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Ocena natančnosti satelitske navigacije pri upravljanju naravnih virov

An Accuracy Assessment of Satellite Navigation in Natural-Resource Management

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Prispevek obravnava možnosti uporabe navigacijske tehnologije satelitskega določanja lege (SDL - GPS) pri upravljanju z naravnimi viri. Nastal je na podlagi rezultatov SDL prikazov zemljišč na približno 30 krajih v Baranji (vzhodna Hrvaška). Sprejemniki SDL so bili uporabljeni predvsem za določanje lege izbranih zemljišč. Dinamičnega kartiranja zemljišč nismo spremljali. Raziskave smo se lotili z namenom, da bi dogradili svoje znanje o delu s podatki SDL, o vključevanju sistema SDL v sistem zemeljskega informacijskega sistema ter preizkusili delovanje bolj natančnega sistema diferencialnega satelitskega določanja lege (DSDL). Raziskali smo razlike med podatki, pridobljenimi s tremi metodami določanja lege v prostoru: a) georeferenčnoim zračnim fotografiranjem (AERO), b) standardnim signalom SDL, in c) popravljenim signalom DSDL. Glede na referenčno vrednost smo ugotovili sistematično odstopanje in polmer napake (rezultati DSDL). Ugotavljanje razlik med metodama SDL in AERO ni dalo statistično pomembnih razlik. Glede na rezultate raziskave moramo povzeti, da lahko metodo SDL uspešno uporabimo pri kartiranju zemljišč ter tudi sicer pri prepoznavanju drugih naravnih virov. Določanje lege z nekorigiranim signalom SDL omogoča enako dobro ali celo večjo natančnost določitve lege, kakršno dobimo z zračnimi fotografijami v povprečnem merilu 1:20.000. Uporaba satelitskega določanja lege je odvisna od potreb posameznih uporabniških skupin, pri čemer so posebno pomembni vidiki natančnosti, polmera 95% verjetnosti, zanesljivosti rezultatov in izvedljivosti.

(Ključne besede: navigacija satelitska, satelitsko določanje lege, kmetijstvo usmerjeno, upravljanje z gozdovi, ocena natančnosti)

This article deals with the possibilities of applying GPS navigation technology to the management of natural resources. It is based on the results of GPS soil mapping at about 30 locations in Baranja (eastern Croatia). The GPS receivers were used primarily for the positioning of the soil-sampling sites. Dynamic mapping was not monitored. The practical purpose of the research was to learn more about working with GPS data, integrating GPS into geographic information system (GIS), and testing the possibilities of the more precise Differential GPS (DGPS). The differences between the data obtained using three methods of point positioning in space were tested: a) geo-referenced aerial photographs (AERO), b) a standard GPS signal, and c) a corrected DGPS signal. A systematic deviation and an error radius were established with respect to the reference value (the DGPS results). Testing the difference between the GPS and AERO did not show any statistically significant difference between these two methods. According to the results of the research, GPS positioning can be successfully applied to soil mapping and to natural-resource inventories in general. Positioning with an uncorrected GPS signal provides equal or better positioning accuracy than that obtained from aerial photographs at an approximate scale of 1:20,000. The use of satellite positioning depends on the needs of a given user group, where aspects relating to precision, a 95% probability radius, the reliability of results and the feasibility are of particular importance.

(Keywords: satellite navigation, GPS, precision agriculture, forest management, accuracy assessment)

0 UVOD

Navigacijski sistemi SDL postajajo vse bolj popularni, saj so lahko v pomoč pri zelo različnih

0 INTRODUCTION

GPS (Global Positioning System) navigational systems are becoming increasingly dejavnostih. Sisteme, kakor na primer Trimble's AVL (avtomatsko lociranje vozila), pogosto uporabljajo policija, zdravstveno reševalna služba, druge reševalne službe, gasilske čete, pa tudi mnogi drugi strokovnjaki, ki želijo zanesljivo in hitro doseči kraj nesreče. Zaradi načina sledenja reševalnim vozilom s SDL, ki so ga uvedli v Chicagu, je reševalna služba v tem mestu postala veliko bolj učinkovita in zanesljiva. Dve taksi družbi v Avstraliji sledita svojim taksistom s tehnologijo SDL in sta zaradi novega načina dela že povečali svoj dobiček. Neka ribolovna družba na Novi Zelandiji uporablja SDL pri usmerjanju ladij, ki se tako na svoje začetne lokacije lahko vrnejo brez zamudnega izgubljanja smeri. V Skandinaviji pa so razvili alarmni sistem, ki omogoča hitro in učinkovito zdravstveno pomoč pri nesrečah v gozdovih [1]. Na Hrvaškem se SDL uporablja za sledenje medvedov, volkov in risov, da bi zagotavljali nadzor nad premiki velikih zveri [2]. Da bi čim bolj zmanjšali število poškodb, ki jih povzroči gozdarska mehanizacija, se SDL uporablja tudi za prepoznavo površin s težko zemljo, ki tlači gozdni ekosistem.

Zamisel o uporabi satelitskega določanja lege, ki bi nadomestilo sedanji radijski ali radarski sistem, se je pojavila v sedemdesetih letih prejšnjega stoletja. V začetku so te sisteme določanja lege razvijali predvsem za vojaške namene in je bila njihova raba lokalno omejena. Predhodniki modernega sistema SDL so »Omega«, kasneje pa tudi "Loran-C" in "Transit". Čeprav so ga razvijali predvsem v vojaške namene, je SDL od leta 1978 rabljen tudi v civilne namene. Ob koncu leta 1983 je predsednik Reagan odobril uporabo tako-imenovanega »standardnega določanja lege« (Standard Positioning Service – SPS) z naključnim odstopanjem 100 metrov za civilne potrebe. Od zgodnjih devetdesetih let prejšnjega stoletja se je trg SDL večal z izjemno hitrostjo, ki v mnogih pogledih spominja na razmah uporabe interneta.

