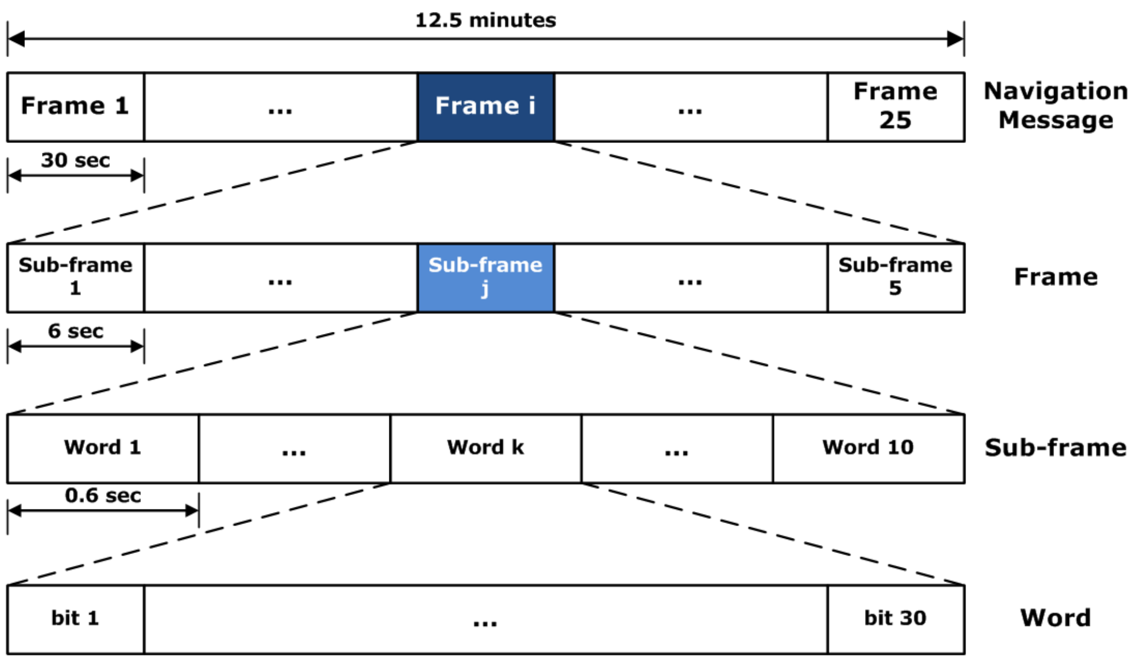


Figure 3.4 – Navigation message structure

In accordance with this structure, the signals of the Beidou, Galileo, GPS, GLONASS signals with frequency division were formed. Depending on the system, the size of frames, sub-frames may differ, but the formation principle remains the same.

Most signals now use a flexible string structure. In this structure, the navigation message is formed as a variable stream of lines of various types. Each type of line has its own unique structure and contains a certain type of information. The tracking device selects the next line from the stream, determines its type and selects the information contained in this line according to the type. Thus, first sub-frame contains information about time corrections, second and third contains ephemeris data, and last two transmits the current almanac frames.

The flexible string structure of the navigation message makes it possible to use the data transmission channel bandwidth much more efficiently. But the main advantage of the navigation message with a flexible string structure is the possibility of its evolutionary modernization while respecting the principle of backward compatibility. This allows the user to add in the process of upgrading GNSS to the previously existing row types with new types of strings. The tracking devices, which released earlier, ignore lines with new types and, therefore, do not use those innovations that are introduced in the process of GNSS modernization, but at the same time its performance is not impaired. Messages of the GLONASS signals with code division have a string structure.

3.4. Navigation messages protocols

Despite the fact that satellites continuously transmit auxiliary information, such as ephemeris and almanac, the received data need to be post-processed. This task is performed by the GNSS receiver. Based on the received data and their processing, the receiver determines the current location of the object. As a result, most users do not have access to the raw data transmitted by satellites. Instead of this the receiver provides the results of the calculations using special protocols. The u-blox devices support NMEA and UBX protocols.

NMEA is abbreviation of National Marine Electronics Association. Each NMEA message starts with a special symbol “$” after which follows an address block consisting of a talker id, defining the GNSS system type and a sentence formatter, that determines the type of message and its content. This is followed by all the transmitted information (payload). The data in the payload is separated by a comma to identify the beginning and end of each value, since there can be transferred data of different formats. Based on the payload content, a hash sum is calculated that will be unique for each different message. Symbol “*” identifies the beginning of checksum block and after that two special characters <CR> and <LF> are followed. They are indicate the end of a message and are used to stop receiving the current message.

Talker ID consists of 2 characters, which in most cases are a shortened version of the GNSS used. So, GPS = GP, GLONASS = GL, Galileo = GA, BeiDou = GB and any other combination is GN. Sentence formatter consists of 3 characters. A complete list of available items can be seen in Table 3.1. In short, using the NMEA protocol, the user receives the information of number of visible satellites, their coordinates and status, the calculated coordinates of the receiver, accuracy, time, speed and more. Thus, the protocol has 5 letter message identification. The NMEA protocol was designed exclusively for data exchange and is supported by most receivers. So this protocol is used only for data exchange between receiver and user.

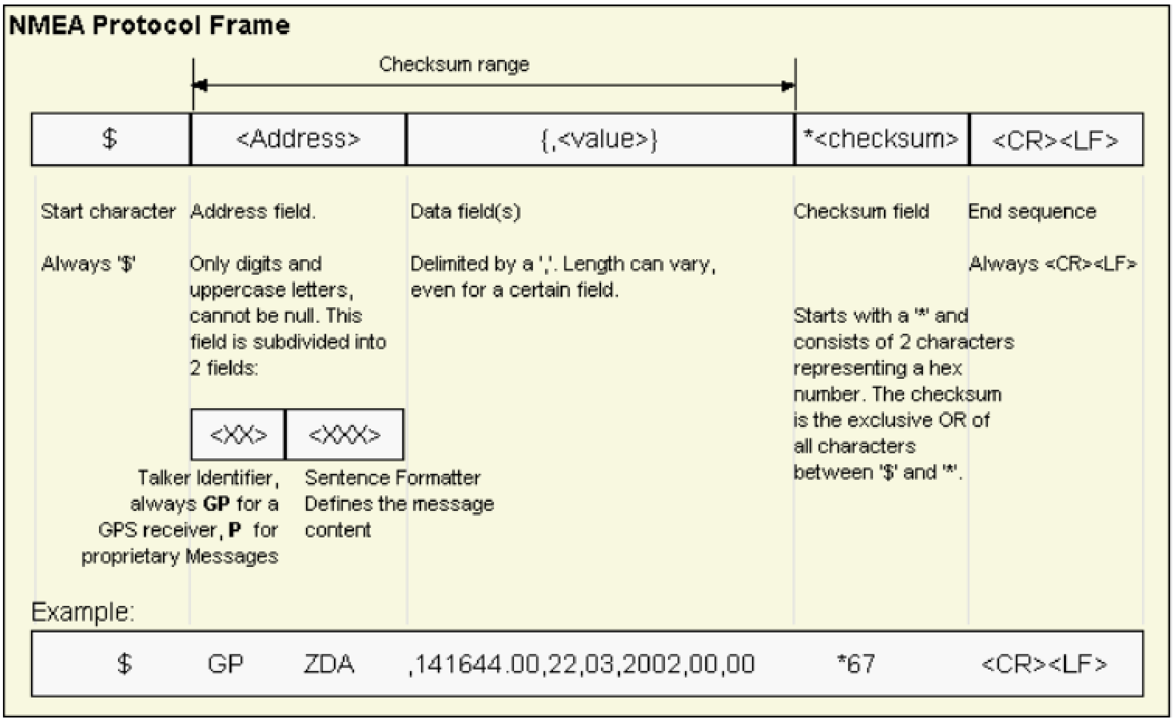


Figure 3.5 – NMEA protocol frame structure [10]

Mnemonic	Class/ID	Description
DTM	0xF0 0x0A	Datum Reference
GBQ	0xF0 0x44	Poll a standard message (if the current Talker ID is GB)
GBS	0xF0 0x09	GNSS Satellite Fault Detection
GGA	0xF0 0x00	Global positioning system fix data
GLL	0xF0 0x01	Latitude and longitude, with time of position fix and status
GLQ	0xF0 0x43	Poll a standard message (if the current Talker ID is GL)
GNQ	0xF0 0x42	Poll a standard message (if the current Talker ID is GN)
GNS	0xF0 0x0D	GNSS fix data
GPQ	0xF0 0x40	Poll a standard message (if the current Talker ID is GP)
GRS	0xF0 0x06	GNSS Range Residuals
GSA	0xF0 0x02	GNSS DOP and Active Satellites
GST	0xF0 0x07	GNSS Pseudo Range Error Statistics
GSV	0xF0 0x03	GNSS Satellites in View
RMC	0xF0 0x04	Recommended Minimum data
TXT	0xF0 0x41	Text Transmission
VLW	0xF0 0x0F	Dual ground/water distance
VTG	0xF0 0x05	Course over ground and Ground speed
ZDA	0xF0 0x08	Time and Date

Table 3.1 – NMEA protocol message classes [10]

As for the UBX protocol, its structure is noticeably different. This protocol was developed by the Swiss u-blox company and is actively used in their receivers. While NMEA messages are generated in a human readable form, UBX messages content is quite difficult to understand. The messages are transferred in hexadecimal form and it is identified by a sequence of two characters at once - ‘B5’ and ‘62’. This is due to the fact that it was possible to distinguish the beginning of the message, from its contents, since these values may occur repeatedly in the transmitted information. The structure of UBX frame is below:

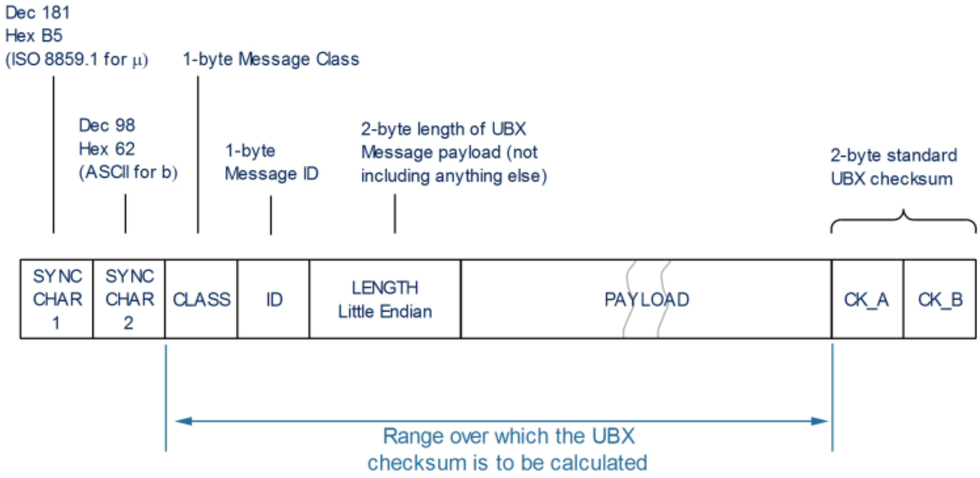


Figure 3.6 – UBX protocol frame structure [10]

This is followed by a 1 bit identifying the class of the message, followed by message id. The value of a class or message depends on the version of the protocol used. This chapter presents the values for version 15.00 which is supported by EVK-M8C device. Inconsistency in numbering is associated with constant changes in protocol versions, when new messages are added, and old ones lose their significance. In total, UBX includes a few dozens of message IDs, a complete list of which can be found in document [7]. This protocol is designed not only for receiving information from the receiver, but also for implementing receiver configuration. In other words, by sending a UBX message, you can change one or another receiver setting (change the port, configure the used GNSS, etc.)

Name	Class	Description
NAV	0x01	Navigation Results Messages: Position, Speed, Time, Acceleration, Heading, DOP, SVs used
RXM	0x02	Receiver Manager Messages: Satellite Status, RTC Status
INF	0x04	Information Messages: Printf-Style Messages, with IDs such as Error, Warning, Notice
ACK	0x05	ACK/NACK Messages: Acknowledge or Reject messages to UBX-CFG input messages
CFG	0x06	Configuration Input Messages: Set Dynamic Model, Set DOP Mask, Set Baud Rate, etc.
UPD	0x09	Firmware Update Messages: Memory/Flash erase/write, Reboot, Flash identification, etc.
MON	0x0A	Monitoring Messages: Communication Status, CPU Load, Stack Usage, Task Status
AID	0x0B	AssistNow Aiding Messages: Ephemeris, Almanac, other A-GPS data input
TIM	0x0D	Timing Messages: Time Pulse Output, Time Mark Results
ESF	0x10	External Sensor Fusion Messages: External Sensor Measurements and Status Information
MGA	0x13	Multiple GNSS Assistance Messages: Assistance data for various GNSS
LOG	0x21	Logging Messages: Log creation, deletion, info and retrieval
SEC	0x27	Security Feature Messages
HNR	0x28	High Rate Navigation Results Messages: High rate time, position, speed, heading

Table 3.2 – UBX protocol message ids [10]

This is followed by 2 bits describing the length of the payload of the transmitted message, and then the payload itself. The payload does not use any delimiting characters and the total numbers of bits are determined according to the protocol description. The frame ends with two bits of checksum, which is calculated by the 8-Bit Fletcher Algorithm, which is used in the TCP standard. In python it could be represented as:

```
CK_A, CK_B = 0, 0
for element in buffer:
   CK_A = CK_A + element
   CK_B = CK_A + CK_B
CK_A = CK_A % 256
CK_B = CK_B % 256
```

The first CK_A element is the sum of all message elements, with the exception of UBX prefix (the first two bits of the sequence). During each iteration the new CK_A value is added to CK_B, which was initially equal to 0. Thus, we obtain individual numerical sequences that are distinguishable from each other. The buffer contains the data over which the checksum is to be calculated. In contrast to the algorithm described in the documentation [10], the modulus procedure (%) is necessary to obtain the Unsigned Char format, which takes values from 0 to 255. The last two lines of code are responsible for the translating data into that format.

3.5. Time To First Fix

To determine the location of the object, the receiver requires relevant data of ephemeris and almanac. The receiver gets this data from the signals emitted by each satellite independently. Starting navigation immediately is expected for people once their GPS receivers are turned on, but this process can take up to several minutes, what is unacceptable in emergency and special situations. The time depends on many factors, such as signal level, influence of the ionosphere, multipath propagation, sky visibility (clear sky or urban environment), etc. In addition, the size of ephemeris and almanac is significantly different. If the ephemeris contains data for one satellite, the almanac contains data of the entire constellation. As a result, the receiver will take some time to get the orbital data and calculate the current position. This time is called *Time To First Fix*. Its value lies in the range from 18 to 36 seconds and depends both on the above factors and on the moment when the receiver began to receive data (Figure 3.7).

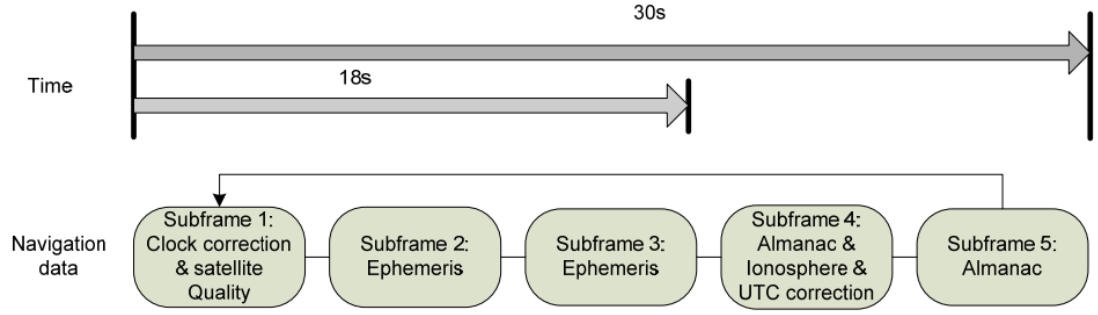


Figure 3.7 – Navigation message data stream to be downloaded [11]

In urban conditions, it may take several minutes to calculate a location. In other words, this time depends on what information the receiver has. According to the article [12] the TTFF mathematically can be represented as:

$$TTFF = T_w + T_{acq} + T_{tr} + T_{nm} + T_c, \quad (2)$$

where T_w means the receiver warm-up time, T_{acq} is the acquisition time, T_{tr} means the settling time for tracking, T_{nm} represents the navigation message decode time and T_c is the time to compute the position. Values of T_w and T_c are negligible in modern receivers. The value of T_{tr} can also be considered as relatively small value. Thus the total TTFF value depends mostly of acquisition time T_{acq} and time for reading data T_{nm}, and to reduce the total value of TTFF, it is necessary to minimize each of them. Also, the value of TTFF depends on resources, which receiver has, and on quality of signals. Thus, environment conditions (for example urban area) may have a critical effect of TTFF value. The signal may be multi-reflected or even blocked.

