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Positioning Using Locatalites

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Abstract: **GNSS has become one of the most widespread measurement technologies, allowing the achievement of cm-level positioning accuracy, especially with the use of differential techniques. The solution accuracy is heavily dependent on the number and geometric distribution of the visible satellites. This makes GNSS quite ineffective in dense city areas where there is a limited view of the sky. Research at the University of Nottingham [1] also outlined problems with using GNSS systems in the North-South orientated monitoring work in the Europe.**

Keywords: Locata, GNSS, precise positioning, integration, Pseudolite

I. INTRODUCTION

In 2003 bridge monitoring studies, conducted at the University of Nottingham [2] concluded that using pseudolites to augment GNSS geometry significantly improved the vertical and horizontal components. Following that the University concentrated on the Locata system - a terrestrial positioning technology, operating in the 2.4 GHz license free frequency band. Created by Locata Corp, it allows the network to be synchronised to the nanosecond level, using a novel procedure known as TimeLoc. The working concept of Locata is very similar to that of a GNSS or pseudolite system. The rover needs to solve for position and time, therefore it requires visibility of at least four Locatalites for successful 3D triangulation. As a terrestrial based navigation system it offers a much stronger signal than GNSS but is also very prone to fading multipath effects. Research work at the University of Nottingham [3] and the University of New South Wales [4] indicated that the Locata system is capable of maintaining centimetre level accuracy in areas difficult for GNSS.

This paper presents results showing how Locatalites perform in several different environments such as open sky, urban and indoor. There is also a discussion about the preliminary research that is currently being carried out into the integration of Locata and GNSS. This includes feasibility study for the integrated system, outline of the loose software integration and brief outline of the working algorithms.

II. BACKGROUND ON LOCATA

Since the beginning of the GPS concept (1978), ground based transmitters have been under development to compliment satellite constellations. The first of these ground based transmitters were called pseudo-satellites or pseudolites. They have been used to test GPS system elements and enhance GPS in certain applications by providing better accuracy, integrity or availability through the use of Pseudolite signals in addition to the GPS signals. Pseudolites were also a promising technology for providing positioning in high multipath environments where GPS signals are generally unavailable, severely attenuated, or of poor quality. Thus they presented the prospect of being useful for both indoor and outdoor positioning applications by transmitting a GPS like signal [5]. Pseudolites work in an unsynchronised mode and double differencing must be used to eliminate the Pseudolites and receivers clock biases. Growing interest in the mid 1990s foresaw pseudolite technology as the next “big thing”. Since then numerous pseudolite applications have been attempted: Local Area Augmentation System (LAAS), plane landing, bridge deformation monitoring, open pit mining, and reducing street works [6] [7] [8] [9] [1].

However, there are many fundamental issues that limit the effectiveness of a pseudolite system using C/A code on L1/L2. They include the illegality of transmitting on L1/L2, cross correlation between pseudolites and GPS signals (GPS jamming), saturation of the GPS receiver front end, and the limited multipath mitigation offered by C/A codes. This further complicates the design and deployment of such systems and places limits on any operational effectiveness. If Pseudolites can be synchronised in some manner, stand alone positioning can be achieved without base station data (and without the need for a radio modem data link) [10]. Several of years ago, attempts to synchronise Pseudolites resulted in position solutions that are up to six times worse in comparison to an unsynchronised approach using double differencing [11].

Recently, two positioning solutions have emerged from the development of pseudolite technology: *Terralites* [12] and *Locatalites*, a new breakthrough in ground based positioning world. The technology consists of a network of time synchronised transceivers allowing point positioning of a rover with centimetre accuracy (using carrier phase measurements) [13].

Locata Technology

Locata technology is built on a novel proprietary synchronization which is able to overcome some of the challenges presented by ground based receivers outlined previously. Locatalite transceivers transmit and receive a signal modulated in the same way as the GPS code allowing a rover to trilaterate to calculate its position. A LocataNet is a network of Locatalites; it consists of two types of device: Locatalites transmitters and the Locata receiver. The Locatalite transmitter generates a carrier phase signal modulated with a proprietary ranging code in the 2.4GHz Industrial Scientific Medical (ISM) band [14].

