Integration of A-GNSS and IEEE 802.15.4a CSS for Seamless Positioning

Yong-Soo Kim, Byung-Hyun Lee, Gyu-In Jee

Navigation and Control system Lab
Dept. of Electronics Engineering
Konkuk University
Seoul 143-701 KOREA

Biography

Yong-Soo Kim is a Ph.D student in Navigation and Control System laboratory, the department of Electronics Engineering at Konkuk University in Seoul, Korea. He received B.Sc degree from Hongik University in 1999 and M.Sc degree from Konkuk University in 2005. He is interested in Assisted-GNSS receivers, Real-Time Software GNSS receivers, Indoor location system using IEEE 802.15.4a, Navigation sensor integration, etc

Gyu-In Jee is a professor in the department of Electronics Engineering at Konkuk University in Seoul, Korea. He received his Ph.D. in Systems Engineering from Case Western Reserve University. His research has been focused on GPS and navigation system. He has worked on several research and development projects: WLAN based wireless positioning system, Indoor GPS positioning using GPS repeaters, Software GPS receiver, GPS/Galileo baseband FPGA design, IEEE 802.16e based wireless location system, etc.

Abstract

In this paper, the author will descrie two integration approaches using EKF(Extended Kalman Filter). The first approach is the position domain integration which is combination of A-GNSS position measurement and IEEE 802.15.4a CSS(Chirp Spread Spectrum) position measurement to estimate a statistically optimal solution under restricted geometrical condition. The second approach is the range domain integration which is combines the raw measurement of A-GNSS with the CSS measurement in order to provide the best solution of the transition region. Also, in this paper, the author will describe a new approach to improve the performance of seamless positioning, the A-GNSS using IEEE 802.15.4a CSSS Data-link which is received aiding information through the IEEE 802.15.4a data-link, it is expected that seamless positioning service can be provided in any transition region without replacing existing A-GNSS receivers. It is necessary to verify how the IEEE 802.15.4a system can complement the existing A-GNSS positioning.

1. Introduction

GNSS based positioning is able to operate satisfactorily in outdoor of open sky but do not provide accurate positioning such as inside buildings. In order to overcome this problem, there are researching in indoor positioning technology. However, indoor and outdoor positioning technologies are studied individually. There is no solution to provide seamless positioning. One of the key requirements of seamless positioning is that the positioning function should be continuous, and at least as accurate as clear-sky GNSS, both indoors and in any transition region. Unfortunately, just inside and just outside a building are very difficult places to position. Just outside a building, its shadow greatly reduces the number of satellite visible. Also, indoor system, providing full coverage right to the outer edges is expensive, and would result in over-coverage in the interior. The effect of these features is not to provide the required seamless positioning on entering and leaving the building. Therefore, in order to provide the seamless positioning, the integration of A-GNSS with IEEE 802.15.4a CSS technology has been proposed without wasting indoor sensors. This paper was proposed to integration of position and range domain of A-GNSS and IEEE 802.15.4a CSS in transition region. The experimental field test evaluate whether or not the integrated solution was able to be provided between outdoor to indoor navigation solutions. Several points of outdoors and indoors were surveyed by a total station so that their absolute positions would be known and could be used to compare the integrated solutions. We have investigated under restrict geometrical condition, which integrated solution is the best performance and DOP is able to reflect the accuracy and reliability of the integrated position system. Also, the author will propose Assisted GNSS using IEEE 802.15.4a Data-link which is provided initial aiding information for sufficiently close to the user position.

2. A-GNSS using IEEE 802.15.4a CSS Data-link

Aiding the initial position

The table 1 Show that the data rate of IEEE 802.15.4a Chirp Spread Spectrum physical layer shall be 1 Mb/s basically. 80MHz or 22MHz Bandwidth is required for chirp spread spectrum ranging and 2MHz bandwidth is required for Data Communication.