0.1 Satelitski navigacijski sistemi

SDL temelji na delovanju 24 satelitov, ki jih upravlja *obrambno ministrstvo ZDA.* Ti sateliti krožijo okoli Zemlje na povprečni višini 20.200 km in s povprečnim obhodnim časom 12 h. Na ta način so, s katerekoli točke na 95% Zemljine površine, izmed desetih satelitov najmanj štirje sateliti »vidni« 24 ur dnevno. Merjenje lege sprejemnika v trirazsežnem sistemu temelji na izračunu vektorja razdalje – med satelitom in sprejemnikom. Tu ima najpomembnejšo vlogo osnovni del satelita –

popular with many people taking part in a variety of activities. Systems such as Trimble's AVL (Automatic Vehicle Location), for example, are widely used by the police, emergency medical services, search-and-rescue services, fire brigades, but also by many others who want to reach the scene of an accident both reliably and quickly. The GPS emergency-vehicle tracking system introduced in Chicago has made the 911 service more efficient and reliable. Two taxi companies in Australia now track their taxi drivers with GPS and are already increasing their profits. A New Zealand fishing company uses GPS to facilitate the return of its ships to the same locations without unnecessary straying off course. A GPS alert system has been developed in Scandinavia to provide rapid and efficient medical aid to the casualties of forestry accidents [1]. Croatia uses a GPS system to track the movement of bears, wolves and lynxes for the purpose of large-game management [2]. To minimize the damage due to forestry mechanization, a GPS is used to map the areas of heavy soil trampling in forest ecosystems.

The idea of using a satellite positioning system as opposed to existing radio and radar systems was born in the 1970s. In the beginning, these positioning systems were developed primarily for military purposes and were of local character. The predecessors of the modern GPS are "Omega", and more recently "Loran-C" and "Transit". Although developed primarily for the military, GPS began to be used for civilian purposes in 1978. In late 1983, president Reagan authorized the use of the so-called Standard Positioning Service (SPS) with an uncertainty of about 100 m for civilian use. Since the early 1990s, the GPS market has been growing at an exponential rate, similar in many ways to the expanding use of the internet.

0.1 Satellite Navigation Systems

GPS is based on 24 satellites maintained by the *US Department of Defense*. These satellites orbit the earth at a mean altitude of about 20,200 km, with a mean orbit time of 12 h. In this way at least four (of ten) satellites are "visible" 24 hours a day from any position on 95% of the Earth's surface. Measuring the position of the receiver in the 3D system is based on the measurement of a distance vector – from the satellite to the receiver. Here, the most important role is played by the fundamental part of the satellite – the atomic clock – which measures atomska ura – ki meri čas v milijoninkah sekunde (čas, ki je potreben, da elektromagnetni val naredi pot od satelita do Zemlje znaša približno 0,07 sekunde). Ker poznamo ta čas, lahko vektor poti (d) izrazimo na dva načina:

the time in millionths of seconds (the time needed for the electromagnetic wave to cover the distance from the satellite to the earth is of the order of 0.07 seconds). With a knowledge of this time, this vector (d) of the route can be expressed in two ways:

$$d = \sqrt{(X_s - X_p)^2 + (Y_s - Y_p)^2 + (Z_s - Z_p)^2} = c \cdot (t - \Delta t) \quad (1),$$

kjer so:
X_s, Y_s, Z_s prostorske koordinate satelita in X_p, Y_p, Z_p prostorske koordinate sprejemnika,
c je hitrost elektromagnetnih valov,
t je čas potreben, da elektromagnetni val naredi pot od satelita do sprejemnika
Δt je napaka ure v sprejemniku.

Za določitev neznank v enačbi (*Xp, Yp, Zp,* Δt) so potrebne najmanj štiri neodvisne enačbe istega tipa. In prav zato je SDL organiziran tako, da so ob kateremkoli času iz katerekoli točke na Zemlji vidni vsaj štirje sateliti.

Vsak satelit oddaja tri vrste binarnih kodiranih sporočil (takoimenovana psevdonaključna sporočila):
a) C/A označuje grobo oceno
b) P označuje natančnost
c) Y označuje stanje

Kodni sporočili C/A in P sta pri vsakem satelitu drugačni, tretja koda, Y, pa je signal, ki prenaša podatke o legi satelita v danem trenutku. Te tri kode se prenašajo na dveh mikrovalovnih frekvencah: na pasu L1 (1575,42 MHz) in na L2 (1227,60 MHz). Pas L2 prenaša podatke o natančnosti (P), kar omogoči natančnost določitve lege na vsaj 22 m. Ta signal je trenutno dosegljiv le pooblaščenim uporabnikom (vojska in nekatere gospodarske družbe) [3].

where:
X_s, Y_s, Z_s are the spatial satellite coordinates, and X_p, Y_p, Z_p are the spatial receiver coordinates,
c is the speed of the electromagnetic waves,
t is the time needed for the electromagnetic wave to travel from the satellite to the receiver
Δt is the clock error in the receiver.

To determine the unknowns in the equation (*Xp, Yp, Zp,* Δt), a minimum of four independent equations of this form are needed. It is for this reason that GPS is organized so that at least four satellites are visible at all times from any position on earth.

Each satellite in fact broadcasts three types of binary codes (the so-called Pseudo Random Codes):
a) C/A or Coarse Acquisition
b) P or Precision
c) Y or Status Information

The C/A and P codes are specific to each satellite, while the third, Y, signal carries the data relating to a satellite's position at any given moment. These three code types are broadcast on two microwave frequencies: the L1 band (1575.42 MHz) and the L2 band (1227.60 MHz). The L2 band carries the data of the precise code (P), which enables a positioning accuracy of at least 22 m. This signal is currently available only to authorized users (the military and some companies) [3].

0.2 Tržne usmeritve

Mednarodni trg popolnoma obvladujejo ameriške naprave SDL. Zato je razumljivo, da je v literaturi drugih narodov satelitska navigacija pogosto imenovana kar SDL. Podobno kakor digitalna informacijska oprema je tudi SDL v zadnjih letih postalo pomemben del vsakodnevnega življenja. Uporabniki in izvedbe tehnologije SDL so prikazani v preglednici 1.