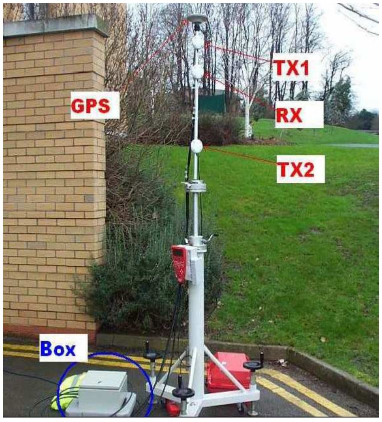

Fig. 1. A Locatalite setup

Locatalites transmit two positioning signals at the same frequency with different Pseudo Random Noise (PRN) ranging codes from the two transmitting antennas. A third antenna is used by the Locatalite to receive signals. Figure 1 shows a typical Locatalite installation. Notice that there is a GPS receiver at the very top of the mast. This GPS receiver is used only to give the exact initial location of the Locatalite antennas (Tx1, Tx2 and Rx). The waterproof metallic box (circled) protects the Locata hardware. In the network calibration process, the positions of all transmitting antennas are monitored precisely, and are registered in the memory of each Locatalites [15]. Deploying an antenna array rather than a single antenna at the transmitter side helps to protect the radio signals from fading effects at the receiver side [16]. As a rover receives two signals, each distorted by different propagation paths after being transmitted from a Locatalite, it can compare the Signal to Noise Ratio (SNR) and other multipath mitigation qualities of the two incoming signals. The rover can then detect if the signal transmitted from one antenna is in a deeper multipath fading zone than another, and can modify the processing of the signals in trilateration process.

III. OUTDOOR STATIC TESTS

In **Error! Reference source not found.** the results of static tests, using carrier phase measurements, in each scenario, have been recorded as mean and standard deviation averaged over 2000 seconds. Examining the mean values, it can be seen that the best overall accuracy is approximately 34mm in the Downs and the worst results are 82mm in the IESSG Car Park.

TABLE 1.
Results of test Carried out in Various Environments

RMSE (m)	Downs	GGL1	GGL2	Parking
Locatalites	8	7	7	5
HDOP	0.79	1.02	0.79	1.91
(E)	0.034	0.049	0.041	0.082
StD (E)	0.002	0.008	0.004	0.005
(N)	0.010	0.034	0.034	0.012
StD (N)	0.002	0.004	0.003	0.008

IV. OUTDOOR KINEMATIC TESTS

The results were extracted based on two different scenarios: the first one was performed in the same yard at the University of Nottingham used for GGL1 above; the second scenario took place in the yard at the University of New South Wales in Australia (UNSW). In the scenario at the University of Nottingham, the difference with GGL1 is that there were now three Locatalites set up on the roof of one of the buildings. This will now be called GGL1b. The trajectory of the rover during this experiment was from the point named “tree” moving toward the point “hole” and then the rover being moved back to the point “tree” again. The rover is initialized over a point with known coordinates in each of these experiments. During this particular experiment the Locata equipment used was single frequency only.

Table 1 shows the results of the kinematic tests carried out at the University of Nottingham.

TABLE 1
Results of the University of Nottingham tests

GGL1b	Tree	Hole	Tree
HDOP	0.602	1.253	0.602
Mean Error (E)	0.004	0.048	0.014
StD (E)	0.002	0.013	0.007
Mean Error (N)	0.019	0.051	0.070
StD (N)	0.014	0.039	0.040

The statistics are averaged over 60 epochs at each point and eight Locatalites were used in this scenario. The reference point is referred to as TS in the table. The distance between the 2 points is 17.04m. The rover was set up over the known point “tree” and data was collected for 60 seconds and compared with the known value. From

Table 1 it can be seen that as the rover moves from ‘Tree’ to ‘Hole’ the errors increase. As the rover is moved back toward the original point the easting errors decrease while the northing errors decrease. This is likely to be caused by the geometry of the network.