So, there are three types of start of the receiver: cold, warm and hot.

Hot start is the fastest possible option. In this case the receiver was not active for short time(less than 4 hours), which means that the ephemeris data is still relevant. In other words, the receiver does not need to download ephemeris data and it can immediately begin to calculate the position. In addition to the ephemeris, the receiver has other data such as almanac, last position, time, ionosphere correction and so on.

The next type is a *warm start*. In this case, the receiver was not active for more than 4 hours so that the ephemeris is already outdated, but other data is still relevant. Thus, the receiver may have information about the current time, its last position and almanac. This allows the receiver to quickly calculate its current position because it needs to download only current ephemeris data.

Finally, a *cold start* is a start in which the receiver has no additional information. Such a start occurs when the device is first turned on or if the device has been inactive for several days. After a cold start the receiver starts searching for all available satellites and downloading new ephemeris, almanac and other data as well as synchronizing the time. The receiver must decode data from several satellites and then first fix will be established. This type of start is also called a factory startup.

The value of TTFF at each type of start can significantly vary and depends of the model of the receiver used. Considered, that on average receiver may need about 26 seconds to get the first position at the cold start and 1 and 3 seconds at hot and ward start respectively. In addition, the u-blox company provides the ability to Controlled Software Reset. In this case, the user can choose which data the receiver will store and which data should be deleted. A complete list of data that the user can manage is shown in Figure 3.8

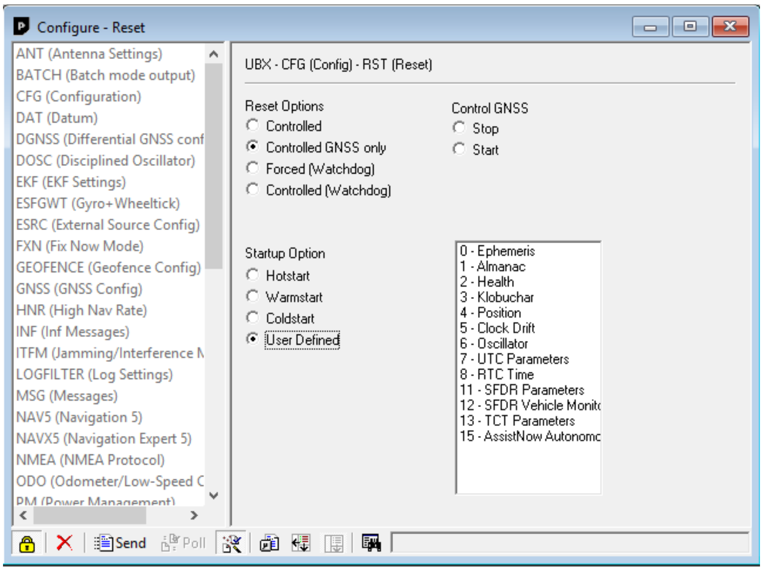


Figure 3.8 – The u-center CFG-RST features.

4. HARDWARE AND SOFTWARE DESCRIPTION

In this chapter the equipment and software used are described. Firstly, we will describe the general features and characteristics of evaluation board EVK M8C and GSG-54 Pendulum simulator, which were used in experiments of this work. Also, we will briefly talk about used software and describe the main algorithm of a test bench, using which all experiments were performed.

4.1. Device description

As part of this study, the receivers of the u-blox company, which is one of the world leaders in the field of navigation, were chosen as test devices. The experiments used two the same evaluation boards EVK-M8. General view of the device is presented in the Figure 4.1.

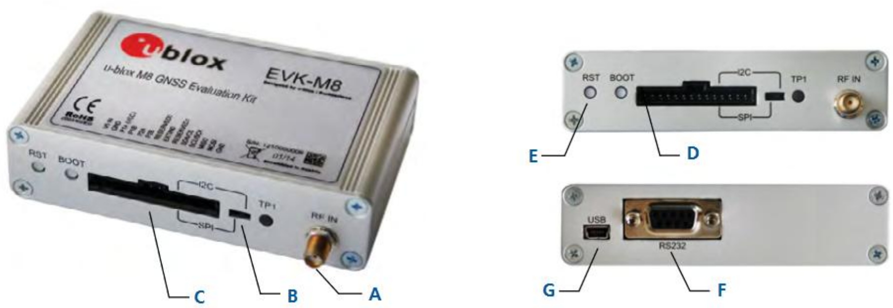


Figure 4.1 – EVK M8 evaluation board view [14]

According to receiver description [13] the device contains female type RF Input (A) for receiving antenna connection. The device supports the usage of both active and passive antennas. Active GPS / Galileo / GLONASS / BeiDou antenna is supplied as standard. The maximum current supply is 30 mA. The receiver MAX-M8C, which supports up to 3 global navigation systems at the same time, is installed inside the device. Also it supports differential correction systems such as SBAS, QZSS, etc. During operation, the board should be permanently connected to a power source, which can be supplied in two ways: via the USB cable (G) from the back or via V5 IN pin (D) on the front. Communication between the receiver and the computer can be carried out at once in several ways:

1) USB (G)
2) UART via RS232 (F)
3) SPI or I2C (C) depending on the position of the switch (B).

In addition, there is a button RST (E) to reset the device to the factory settings and the button BOOT to set the unit in safe boot mode. The u-blox receivers include a time pulse function providing clock pulses with a configurable pulse period, pulse length and polarity (rising or falling edge), which connected to the led on front panel. Also it has a backup battery inside. It using to store orbital information between operations and to enable faster start-up. By default it is a RENATA 3.0 V Li / MnO^2 battery of the type CR2450 (Figure 4.2). The battery has a rated capacity of 540 mA. The battery could operate temperature range is -40° C to +85° C.

The receiver contains a crystal oscillator for own time counting. Oscillator frequency is 26 MHz, but u-blox receivers are constructed in such way, that to provide a 1 kHz reference clock signal. After warm-up of device it starts counting the ticks of oscillator and provides 1 ms accuracy. Of course the accuracy of oscillator inferior accuracy of satellite atomic clocks. That's why the receiver will jump to an estimate of GNSS time, when it got the time from satellite.

Figure 4.2 – EVK-M8C inside view [14]

4.2. GNSS Simulator and GSG StudioView description

As the positioning procedure uses data from satellites, the position accuracy and time, which required for its calculation strongly depends on a lot of factors. Firstly clear sky view is necessary for the best performance. If the receiver is located in urban area with a lot of obstructions, than signal quality could be poor. In other words the tracking device could use the wrong data for fix calculations. And the problem is that is impossible to predict the error value. The main sources of such errors could be ionosphere, troposphere, multipath, interference and etc. For these reasons the accuracy estimation at the specific time moment could be incorrect. In order to evaluate the value, a large series of measurements is necessary to obtain an average value with a minimum error. As alternative the GNSS simulator can be used. It generates the satellite data with a predefined by user characteristics. It means that the environment conditions will be same during all measurements process. Basically using a simulator, you can test receiver characteristics such as:

- Position accuracy
- Time accuracy
- Multiple constellation testing
- Simulate trajectories and generate tracks
- Dynamic range
- Susceptibility to noise
- Sensitivity to loss of satellites
- Multi-path
- Interference
- Atmospheric conditions
- Jamming and spoofing

In some our tests we are used the Pendulum GSG-54 simulator (Figure 4.3). It is able to generate any combination of GPS, GLONASS, BeiDou, QZSS and SBAS satellite signals at the same time.

In total it allows to generate up to 64 simultaneous signals what more than enough (for example, EVK M8 supports maximum 32 channels for searching satellites at the same time). The simulator provides the full control over all test parameters, such as signal level, number of channels, satellites, level of interference, atmospheric model and so on. In additional, user can create personal route and upload it on simulator. It is possible to make tests for stationary and for moving object. Except of control buttons simulator has a display, which is able to present some graphics. So, even the most inexperienced operator can configure scenarios on-the-fly without the need for an external PC and pre-compilation phase. Via the front panel, the user can swiftly modify parameters. The simulated data arrives to tracking device via coax cable, which connected to RF-out (N-connector) of simulator. The pseudorange accuracy of output data for any one frequency band is 1 mm and 30 cm for different bands respectively [15].

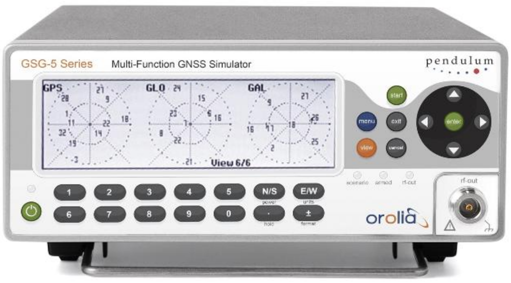


Figure 4.3 – Pendulum GSG-54 simulator front panel view

To create a track for a device the GSG StudioView software is used. The track is creating as a sequence of Google maps points. Points are added one by one. The program does not contain smoothing algorithms and the next point is connected to the previous straight line. Thus, to describe such elements as turning a road, it is necessary to use several points that are slightly distant from each other (Figure 4.4). So the trajectory curve is totally up to user. In addition to the exact coordinates of point the program automatically calculates the time moment in which the device will be at defined point. The calculations are based on the speed of the device, which assume will be constant during all path. To upload the trajectory file to the simulator it is necessary to have 3 files: “nmea”, “.traj” and “.scen”. The file with “.nmea” format contains the route information such as coordinates, speed, direction, time and etc. The “.traj” file contains the settings for the simulator and “.scen” file consist of information about scenario. After uploading these 3 files into simulator the user can choose the necessary scenario and start it. The simulator needs some time to launch it and directly after that it will start sending simulated data to connected device. The main advantage of such method is that the data is every time constant. It means that, if we are starting the same scenario several times, each time we have the same conditions for device. It allows excluding some factors of errors and get more reliable results. Another important advantage is that it is possible to control the simulator using a computer. In this case, communication between the computer and the simulator occurs via a USB cable. This function is useful for automating the measurement process, because the measurements may take several hours. You can start the device without a human intervention at any time (for example, at the night). To control the device, the syntax of SCPI (Standard Commands for Programmable Instruments) is used. This method uses string type commands and is intuitive for the user. Usually, command names are limited to the first 4 characters of the original word in English. So, to run the script, you need to send the simulator the command “SOURce: SCENario: LOAD” or, what is equivalent to “SOUR: SCEN: LOAD” [16]. In Python to communicate with simulator *pyvisa* library [17] was used.

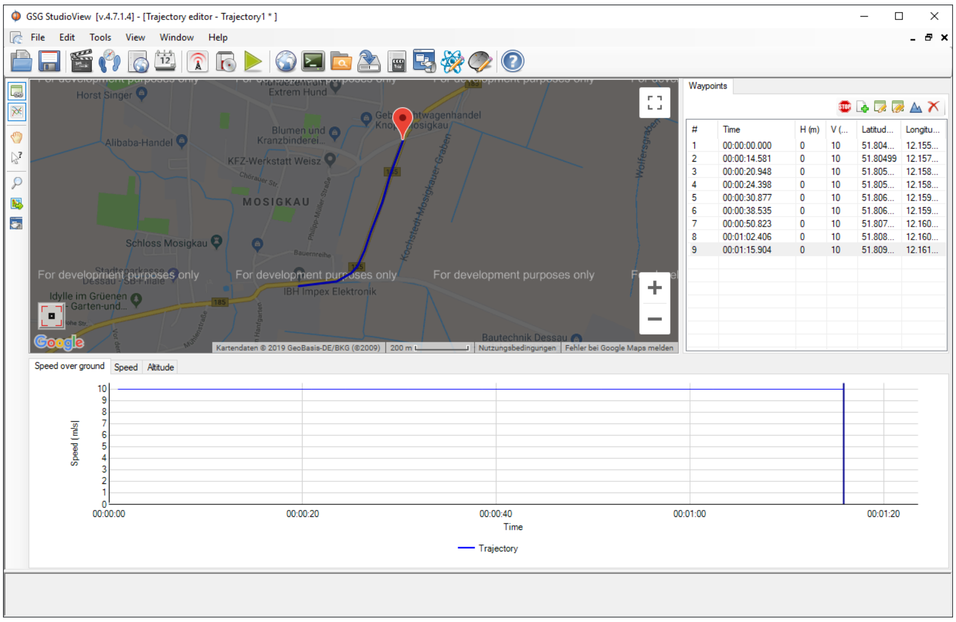


Figure 4.4 – GSG StudioView trajectory creation process

4.3. Measurement procedure prototype

To receive messages and send control commands to the receiver USB connection is using. It is possible to communicate with receiver via u-blox software called *u-center*, but it is not suitable for our experiments for several reasons. For example, it is not possible to make a cyclic reset of device without human intervention, but it is the simplest task for this research. So it was decided to write an own script on Python to communicate with device. At the beginning it was important to write a small script for sending and receiving commands but during time it was modified a lot. To start communication need to open COM-port on PC and for these purposes the *pyserial* library [18] was used. For sending and receiving information it has a *write* and *read* functions respectively. By default the data is transmitted in bytes, but it is easy to convert it into hex or decimal format. The data transmitted using NMEA and UBX protocols at the same time, so in the output we receive the mixture of it. To send the command need to convert it into decimal or hexadecimal values. So the command for a cold start of device has a following view:

coldstart = [0xB5, 0x62, 0x06, 0x04, 0x04, 0x00, 0xFF, 0xFF, 0x02, 0x00, 0x0E, 0x61]

Now, when we are able to receive and send commands, let's speak about algorithm for device testing. Firstly need to change the configuration of receiver by sending to it corresponding command. After that it is necessary to make a cold start of device to delete all stored data. Depending on the types of start described earlier, you can leave this or that information in the receiver. In our experiments a cold start command was sent to the devices. When receiver will get the fix, the received data will be written into a file for analyzing. Of course, one such measurement will not be enough, because GNSS performance affected by a lot of unpredictable factors such as ionosphere affection, noise, multipath propagation, etc. To avoid the influence of it is necessary to repeat this procedure several times in order to obtain the average values for this time period. Finally, algorithm can be represented as following view, where *n* is amount of measurements:

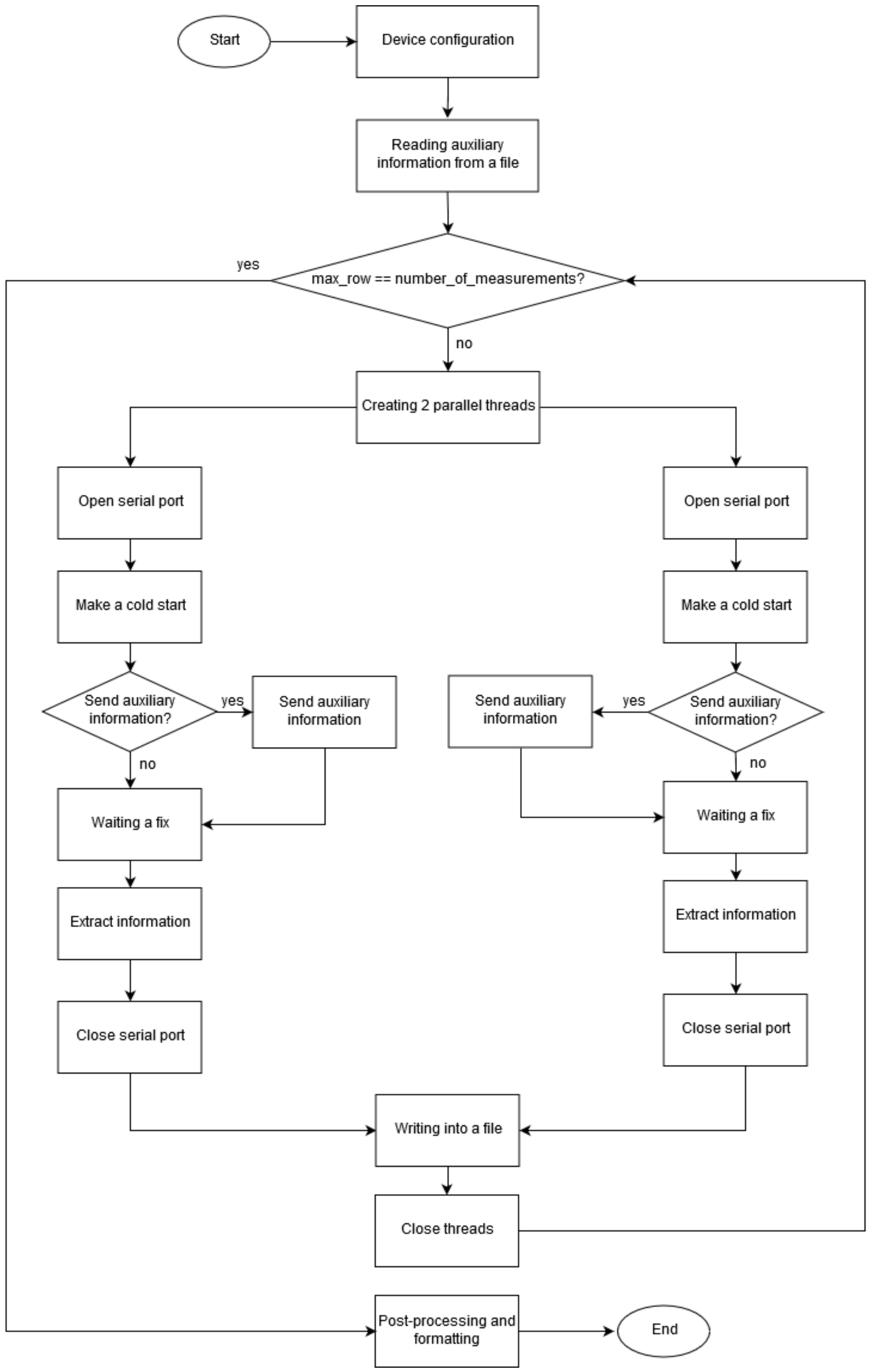


Figure 4.5 – Measurement procedure algorithm prototype

Let’s consider each block more detailed. The first two steps are reached by sending to receiver specific commands. These commands are using UBX protocol format, which doesn’t support acknowledges. According to that, some delays between sending are necessary, which avoids data loss. After resetting the devices, program enters the listening state and starts receiving messages from both devices separately. It waits UBX-NAV-STATUS message, which contain information about *time to first fix*. At the same time, the receiver continuously receives signals from satellites and is engaged in their processing and decoding. When the receiver receives all the necessary data, it begins to determine the position of the device and sends a message containing a TTFF. As mentioned earlier the data receiving in hex format, so after getting a fix it needs to convert extracted data into decimal values. Exactly this data will be written into Excel file for further analysis. For data writing *openpyxl* library [19] was used. It allows creating and editing Excel files using Python. It means that after test the user will get already processed data, which is easy to analyze.

To identify which configuration is better, need to use at least two same devices. In our test it will be two evaluation boards EVK-M8C. One of them will use the default configuration of manufacture and other is the testable. To achieve the better accuracy results, it is necessary to create the identical conditions for both devices. In other words, both antennas should be placed in the same place, or both receivers must use one shared antenna using RF splitter. It allows having equal RF environment and avoiding influence of different noises, providing the same sky view with same angles. Also both devices must use identical equipment (USB cables and etc). The procedure, which was described before, should be executed for both devices simultaneously. Thus for one configuration test need to create two threads in parallel for both devices and made a cycle measurements a certain number of times.

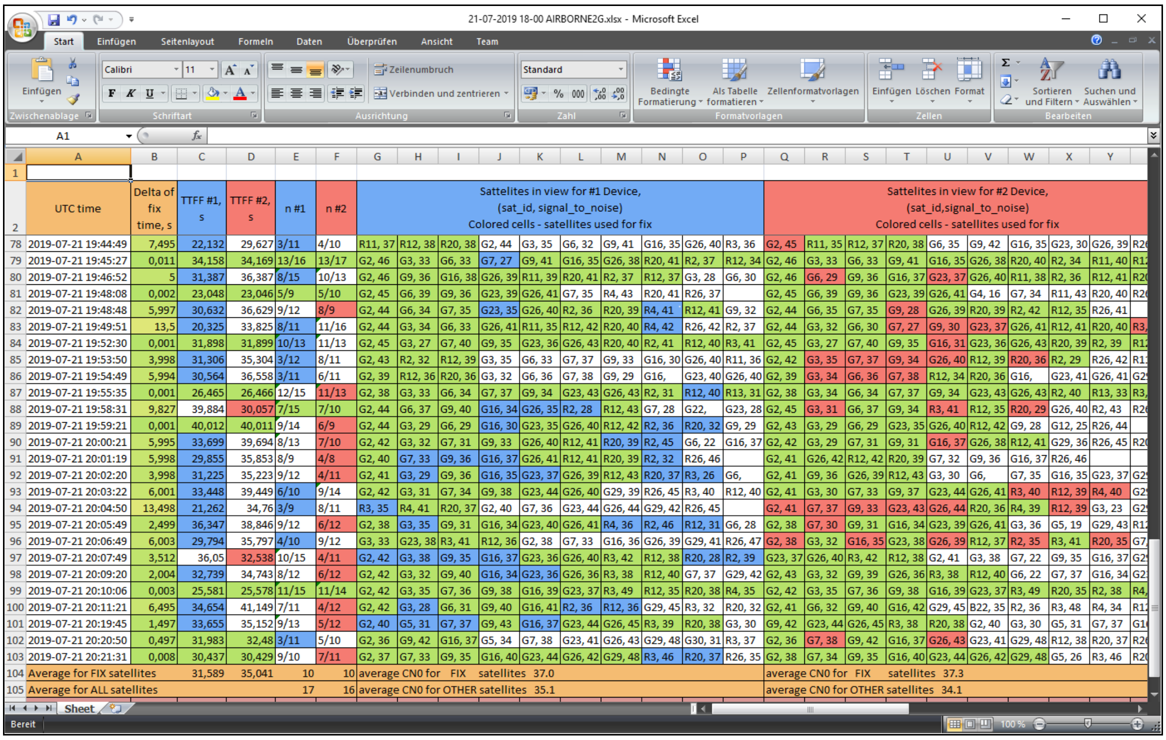
Figure 4.6 – Measurement stand

Thus, the application was written in Python and has the following features:

- Sending control commands
- Receiving messages
- Decryption and extraction of necessary information
- Data processing
- Logging
- Writing into a file

In addition to the main functionality, there are also a number of additional features that are used when necessary. So, the program is able to analyze data in Excel tables and format them for better visualization, control other devices, such as GNNS simulator, track the location of an object, as well as take measurements at the specified time. The listed features of the test bench can minimize the need for human control. Thus, measurements can take place without user intervention, for example at the night time. This primarily saves time. For example, to carry out the simplest cyclic restart of a device after receiving a fix in the u-center, continuous human intervention and constant monitoring of the status of a message are necessary. A full cycle of 100 parallel measurements may require about 2.5 to 3 hours with a standard configuration. In addition, user can create a mixture of data from information messages of different classes and track their changes simultaneously in one table. All this increases the efficiency and allows you to most accurately evaluate the performance of a particular setting. The program is capable of controlling two receivers at once in parallel.

The structure of the output file can be seen in Figure 4.7.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y
1																									
2	UTC time	Delta of fix time, s	TTFF #1, s	TTFF #2, s	n #1	n #2	Sattelites in view for #1 Device, (sat_id, signal_to_noise) Colored cells - satellites used for fix										Sattelites in view for #2 Device, (sat_id,signal_to_noise) Colored cells - satellites used for fix								
78	2019-07-21 19:44:49	7,495	22,132	29,627	3/11	4/10	R11, 37	R12, 38	R20, 38	G2, 44	G3, 35	G6, 32	G9, 41	G16, 35	G26, 40	R3, 36	G2, 45	R11, 35	R12, 37	R20, 38	G6, 35	G9, 42	G16, 35	G23, 30	G26, 39
79	2019-07-21 19:45:27	0,011	34,158	34,169	13/16	13/17	G2, 46	G3, 33	G6, 33	G7, 27	G9, 41	G16, 35	G26, 38	R20, 41	R2, 37	R12, 34	G2, 46	G3, 33	G6, 33	G9, 41	G16, 35	G26, 38	R20, 40	R2, 34	R11, 40
80	2019-07-21 19:46:52	5	31,387	36,387	8/15	10/13	G2, 46	G9, 36	G16, 38	G26, 39	R11, 39	R20, 41	R2, 37	R12, 37	G3, 28	G6, 30	G2, 46	G6, 29	G9, 36	G16, 37	G23, 37	G26, 40	R11, 38	R2, 36	R12, 41
81	2019-07-21 19:48:08	0,002	23,048	23,046	5/9	5/10	G2, 45	G6, 39	G9, 36	G23, 39	G26, 41	G7, 35	R4, 43	R20, 41	R26, 37		G2, 45	G6, 39	G9, 36	G23, 39	G26, 41	G4, 16	G7, 34	R11, 43	R20, 40
82	2019-07-21 19:48:48	5,997	30,632	36,629	9/12	8/9	G2, 44	G6, 34	G7, 35	G23, 35	G26, 40	R2, 36	R20, 39	R4, 41	R12, 41	G9, 32	G2, 44	G6, 35	G7, 35	G9, 28	G26, 39	R20, 39	R2, 42	R12, 35	R26, 41
83	2019-07-21 19:49:51	13,5	20,325	33,825	8/11	11/16	G2, 44	G3, 34	G6, 33	G26, 41	R11, 35	R12, 42	R20, 40	R4, 42	R26, 42	R2, 37	G2, 44	G3, 32	G6, 30	G7, 27	G9, 30	G23, 37	G26, 41	R12, 41	R20, 40
84	2019-07-21 19:52:30	0,001	31,898	31,899	10/13	11/13	G2, 45	G3, 27	G7, 40	G9, 35	G23, 36	G26, 43	R20, 40	R2, 41	R12, 40	R3, 41	G2, 45	G3, 27	G7, 40	G9, 35	G16, 31	G23, 36	G26, 43	R20, 39	R2, 39
85	2019-07-21 19:53:50	3,998	31,306	35,304	3/12	8/11	G2, 43	R2, 32	R12, 39	G3, 35	G6, 33	G7, 37	G9, 33	G16, 30	G26, 40	R11, 36	G2, 42	G3, 35	G7, 37	G9, 34	G26, 40	R12, 39	R20, 36	R2, 29	R26, 42
86	2019-07-21 19:54:49	5,994	30,564	36,558	3/11	6/11	G2, 39	R12, 36	R20, 36	G3, 32	G6, 36	G7, 38	G9, 29	G16,	G23, 40	G26, 40	G2, 39	G3, 34	G6, 36	G7, 38	R12, 34	R20, 36	G16,	G23, 41	G26, 41
87	2019-07-21 19:55:35	0,001	26,465	26,466	12/15	11/13	G2, 38	G3, 33	G6, 34	G7, 37	G9, 34	G23, 43	G26, 43	R2, 31	R12, 40	R13, 31	G2, 38	G3, 34	G6, 34	G7, 37	G9, 34	G23, 43	G26, 43	R2, 40	R13, 33
88	2019-07-21 19:58:31	9,827	39,884	30,057	7/15	7/10	G2, 44	G6, 37	G9, 40	G16, 34	G26, 35	R2, 28	R12, 43	G7, 28	G22,	G23, 28	G2, 45	G3, 31	G6, 37	G9, 34	R3, 41	R12, 35	R20, 29	G26, 40	R2, 43
89	2019-07-21 19:59:21	0,001	40,012	40,011	9/14	6/9	G2, 44	G3, 29	G6, 29	G16, 30	G23, 35	G26, 40	R12, 42	R2, 36	R20, 32	G9, 29	G2, 43	G3, 29	G6, 29	G23, 35	G26, 40	R12, 42	G9, 28	G12, 25	R26, 44
90	2019-07-21 20:00:21	5,995	33,699	39,694	8/13	7/10	G2, 42	G3, 32	G7, 31	G9, 33	G26, 40	R12, 41	R20, 39	R2, 45	G6, 22	G16, 37	G2, 42	G3, 29	G7, 31	G9, 31	G16, 37	G26, 38	R12, 41	G29, 36	R26, 45
91	2019-07-21 20:01:19	5,998	29,855	35,853	8/9	4/8	G2, 40	G7, 33	G9, 36	G16, 37	G26, 41	R12, 41	R20, 39	R2, 32	R26, 46		G2, 41	G26, 42	R12, 42	R20, 39	G7, 32	G9, 36	G16, 37	R26, 46	
92	2019-07-21 20:02:20	3,998	31,225	35,223	9/12	4/11	G2, 41	G3, 29	G9, 36	G16, 35	G23, 37	G26, 39	R12, 43	R20, 37	R3, 26	G6,	G2, 41	G9, 36	G26, 39	R12, 43	G3, 30	G6,	G7, 35	G16, 35	G23, 37
93	2019-07-21 20:03:22	6,001	33,448	39,449	6/10	9/14	G2, 42	G3, 31	G7, 34	G9, 38	G23, 44	G26, 40	G29, 39	R26, 45	R3, 40	R12, 40	G2, 41	G3, 30	G7, 33	G9, 37	G23, 44	G26, 41	R3, 40	R12, 39	R4, 40
94	2019-07-21 20:04:50	13,498	21,262	34,76	3/9	8/11	R3, 35	R4, 41	R20, 37	G2, 40	G7, 36	G23, 44	G26, 44	G29, 42	R26, 45		G2, 41	G7, 37	G9, 33	G23, 43	G26, 44	R20, 36	R4, 39	R12, 39	G3, 23
95	2019-07-21 20:05:49	2,499	36,347	38,846	9/12	6/12	G2, 38	G3, 35	G9, 31	G16, 34	G23, 40	G26, 41	R4, 36	R2, 46	R12, 31	G6, 28	G2, 38	G7, 30	G9, 31	G16, 34	G23, 39	G26, 41	G3, 36	G5, 19	G29, 43
96	2019-07-21 20:06:49	6,003	29,794	35,797	4/10	9/12	G3, 33	G23, 38	R3, 41	R12, 36	G2, 38	G7, 33	G16, 36	G26, 39	G29, 41	R26, 47	G2, 38	G3, 32	G16, 35	G23, 38	G26, 39	R12, 37	R2, 35	R3, 41	R20, 35
97	2019-07-21 20:07:49	3,512	36,05	32,538	10/15	4/11	G2, 42	G3, 38	G9, 35	G16, 37	G23, 36	G26, 40	R3, 42	R12, 38	R20, 28	R2, 39	G23, 37	G26, 40	R3, 42	R12, 38	G2, 41	G3, 38	G7, 22	G9, 35	G16, 37
98	2019-07-21 20:09:20	2,004	32,739	34,743	8/12	6/12	G2, 42	G3, 32	G9, 40	G16, 34	G23, 36	G26, 36	R3, 38	R12, 40	G7, 37	G29, 42	G2, 43	G3, 32	G9, 39	G26, 36	R3, 38	R12, 40	G6, 22	G7, 37	G16, 34
99	2019-07-21 20:10:06	0,003	25,581	25,578	11/15	11/14	G2, 42	G3, 35	G7, 36	G9, 38	G16, 39	G23, 37	R3, 49	R12, 35	R20, 38	R4, 35	G2, 42	G3, 35	G7, 36	G9, 38	G16, 39	G23, 37	R3, 49	R20, 35	R2, 38
100	2019-07-21 20:11:21	6,495	34,654	41,149	7/11	4/12	G2, 42	G3, 28	G6, 31	G9, 40	G16, 41	R2, 36	R12, 36	G29, 45	R3, 32	R20, 32	G2, 41	G6, 32	G9, 40	G16, 42	G29, 45	B22, 35	R2, 36	R3, 48	R4, 34
101	2019-07-21 20:19:45	1,497	33,655	35,152	9/13	5/12	G2, 40	G5, 31	G7, 37	G9, 43	G16, 37	G23, 44	G26, 45	R3, 39	R20, 38	G3, 30	G9, 42	G23, 44	G26, 45	R3, 38	R20, 38	G2, 40	G3, 30	G5, 31	G7, 37
102	2019-07-21 20:20:50	0,497	31,983	32,48	3/11	5/10	G2, 36	G9, 42	G16, 37	G5, 34	G7, 38	G23, 41	G26, 43	G29, 48	G30, 31	R3, 37	G2, 36	G7, 38	G9, 42	G16, 37	G26, 43	G23, 41	G29, 48	R12, 38	R20, 37
103	2019-07-21 20:21:31	0,008	30,437	30,429	9/10	7/11	G2, 37	G7, 33	G9, 35	G16, 40	G23, 44	G26, 42	G29, 48	R3, 46	R20, 37	R26, 35	G2, 38	G7, 34	G9, 35	G16, 40	G23, 44	G26, 42	G29, 48	G5, 26	R3, 46
104	Average for FIX satellites		31,589	35,041	10	10	average CN0 for FIX satellites 37.0										average CN0 for FIX satellites 37.3								
105	Average for ALL satellites				17	16	average CN0 for OTHER satellites 35.1										average CN0 for OTHER satellites 34.1								

