SVEUČILIŠTE U ZAGREBU

PRIRODOSLOVNO–MATEMATIČKI FAKULTET

MATEMATIČKI ODSJEK

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ANALIZA POSTUPKA PROCJENE POLOžAJA TEMELJEM ZADANIH PSEUDOUDALJENOSTI U PROGRAMSKI O DREđENOM PRIJAMNIKU ZA SATELITSKU NAVIGACIJU

Diplomski rad

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Ovaj diplomski rad obranjen je dana ____________________ pred ispitnim povjerenstvom u sastavu:

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Na kraju

Sadržaj

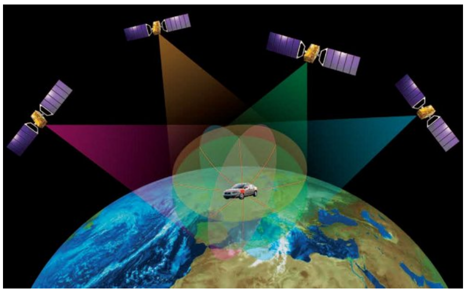
Uvod

Satelitsko određivanje položja predstavlja temeljnu tehnologiju rastućeg broja tehnoloških i društveno-ekonomskih sustava. Kvaliteta njihovih usluga određena je točnoću procjene položja satelitskim sustavima. Programski određen radioprijamnik za satelitsku navigaciju procesira signale za određivanje položja i podatke iz navigacijske poruke u tri osnovne domene: radiofrekvencijskoj, u domeni osnovnog frekvencijskog područja te u domeni navigacijske primjene. Ovaj rad analizira postupak procjene položaja u domeni navigacijske primjene. U tu svrhu, koriste se na osobnom računalu izveden programski određen GPS prijamnik i ulazni podatci o opaženim pseudoudaljenostima spremljeni u RINEX podatkovnom formatu. Analiza korištenog algoritma procjene položaja temelji se na izmjerenim pseudoudaljenosti (Sanz Subirana et al, 2013, Chapter 6.1) te se otkrivaju potencijalne slabosti algoritma s učincima na točnost procjene položja. Na kraju, predlažu se poboljšanja algoritma te ih se izvodi u programskom okruženju R. Poboljšanja algoritma su vrednovana komparativnom analizom obilježja poboljšanog i izvornog algoritma.

Poglavlje 1

Globalni pozicijski sustav (GPS, engl. Global Positioning System)

1.1 Global Navigation Satellite System (GNSS)



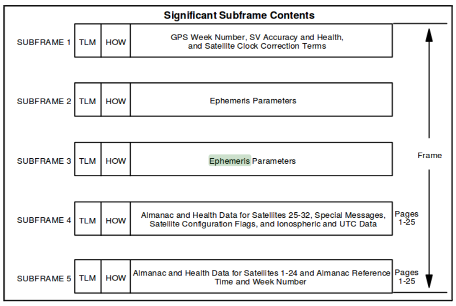
Slika 1.1: Satellite navigation [2]

The Global Navigation Satellite System term refers to the constellation of satellites broadcasting ranging signals and Navigation Messages (NM). By definition, the GNSS has a global coverage.

Nowdays, there are several GNSSs. The US-operated Global Positioning System (GPS) is most commonly used in commercial applications. GPS is owned by US Government and operated by US Air Force. It provides two levels of operability. While one is restricted to authorised (often military) users, the other is free of charge for everyone with the GPS-capable receiver. The second one is Russia Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS). The third is Galileo, owned and operated by European Union and scheduled to become full operable by 2020 [2]. China is in process of expanding its regional BeiDou Navigation Satellite System into global one by 2020 [2]. In remaining sections, we will concentrate on the GPS system.

Navigation Message

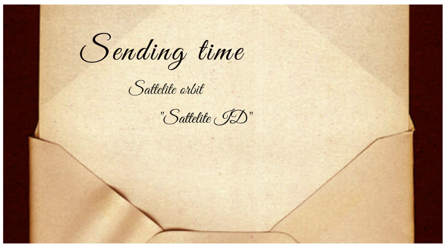
Each satellite provides data required for utilisation of the positioning determination process in a form of Navigation Message (NM). Figure 1.2 shows the overview of content and structure of the satellite navigation message [3].



Slika 1.2: Navigation Message Content and Format Overview - one frame [3]

A navigation message consists of 25 frames [2]. One frame contains 5 sub-frames. Each frame contains information about the satellite system time when the next frame is transmitted. Each sub-frame needs 6 seconds to be transmitted. The receiver is potentially capable of getting a new pseudo-range at the beginning of each sub-frame, or every 6 seconds. The pseudo-range is indirectly measured distance from transmitting satellite to the receiver.

For the purposes of the discussion, it is sufficient to understand that each navigation message is a set of binary data where each contains positioning and timing data (sending time, sender-satellite orbit, "satellite ID").