Največji trg za uporabe SDL nedvomno predstavljajo kopenska navigacija (tovornjaki, traktorji in osebna vozila) in potrošne dobrine. Kopenska navigacija, sprejemniki mobilnih telefonov, osebni računalniki, rekreativne in druge podobne dejavnosti trenutno zavzemajo približno 60% trga z napravami za SDL. Sickle [5] predvideva, da bo v prihodnosti vsako

0.2 Commercial trends

The international market is completely dominated by the American GPS. It is understandable, therefore, that in foreign literature satellite navigation is often referred to as GPS. In recent years GPS has increasingly become a part of everyday life, in a similar way to digital information equipment. The basic user groups and applications are presented in Table 1.

Clearly, the largest market for GPS applications is land-based navigation (trucks, tractors and personal vehicles) and consumer goods. Currently, land-based navigation, mobile-phone receivers, PCs, recreation and others account for about 60% of the GPS market. According to Sickle [5], there will come a time when every vehicle, whether

Preglednica 1. *Glavna področja uporabe SDL, razpon stroškov sprejemnika in ocena velikosti celotnega trga [4]*
Table 1. *Main groups of GPS applications, range of receiver costs and estimation of total market size [4]*

Področja uporabe Group of applications	Razpon stroškov sprejemnika v USD Range of receiver costs in $	Skupno število modelov / gospod.družb (pribl.) Total models /companies (app.)	Celotna velikost trga v milijonih USD (1994) Total market size in millions of $ (1994)
kopenska navigacija land-based navigation	299 do/to 82.000	200 / 35	180
geodezija land surveying	355 do/to 82.100	102 / 34	145
aeronavtična navigacija aeronautical navigation	355 do/to 60.000	144 / 30	62
navtična navigacija nautical navigation	299 do/to 60.000	166 / 43	100
neposredno trženje consumer direct market	-	-	-

vozilo – osebno, javno, policijsko ali transportno – uporabljalo satelitski navigacijski sistem.

Ocena števila prodanih sprejemnikov SDL v Evropi dosega stotine tisočev prodanih enot, na Hrvaškem pa je to število še vedno neznatno.

0.3 Napake SDL in njihovi viri

Nekatere mogoče vire napak SDL lahko razdelimo v dve skupini:

a) Sistemske napake: na primer napake atomske ure, atmosferske zakasnitve (zamuda signala, ki jo

civilian or public, police or transport, will be using a satellite navigation system.

The number of GPS receivers sold in Europe is estimated at hundreds of thousands; however, in Croatia this number is still insignificant.

0.3 GPS errors and their sources

Some possible sources of GPS errors can be divided into two groups:

a) System errors: for example, satellite-clock errors, atmospheric delay (delayed signal caused by

Preglednica 2. *Tipi SDL*
Table 2. *Types of GPS positioning*

Tip določanja lege Type of positioning	Približna vodoravna natančnost (polmer 95% verjetnosti) Approximate horizontal accuracy (95% probability radius)		Približna cena (USD) Approximate price ($)
	idealna* ideal*	povprečna mean	
SDL – standardni sistem, (enkratna določitev položaja) SPS – standard system, (single fix)	50 m	100 m	100 do/to1000
SDL – standardni sistem, (povprečenje) SPS – standard system, (averaging)	30 m	50 m	100 do/to1000
DSDL – diferencialni sistem (<30 km) DGPS – differential system (<30 km)	1,3 m	< 5 m	1000 do/to5000
NDL – natančen sistem PPS – precise system	22 m	-	-
kombiniran sistem SDL-GLONASS (nediferenciabilen) Combined GPS-GLONASS (non-differentiated)	15 m		> 2000
zelo natančen sistem highly precise system	< 0,001 m		> 5000

* - na natančnost ne vplivajo sistemske napake, vplivajo le naključne napake, ki so majhne.
* - accuracy not affected by any system error but only by random errors, which are minimal.

povzročijo vplivi ozračja), izbiralna dostopnost (ID) in drugo.

b) Naključne napake: napake sprejemnikove ure, uporabniške napake in drugo.

Preglednica 3 vsebuje prikaz strukture napak SDL.

Očitno je največji delež napak povezan s sistemskimi napakami signala SDL. Ker se število napak SDL bistveno ne poveča v polmeru 30 km, lahko povečamo natančnost standardnega signala na en meter (v kombinaciji z izračunom povprečja), če poznamo natančni čas izračuna določene napake. Z uporabo krmilnega sprejemnika, ki z veliko natančnostjo meri koordinate na mestih, kjer so le-te poznane, je mogoče izračunati napako SDL za vsak merilni korak (ID, atmosferska zakasnitev). Ta metoda se imenuje diferencialno SDL (DSDL) in je trenutno najpogosteje uporabljena metoda določanja položaja v komercialnih uporabah. DSDL praviloma potrebuje najmanj dva sprejemnika. Poznamo dva glavna tipa metode DSDL:

a) DSDL v realnem času ali trenutna odprava napak (dva sprejemnika uporabljamo za odpravo napake – GSP in sprejemnik radijskih ali satelitskih signalov),
b) DSDL v času po obdelavi podatkov ali poznejša odprava napak.

atmospheric influences), selective availability (SA) and others.

b) Random errors: receiver-clock errors, errors caused by user handling and others.

A summary of the GPS error structure is presented in Table 3.

Clearly, the largest portion of all errors relates to system errors in the GPS signal. As the amount of GPS errors does not change substantially within a 30-km radius, knowing the exact time when a certain error has been calculated makes it possible to improve the standard signal to about a 1-m accuracy (in combination with averaging). Using a control receiver that measures the coordinates, where they are known, with a much higher precision, it is possible to calculate a GPS error for every measuring interval (SA, atmospheric delay). This method is called Differential GPS (DGPS) and is currently the most frequently used positioning method in commercial applications. As a rule, DGPS requires at least two receivers. There are two main types of DGPS:

a) Real-time DGPS or momentary error elimination (two receivers are used to eliminate an error – GPS and a receiver of radio or satellite signals),
b) Post-processing DGPS or subsequent error elimination.