Figure 4.7 – Example of output data table

4.4. Estimation parameters using in observations

As assessment criteria, we will use the values of position accuracy 3D and horizontal accuracy 2D provided by the receiver in the UBX-NAV-POSECEF and UBX-NAV-POSLLH messages. The values will be extracted by the program after the device gets the fix. After carrying out a test experiment in which the cold start command was sent cyclically to both receivers, it was found that the values of these quantities vary over a wide range. So, along with an accuracy of 10 or even 5 meters, the results reaching several thousand meters were obtained. However, this does not mean that the obtained coordinates are so incorrect. As mentioned earlier, the receiver does not know the exact location in which it should be at one or another time, and the accuracy is estimated based on the environmental parameters. Since the simulator always provides data with the same parameters, this leads to the idea that the accuracy values received by the receiver are random in some way and are not suitable for quantifying the accuracy of the received data. Of course, the accuracy will increase to a certain value over time without restarting the device. Is it possible to improve the accuracy of the first correction? Using the simulator allows determining the real location of the object with high accuracy. The difference in the coordinates of the real location of the object and the coordinates received from the receiver will be the amount of accuracy. Thus, an algorithm for determining this difference can be developed. The ".nmea" file contains data on the control points on the basis of which the route was built. In total, the file contains two types of command: RMC and GGA. The information contained in these commands is not very different, so it's enough to use only messages of the RMC class, which is the most informative. Consider the structure of one such message in more detail. (Figure 4.8)

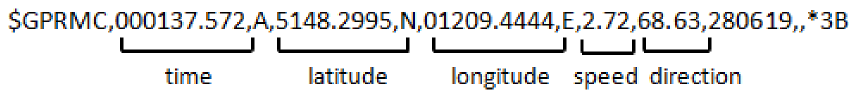


Figure 4.8 – GPRMC message structure

This message contains information about the current time, longitude and latitude of this point, the speed of the object and the direction of its movement. The data format is described in details in document [10]. Thus, we have a set of points with a detailed description of the characteristics of the object. If time, which passed from the moment of the last reference point to the moment of getting the fix, is known, the actual location of the object could be determined.

Suppose that at the moment of the beginning of movement (point A) the application starts its own timer. At the moment of getting the fix (point D), the program captures the value of time and compares its value with the time of the reference points from the file. Having found the last point that the device has crossed (point C), the program calculates the time difference between the time of the point and the timer value. Knowing time and speed, the distance Δd, which the device has passed after the last point, can be defined as $\Delta d = \Delta t \cdot v$, where Δt is the time difference and v is the speed of the object at point C. Knowing this distance and direction of movement, we can calculate the true position (point E) of the object using Vincenty's formulae for direct problem [25].

Now, knowing the coordinates of the true position of the object, and the coordinates received from the receiver, we can estimate the distance Δe between these points using the inverse Vincenty’s problem [25]. This value will act as a parameter for assessing the accuracy of the data obtained. For these calculations the *geopy* python library [26] was used.

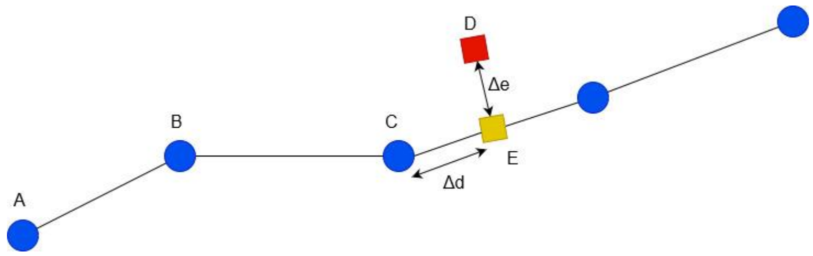


Figure 4.9 – Accuracy estimation algorithm description

5. TTFF IMPROVEMENT TECHNIQUES

In this chapter we will speak about some techniques, which potentially could improve the TTFF value. Test results with providing the current time to GNSS receiver are presented here. Also u-blox GNSS receivers have a various different configurations, which according to official documentation should reduce the TTFF value and increase the accuracy. So, we will test most suitable of them and make an analysis of results. The test results for stationary and moving object are given here.

5.1. Providing of current time

The value of the time of the first fix strongly depends on several factors. First of all, the receiver needs to obtain valid data of ephemeris and almanac. Secondly, the receiver and the satellite clocks must be strictly synchronized. Since the ephemeris data is a function of time, discrepancies in the course of clocks can lead to significant errors. To avoid this, the receiver adjusts its own time based on the received signals. This process occurs simultaneously with the reception of information from satellites and requires a certain time. In the case of urban area GNSS signal can be blocked by obstructions. This can lead to delayed reception of the time or even to the absence of a signal for several minutes.

As mentioned earlier, at least 4 satellites are needed to determine the position of the receiver. The 3 satellites are used to determine the coordinates and 1 for time synchronization. If the determination of the position of the device is impossible without satellites, then with time everything is different. What will happen if after a cold start give the current time to the receiver in other way? Will it speed up the calculations and reduce TTFF? As alternative way the time can be provided by another source. So receivers can be equipped with their own clocks. For simple, let’s use a PC as an external source of time. Time can be obtained using the standard *datetime* library in Python. The receiver supports several commands at once, with which it is possible to provide time to the receiver. The most widely used are UBX-AID-INI and UBX-MGA-INI-TIME_UTC. These commands are distinguished by the fact that for MGA class messages, acknowledges are sent that identify the message receiving status. Only MGA class messages have such feature. However, AID class commands are the most widely used. This is most likely due to the fact that the MGA class is much younger and not so long ago was introduced into use. In this regard, u-blox recommends using the MGA messages, since it is likely that the AID class may soon be excluded. We have connected two EVK-M8C evaluation boards to one antenna using an RF splitter. Let both devices work in standard mode, with the only difference that the second device after the cold start will be given the current time. The receiver supports several types of time such as GPS, UTC, GLONASS, etc. According to the documentation [10], the time in the UBX-AID-INI command should be converted into weeks and seconds. The number of weeks is counted from 5th January of 1980, and the number of seconds is counted from the beginning of the current week. This format corresponds to the GPS time. The important point is to set the correct value of the flag. If its value is incorrect (for example, zero), the receiver will reject the time being sent, no matter how accurate it was. In this manner 100 parallel measurements were made for both devices. Due to the bulkiness of the output results, only last 10 measurements are presented in Table 5.1, but average value is given for all results.

UTC date and time	Difference of fixing time, s	TTFF #1, s	TTFF #2, s
2019-07-24 08:24:17	2,486	35,185	37,671
2019-07-24 08:25:49	0,003	35,542	35,539
2019-07-24 08:27:19	5,504	36,316	30,812
2019-07-24 08:28:28	0,003	27,586	27,583
2019-07-24 08:29:49	0,003	32,949	32,946
2019-07-24 08:31:20	0,503	35,606	35,103
2019-07-24 08:32:50	1,504	34,564	33,06
2019-07-24 08:34:30	0,009	25,294	25,285
2019-07-24 08:35:49	0,007	36,373	36,366
2019-07-24 08:37:17	0,039	38,521	38,482
Total average value		**32,541**	**32,502**

Table 5.1 – Comparison of default configuration (1) and providing UTC time (2)

Measurements were taken one after another. In other words, after the simultaneous restart of both devices, at a fixed time (the first column of table), both devices begin to receive data from the satellites and analyze it, on the basis of which they get a fix. The device that received the TTFF waits until the other device finishes. Immediately after that the received data will be recorded into a table and analyzed by the program. As we can see, there is no difference in fixing time. The difference is only 0.039 seconds, which gives no advantage with such durations. Moreover, in the case of poor conditions, when antenna was placed inside the building on distance of 2 meters from the window, time providing has no positive effect (Table 5.2). In this experiment the sky view was blocked by obstructions and interference was present. The average CN0 value was 22.9 dBHz.

Configuration	TTFF, s	Accuracy, m
Default	184,76	378,462
Time providing	205,25	222,091

Table 5.2 – Time providing under poor conditions

Let's return to the coordinates. Let’s pretend that there be a device that is active while driving, but goes into sleep mode, when it stopped. Suppose that during the movement the device already had a fix and loaded actual ephemeris and almanac. After that, the device stopped for a long time, for example, several days. During all these time period, the device remained stationary, and its position has not changed since the last moment. In this case, if the device starts moving again, the ephemeris data will already become obsolete and the device will need to download new information, which will take some time. At the time of stopping the device already had information about its position. In this case, providing of information about last position of the device should allow more quickly and accurately determine its current location. The receivers will use the last known position as a starting point for searching for the satellite. The position providing is also possible with the help of the above mentioned classes. In the case of the AID class, the position, as well as the time, is transmitted as part of the AID-INI command. In the case of MGA, there are two available messages: MGA-INI-POS_XYZ and MGA-INI-POS_LLH. Based on the name, it is already becoming clear that the choice of the command used is based on the format of the data provided. Position data is stored in the device's internal memory, however, when making a cold start, this and other information will be deleted. To avoid this, the user can use the Battery Backed RAM (BBR) technology and save the necessary information in other storage. In our case, because the device is stationary, it is enough to provide a fixed value of longitude and latitude. For this purposes, we will use the MGA-INI-POS_LLH command, after sending which need to receive acknowledge in order to make sure that the receiver received the information. As can be seen from Table 5.3, the results did not get better; moreover, the second device took 2 seconds more. As receivers used shared antenna the RF conditions should be the equal. Such difference can be caused by the difference in the ephemeris downloading, because it is important at which frame the receiver starts to decode ephemeris.

UTC date and time	Difference of fixing time, s	TTFF #1, s	TTFF #2, s
2019-07-26 08:37:14	0,013	34,743	34,73
2019-07-26 08:38:14	2,995	31,298	34,293
2019-07-26 08:39:24	8,434	30,49	38,924
2019-07-26 08:40:46	0,019	35,801	35,782
2019-07-26 08:41:45	13,504	20,148	33,652
2019-07-26 08:42:45	0,011	31,706	31,695
2019-07-26 08:43:45	0,005	39,549	39,544
2019-07-26 08:48:58	0,005	27,203	27,198
2019-07-26 08:49:44	1,504	32,966	31,462
2019-07-26 08:50:45	0,998	31,968	32,966
Total average value		**34,431**	**36,306**

Table 5.3 – Test result of providing the last position to second device.

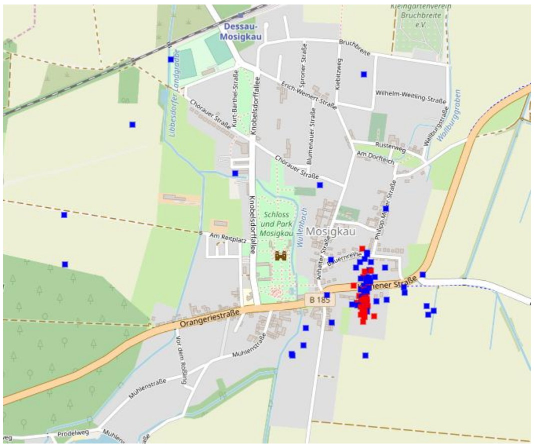


Figure 5.1 – Scatter plot of positions for default configuration (blue) and last position providing (red)

The positions were plotting during all measurements and the final view is presented on Figure 5.1. Blue squares represent the default configuration and red ones is location of the device to which last position was provided. It clear, that in the second device (red squares) is more localized than first one (blue squares).

5.2. Usage of various dynamic platform models

In addition to the standard settings, such as baud rate, COM port, GNSS used, etc., the modules of the u-blox company support various dynamic platform models. The use of a particular model can significantly affect on the output results, since the receiver will interpret input data in another way with filtering and carefully selecting data according to specified parameters. Thus, the usage of this function can both improve the output characteristics and have a negative impact, when using the wrong configuration. Therefore, it is important to find out which mode allows getting the best results in the case of stationary devices, and which for objects of motion.

In total, the u-blox devices support 10 different configurations, but only 9 are available to the EVK-M8C device (except for the "Bike" mode). By default, the "Portable" mode is used. According to this description (Table 5.5), if the object is moving, then it is likely that the usage of the "Pedestrian" or "Automotive" will provide more accurate data. Conversely, in the case of stationary objects, when data is received at a speed other than the specified threshold, the data will be ignored and not participate in the calculation of the position. Limiting factors are listed in Table 5.4 below.

Dynamic Platform Model Details

Platform	*Max Altitude [m]*	*MAX Horizontal Velocity [m/s]*	*MAX Vertical Velocity [m/s]*	*Sanity check type*	*Max Position Deviation*
Portable	12000	310	50	Altitude and Velocity	Medium
Stationary	9000	10	6	Altitude and Velocity	Small
Pedestrian	9000	30	20	Altitude and Velocity	Small
Automotive	6000	100	15	Altitude and Velocity	Medium
At sea	500	25	5	Altitude and Velocity	Medium
Airborne <1g	50000	100	100	Altitude	Large
Airborne <2g	50000	250	100	Altitude	Large
Airborne <4g	50000	500	100	Altitude	Large
Wrist	9000	30	20	Altitude and Velocity	Medium
Bike	6000	100	15	Altitude and Velocity	Medium

Table 5.4 – Dynamic platform models and their limitations

Dynamic Platform Models

Platform	*Description*
Portable	Applications with low acceleration, e.g. portable devices. Suitable for most situations.
Stationary	Used in timing applications (antenna must be stationary) or other stationary applications. Velocity restricted to 0 m/s. Zero dynamics assumed.
Pedestrian	Applications with low acceleration and speed, e.g. how a pedestrian would move. Low acceleration assumed.
Automotive	Used for applications with equivalent dynamics to those of a passenger car. Low vertical acceleration assumed.
At sea	Recommended for applications at sea, with zero vertical velocity. Zero vertical velocity assumed. Sea level assumed.
Airborne <1g	Used for applications with a higher dynamic range and greater vertical acceleration than a passenger car. No 2D position fixes supported.
Airborne <2g	Recommended for typical airborne environments. No 2D position fixes supported.
Airborne <4g	Only recommended for extremely dynamic environments. No 2D position fixes supported.
Wrist	Only recommended for wrist worn applications. Receiver will filter out arm motion. (just available for protocol version > 17)
Bike	Used for applications with equivalent dynamics to those of a motor bike. Low vertical acceleration assumed.