A similar experiment was carried out in the yard of the UNSW. UNSW currently have a permanent Locata network on the university campus (Fig. 2). The UNSW network also has eight Locatalites. Compared with the Nottingham network however the geometry of the system is better as all eight Locatalites have been located on the top of buildings.

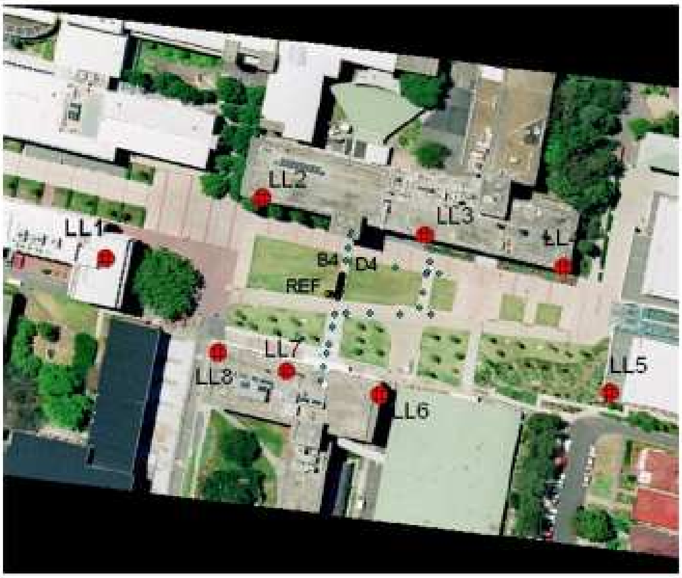

Fig. 2. UNSW Locata Network

The experiment carried out at UNSW moved between three different known points, labeled in Fig. 2 and Table 2 as REF/TS, B4/B5 and D4/B6. The rover was located over the known point TS/REF and data was recorded for 60 seconds. The coordinates calculated from Locata were then averaged and compared with the known coordinates of TS/REF. The mean error has been shown to be 16mm. The rover was then moved from TS/REF to the point B4/B5 and data is recorded for 60 seconds. The error now increases to16mm in Northing and 9mm in Easting. The rover is moved to the point D4/B6 and once again the mean error increases to 49mm in Easting and 129mm in Northing. Finally the rover is moved back to the point REF/TS and the error goes back close to it's original values.

The reader may wonder whether the errors propagate as the rover moves away from the initial known point. It is likely that these errors come partially from the environment around each individual known point and how the geometry of the signals changes from point to point as signals are lost and gained. The environment does not only include the phenomena linked to signal propagation such as multipath, scattering and shadowing (fading environment), but also the variation of the network geometry as the rover moves from the initial point around the network. Furthermore during both experiments the rover was not always in line of sight to all Locatalites, due to obstructions such as trees, other vegetation and buildings.

TABLE 2.
Results of the UNSW tests

UNSW (m)	TS	B5	B6	TS
HDOP	0.660	0.829	0.743	0.660
Mean Error (E)	0.006	0.009	0.049	0.017
StD (E)	0.008	0.004	0.021	0.002
Mean Error (N)	0.007	0.016	0.129	0.014
StD (N)	0.012	0.085	0.060	0.012

This variation of geometry can be seen in the tables as Horizontal Dilution Of Precision (HDOP). The dash dot lines show the threshold for the navigation software ability to detect cycle slips. Any measurements up to this threshold in absolute value are considered as a cycle slip. This threshold can be modified by the user. During this experiment the threshold was set to 0.33 cycles. Fig.3 clearly shows that cycle slips occurred after the rover begins to move. The result of this is that the navigation software resets the ambiguities each time a cycle slip is detected. This means that the number of whole cycles between the antenna and receiver may be solved incorrectly causing an error in the measurements.