Preglednica 3. *Viri napak SDL in njihove vrednosti. Standardne in popravljene (diferencialne) vrednosti*
Table 3. *GPS error sources and their values. Standard and corrected (differential) values*

Vir Source	Tipična vrednost satelita (m) Typical value per satellite (m)	
	Standardna Standard	Diferencialna Differential
atomska ura satellite clock	1,5	0
orbitalne napake orbital errors	2,5	0
ionosfera ionosphere	5,0	0,4
troposfera troposphere	0,5	0,2
šum (sprejemnik) noise (receiver)	0,3	0,3
‘večpotnost’ ‘multipath’	0,6	0,6
ID/SA	30	0
Idealna natančnost Ideal accuracy	Standardna Standard	Diferencialna Differential
vodoravna horizontal	50	1,3
navpična vertical	78	2,0
trirazsežna 3D	93	2,8

Najnaprednejši sistem, ki ga trenutno poznamo, oddaja popravni signal sprejemniku SDL po radijskih valovih. V razvitem svetu takšne sisteme razvijajo na državni ravni, obstojajo pa tudi številne mednarodne družbe, ki ponujajo tovrstne storitve (na primer, Omnistar prek satelita daje DSDL popravni signal na globalni ravni, torej pokriva tudi celotno območje Hrvaške). Po nakupu sprejemnika SDL in potrebnega dodatnega sprejemnika uporabnik ugotovi radijsko frekvenco lokalnega DSDL, na katero se mora mesečno ali letno prijaviti.

1 METODOLOGIJA

Da bi ugotovili možnosti navigacijskih uporab SDL na področju upravljanja z naravnimi viri, smo na približno 30 krajih v Baranji (vzhodna Hrvaška) izvedli raziskavo. Uporabljali smo sistem GARMIN, ki vključuje dva sprejemnika SDL – SDL 100 SRVY II. Glede na ceno (1.500 USD), sprejemnika sodita v srednji razred sprejemnikov SDL. Posamezni sprejemnik tehta približno 300 g, njegov zagonski čas je približno 2 minuti. Ugotavljali smo razlike med tremi metodami določanja lege v prostoru:

1. georeferenčnim zračnim fotografiranjem (AERO) v povprečnem merilu 1:20.000
2. standardnim signalom SDL
3. signalom DSDL – merilno povprečje 180 (interval = 1 s)

Prvi SDL je bil postavljen na kraj s poprej določenimi geodetskimi koordinatami (z merilno natančnostjo približno 0,5 m). To lokacijo smo poimenovali BAZA ali osnovna lokacija. Drugi sprejemnik SDL smo uporabljali za meritve na terenu (TEREN). Po opravljenem delu na terenu, smo podatke iz osnovnega in iz terenskega sprejemnika prenesli v računalnik in jih obdelali. Ker smo koordinate SDL vnesli v sistem geografskih koordinat (z elipsoidom WGS84), so bili izvirni podatki spremenjeni v lokalni Gauss-Kruegerjev sistem (Besslov elipsoid). Spremembo smo izvedli po metodi sedmih parametrov (Trimblovi parametri za področje celotne Hrvaške) [6].

Glede na specifikacije lahko rečemo, da popravljeni signal SDL (DSDL) doseže natančnost 1-5 m pri statičnih meritvah oziroma pri kartiranju zemljišča (povprečna vrednost, dobljena na osnovi več ko 180 posameznih odčitkov). Pri dinamičnih meritvah se natančnost zmanjša na 3 do 10 m. Na tej stopnji raziskave nismo izvedli dinamičnega kartiranja

Today, the most advanced system involves broadcasting a correction signal to a GPS receiver via radio waves. In the developed world, such systems are being developed at the state level, but there are also a number of international companies that provide such services (for example, Omnistar offers a DGPS correction signal via a satellite at the global level, covering the whole territory of Croatia as well). After determining the radio frequency of the local DGPS, when purchasing an additional receiver with the GPS receiver, the user must also subscribe (monthly or annually) to the frequency.

1 METHODOLOGY

In order to investigate the possibilities of GPS navigation applications in natural-resource management mapping, research was conducted at about 30 locations in Baranja (eastern Croatia). The GARMIN system of two GPS receivers – GPS 100 SRVY II – was used in the investigation. These receivers belong to the medium class of GPS receivers in terms of price ($1,500). The receiver weighs about 300g, and its initiation time is about 2 minutes. The differences between three methods of spatial point positioning were tested:

1. Geo-referenced aerial photographs (AERO) at an approximate scale 1:20,000
2. Standard GPS signal
3. DGPS signal – 180 measurement average (interval = 1 s)

One GPS receiver was positioned at a location of previously determined surveying coordinates (measurement accuracy about 0.5 m). This location was called BASE or the base location. The second receiver was used for the field measurement (FIELD). After completing the fieldwork, data from the BASE and the FIELD receivers were transferred to a PC and processed. Since the GPS coordinates were read in the geographic coordinate system (with WGS84 ellipsoid), the original data were converted into the local Gauss-Krueger system (Bessel's ellipsoid). The conversion was accomplished according to the 7-parameter method (Trimble's parameters for the whole of Croatia) [6].

According to the specifications, the corrected GPS signal (DGPS) achieves an accuracy of 1–5 m during a static measurement or for location mapping (average value of over 180 individual readings). For dynamic measurements the accuracy decreases to 3–10 m. At this stage of the research, dynamic mapping (lines) was not ob-

(črt). Sprejemnika SDL smo uporabili predvsem za določanje leg vzorčnih zemljišč. Te podatke smo kasneje obdelali s sistemom GIS, da bi preverili našo glavno raziskovalno domnevo: nujnost uporabe orodja GIS pri kartiranju in modeliranju prostorskih parametrov zemljišča. Praktični namen raziskave pa je bil pridobitev znanja in izkušenj pri delu s podatki SDL, njihovo vključevanje v sistem GIS in preverjanje možnosti, ki jo ponuja bolj natančna metoda DSDL.

2 REZULTATI

Rezultate naše raziskave moramo razdeliti v dve skupini: na tiste, ki smo jih pridobili z izkušnjami, in tiste, ki smo jih pridobili z obdelavo statističnih podatkov.