Table 5.5 – Dynamic platform models description [10]

According to the restrictions, there are a number of situations, where several dynamic models are suitable for a particular case. In this case, there is an ambiguity in the application of a particular configuration, and to eliminate it, it is necessary to make a series of observations. First of all, let's take measurements for a stationary object, when the device remains motionless throughout all measurements. The measurements were carried out at fixed intervals for several days (Table 5.6). For these purposes *schedule* python library [20] was used. It allows executing a program in specific time and with defined intervals. It is worth noting that the experiment was carried out in the evening and at night time. This decision was made due to the fact that during the day the jamming level was high (more then 20%), which greatly distorted the overall picture. If some measurements were taken during the day with a high level of interference, then others at night, when there is practically no interference. One of such sources of interference is computer monitors. That’s why the measurements were made with interval of 3 hours after 15:00 of UTC time, when other equipment was off. Thus, the program was executing at a strictly specified time. The measurement process began with a change in the configuration of one of the devices, after which a cold start command was sent to both devices. After a hundred measurements, the program went into standby mode until the next measurement time point arrived and then repeats this procedure.

Mode	UTC date and time	Average TTFF, s	Average number of fix satellites	Average CN0, dBHz
Automotive	16.07.2019 15:00	35,945	8	34.9
Pedestrian	16.07.2019 18:00	35,734	8	34.9
Stationary	16.07.2019 21:00	41,704	7	34.0
Sea	17.07.2019 00:00	39,451	7	34.8
Airborne1g	17.07.2019 03:00	43,997	7	34.8
Airborne2g	21.07.2019 18:00	35,041	8	37.3
Airborne4g	21.07.2019 21:00	36,059	8	37.4
Portable	23.07.2019 18:00	30,246	8	37.4
Wrist	23.07.2019 21:00	30,612	8	37.1

Table 5.6 – Dynamic platform models test results

As the comparison parameters, the average values of TTFF, the number of satellites involved in determining the position, and the average signal-to-noise value were chosen. From the results obtained, it is seen that the TTFF value varies in the range from 30 to 41 seconds. In addition, it can be seen that the number of satellites used and the average value of carrier-to-noise density (CN0) also differ. It is not clear whether these changes are related to the configuration used or whether this is due to differences in the number of satellites and signal level. Over the time the geometry of the satellites will be different. In addition, some satellites leave the field of view of the antenna and new ones appear. Thus, the receiver can use different satellites to determine the position at different times. To eliminate this ambiguity it is necessary to take measurements at the same time for several days. Of course, the average value of the carrier-to-noise density also depends on the day of measurement. This is due to the fact that the value of CN0 depends on the state of the ionosphere, such as electron density, which distorts the propagation path and weakens the signal level. Thus, the measurement results are presented in Table 5.7.

Mode	UTC date and time	Average TTFF, s	Average number of fix satellites	Average CN0, dBHz
Pedestrian	16.07.2019 18:00	35,734	8	34.9
Airborne2g	21.07.2019 18:00	35,041	8	37.3
Portable	23.07.2019 18:00	30,246	8	37.4
Automotive	25.07.2019 18:00	31,042	9	36.6
Stationary	26.07.2019 18:00	32,980	8	36.6
Sea	30.07.2019 18:00	31,902	8	37.4
Airborne1g	31.07.2019 18:00	34,121	8	37.3
Airborne4g	01.08.2019 18:00	34,638	8	37.3
Wrist	02.08.2019 18:00	31,836	8	36.9

Table 5.7 – Test results for different dynamic models at the fixing time

As we can see, the average fixing time is more than 30 seconds and difference between values reaches 5 seconds. Because the device was stationary during all experiments, it was expected that the “Stationary” mode would show the best performance. Despite its description, in both cases, this configuration did not show a time reducing, and moreover, it is inferior to models created for moving objects (for example, Automotive). The best results were shown by “Portable” dynamic model, which, according to the manufacturer, is suitable for most situations. This experiment showed that the usage of other dynamic model, which differs from the standard, unfortunately, does not provide a shorter fixing time for stationary object, but it significantly improves accuracy.

5.3. Various configurations analyzing

The u-blox devices are designed in such way that they have a wide range of settings for various situations. The use of other settings can lead both increase and decrease the accuracy of positioning. For example, user can change the minimum number of satellites involved in position calculation. According to the basics of navigation, accuracy of two satellites will be significantly worse than its value of three satellites. At the same time, decoding data from two satellites will require less time. Depending on the application, this or that parameter will have the greatest value. So, each user independently determines which one is most significant. The full functionality of the device is described in details in document [10]. After a thorough study, as well as taking into account the recommendations of technical support and information from the official forum of the company, an analysis of the available configurations was conducted. This study was conducted in order to identify options that can optimize the value of TTFF and the accuracy of positioning.

Earlier it was shown that the geometry of satellites plays a decisive role and has a huge impact on the accuracy obtained. However, the geometry of the constellation can also affect the magnitude of the TFFF. So, if the satellite is located at a low elevation angle, then the signal will pass through a thicker layer of the ionosphere. This means that the signal delay will be longer. For this reason, the u-blox sets a default limit of 5 degrees for satellite filtering. In other words, satellites whose elevation angle is less than the set threshold are not used for calculations. Thus, the use of this filtering will make it possible to exclude satellites, whose data may contain unpredictable time delays and reduce the data decoding time.

The other important feature is the *Static Hold*. The option is intended for stationary objects. In other words, the object will be considered as stationary until the receiver gets data of the speed and position deviation exceeding their predetermined threshold values. Observations showed that even in the case of a stationary object, its speed is different from 0 and can change over time. This option will reduce position deviations caused by factors such as multipath propagation.

In addition, the device contains a number of functions that are responsible for energy consumption. An increase in energy consumption implies an increase in the number and frequency of calculations. Accordingly, working in unlimited mode (*fullPower* function), it is assumed that the receiver will conduct the maximum number of measurements and calculations, which will allow a more accurate and quick assessment of the current location. The *waitTimeFix* function allows the device to synchronize time in the shortest possible time. The *doNotEnterOff* option prevents the receiver from becoming inactive even if positioning was not possible. Another way to speed up computation may be to reduce accuracy. The device supports 2 types of positioning: 3D and 2D fix. Their difference is that if in the first case, the receiver needs to determine all 3 coordinates, then in the second the height value remains fixed and the receiver calculates only two coordinates. Accordingly, the number of satellites for obtaining a 2D fix requires fewer satellites, and therefore less time for decoding. According to the standard, the receiver uses a combination of two types of fixes, when the receiver independently decides which type of fix will be calculated based on the available data. It makes sense to check whether position determination will be faster if user always calculate only 2D fix or not.

Thus, a complete list of analyzed functions is presented in table below.

	Configuration	**Date**	**TTFF, s**	**Accuracy, m**
1	MIN EL = 5 (Default)	22.08.2019	42,326	144,29
	MIN EL = 0		42,915	128,59
2	MIN EL = 5 (Default)	22.08.2019	37,251	104,232
	MIN EL = 15		39,72	139,696
3	Default	22.08.2019	26,372	46,67
	Static Hold Threshold = 1m/s Exit Dist = 0 m		26,927	62,516
4	Default	27.08.2019	41,377	124,245
	Static Hold Threshold = 1m/s Exit Dist = 500 m		41,749	105,642
5	Default	27.08.2019	42,909	133,131
	Static Hold Threshold = 1m/s Exit Dist = 300 m		42,36	149,744
6	Update period = 1 s (Default) Search period = 10 s	28.08.2019	46,999	129,158
	Update period = 0 Search period = 0		**44,461**	139,237
7	Update period = 1 s (Default) Search period = 10 s	28.08.2019	42,368	149,708
	Update period = 1 ms Search period = 1 s		42,913	136,121
8	Default	04.09.2019	47,32	87,034
	waitTimeFix		46,876	109,457
9	Default	04.09.2019	35,399	68,824
	doNotEnterOff		36,287	87,688
10	Default	04.09.2019	34,886	93,385
	fullPower		35,658	82,042
11	MIN SV = 3 (Default)	04.09.2019	38,691	115,109
	Min SV = 2		**36,681**	116,879
12	Rate = 1000 ms (Default)	05.09.2019	41,998	69,939
	Rate = 100 ms		41,888	**12,316**
13	3D/2D fix	06.09.2019	31,239	77,893
	2D only		31,305	55,433

Table 5.8 – Results of testing various configurations

The results of multiple measurements have shown that increasing the limit of elevation angle leads to increasing of TTFF value, and the use of satellite signals with low values does not have an effect at the cold start (cases 1, 2). The function of *Static Hold* did not give a gain either in time or in accuracy of positioning during a cold start (cases 3-5).It is assumed that its use can still be useful in the presence of a constant signal, to reduce power consumption.

The value of the *update period* determines the time between two position calculations. If within a certain time the receiver cannot obtain a position, then the device will retry after a time equal to the *search period*. According to the description, setting the update period to 0 will lead to inactive state of the receiver until it will not woken up by the user. Setting the search period to zero causes the receiver to wait in inactive state undefined. Nevertheless, the experiment shows that in this case the

TTFF was shorter than by default configuration (case 6) and usage other values don't provide such performance (case 7). We got a similar picture with set up minimum SV threshold to value of 2 (case 11). Nevertheless, both devices keep using 3 or more satellites for calculations. Rate reducing increasing the amount and frequency of calculations, what provides the better accuracy.

6. ASSISTED GPS TECHNOLOGY

Assisted GPS technology concept is described here and the u-blox company's AssistNow services are briefly explained. The chapter talks about their benefits and circumstances of use. The AssistNow Online performance is analyzed here.

6.1. General information

To determine the location receiver needs information about satellites positions. If the signal level is weak enough (below 30 dBHz), then it may take about 15 minutes, or even more. In satellite navigation, a technology called A-GPS is widely used and it is newest mechanism of TTFF improvement. The abbreviation is embroidered as Assisted GPS. This technology allows accelerating the cold start time of the tracking device. Acceleration occurs due to the provision of necessary information through alternative communication channels (for example, internet connection). This technology is widely used in cell phones that contain GPS receivers. Thanks to A-GPS technology, after turning on the receiver, it almost instantly determines the location. Satellites can be searched even in closed rooms, and floor decks are not a hindrance.

The idea of creating A-GPS first arose from engineers Jimi Sennot and Ralph Taylor in 1981. In particular, they proposed a signal that helps to capture a target for automatic tracking generated by a ground station, broadcast to user terminals [21]. The system debuted on October 1, 2001 in the United States on the 911 rescue network. The essence of the idea is simple. The main task of the A-GPS is to provide information, to receive which the receiver takes most of the time. If the device was inactive long enough, then a situation is possible, when ephemeris or almanacs had already become obsolete. When the device is turned on, the receiver needs to obtain up-to-date information about the satellites. The A-GPS is an auxiliary source that provides the necessary information to the receiver in much less time. The structure of the technology is shown on figure below:

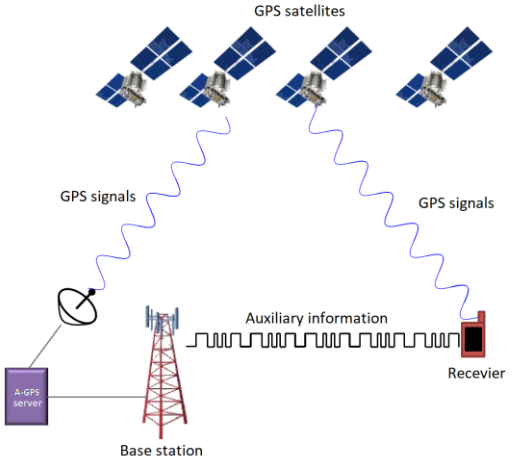


Figure 6.1 – A-GPS technology

A-GPS server, have an own receiver, which permanently receives the signals from satellites. It downloads the current orbital information and stores it. When receiver sends the request, the server's base station sends the auxiliary information to receiver through the network.

Thus, A-GPS can be divided into 2 types: online and offline. In the first case, the information comes to the receiver by downloading data using a mobile network. This type has a high speed of providing information and a shorter time of the first fix. This technology shows the best results in the urban environment, where the coverage of the operator's mobile network has the largest area. In addition, the use of this technology allows you to reduce the influence of multipath and allows the receiver to get a fix even with a low signal level of the satellites. Nevertheless, it has several disadvantages. First of all, the usage of this technology will be impossible in the absence of a network (for example, in fields or wilderness) or it can be extremely costly if the user is abroad in roaming conditions. The use of mobile technologies also significantly increases the power consumption of the device, which is critical in certain cases. If the power consumption is an important criterion for the user, as well as if you can use a good connection, then the offline version will give the best results. In this case, the data must be loaded in advance into the device's memory or onto external media, from which the receiver can retrieve the valid data at any time. If the online data has a size of 5-7 kb, then the offline version reaches 100 kb or more. Despite the long validity period of offline data, it will be better to provide the receiver with the most up-to-date data, since their accuracy deteriorates over time.

According to the [22] document AssistNow Online services provides the fix time about 1 second for the cold start and the offline version ensures the fixing time about 5 seconds.

In addition, the company has developed an AssistNow Autonomous mechanism for the case when the use of two previous AGPS is impossible. In this case, the receiver does not receive additional data. Conversely, it uses the broadcast satellite data for future orbit generation. The receiver independently calculates the orbits of GNSS satellites. This orbit information will store in a device. When signal is blocked or connection with satellite was not established, receiver uses predicted data, which reduces the time required for the device to determine the location. Of course, the load on the device increases significantly, fixing time is also inferior to online and offline versions. Nevertheless, the usage of this function is justified. Moreover, this technology can be used in conjunction with the other AssistNow service version according to documentation. The observations during the experiments showed that this function works only with the online version. Besides, this function only works with GPS satellites and doesn't supporting others.

6.2. A-GPS test

A-GPS technology is a powerful tool for satellite navigation. Nowadays, when the network covers really vast areas, and the Internet is a constant companion of every person's life and providing information using the network can reduce the time spent on location.

The u-blox provides such information like ephemeris and almanac, which is the main advantage of this technology. In addition to this, user can get information about current time, last position and other auxiliary information, such as ionosphere corrections. Data is available for all major navigation systems. To download the data file *urllib* python built-in library was used.

The user has the right to independently choose the algorithm for providing information. The u-blox company does not recommend sending the entire file. Instead of this, its recommend to send data by separate commands with some delay between sending. The use of delays is not a rational way. The TTFF value depends on the speed of information transferring and the use of delays will in reduce it. This will be especially critical with a large number of commands. The GPS constellation has 31 satellites, and GLONASS currently has 23 satellites. Then if you provide the receiver with information about the current ephemeris and almanac, then for this you will need to send (31+23)•2= 108 commands. Even if user make a delay of 0.1 second between sending, in total this procedure will take about 11 seconds. This value of TTFF can be critical especially in emergency situations. The user can use a faster algorithm, such as selective repeat. In this algorithm, delays are completely eliminated and initially the entire file is transmitted to the receiver. After this, the program should receive appropriate acknowledges for received messages. Based on the received acknowledges, the program should calculate the numbers of the lost packets and send only them to the receiver. This procedure will be performed until the receiver sends all acknowledgments. In total, it takes not more than 1.5 seconds to send the entire file, what sounds more optimistic.