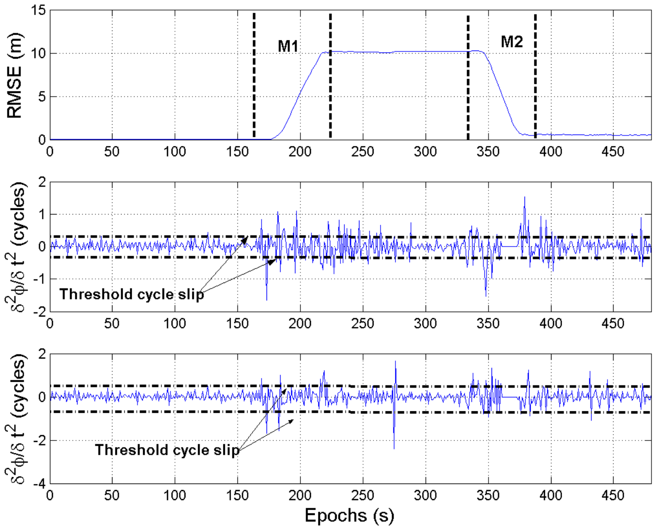

Fig.3. Carrier phase measurements showing cycle slips

From Fig.3 analysis of the carrier phase measurements show that several cycle slips occurred during the measurements. Fig.3 shows the RMS Error and the double difference of the carrier phase measurements for LL1 and LL6. M1 and M2 are the periods when the rover moves from "Tree" to "Hole".

V. INDOOR TESTS

The indoor tests were carried out in a barn environment. The advantage of performing the test indoors is that the vertical geometry of the LocataNet can be greatly improved. The set up of the LocataNet is shown in Fig. 4.

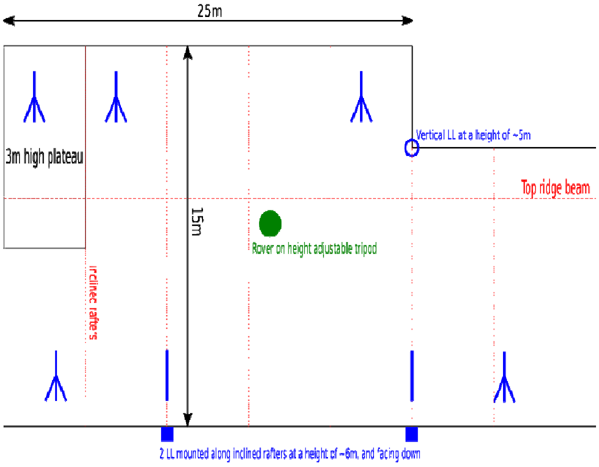

Fig. 4. Indoor LocataNet Setup

The rover was mounted on a height adjustable tripod in the centre of the LocataNet. The distance between the top setting on the tripod and the bottom setting was known to be 0.29 meters. Data was then recorded at first whilst the tripod was stationary and then whilst the tripod was being wound from its lowest point to its highest point and back again. The results of one of these tests can be seen in Fig. 5.

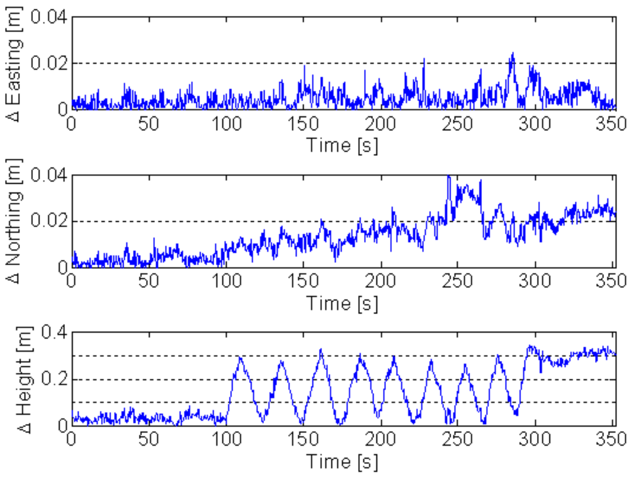

Fig. 5. Mean errors of indoor test

The results in Fig. 5 show that the errors in an indoor environment can be accurate to the centimeter level both in plan and in height. The improved geometry of the network resulted in vastly improved height information compared with the outdoor experiments.