Izkušnje z uporabo metode SDL zadevajo ravnanje z napravo, porabo časa in praktične pomanjkljivosti metode:
Ravnanje: Za uporabo sprejemnika Garmin ne potrebujemo posebnega znanja, vendar pa lahko neizkušenost pri njegovi uporabi povzroči resne napake in nepravilne razlage.
Poraba časa: Zagonski čas naprave je 2 do 4 minute. Dodatni čas (približno 1,5 ure) je potreben za prenos podatkov (do 3 MB za vsak snemalni dan) na osebni računalnik.
Pomanjkljivosti: Pričakovano natančnost smo dosegli le na prostem. V primeru gostih krošenj (na primer v sto let starem hrastovem gozdu) signal postane šibek, vrednosti lahko odstopajo za 200 m, in meritve pogosto postanejo neizvedljive. Za štiri kraje nismo mogli obdelati podatkov, ker le-ti niso ustrezali zahtevam. Poglavitna pomanjkljivost pa zadeva odpravo napak SDL. Med postopkom DSDL bi moral biti merilni čas daljši kot je sicer določeno (3 minute za vsak kraj), ker je bilo v povprečju le 60% podatkov (psevdorazdalje) primernih za obdelavo. Glavni problem je torej nezadostno pokritje krajev.

Podatke smo statistično obdelali s statističnim paketom Minitab12 (1998, Minitab Inc.). Primerjali smo podatke, pridobljene s tremi metodami določanja lege. Rezultate DSDL smo uporabili kot referenčne vrednosti. Vse navedene vrednosti se nanašajo na vodoravno določanje lege, z drugimi besedami, upoštevali smo le koordinati XY. Izračunano sistematično odstopanje metode SDL od referenčnih vrednosti DSDL (povprečje za 25 krajev) je bilo 13,0 m, in 16,1 m od metode AERO. Da bi pridobili dejanski vrednosti odstopanja – 16,0 m za SDL in 19,1 m za AERO – bi moralo biti to odstopanje kombinirano z ocenjeno srednjo vrednostjo napake DSDL, ki znaša

served. The GPS receivers were primarily used to position soil-sampling sites. These data will later be processed with GIS in order to test the main research hypotheses: the mapping and modeling of spatial soil parameters using GIS tools. The practical purpose of the research was to learn more about working with GPS data, how to integrate GIS, and to test the possibilities of the more precise DGPS.

2 RESULTS

The results of this research can be divided into two groups: those gained from experience and those gained from statistical data processing.

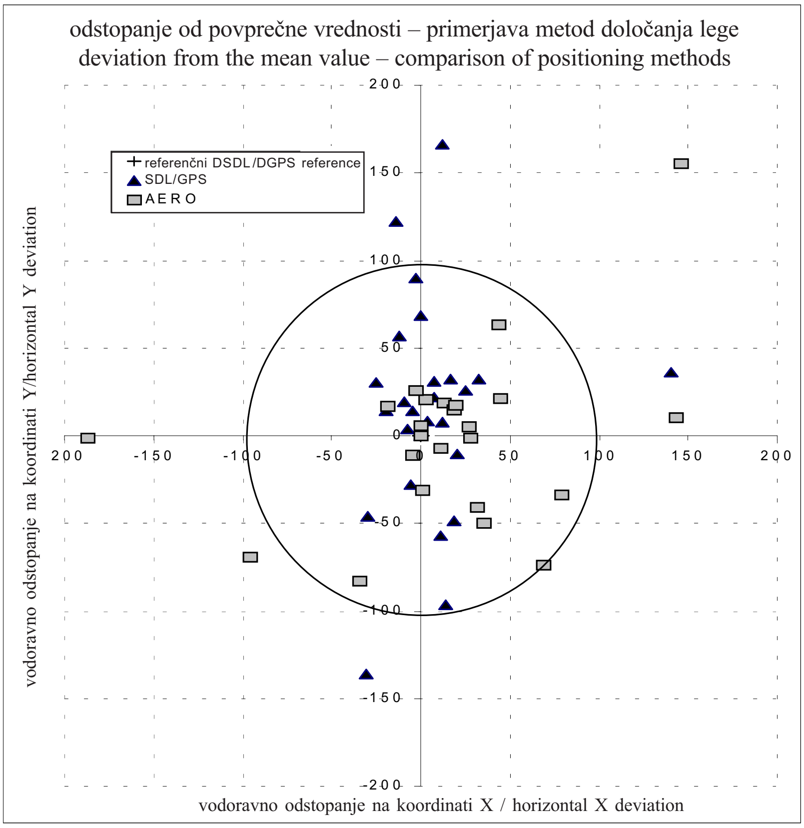
The experience with the use of GPS relates to handling, time consumption and practical drawbacks:
Handling: The Garmin receiver does not require any special knowledge, yet inexperience may cause large errors and incorrect interpretations.
Time consumption: The initialization time lasts from 2 to 4 minutes. Additional time (about 1½ hours) is spent transferring the data (up to 3 MB for one day of recording) to a PC.
Drawbacks: The expected accuracy is only achieved in the open. In the case of dense tree cover (for example, a 100-year-old oak forest) the signal is weak, the values may deviate by 200 m, and a measurement is often impossible. During data processing four locations were rejected because they did not satisfy the requirements for a calculation. The main drawback involves the elimination of GPS errors. In the DGPS procedure, the measuring time must be longer than planned (3 minutes per location), because only 60% of the data (pseudo-ranges) were on average suitable for processing. The main problem was insufficient coverage.

The data were statistically processed with the Minitab12 statistical package (1998, Minitab Inc.). The data from three positioning methods were compared. The DGPS results were used as the reference values. All the mentioned values relate to horizontal positioning; in other words, only the XY coordinates were taken into account. The calculated systematic deviation of the GPS method from reference DGPS values (average for 25 locations) was 13.0 m, and 16.1 m for the AERO method. To obtain the true deviation value – 16.0 m for GPS and 19.1 m for AERO – this deviation should be combined with the estimated mean DGPS error

Preglednica 4. *Indikatorji primerjave med tremi metodami določanja lege*
Table 4. *Indicators of the comparison of three positioning types*

Statistični parameter N = 180 ali 3 min Statistical parameter N = 180 or 3 min	povprečje mean (m)	povprečno odstopanje mean deviation s_x (m)	minimum (m)	maksimum maximum (m)	porazdelitev distribution
DSDL*/DGPS*	25	2	0	10	logaritemsko normalna log-normal
odstopanje SDL-DSDL deviation GPS-DGPS	59,6	48,3	9	167	logaritemsko normalna log-normal
odstopanje AERO-DSDL deviation AERO-DGPS	64,2	57,9	6	213	logaritemsko normalna log-normal