In previous chapter was showed, that providing current time not allows to receiver faster determine its location. This is due to the fact that most of the time receiver spends on ephemeris downloading and during this time period receiver is able to synchronize the time. The situation is opposite, when the receiver already has actual ephemeris. In this case it will need 10 or even more seconds on time synchronization, and here providing current time may help. For these purposes the u-blox by default includes the current time information into AssistNow Online services. Interesting moment will be to understand how helps other information, such as last position and auxiliary data. To check it let both devices work in standard mode. AssistNow Online ephemeris and almanac data will be provided to both devices. In additional, the second device also will be provided last position using MGA-INI-POSLLH in first test, and with auxiliary data using in second experiment. To avoid delays associated with downloading data, it would be downloaded before making a cold start. Since the device was stationary during all time, we will provide the fixed coordinates. It’s expected that it also could improve both accuracy and TTFF values.

The result of both experiments are presented in table below

Configuration	**Date**	**TTFF, s**	**Accuracy, m**
AssistNow Online	06.09.2019	10,951	16,443
AssistNow Online + Position		8,325	15,213
AssistNow Online	12.09.2019	14,519	17,646
AssistNow Online + Auxiliary		15,719	15,894

Table 6.1 – AssistNow Online test results

As expected, the experiment showed that last position providing could reduce the TTFF value as well as improve the accuracy. Of course, the difference in accuracy is not so huge, but it is worth noting, that for shorter time receiver gets the better accuracy. Thus, providing last position could be helpful also when receiver has actual ephemeris data. Providing auxiliary data improves the accuracy, but increases the TTFF value. The usage of auxiliary is necessary for high precision devices, but not important for timing products. Besides, the TTFF values gotten during our experiment significantly differs from the values stated in the documentation. Nevertheless, it is worth considering that conditions of experiment was not perfect and were as close as possible to real situations. In previous chapter was showed that reducing rate’s value could improve the accuracy output. An interesting fact was also noticed when both receivers had assist data, but one of them determined the position in less than 10 seconds, and the second required about 30. This phenomenon has been observed repeatedly, which eliminates the possibility of accidental error.

7. POSITIONING ACCURACY ISSUES OF MOVING OBJECTS

The chapter provides the basic theory about accuracy estimation methods and describes the main values, which could be used in estimation of test performances. The main sources of positioning errors are listed here. The values of accuracy parameters provided by u-blox tracking devices are considered and the algorithm for more precise estimation was developed. In this series of measurements the Pendulum GSG-54 simulator was used to modulate the movement object.

7.1. Accuracy values and calculation methods

In tracking devices, the step-by-step determination of position together with the TTFF value plays an important role. In special situations, a person's life may depend on the accuracy and speed of determining the coordinates. The positioning process is iterative. Step by step, the position accuracy is calculated and after some time reaches the maximum possible value. It is expected that the receiver must immediately determine the exact location after switching on. However, the position obtained during the first correction may turn out to be rather poor and inaccurate. Positioning is based on data received from satellites, in many respects depends on how correct the received data is. If the data contains erroneous information, then the location will be determined incorrectly. The two sources of these errors are the ionosphere and multipath propagation. In addition, errors can be caused by inaccurate ephemeris data and time synchronization. Thus, all main sources of errors and value of their influence are listed below.

Source	Effect (m)
Ionospheric effects	±5
Tropospheric effects	±0.5
Ephemeris errors	±2.5
Satellite clock errors	±2
Multipath distortion	±1

Table 7.1 – Sources of positioning errors [23]

Accuracy information is not transmitted by satellites; its value is calculated based on the measured data. At the moment the device is turned on, accuracy takes on the starting value and remains constant until the receiver establishes communication with the satellites. Receiving data from satellites and assessing the state of the environment, the receiver recounts the accuracy value. First of all, the accuracy depends on the geometry of the satellites used. Depending on their location, the accuracy value will vary. To describe the geometric mutual arrangement of satellites in navigation, the term DOP (decrease in accuracy) is used. So, when the satellites are located to each other (Figure 7.1 (a)) speak of a weak geometry of location. In this case, the intersection area is significant and the object can be at any point in this area. In this case, the accuracy of the obtained coordinates will be low, and the DOP value will be high. In the case, when the satellites are quite distant (Figure 7.1 (b)), the intersection area will be smaller, which means that the accuracy is higher. In total the 5 types of DOP are distinguished:

- HDOP (Horizontal Dilution of Precision) — reduced accuracy in the horizontal plane
- VDOP (Vertical Dilution of Precision) — reduced accuracy in the horizontal plane
- PDOP (Position Dilution of Precision) — reduced accuracy in the location
- TDOP (Time Dilution of Precision) — reduced accuracy in the time
- GDOP (Geometric Dilution of Precision) — total geometric decrease in accuracy by location and time

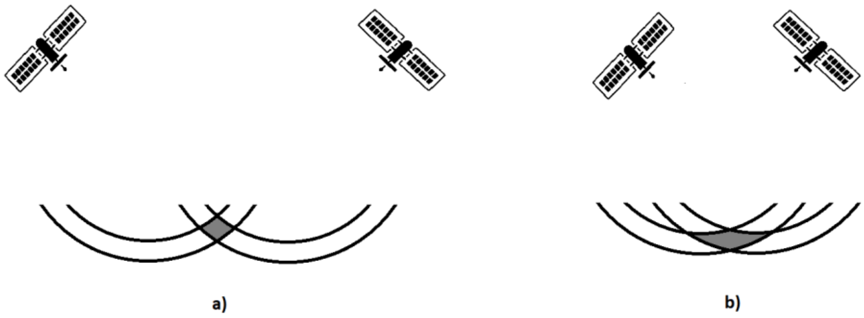


Figure 7.1 – The effect of constellation geometry

Therefore, the good satellite geometry is essential to ensure good accuracy. In addition, the receiver takes into account signal strength, noise, and the amount of visible interference. This helps the device better assess the value of the resulting accuracy. In fact, the receiver does not know the exact location. To estimate accuracy, the receiver plots the positions over the time. Due to measurement errors the positions are scattered across the area. The radius of a circle describes the probability that the position will be within the specified accuracy. In general, there are several ways to measure accuracy. They differ in the level of provided probability (Table 7.2). Each manufacturer independently decides which method is used, but it is believed that most GNSS receivers use the Circular Error Probability (CEP) algorithm with 50% of probability.

Type	Accuracy Measure	Probability, %	Typical Usage	Definition
1D	RMS	68	Vertical	Square root of the average of the square errors
2D	CEP	50	Horizontal	A circle's radius, centered at the true antenna position, containing 50% of the points in the horizontal scatter plot
2D	DRMS	63-68	Horizontal	Square root of the average of the square errors
2D	R95	95	Horizontal	The radius of circle centered at the true position, containing the position estimate with probability of 95%
2D	2DRMS	95-98	Horizontal	Twice the RMS of the horizontal errors
3D	RMS	61-68	3D	Square root of the average of the square errors
3D	SEP	50	3D	The radius of sphere centered at the true position, containing the position estimate in 3D with probability of 50%

Table 7.2 – General accuracy estimation methods [24]

7.2. Experiment with simulated data

In practice, users often encounter a problem, when position of the tracking a device is different from the true one. So when tracking the movement of a car along the highway, sometimes the receiver shows that the device is off the road, which in these conditions is impossible. This raises the question: how accurate the GNSS receivers?

The purpose of this experiment is to study of dependency of the value of accuracy on the speed of the object. Along with this, the influence of several dynamic models on the value of accuracy was investigated. It has already been shown earlier that in the case of a stationary object, the usage of another dynamic model different from default option does not provide a shorter TTFF. However, it follows from the description of dynamic models (Table 5.5) that the effectiveness of using the correct dynamic model should improve positioning accuracy. To proof it in the GSG StudioView program, the motion trajectory for the device was simulated. Its final form is presented in Figure 7.2. It is supposed to check the performance for different speeds (50, 15 and 5 km/h), that corresponds to different types of movement. The effectiveness of three configurations will be compared: Portable, Pedestrian and Automotive. It is assumed that these configurations are most applicable for tracking moving objects. Since in the course of the previous comparison of configurations, the Portable mode showed the best performance, for that reason its results will be taken as reference ones and will be compared with the results of other configurations. In other words, the first device will always work in Portable mode, and the second device will use Automotive and Pedestrian modes one by one. Using the simulator will create identical and reproducible conditions. Thus, at each moment of time, the receiver will have signals with constant characteristics and without interference.

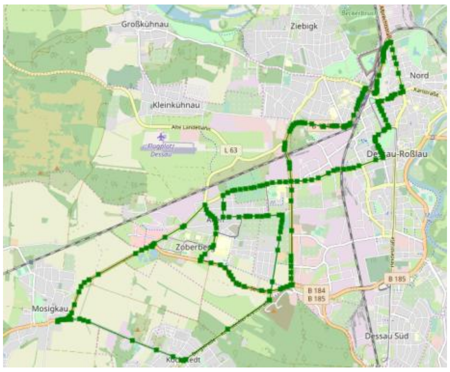


Figure 7.2 – View of simulated track for the devices

For each scenario (each speed), two experiments were performed. In the first case, both devices was restarted only once at the starting point. In the second experiment the devices restarted cyclically after getting a fix. By restart is meant making a cold start of a device. As expected, in the first experiment, for each speed, the position was determined with quite good accuracy (Table 7.3). A significant difference between the accuracy values received from the receiver and the calculated accuracy is already becoming noticeable from the obtained data. The smallest accuracy value indicates a more precise positioning. Surprisingly, the lowest value of 3D and 2D accuracy was obtained at the highest speed in all cases, and their maximum value was at a speed of 15 km/h. Meanwhile, the magnitude of the calculated accuracy decreases with decreasing speed. In other words, the lower the speed, the higher the accuracy.

	Portable			**Pedestrian**			**Automotive**		
Speed, km/h	50	15	5	50	15	5	50	15	5
Position 3D accuracy, m	7,6	50,4	30,8	2,4	63,1	35,3	2,3	67,0	31,1
Horizontal 2D accuracy, m	3,4	16,8	11,4	1,3	19,1	13,6	1,3	22,4	11,5
Calculated accuracy, m	6,8	1,4	0,8	9,4	2,8	1,5	7,9	1,4	0,9

Table 7.3 – Average accuracy values with only one cold start

Throughout the experiment, the position of the devices was monitored, and at the end of the measurements their track was built. The blue squares describe the Portable mode, the red one is the tested mode (Automotive or Pedestrian). The pink squares correspond to the calculated position. So, if you look at the whole picture at Figure 7.3, you can see that the shape of the resulting grater completely repeats the shape of the original (Figure 7.2). If we will look at it in more detail (Figure 7.4), it becomes clear that each of three points is located close to each other. This means that the positions of the devices are determined correctly and with good accuracy, clearly less than 10 meters.

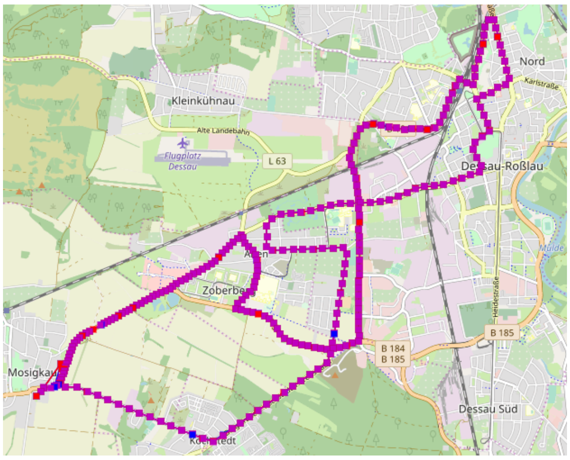


Figure 7.3 – Full track of an automotive mode at 15 km/h

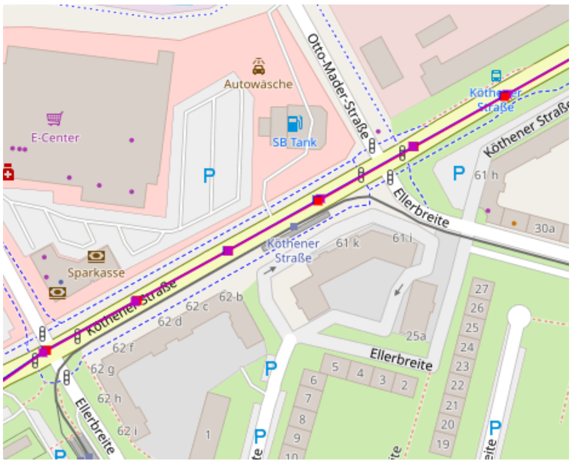


Figure 7.4 – Part of track of an automotive mode at 15 km/h

Table 7.4 presents the results of the second experiment, when each device cyclically made a cold start. As in the previous test, it can be seen that accuracy values are several times higher than the calculated values. In this case, regardless of speed, we get approximately the same 3D and 2D accuracy. If in the previous experiment the value of the calculated accuracy was minimal at the minimum speed, now we have the opposite picture. In order to find out what the problem is, let's take a look at the same section of both tracks at 50 and 5 km/h (Figure 7.5 and Figure 7.6**).** As we can see, at a speed of 50 km/h almost all points lie on the simulated section of the track. The difference in the location of the points is explained by the different moment of receiving TTFF. At a speed of 5 km/h, the device’s position is most of the time off the road. The shape of the resulting curve almost completely repeats the original track. Only in some moments the position of the devices coincides with the calculated one. In addition, it is seen that when receiving the very first fix, positioning accuracy is the worst, and over time it increases. This suggests that, even with a cold start, the receiver uses the previously obtained data to estimate the current location, gradually making changes.

	Portable			**Pedestrian**			**Automotive**		
Speed, km/h	50	15	5	50	15	5	50	15	5
Position 3D accuracy, m	223,2	255,5	250,6	290,9	247,9	278,1	272,1	227,9	259,4
Horisontal 2D accuracy, m	181,4	65,3	60,2	114,3	66,2	66,6	55,3	59,4	63,1
Calculated accuracy, m	79,9	126,5	104,1	70,8	117,3	124,5	80,9	113,9	113,0

Table 7.4 – Average accuracy values with cyclic cold start

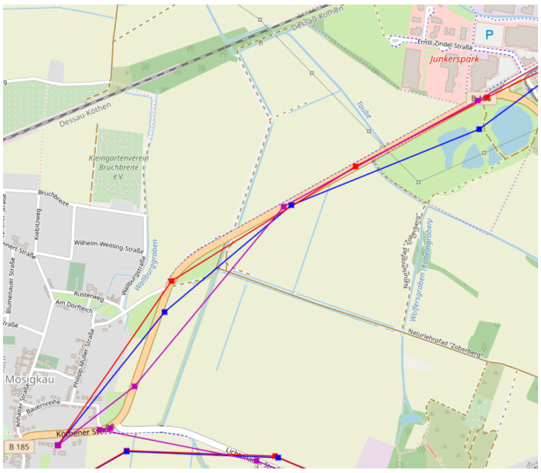


Figure 7.5 – Pedestrian mode at 50 km/h

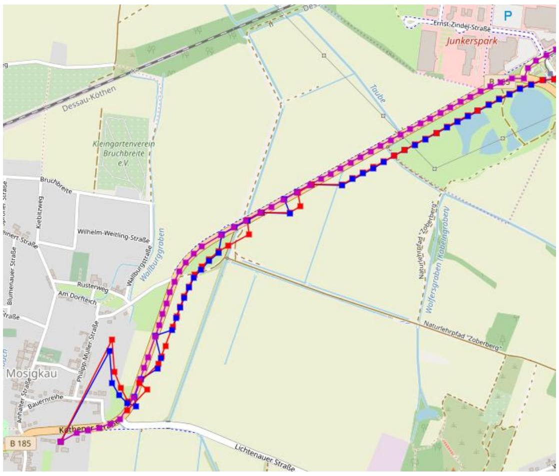


Figure 7.6 – Pedestrian mode at 5 km/h

The reason for this problem becomes clear if you look at the resulting table for 5 km/h (Table 7.5). Most of the time, the device used GLONASS satellites to determine the location and their number did not exceed three. From this it follows that there can be two factors causing this error: using only one GNSS does not provide good accuracy or the receiver used an insufficient number of satellites. In view of the large amount of data, Table 7.5 contains the results only of 10 measurements. In most measurements, accuracy of less than 10 m (meaning calculated accuracy) is achieved using at least 4 satellites, or using satellites of both navigation systems. There are a number of cases, where 3 GPS satellites provided accuracy below 10 meters. Unfortunately, this does not always happen and most of the time accuracy was several tens. Therefore, this phenomenon is the exception rather than the rule. Nevertheless, during several series of measurements this was not observed for GLONASS satellites.