There was however a drawback to using the current Locata technology indoors. The same test as described previously was carried out 15 times. Only on three occasions were the results of the test comparable to those shown in Fig. 5. To investigate the reason behind this the Signal to Noise Ration (SNR) is shown in Fig. 6 for two separate tests. On the left is shown the SNR that corresponds to the results in Fig. 5 and on the right is shown the SNR from one of the other 12 tests that did not produce any meaningful results.

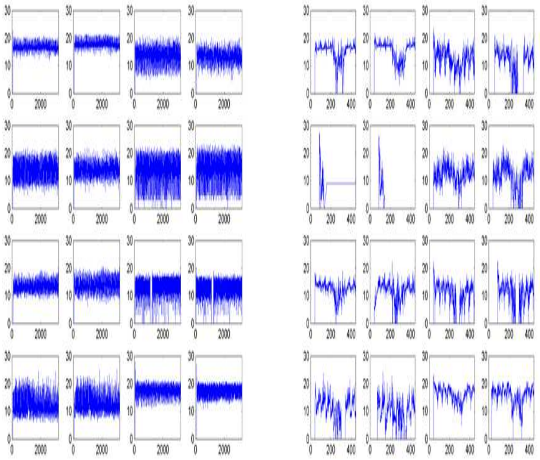

Fig. 6. SNR from indoor tests. SNR corresponding to Fig. 5 (left) and from another test (right)

The results show that in three of the tests the SNR of the signals was very stable. When this was the case the results of the test were accurate to the centimeter level as previously discussed. In the majority of our tests however the SNR was very unstable and resulted in results that were meaningless. The authors currently do not know the exact cause of these reliability problems other than the system has not been designed primarily for indoor use.

VI. INTEGRATION FEASIBILITY STUDY

The main goal of integration is to maintain accuracy of continuous measurements at the centimetre level despite environmental restrictions, so severely penalise GNSS systems. This is especially relevant to such difficult areas as urban canyons and semi-indoors areas.

The integrated system is expected to be especially beneficial as a supporting tool for engineering works such as deformation monitoring.

VII. TIME

Locata utilizes a proprietary time, which, apart from the similarity in structure, is not correlated with the GPS time. It shares architecture similarities with the GPS receivers, utilising a temperature compensated crystal oscillator (TCXO). The LocataNet Master-Slave procedure allows the mitigation of the effect of clock drift and aids the maintenance of constant time. This also simplifies the integration process, as only one device in the LocataNet has to be precisely synchronized with GPS time. The key to integration is the use of same timeframe for both systems. GPS time, with its high accuracy and consistency, is suggested as a base for an integrated system. Research at the University of Nottingham [Roberts 2009], calculate this value to be at least 10^{-7}s and conclude that Locata is able to maintain time at the level of precision required for successful integration. Results indicated that synchronisation as frequent as 10s are able to maintain time at the level precise enough for kinematic applications (10^{-6} s).

VII. GEOMETRY

With systems based on distance measurements, geometry can be used as a quality determinant. In the GNSS systems it is usually characterized by the Dilution of Precision (DOP) parameter. It has also been used in existing research on pseudolites [Meng 2003] to quantify the improvement of the combined geometry. Calculations indicate that while the independent Locata system, due to nearly coplanar placement of the transmitters and receiver, has a weaker vertical coordinate component than GNSS, the integrated system is able to surpass this limitation and maintain a much higher VDOP value.

The authors have argued that the DOP parameter is not best suited for an integrated system [Bonenberg 2009]. The Locata network is usually of a much smaller scale than the GNSS network and other factors such as noise and multipath have a large effect on the final position. To prove this a number of tests have been conducted a number of tests.

- Roof 1 – Small Network with obstructed line of sight, weak signals and multipath
- Roof 2 – Same as Roof 1 but with improved geometry.
- UNSW – Small Network in open courtyard, good VDOP limited multipath.
- Locata – Large Network distances exceeding 2km, Good VDOP.