* - domnevno odstopanje od dejanske vrednosti
* - assumed deviation from true value



Sl. 1. *Primerjava treh metod določanja lege. Rezultati metode DSDL so uporabljeni kot referenčne vrednosti (domnevna napaka je < 5 m). Diagram prikazuje odstopanja osnovne SDL meritve, pa tudi meritve izven polmera 95% verjetnosti.*

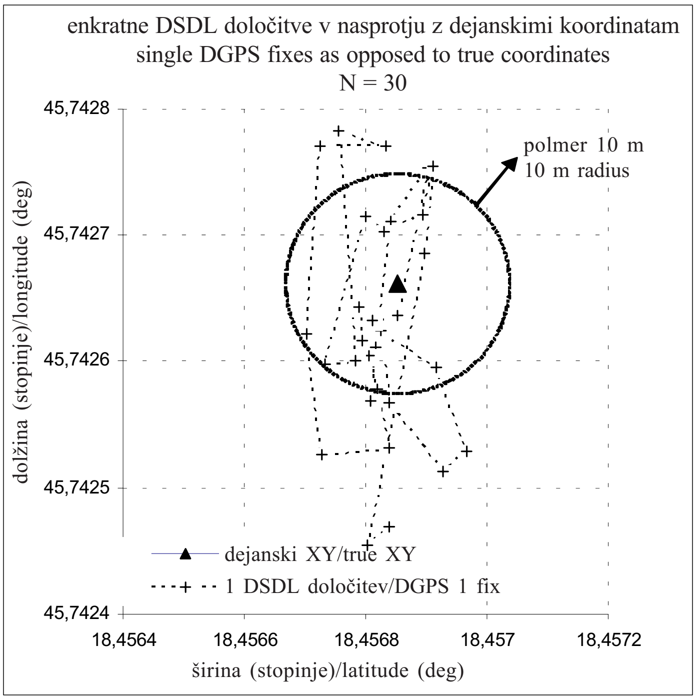
Fig. 1. *Comparison of three methods of field positioning. The results of the DGPS method are used as the reference value (assumed error is < 5 m). The deviation of the raw GPS, as well as the outliers of the 95% probability radius, can be seen.*

približno 3 m. Polmer napake SDL, ki znaša 16 m in smo ga pridobili s povprečenjem, se nanaša na neodvisne vzorce, tj. na vzorce, pridobljene v različnih časovnih korakih, daljših od ene ure. Glede na podobno raziskavo [7], v kateri je uporabljena metoda nepopravljenega signala SDL, ki izraža povprečje nepretrganega merjenja (brez daljših časovnih korakov), je mogoče povečati natančnost na približno 25 m (povprečje 600 vrednosti – sekunde). Vrednost te sistematične namerne napake je večinoma določena s selektivno dostopnostjo. Hkrati pa polmer, znotraj katerega smo izvedli večino meritev, oziroma polmer 95% verjetnosti, znaša približno 100 m v primeru enkratnega prebiranja pri metodi SDL. Povprečenje (za 300 vrednosti) ga zmanjša na približno 70 m [8] (slika 1), medtem ko pri metodi DSDL polmer znaša med 10 m v primeru enkratnega odčitavanja DSDL do 6 m (povprečje 180 vrednosti) (slika 2).

S primerjanjem metod SDL in AERO nismo odkrili statistično pomembnih razlik (t-test dveh vzorcev, $P_{0,05} = 0,77$).

of about 3 m. The GPS error radius of 16 m, derived from averaging, relates to independent samples, i.e., to samples taken at different time intervals longer than 1h. According to similar research [7], using a method of uncorrected GPS signal averaging with continuous measuring (without longer time intervals), it is possible to improve the accuracy to about 25 m (average of 600 values – seconds). The value of this systematic intentional error is mostly dictated by selective availability (SA). On the other hand, the radius within which the majority of the measurements were made, or the 95% probability radius, is about 100 m for a single reading for the GPS method. Averaging (300 values) decreases it to about 70 m [8](Figure 1), while for DGPS it ranges from 10 m for a single DGPS reading to 6 m (average of 180 values) (Figure 2).

Testing the difference between the GPS and the AERO methods revealed no statistically significant differences between these two methods (t-test for two samples, $P_{0.05} = 0.77$).



Sl. 2. *Odstopanja enkratnih določitev DSDL od povprečne/dejanske vrednosti; krog označuje polmer 95 % verjetnosti.*

Fig. 2. *Fluctuation of single DGPS fixes from the averaged/true value; the circle indicates the 95% probability radius.*

3 RAZPRAVA

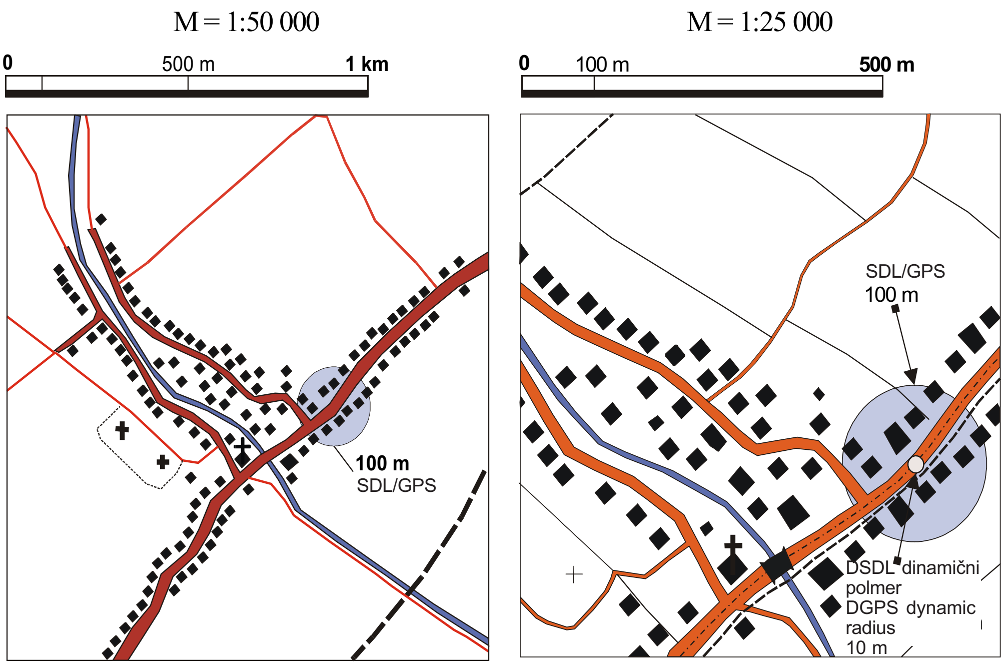
3.1 Inteligentni transportni sistem in upravljanje