Portable mode					Pedestrian mode				
GNSS	Amount of satellites	3D Accuracy, m	2D Accuracy, m	Calculated Accuracy, m	GNSS	Amount of satellites	3D Accuracy, m	2D Accuracy, m	Calculated Accuracy, m
GLO	3	335,15	79,675	59	GLO	3	333,28	72,382	57
GLO	3	334,63	77,921	61	GLO	3	332,58	69,419	60
GLO	3	334,41	76,914	62	GPS	4	332,44	68,735	61
GLO	3	333,64	73,685	64	GLO	8	331,93	66,515	63
GPS+GLO	8	3,54	2,26	3	GLO	3	331,48	64,431	64
GPS+GLO	6	8,76	5,822	3	GLO	3	330,81	61,224	68
GPS	3	24,59	14,508	4	GPS	3	32,19	22,683	4
GPS	5	5,43	3,697	4	GPS+GLO	3	7,62	5,216	5
GLO	3	330,81	61,273	73	GLO	3	329,79	56,098	73
GPS+GLO	3	13,24	8,914	4	GLO	3	329,86	56,446	74

Table 7.5 – Accuracy comparison of Portable and Pedestrian mode at 5 km/h

Let's take a look at the results of sample measurements obtained at the 5 km/h (Table 7.6). GPS satellites are indicated by the symbol 'G', and GLONASS satellites by symbol 'R'. If the receiver used at least 1 GPS satellite, then even when using only 3 satellites, the ensured accuracy was not worse than 5 m. (case 1). In the second case, it is clear that when using the same satellites, but with different configurations, the value of calculated accuracy is seriously different. So, when using the Automotive mode, the resulting accuracy is 165 meters, while using the portable mode gave a value of 13 meters. If we compare this result with the result of another experiment, where instead of the Automotive mode was used Pedestrian (case 3), it becomes clear that the reason for this difference lies precisely in the applied dynamic model. This phenomenon is not accidental or one-time, which is confirmed by cases 4 and 5.

	Mode	Satellites used for fix and CN0 in dBHz						3D Accuracy, m	2D Accuracy, m	Calculated Accuracy, m
1	Portable	G12, 51	R16, 53	R17, 53				13,24	8,914	4
	Pedestrian	R15, 53	R16, 53	R17, 53				329,86	56,446	74
2	Portable	G9, 52	G12, 52	G15, 52				1566,07	777,623	13
	Automotive	G9, 52	G12, 52	G15, 51				303,84	114,189	165
3	Portable	G9, 51	G12, 51	G15, 51				24,59	14,508	4
	Pedestrian	G9, 52	G12, 52	G15, 52				32,19	22,683	4
4	Portable	G9, 52	G12, 52	G15, 52	G17, 52			20,24	13,837	5
	Automotive	G9, 51	G12, 51	G15, 52				159,49	90,333	239
5	Portable	G9, 51	G12, 51	G15, 51	G17, 51	G27, 51	R16, 53	8,03	6,026	5
	Automotive	G9, 51	G27, 51	R16, 52				3370,02	3151,426	119

Table 7.6 – Test results of different modes at 5 km/h

Thus, we can conclude that the use of a particular dynamic model affects the accuracy of the first correction. This effect is observed at each of the considered speeds. The accuracy values generated by the receiver can vary widely and are not suitable for quantifying the accuracy of the first correction. However, they can be used to evaluate the relative importance of the data obtained or for accuracy evaluation with continuous connection.

Most positions are calculated using only GLONASS satellites. This means that the data of this navigation system is decoded by the receiver faster. The accuracy of the coordinates obtained is relatively low. The use of three GPS satellites or a combination of both GNSS provides a more accurate location. But usage of 4 or more GLONASS satellites also provides good (fewer 10 meters) accuracy.

In all three cases, regardless of movement speed, Portable and Pedestrian modes showed the best results. Application of Automotive mode gives low accuracy, when the receiver used three satellites to calculate the position. Talking about the average time it takes to fix, the obtained values differ by a maximum of 1 second, which is not a significant value on these scales (>30 seconds)

8. FAST START CONCEPT

Environmental conditions, in which position determination is carried out, play a decisive role and have a direct impact on both the duration of the determination of coordinates and the accuracy of obtained position. So, a lot depends on the location of the receiving antenna. To get the best performance, it is necessary to provide a complete overview of celestial space. The greatest result will be shown by the case, when antenna will be located on the roof of a tall building. In that situation the antenna will have a stable connection with each of satellites, and there will be practically no sources of interference.

Thus, the device is capable of continuously receiving data using signals reaching 50 dBHz and higher. It is believed that for optimal operation of u-blox receivers it is necessary to have a stable signal from 40 dBHz. The range of 25-30 dBHz is the absolute minimum acceptable for position determination [26]. However, there are many situations where it is not possible to provide good conditions for the receiver. This problem is especially relevant for tracking devices. Often, in these types of devices, size is one of the most important parameters. In this regard, the antenna should also have a small size, and providing clear sky is not always possible. In such situations, it is necessary to use the internal functionality to accelerate a particular mechanism. In addition, it is important to understand which situation is bad and which parameters should be taken into account to detect it.

The u-blox devices have a number of messages that provide information on the current state of the environment and the quality of the signals used. So using UBX-MON-HW user can evaluate the level of visible interference. UBX-NAV-ORB, UBX-NAV-SAT and UBX-NAV-SVINFO provide a detailed description of the data available in the receiver's temporary memory, their validity period and other information.

So, how to identify poor environmental conditions? After a thorough study of the main [3, 10, 27] and additional documentation [23] found in other sources, an algorithm was developed to identify poor conditions. According to our observations, we will assume that the conditions are poor if no fix was received within 3 minutes. This time is sufficient to download the necessary data under good and acceptable conditions, but not enough to download them in bad conditions. This is accomplished by simply checking certain bits with a UBX-NAV-STATUS message. If after this time, there was still no fix, then the algorithm for assessing the current situation begins. For these purposes, the most informative message is UBX-RXM-SVSI. The main advantage of this message is that it contains information about each satellite and, unlike others, allows to instantly determining the validity of the data. So, it is possible to find out for which satellites the receiver already has the necessary information. The receiver must have at least ephemeris data for four or three satellites to establish 3D or 2D fix respectively. Thus, if these data are already in the receiver's memory and they still have not lost their relevance, then the fix will be immediately calculated, and it makes no sense to take any steps. So, after checking all the satellites for the presence of ephemeris, in the absence of the required amount of valid data, it is necessary to receive the message UBX-NAV-SAT. This message contains more detailed information about the status of the signal received from a particular satellite. In addition to the CN0, it contains information like the residual pseudorange and quality index (Qi). The value of residual pseudorange allows determining whether this signal was received with an error or not. So, if the value of this quantity turns out to be sufficiently large, then this indicates that the signal has been reflected and contains interference errors. Thus, the use of such a signal does not lead to a correct location and can significantly affect the output. It is worth noting that the message displays instantaneous values of quantities and for a correct assessment it is necessary to conduct several measurements and compare the average values, because the same signal can be reflected at one time or another.

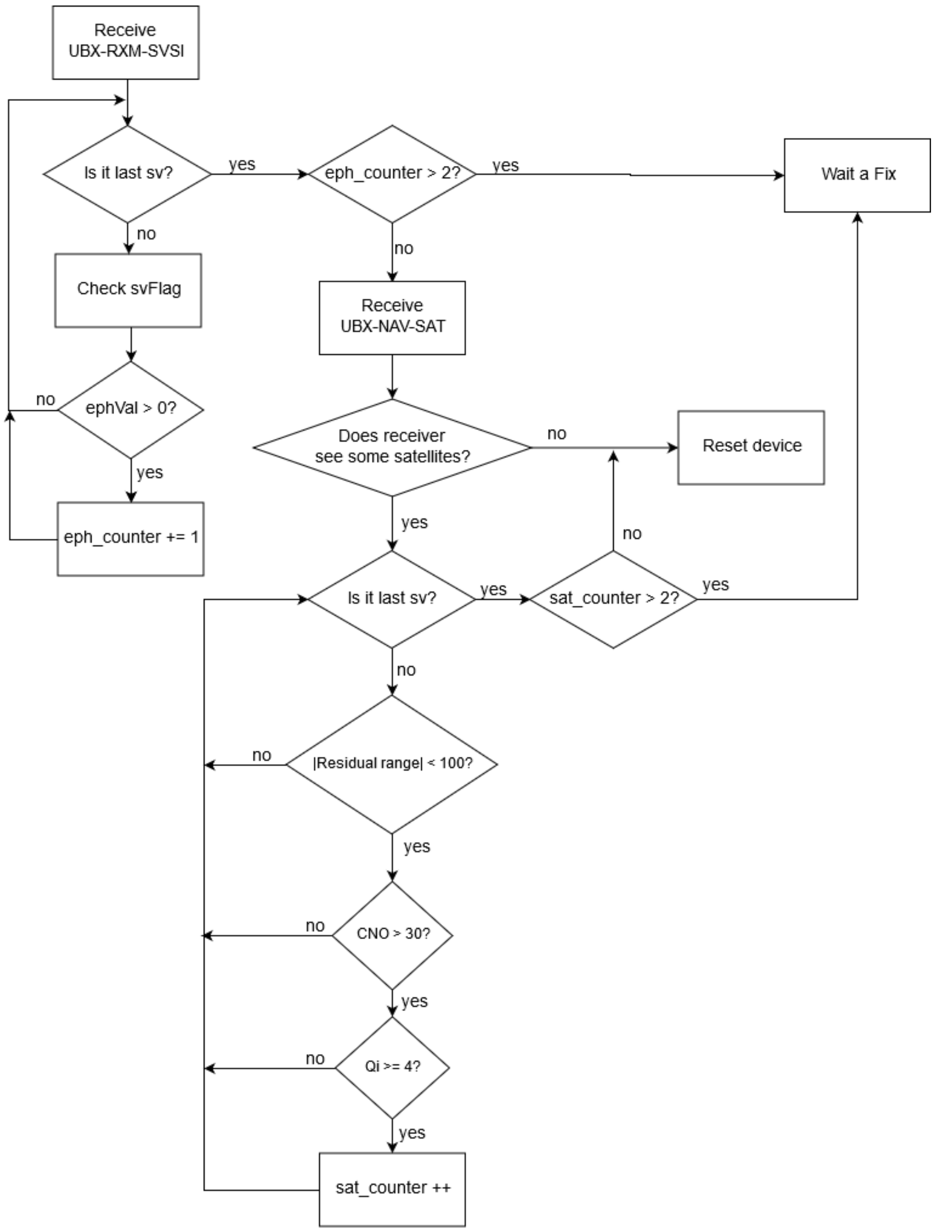


Figure 8.1 – Algorithm for resetting device

If for some time we get high residual range values, then this signal is not suitable for use. The quality index also allows evaluating the quality of the signal. Based on its value, it is possible to determine the applicability of a signal. According to the documentation [10], the signal can be used to calculate the position, if the quality index is not less than 4. Thus, if the device has at least 4 satellites with $|\text{Residual range}| < 100$, with a signal level above 30 dBHz and with $\text{Qi} \geq 4$, then the conditions are acceptable. In other words, the receiver will be able to determine the location of the object. If there are no such signals, then the received data is not suitable and position determination is impossible. In this case, the implementation of the restart will delete irrelevant data and speed up the process of determining the position. This fact is confirmed by an experiment when both receivers were located inside a car. After downloading actual navigation data, the car was placed in underground garage to lose the connection with satellites. After 2 hours of standing, it goes outside. The first device worked in default mode, and the second used the reset algorithm. It seen, that the second device immediately got the fix. As we can see, in the first case (Figure 8.2) the device didn't track a significant piece (2.539 km) of route, and fix was obtained for 3 minutes and 4 seconds. Unlike the second case (Figure 8.3), when the fix was obtained during 26 seconds, and position of the device was monitored throughout the entire experiment. It proofs that under poor conditions, deleting irrelevant data help to speed up the calculations and rapidly determine the location of a device. During whole experiment the CN0 level did not exceed 30 dBHz and average speed of movement was 50 km/h.

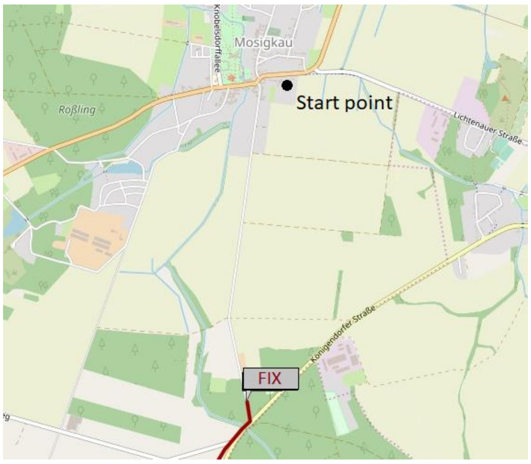


Figure 8.2 – Making a cold start for device

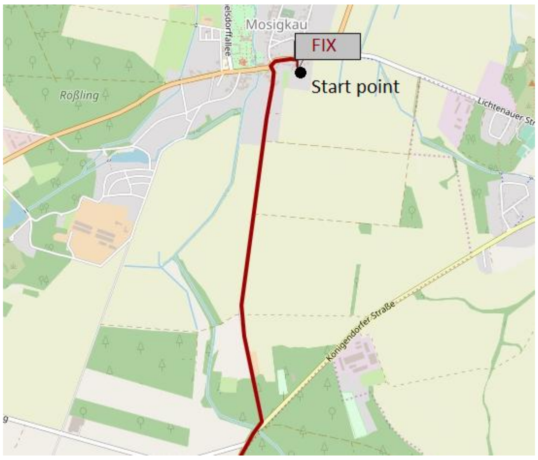


Figure 8.3 – Making a warm start for device

9. CONCLUSION AND FURTHER WORK

In this paper, we investigated a number of configurations that can improve the performance of tracking devices. Studies have been conducted for a stationary, moving object, and for simulated data, to eliminate some factors from consideration. The u-blox receivers, despite the large and varied built-in functionality, are highly optimized. In other words, the use of various combinations of settings in the situations considered does not allow us to obtain a significant gain in either time or accuracy. It is believed that providing current time can speed up the calculation of a position. However, in this paper it was clearly shown that this statement is true only for receivers of the previous generation. The u-blox receivers are well optimized and allow quickly get time information from satellites, and the receiver spends the lion's part of the time to receive data on the current ephemeris and almanac. However, time information may be useful when using AGPS services. Since the ephemeris and almanac data are loaded into the device within a few seconds, obtaining accurate time can significantly reduce the fix time. Various dynamic models have also been investigated. A number of measurements were carried out under various conditions during which the Portable configuration, which is used as a standard setting, showed the best result. Moreover, the best results were obtained, both in terms of TTFF and in accuracy. In experiments with the simulator, it was found that when driving at speeds below 50 km/h, accuracy of first fix is worse and most of the time the receiver uses only 3 GLONASS satellites to determine the location. Moreover, the accuracy decreases over time, and the magnitude of the error increases iteratively. Despite this, the device completely repeats the original path, and the movement is parallel to the specified path. This is not observed when using 4 satellites or more. However, 3 GPS satellites are able to provide good accuracy. The use of various dynamic models has a direct effect on both accuracy and the TFFF value.