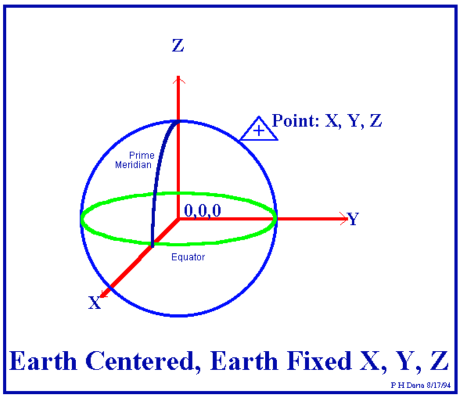
Slika 1.3: Navigation Message simplified

A detailed description of GPS and GLONASS Navigation Message and the positioning determination algorithm can be found in [2]. The same source contains detailed description of positioning determination process. General approach is described in next subsection.

Position determination process

To determine receiver position, the latitude, longitude and altitude need to be determined. Having 3 unknown parameters, there is need for at least 3, actually 4 (explained later), lineary independent equations.

The orbital data allows the receiver to calculate satellite position in Earth-Centered, Earth-Fixed X, Y, Z (ECEF XYZ) coordinates. [1]



Slika 1.4: Earth-Centered, Earth-Fixed X, Y, Z (ECEF XYZ) coordinates [1]

Each receiver has a clock which enables calculation of the signal, navigation message, received time t'. Let denote the "sending time" of the message of i-th satellite with t_i. Message travelling time is computed as $(t_i' - t_i)$[1]

The receiver-satellite pseudo-ranges are defined as follows:

$$d_i = c \times (t_i' - t_i)$$

The assumption that satellite signals travel at the speed of light, approximately 300 000 km per second, as they do in vacuum, can be made.

The satellite positioning process requires the perfect syncronisation of the receiver's clock with the common GPS system time (UTC). However, the receiver's clock is usually a quarz electronic clock with the time syncronisation error of approximately 10^{-6} s (equivalent to approximately 300m pseudo-range error) due to requirements for affordable price of user equipment. Still, the significant user clock error remains the same for all the pseudo-range measurments and regardless of the satellite. This makes the user clock error the forth unknown that describes the user's state , along with three unknown coordinates of positioning.

The pseudo-ranges equation is then following:

$$d_i = c \times (t_i' - t_i + d_t)$$

Let $(x_i, y_i, z_i), i \in \{1, 2, 3, 4\}$ be the positions of 4 different satellites and (x, y, z) the unknown receiver position expressed in ECEF coordinates.

The following (positioning estimation) equations in respect to x, y, z and d_t need to be solved:

$$\begin{aligned}
d_1 = c \times (t_1' - t_1 + d_t) &= \sqrt{(x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2} \\
d_2 = c \times (t_2' - t_2 + d_t) &= \sqrt{(x - x_2)^2 + (y - y_2)^2 + (z - z_2)^2} \\
d_3 = c \times (t_3' - t_3 + d_t) &= \sqrt{(x - x_3)^2 + (y - y_3)^2 + (z - z_3)^2} \\
d_4 = c \times (t_4' - t_4 + d_t) &= \sqrt{(x - x_4)^2 + (y - y_4)^2 + (z - z_4)^2}
\end{aligned}$$

As we can observe, at least 4 visible satellites need to be visible [2]. Visible satellite S by the receiver R at the time T is every satellite from which R, at the time T,

[1] More precise, travelling time is actually calculated by aligning pseudocode sequences (PRN codes). Both the satellite and GPS receiver generate the same pseudocode at the same time. The satellite transmits the pseudocode which is received by the GPS receiver. The receiver is still producing the pseudocode while the satellite's code is travelling. Eventually, the 2 signals are compared. The difference between the 2 signals is the travel time.

[2] In practice, even larger number of satellites is used to improve the accuracy of positioning determination process.

measures the signal propagation time (i.e., determine the pseudo-range) and derives the positioning estimation equation.

Each receiver is able to transform ECEF coordinates into geodetic latitude, longitude and altitude.

Poglavlje 2

Algoritam procjene položaja u domeni navigacijske primjene

2.1 Osnovni algoritma

2.2 Izvedba algoritma i procjena točnosti

Kratki opis koraka koje smo napravili prilikom izvedbe.

Zahtjevi algoritma

Ulaz (U rinex) + uzorak za usporedbu(RINEX)

RINEX

-objašnjenje pojma + primjeri. + otkuda nam.

Programski određen GPS prijemnik

+zašto i kako smo ga koristili. i dobili podatke. (User manual?)

Izvedba

R kod

Procjena točnosti

+uočene pogreške, uvjetovanost matrice.

2.3 Poboljšani algoritam i njegova izvedba

Zašto , kako smo došli do toga!

Izvedba

R kod

Procjena točnosti

kako već

2.4 Usporedba osnovnog i poboljšanog algoritma

+ zaključak zašto je bolji.

2.5 Zaključak

Bibliografija

[1] DANA, P. H., *Global positioning system overview*, `http://www.colorado.edu/geography/gcraft/notes/`, 1994, [Online; accessed 9-Feb-2017].

[2] J. Sanz Subirana, J.M. Juan Zornoza and M. Hernández-Pajares, *Fundamentals and Algorithms*, sv. 1, May 2013, [Online; accessed 9-Feb-2017].

[3] United States military, *GLOBAL POSITIONING SYSTEM STANDARD POSITIONING SERVICE SIGNAL SPECIFICATION*, `http://www.gps.gov/technical/ps/1995-SPS-signal-specification.pdf`, 1995, [Online; accessed 30-Jan-2017].

Sažetak

Ukratko ...

Summary

In this ...

Životopis

Dana ...