V uvodu smo omenili le nekaj primerov vsakodnevne rabe satelitske navigacije v tržne civilne namene. Od namestitve navigacijskega sistema SDL v vozila v zgodnjih devetdesetih letih prejšnjega stoletja, je njegova tržna raba postala zelo raznolika. Sisteme avtomatske navigacije in načrtovano upravljanje prometa v prihodnosti običajno imenujemo *pametni transportni sistemi* [9]. Razvoj in uporaba teh sistemov v upravljanju sta, na primer, že pripeljala do oblikovanja nove ekonomske smeri, imenovane *znanstveno usmerjeno upravljanje*. Izraz *znanstveno usmerjeno kmetijstvo/znanstveno usmerjeno poljedelstvo* se je uveljavil na področju kmetijstva, medtem ko se v gozdarstvu tovrstne uporabe razvijajo počasneje zaradi slabšega sprejema satelitskega signala v gozdovih. Uporabniki SDL v gozdnatih in hribovitih predelih bi morali, ob uporabi že omenjenih komponent, imeti dostop tudi do zunanje antene in zunanjega vira napajanja, kar pa bi znatno povečalo

3 DISCUSSION

3.1 Intelligent transportation systems in management

The introduction mentions only a few of the commercial civilian uses of satellite navigation in everyday life. Since the installation of the GPS navigation system in vehicles in the early 1990s, its commercial uses have diversified. Systems with automated navigation, and the envisaged traffic management of the future, are commonly known as *Intelligent Transportation Systems* [9]. The development and application of these systems in management, for example, has led to the establishment of a new branch of the economy called *Precision management*. The term *Precision agriculture/Precision farming* has become established in the field of agriculture, whereas in forestry the applications are developing at a slower rate due to poorer signal reception in forests. GPS users in forested and hilly areas should, along with the already mentioned components, have at their disposal an external antenna and an external source of power, which considerably increases the size of



Sl. 3. *Razlika v določitvi lege glede na različna merila – 1:25000 in 1:50000. Medtem ko za manjša merila zadostuje celo nepopravljen signal SDL, pa mora biti za večja merila navigacijska napaka manjša od 5 m. Kroga označujeta specifični polmer 95% zanesljivosti.*

Fig. 3. *Difference in positioning related to map scale – 1:25000 and 1:50000. While even an uncorrected GPS signal is enough for smaller scales, larger management scales demand a navigation error smaller than 5 m. The circles indicate a specific 95% confidence radius.*

obseg začetne investicije. Trenutna standardna vrednost napake SDL, ki znaša približno 100 m v vodoravni smeri in približno 150 m v navpični smeri, ne zadovolji številnih potencialnih uporabnikov na področju upravljanja (slika 3).

Uporaba DSDL v kmetijstvu je pokazala, da lahko, na primer, ob enakem ali celo boljšem pridelku dosežemo znaten prihranek pri pognojevanju (pogosto celo 30%). Hkrati lahko v polni meri upoštevamo ekološka načela, kot na primer varstvo kakovosti vode. Temeljni cilj znanstveno usmerjenega kmetijstva je podrobna določitev ekoloških in proizvodnih dejavnikov, kakor so lastnosti zemlje, podnebne razmere, raba gnojil, pridelek idr., znotraj danega območja. Gnojenje, na primer, vključuje štiri korake:

- analiziramo in lociramo primere pomanjkanja hranljivih snovi (elementov) v določenem območju,
- podatke obdelamo s programom GIS in izdelamo karto pomanjkanja hranljivih snovi,
- karto pomanjkanja hranljivih snovi uporabimo za izračun celotnih potreb po gnojilih,
- na podlagi karte razdelimo gnojila, pri čemer uporabljamo avtomatiziran sistem (DSDL).

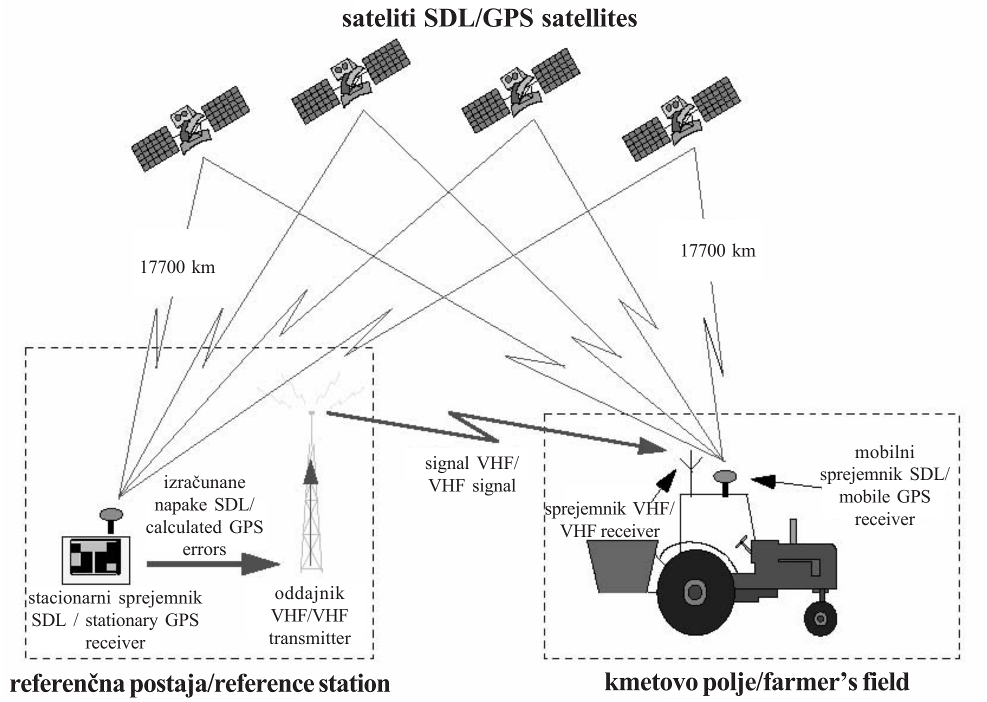
Čeprav so raziskave pokazale, da sprejemno-prikazovalni sistemi DSDL še vedno zahtevajo izdatno naložbo [10], pa upadanje cen opreme informacijske tehnologije kaže na to, da bodo ti

the initial investments. The current standard value of GPS error of about 100 m in the horizontal direction, and about 150 m in the vertical direction does not satisfy numerous potential uses in management (Figure 3).