TABLE 3.
A-priori and a-posteriori comparison of error elipses

95% confiden level	A priori			A posteriori			HDOP	Signals
	A [m]	B [m]	α [°]	A [m]	B [m]	α [°]		
Roof1	0.019	0.016	**87**	0.115	0.021	**155**	1.1	16
Roof2	0.024	0.012	134	0.031	0.006	127	1.6	20
UNSW	0.021	0.015	173	0.025	0.022	142	1.3	16
Locata	0.020	0.009	108	0.006	0.005	117	0.8	39

The results are presented in the Table 3 in the form of error ellipses with a confidence level of 95% (2σ). They show the difference in estimated and calculated geometry accuracy for each of the solutions. The Shape and orientation of the error ellipses indicate that in the smaller deployments, factors other than the geometry constraints are more prominent. Authors believe that this is visualisation of the multipath and channel noise. It is also noticeable that with improved geometry, in small networks, while ellipses orientation remains roughly constant (as expected) those effects affect its shape.

IX.MULTIPATH AND NOISE

The areas intended for combined systems, such as urban canyons, are notorious for multipath and noise. In terrestrial based receivers the signal can arrive at a very low (less than 10°) or even a negative elevation angle and is subject to signal fading (surface glance).
This manifests as severe signal power fluctuations (constructive and destructive multipath) and usually leads to signal loss. The Locata system is trying to compensate for this by using spatial separation of the antennas. It also utilises pulse signal and dual frequency to battle any environment generated noise.

These effects usually identify themselves in the form of cycle slips. The Locata wave is only 12 cm long with a narrowlane of 6 cm and widelane of 5m. This makes cycle slip detection problematic. Research papers [3] identify cycle slips as one of the main accuracy factors in kinematic use of the Locata system, since undetected cycle slips can create decimetre level biases. Certain solutions to this problem have been described in [4]. These problems could have contributed to the results discussed above.

VIII. INTEGRATED SYSTEM DESIGN

The main goal of this research is to create a functional integration of GNSS and Locata. The main requirement of this integration is the capability of maintaining centimetre level accuracy, especially in areas traditionally regarded as “difficult” or impossible for GNSS – such as urban canyons and semi-indoors areas. An Integrated system is expected to be deployed in the following scenarios:

- Online system, maintained by a qualified personnel, freestanding and continuously collecting observation data (monitoring)
- Manual system, deployed as per user requirements and on much shorter time scales.

Based on this, the integrated system should be able to fulfil the following criteria:

- Maintain constant accuracy in most environmental conditions
- Assess and monitor current accuracy and alert the user of any biases
- Simplify operational procedure and user output

The Software integration is intended to work with the observables from the sensors. The intention is to use GPS (GNSS) and Locata receivers as a ‘black box’ – pseudoranges (code), carrier phase, SNR, Doppler corrections and ephemeris (for GNSS) from the sensors will be collected.

CONCLUSION

Locatalites are a relatively new ground based positioning system that work in a similar way to GNSS systems. Using Locatalites for structural monitoring gives the advantage of being able to design the network to suit the particular project but gives the disadvantage that vertical geometry can often cause problems due to having all Locata transceivers in a similar plane. Locatalites are also susceptible to multipath errors.

This paper has presented the results of experiments carried out by the University of Nottingham and Locata Corp in several different environments. The results of these tests have shown that Locata networks are capable of providing centimetre level static positioning in open, urban and indoor environments. Further experiments have been conducted in an indoor environment to investigate the effects of multipath on the Locata system.

The paper has also discussed the feasibility of integrating GNSS and Locata. Since Locata is seen as complimentary system to GNSS for the monitoring of manmade structures. GPS and Locata share a large similarity in design and in concept of working. They also seem to complement each other in many aspects. The Locatalites strong terrestrial signal, up to 23dBm in comparison to -130 dBm from the GNSS and the possibility of the GNSS systems ability to detect system errors, due to ever-changing constellations can be given as example. But the highlight is the enhancement provided by the combined geometry of both systems.