As part of this work, performance was not investigated when using SBAS services. This function was not taken into account due to the fact that under the conditions in which most of the measurements were carried out, SBAS satellites were not available. The device detected at least 3 SBAS satellites and even had some data from them. However, the use of this data by the receiver was not possible. It is assumed that this service will significantly improve accuracy, down to the centimeter level. In addition, based on the corrections obtained, it is possible to decrease the TTFF value. In situations, when receiving a signal from satellites is difficult, it is possible to use a signal from ground reference stations. In this case data can be obtained through an Internet connection. It should be noted that in the case of a moving object the choice of station should be carried out dynamically, because the accuracy provided will depend on the distance from the receiver to the station. Fortunately, now there is a huge variety of loose-leaf services that provide coverage in most countries. In other words, in most cases, you can find a station that will be closest to the object. There is also an NTRIP function, with which it is possible to download ephemeris directly via the Internet. It is difficult to say whether the results will be comparable with the results of AssistNow Online. This issue requires a separate consideration. In addition, some versions of the u-blox products used the CellLocate feature [28]. In EVK M8C products, this option is not available. The technology allows determining the location using a mobile operator based on the location of the base station. Since IBH-IMPEX has a GSM module, this function, or its analogue, can significantly speed up the positioning time. So, as the first correction, you can use the position received from the operator; upon receipt of the required number of ephemeris, the device can make a new location estimate and clarify the previously received position. Of course, the first location may turn out to be rather rough. Accuracy of cellular networks are varies and according to paper [29] its value 50-100 meters. Nevertheless, since mobile networks have almost over the world coverage, using this method it is possible to get relatively good accuracy. In addition, access to raw data obtained from satellites is desirable. As already mentioned, the u-blox devices are well optimized and the built-in functionality does not allow improving the performance. Therefore, it makes sense to develop own improvement algorithms. So, according to the work [30], the usage of a multi-hypothesized Kalman filter can enhance something. Also, the results obtained in project [31] allow one to obtain higher accuracy. However, not all of these methods are easily accessible and feasible. For this reason, these technologies require separate careful consideration and will serve as the basis for new research.

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Приложение А

Патентные исследования

УТВЕРЖДАЮ

________________/В.П. Якубов/

должность, личная подпись и расшифровка подписи ответственного руководителя работы

"__" ________201_г.

З А Д А Н И Е № 1
на проведение патентных исследований

Наименование работы (темы) Разработка и обоснование концепции быстрого запуска устройств спутникового слежения GNSS на базе модулей u-blox.

шифр работы (темы) 03.04.03

Этап работы завершающий, сроки его выполнения 04.03.2019-04.04. 2019

Задачи патентных исследований Основная исследование технического уровня и анализ тенденций равзвития технологий спутниковой навигации. Особое внимание должно быть сосредоточено на методах по уменьшению величины времени первого исправления.

КАЛЕНДАРНЫЙ ПЛАН

Виды патентных исследований	Подразделения-исполнители (соисполнители)	Ответственные исполнители (Ф.И.О.)	Сроки выполнения патентных исследований. Начало. Окончание	Отчетные документы
1. Исследование технического уровня	Кафедра радиофизики ТГУ	Вайман Е.В.	04.03.2019-04.04.2019	отчет о поиске
2. Анализ тенденций развития	Кафедра радиофизики ТГУ	Вайман Е.В.	04.03.2019-04.04.2019	отчет о поиске
3. Обоснование технического уровня объектов разработки	Кафедра радиофизики ТГУ	Вайман Е.В.	04.03.2019-04.04.2019	отчет о поиске

Руководитель патентного подразделения	личная подпись	Беличенко В.П. расшифровка подписи	05.04.2019 дата
Руководитель подразделения исполнителя работы (руководители подразделений-соисполнителей)	личная подпись	Якубов В.П. расшифровка подписи	05.04.2019 дата

Регламент поиска № 1

04.03.2019
дата составления регламента

Наименование работы (темы) Разработка и обоснование концепции быстрого запуска устройств спутникового слежения GNSS на базе модулей u-blox
Шифр работы (темы) 03.04.03
Номер и дата утверждения задания №1 от 04.03.2019 Этап работы завершающий
при необходимости
Цель поиска информации (в зависимости от задач патентных исследований, указанных в задании)
На основе исследования технического уровня и анализа тенденций равзития спутниковой навигации сформулировать концептуальную стратегию разработки: программно-аппаратного комплекса, позволяющего проводить анализ паарметров времени и точности при различных условиях. Выявить наличие описаний в патентной и научно-технической литературе способо быстро старта приемника.

Обоснование регламента поиска поиск провести в базах данных ФИПС (Россия) и USPTO (США)
Начало поиска 11.12.2017. Окончание поиска 23.12.2017

Предмет поиска (объект исследования, его составные части, товар)	Страна поиска	Источники информации, по которым будет проводиться поиск				Ретроспективность	Наименование информационной базы
		патентные		НТИ			
		Наименование	Классификационные рубрики МПК	Наименование	Рубрики УДК		
1	2	3	4	5	6	7	8
TTFF Time to first fix Cold start	Россия, США	База данных ФИПС (Россия) База данных USPTO (США)	МПК H01Q 11/12, 342/125; 342/118; 342/127 G01S 13/08, 342/125; 342/90	**Журнал** «Зарубежная радиоэлектроника»	621.396.676 621.396.946 621.396.962.3.001.5 621.391.1 621.374 621.396.677.3	1994-2017 (Россия) 1976-2017 (США)	База данных ФИПС (Россия) База данных USPTO (США)

Fast start			G01S 11/00 G01S 13/84 343/718; 455/41.1	**Журнал** «Радиотехника и жектроника **Журнал** «Успехи физических наук» **Журнал** «Радиоэлектроники» (электронный журнал) Журнал «The journal of navigation»	621.396.67 621.396.67:523.16.4 621.396.67.620.1.08 517.535.4/530 621.371.537.86 621.3.049.77(075) 550.835 550.839		

Руководитель (руководители) подразделения-исполнителя работы	личная подпись	Якубов В.П. расшифровка подписи	05.04.2019 дата
Руководитель патентного подразделения	личная подпись	Беличенко В.П. расшифровка подписи	05.04.19 дата

ОТЧЕТ О ПОИСКЕ

В.1 Поиск проведен в соответствии с заданием

№_1__ от __04.03.2019_ и Регламентом поиска № _1 от 04.03.2019
В.2 Этап работы завершающий
В.3 Начало поиска 04.03.2019 Окончание поиска 04.04.2019
В.4 Сведения о выполнении регламента поиска (указывают степень выполнения регламента поиска, отступления от требований регламента, причины этих отступлений) – регламент поиска выполнен **полностью.**
В.5 Предложения по дальнейшему проведению поиска и патентных исследований – провести поиск патентов аналогов наиболее значимых патентов, обнаруженных при проведении патентных исследований. Более детально проанализировать направления исследований ведущих в рассматриваемых областях фирм. Расширить поиск текущей научной и патентной информации в смежных областях.
В.6 Материалы, отобранные для последующего анализа

Таблица В.6.1 – Патентная документация

Предмет поиска (объект исследования, его составные части)	Страна выдачи, вид и номер охранного документа. Классификационный индекс	Заявитель (патентообладатель), страна. Номер заявки, дата приоритета.	Название изобретения	Сведения о действии охранного документа
1	2	3	4	5
TTFF Time to first fix Cold start	1. Патент РФ № 2009130399, МПК G01S 1/00 (2006.01)	ТОМТОМ ИНТЕРНЭШНЛ Б.В. (NL) 2009130399/09, 09.01.2008	НАВИГАЦИОННОЕ УСТРОЙСТВО И СПОСОБ СОКРАЩЕНИЯ ВРЕМЕНИ ИДЕНТИФИКАЦИИ МЕСТОПОЛОЖЕНИЯ НАВИГАЦИОННОГО УСТРОЙСТВА	Не действует. Заявка отозвана 18.10.2011
	2. Патент РФ №2014124148, МПК G01S 19/34 (2010.01)	ТЕЛЕФОНАКТИЕБОЛАГЕТ Л М ЭРИКССОН (ПАБЛ) (SE) 2014124148/07, 14.11.2011	УЛУЧШЕННЫЕ ВРЕМЯ ПЕРВОГО ОПРЕДЕЛЕНИЯ МЕСТОПОЛОЖЕНИЯ, TTFF, ЧУВСТВИТЕЛЬНОСТЬ И ТОЧНОСТЬ ДЛЯ УСТРОЙСТВА ОПРЕДЕЛЕНИЯ ПОЛОЖЕНИЯ С ПОМОЩЬЮ ГЛОБАЛЬНОЙ НАВИГАЦИОННОЙ СПУТНИКОВОЙ СИСТЕМЫ	Экспертиза по существу завершена. Учтена пошлина за регистрацию и выдачу патента

	5. Патент РФ № 2604872, МПК *G01S 19/34* (2010.01) *G01S 19/25* (2010.01)	ЭЛЬФСТРЕМ Торбьерн (SE), ПЕРСС ОН Ларс (SE), 2014124148/07, 14.11.2011	УЛУЧШЕННЫЕ ВРЕМЯ ПЕРВОГО ОПРЕДЕЛЕНИЯ МЕСТОПОЛОЖЕНИЯ, TTFF ,ЧУВСТВИТЕЛЬНОСТЬ И ТОЧНОСТЬ ДЛЯ УСТРОЙСТВА ОПРЕДЕЛЕНИЯ ПОЛОЖЕНИЯ С ПОМОЩЬЮ ГЛОБАЛЬНОЙ НАВИГАЦИОННОЙ СПУТНИКОВОЙ СИСТЕМЫ	Действует Учтена пошлина за 8 год с 15.11.2018 по 14.11.2019
	6. Патент РФ № 2628769, МПК *H05K 5/02* (2006.01) *B63C 7/26* (2006.01)	ТЕ ДИРЕКТОР ДЖЕНЕРАЛ, ДИФЕНСРИСЕРЧ ЭНД ДИВЕЛОПМЕНТ ОРГАНИЗЕЙШН (ДРДО) (IN), 2016107010, 30.07.2014	УСТРОЙСТВО (BSAT) ЗАПИСИ, ЯВЛЯЮЩЕЕСЯ ЧЕРНЫМ ЯЩИКОМ СО СПУТНИКОВЫМ УСТРОЙСТВОМ ПЕРЕДАЧИ ДЛЯ ПОДВОДНЫХ СУДОВ	Действует Учтена пошлина 6 год с 31.07.2019 по 30.07.2020
	7. Патент US № 10051499 H04W 28/02 (20090101); H04W 24/08 (20090101); H04W 36/30 (20090101)	AMAZON TECHNOLOGIES, INC, SEATTLE, WA, (US)\ DECEMBER 4, 2014	INDIVIDUAL RADIO FREQUENCY CONFIGURATION FOR USER DEVICES	Действует
	8. Патент US № 9989648 G01S 19/34 (20100101); G01S 19/19 (20100101)	SEIKO EPSON CORPORATION, SHINJUKU-KU, N/A (JP) 16.10 2014	ELECTRONIC DEVICE AND RECEPTION CONTROL METHOD	Действует
	9. Патент US № 9007261 G01S 19/27 (20100101); G01S 19/42 (20100101)	WENG, CHIN-TANG, KAOHSIUNG(TW), YAU, WEI GUAN, HSINSCHU (TW) 05.2011	METHOD AND APPARATUS FOR FAST TTFF	Действует
	10. Патент US № 8009091	MEDIATEK INC, SCIENNCE-BASED INDUSTRIAL PARK, HSIN-CHU (TW) 04.12.2008	METHOD AND APPARATUS FOR REDUCING TIME TO FIRST FIX (TTFF) OF GNSS RECEIVER WITHOUT ACCURATE TIME INFORMATION	Действует

Таблица В.6.2 – Научно техническая, конъюнктурная, нормативная документация и материалы государственной регистрации (отчеты о научно-исследовательских работах)

Предмет поиска	Наименование источника информации с указанием страницы источника	Автор, фирма (держатель) технической документации	Год место и орган издания (утверждения, депонирования источника)
1	2	3	4
TTFF Time to first fix Cold start	“Реализация многогипотезного фильтра Калмана высокоточного позиционирования”	Захаров Г.И.	Санкт-Петерсбург, 2018
	“How good is Assisted GPS?”	B. Li, J. Zhang, P.Mumford, A. G.Dempster	IGNSS Symposium, 2011
	“A fast cold-start method of GPS receiver based on satellite orbit prediction”	R.Yang, Z.Song, J.Zhang, X. Xi 1	MATEC Web of Conferences, 2018
	“Future positioning technologies and their application to the automotive sector”	Sage A.	“The Journal of navigation”, 2001
	“Method of fast first fix using low cost gnss receivers”	Chistyakov V.V., Mikhailov N.V., Pospelov S.S., Vasilyev M.V., Vasilyeva N.V.	Санкт-Петерсбург, ICINS, 2010
	“Improving TTFF by two-satellite GNSS positiomimg”	J.Collin, J.Takala, J.Parvianen	IEEE Transactions on Aerospace and Electronic Systems, 2012

Отчет о проверке на заимствования №1

Автор: icanf1y@ya.ru / ID: 4298689
Проверяющий: (icanf1y@ya.ru / ID: 4298689)

Отчет предоставлен сервисом «Антиплагиат»- http://users.antiplagiat.ru

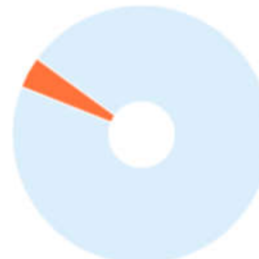
ИНФОРМАЦИЯ О ДОКУМЕНТЕ

№ документа: 14
Начало загрузки: 18.09.2019 10:09:10
Длительность загрузки: 00:00:07
Имя исходного файла: Master_thesis
Размер текста: 3793 кБ
Символов в тексте: 149606
Слов в тексте: 20790
Число предложений: 1070

ИНФОРМАЦИЯ ОБ ОТЧЕТЕ

Последний готовый отчет (ред.)
Начало проверки: 18.09.2019 10:09:17
Длительность проверки: 00:00:13
Комментарии: не указано
Модули поиска: Модуль поиска Интернет

ЗАИМСТВОВАНИЯ	ЦИТИРОВАНИЯ	ОРИГИНАЛЬНОСТЬ
3,95%	0%	96,05%



Заимствования — доля всех найденных текстовых пересечений, за исключением тех, которые система отнесла к цитированиям, по отношению к общему объему документа.
Цитирования — доля текстовых пересечений, которые не являются авторскими, но система посчитала их использование корректным, по отношению к общему объему документа. Сюда относятся оформленные по ГОСТу цитаты; общеупотребительные выражения; фрагменты текста, найденные в источниках из коллекций нормативно-правовой документации.
Текстовое пересечение — фрагмент текста проверяемого документа, совпадающий или почти совпадающий с фрагментом текста источника.
Источник — документ, проиндексированный в системе и содержащийся в модуле поиска, по которому проводится проверка.
Оригинальность — доля фрагментов текста проверяемого документа, не обнаруженных ни в одном источнике, по которым шла проверка, по отношению к общему объему документа.
Заимствования, цитирования и оригинальность являются отдельными показателями и в сумме дают 100%, что соответствует всему тексту проверяемого документа.
Обращаем Ваше внимание, что система находит текстовые пересечения проверяемого документа с проиндексированными в системе текстовыми источниками. При этом система является вспомогательным инструментом, определение корректности и правомерности заимствований или цитирований, а также авторства текстовых фрагментов проверяемого документа остается в компетенции проверяющего.

№	Доля в отчете	Доля в тексте	Источник	Ссылка	Актуален на	Модуль поиска	Блоков в отчете	Блоков в тексте
[01]	1,04%	1,35%	Материалы ИС	http://technolog.edu.ru	27 Авг 2017	Модуль поиска Интернет	1553	14
[02]	0%	1,35%	ГОСТ Р 15.011-96 Система ра...	http://docs.cntd.ru	20 Июн 2019	Модуль поиска Интернет	0	14
[03]	0,39%	1,14%	Методические указания Вол...	http://rudocs.exdat.com	24 Июн 2015	Модуль поиска Интернет	578	14

Еще источников: 17
Еще заимствований: 2,52%