DGPS application in agriculture has proved that, for example, considerable savings can be made with fertilizers (often as much as 30%) at equal or even better crop yields. At the same time, ecological principles, such as water-quality protection, are fully observed. The basic goal of precision agriculture is to map in detail the ecological and production factors within a given field, such as soil attributes, climatic conditions, fertilizer input, yield and others. For example, fertilizing involves three steps:

- nutrient (elements) deficiency in the field is sampled and geo-referenced,
- data are processed within the GIS program and a nutrient-deficiency map is generated,
- the nutrient-deficiency map is used to calculate the total fertilizer requirement,
- based on the map, fertilizers are distributed using the automated and oriented (DGPS) system.

Although investigations have shown that DGPS display receiver systems still require a large investment [10], a falling trend in the prices of information-technology equipment indicates that



Sl. 4. *Shematičen prikaz storitve DSDL na področju znanstveno usmerjenega kmetijstva (povzeto iz vira [9])*
Fig. 4. *Schematic overview of DGPS service for application in precision agriculture (taken from [9])*

sistemi kmalu postali običajna in široko uporabljana orodja (podobno kakor računalniki). Takšne sisteme že izdatno uporabljajo v Nemčiji, Avstriji, Veliki Britaniji in nekaterih drugih evropskih državah.

they will soon become a common and widely available tool (like computers). Such systems already have large-scale uses in Germany, Austria, the UK and other European countries.

4 SKLEPI

Rezultati raziskave kažejo, da lahko metodo SDL uspešno uporabljamo pri kartiranju zemljišč in pri prepoznavanju drugih naravnih virov. Določanje lege z nepopravljenim signalom SDL omogoči enako dobro ali celo boljšo natančnost določitve lege, kakor jo dobimo z zračnimi fotografijami v povprečnem merilu 1:20.000. Uporaba satelitskega določanja lege je odvisna od potreb posameznih uporabniških skupin. Da bi lahko objektivno ocenili funkcionalnost postopka SDL za določene potrebe, moramo upoštevati naslednje elemente:

- Gre za enkratno meritev ali za povprečenje?
- Kakšna je sistemska napaka za dani čas meritve?
- Kolikšna je natančnost oziroma napaka povprečne vrednosti rezultata?
- Kakšen je polmer 95-odstotne verjetnosti za izbrano metodo določanja lege?
- Kolikšna je zanesljivost rezultatov v primeru uporabe metode DSDL, in kako to zanesljivost merimo?
- Katera metoda je najbolj donosna za določeno uporabo?

Vrednost povprečne napake DSDL (enkratna določitev) je, na primer, sprejemljiva za kartiranje v delovnem merilu 1:25.000 (to merilo je primerno za

4 CONCLUSIONS

The results of this research indicate that GPS positioning can successfully be applied to soil mapping and to natural resource inventories in general. Positioning with an uncorrected GPS signal provides equal or better positioning possibilities than aerial photographs with an approximate scale of 1:20,000. The use of satellite positioning depends on the needs of a given user group. In order to make an objective assessment of GPS functionality for a defined need, the following elements should be considered:

- Is it a single measurement or is it averaging?
- What is the system error for the given measurement time?
- What is the precision or the mean error of the averaged result?
- What is the 95% probability radius for the selected positioning method?
- If the DGPS method is used, what is the result reliability and how is it tested?
- Which method is the most profitable for the application?

The value of the mean DGPS error (single fix) is sufficient for a working scale of 1:25,000, for example (scale suitable for detailed management

Preglednica 5. *Delovno merilo in ustrezen sistem določanja lege. Največja natančnost določitve lege = 0,2 mm na zemljevidu.*

Table 5. *Working scale and adjacent position system. Maximum location accuracy = 0.2 mm on map.*

Delovno merilo Working scale	**Kartografski detajl Mapping Detail**	**Primerna metoda določanja lege Suitable positioning method**	**Razpon uporabnosti Application range**
1:5000	1 m	natančne kombinirane metode highly accurate combined methods	geodezija, gradbeništvo surveying, civil engineering
1:25000 - 1:50000	5 m - 10 m	DSDL (enkratna določitev) DGPS (single fix)	navigacija vozil na področju upravljanja (traktorji, reševalne službe, policija, gasilske čete); navigacija ladij in letal; izdelava organizacijskih načrtov in drugo vehicle navigation in management (tractors, emergency service, police, fire fighter service); ship and airplane navigation; construction of management plans and others
<1:100000	> 20 m	SDL (enkratna določitev) GPS (single fix)	navigacija vozil za osebne namene, osebna navigacija vehicle navigation for personal use, personal navigation

podrobne organizacijske načrte). Preglednica 5 prikazuje glavne uporabniške skupine SDL glede na natančnost metode in ceno naprave.

Treba je poudariti, da nakup sistema DSDL še ne zagotavlja uspeha projekta. Nepogrešljiv del opreme je njen osnovni del, digitalni zemljevid (ali GIS) v ustreznem merilu in z vsebino, ki se spreminja glede na tip sistema. Z drugimi besedami, v delo je treba vključiti tudi tehnologijo GIS.

plans). Table 5 lists the main GPS application groups in terms of accuracy/price.

It should be pointed out that the purchase of a DGPS system does not guarantee the success of the application. An indispensable part of the equipment is the base, i.e., a digital map (or GIS) with a suitable scale and content, depending on the type. In other words, the use of GIS technology should be integrated.

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