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Craig Matthew Hancock, Gethin Wyn Roberts, Lukasz Kosma Bonenberg. Pozicionēšana pielietojot jauno tehnologiju "Locatalites"
GNSS ir kļuvusi par vienu no pasaulē izplatītākajām uzmērījumu tehonologijām, kas ļauj sasniegt pozicionēšanas precizitāti līdz 1 centimetram. Diemžēl, sistēmas galvenais trūkums ir nepieciešamība pēc skaidrām debesīm un mērījumu precizitātes atkarība no satelītu ģeometriskā izvietojuma, kas mainās dienas laikā. Ir vairāki svarīgi GNSS pielietojumi cm precizitātes līmeņa pozicionēšanā, piem., inženierģeodēzijā, tehnisko struktūru monitoring un būvdarbu geodēzijā. Daudzas no aktivitātēm jāveic teritorijās ar daļēju debess redzamībuun vispārzināmiem Multipath efektiem. Šīs problēmas viens no risinājumiem varētu būt tādas atbalsta sistēmas kā Locatalites attīstība. Tā ir terrestriālās pozicionēšanas tehnoloģija, kurai nav vajadzīga skaidras debess redzamība. Rakstā pirmoreiz analizētas iepriekšpārbaudes izmantojot Locatalites aprīkojumu dažādos apstākļos. Pārbaudes apstiprināja, ka Locatalites derīga pozicionēšanas risinājumiem ar dažu centimetru precizitāti statiskā un kinematiskā režīmā arī slēgtā vidē. Pārbaudes veica Nottingemas universitātē (Lielbritānija) un Dienvidvelsas universitātē (Austrālija). Jādiskutē par iespējām pētīt GNSS un Locatalites sistemu iecerēto integrāciju. Pārbaužu laikā tika arī pētīta Locatalites pulksteņu uzrādījumu stabilitāte, aprēķināts cik precīzi šie pulksteņi var saskaņoties ar GPS laiku integrēšanas iespējamai risināšanai. Tika pārbaudīta Locatalites rezultātu precizitāte, ko ietekmē tīkla ģeometrija. To veica, lai nākotnē būtu iespējams kombinēt abas sistēmas pēc precizitātes. Rakstā tiek analizēta labākā metode ģeometrijas efekta uz integrēto sistēmu novērtēšanai. Šis pētījums parāda, ka Locatalites un GNSS brīva integrēšana ir iespējama, darbs turpinās.

Крейг Мэтью Хенкок, Гетин Вин Робертс, Лукаш Косма Боненберг. Позиционирование с использованием новой технологии „Locatalites".
ГНСС стала одной из наиболее распространенных в мире технологий, позволяющих достигнуть точности позицирования до см. К сожалению, главным недостатком системы является необходимость открытого неба и зависимость точности измерений от геометрического расположения сателлитов (меняющегося в течение дня). Есть несколько важных видов использования ГНСС на уровне см позицирования, напр., в инженерной геодезии, геодезических работах в строительстве. Многие из этих активностей проводятся на территории с частичной видимостью неба и общеизвестным

эффектом многократного отражения. Одним из решений данной проблемы может быть развитие системы, подобной „Locatalites". Эта технология террестриального позиционирования, при использовании которой нет строгой необходимости в видимости открытого неба. В данной статье впервые анализируется проверка Locatalites, оборудования в разных условиях. Проверка подтвердила, что Locatalites пригодна для позиционирования с точностью в несколько см в статическом и кинематическом режимах при разных условиях, включая полностью закрытую среду. Эту проверку провели в Ноттингемском университете (Великобритания) и в Южновелсском университете (Австралия). Предлагается в будущем обсудить возможности исследования предпологаемой интеграции систем ГНСС и Locatalites. Во время проверки также исследовали и стабильность показаний часов Locatalites, вычислялось, насколько точно эти часы могут быть согласованы со временем ГНСС для возможности интеграции. Проверялась точность результатов Locatalites, на которую влияет геометрия сети. Цель данной проверки в том, чтобы в будущем совместить обе системы по точности. В статье описан лучший метод оценки геометрического эффекта на интегрированную систему. Это исследование показало, что свободная интеграция Locatalites и ГНСС возможна, и работа в данном направлении продолжается.