Table.1 IEEE 802.15.4a Chirp Spread Spectrum Frequency band and data rate

PHY	Frequency band(MHz)	Data Parameter	
		Bit rate(kb/s)	Symbol rate(ksymbols/s)
2540MHz CSS	2400 ~ 2483.5	250	166.667
		1000	20.833

A-GNSS using IEEE 802.15.4a CSS Data-link consists of the reference station part, IEEE 802.15.4a CSS network part and A-GNSS receiver part. When the A-GNSS receiver needs aiding data, it request the IEEE 802.15.4a CSS access point to send aiding information through IEEE 802.15.4a Data-link. The A-GNSS receiver parts are equipped with the A-GNSS receiver and the IEEE 802.15.4a CSS Tag. IEEE 802.15.4a CSS Tag sets up data connection with access point while Chirp Spread Spectrum ranging process. The IEEE 802.15.4a CSS Tag enables A-GNSS receiver to request and receive the aiding data from location server. Fig 1 shows the block diagram of the prototype of A-GNSS using IEEE 802.15.4a CSS Data-link system.

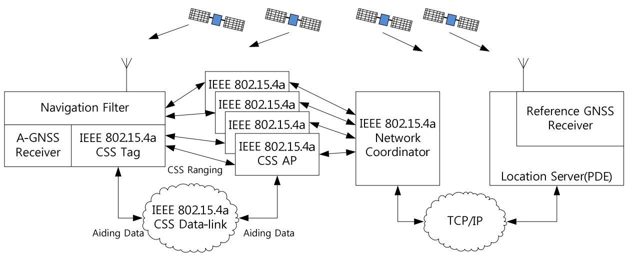


Fig. 1 A prototype system of A-GNSS using IEEE 802.15.4a CSS Data-link

Reference station consists of GNSS receiver and the location server connected with TCP/IP and transmits the aiding data to the IEEE 802.15.4a CSS network coordinator. IEEE 802.15.4a CSS network coordinator receives the aiding data by connecting to the location server in real-time and the received aiding data retransmitted to the IEEE 802.15.4a access point. Fig 2 shows the process of setting IEEE 802.15.4a CSS Data-link connection between A-GNSS receiver, IEEE 802.15.4a CSS network and reference station. The IEEE 802.15.4a CSS coordinator recognizes the A-GNSS receiver through the beacon message. A-GNSS receiver request and receive the aiding information while the Chirp Spread Spectrum ranging process. Reference [5] has proved that indoor position system requires the initial position guess to be sufficiently close to the user position otherwise, the solution would convergence to the wrong position or divergence. Once the aiding data is received, the A-GNSS receiver is able to achieve rapid positioning and CSS tag can get close to user position. We have conducted a number of tests with reference station and the A-GNSS using IEEE 802.15.4a CSS Data-link such as Nanotron's RF transceiver, nanoLOC. The reference station provides A-GNSS with initial position assistance data.

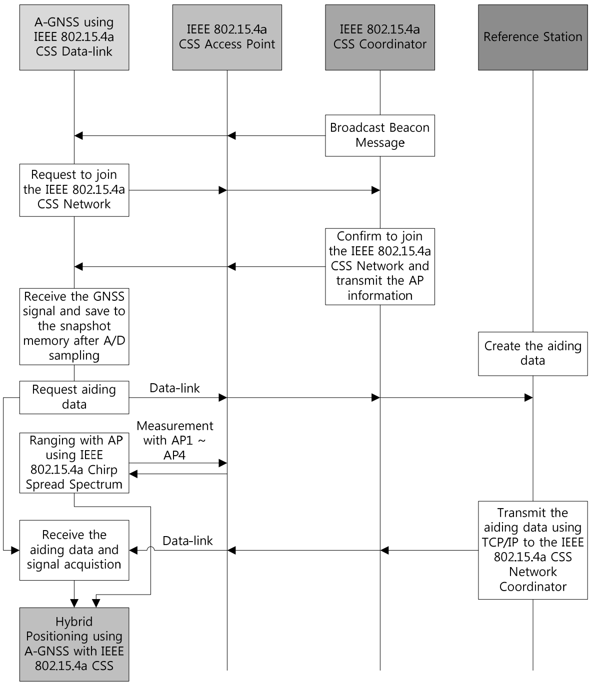


Fig.2. Data Transmission Steps between Reference Station, IEEE 802.15.4a CSS Network and A-GNSS

3. Integration of A-GNSS and IEEE802.15.4a CSS

Position domain integration Filter:

In this integration scheme is that the A-GNSS position measurement and the CSS position measurement are combined together after the EKF estimation method is applied to get the position respectively. The block diagram of the Position domain integration filter is given in the fig 3.

$\hat{x}$, P

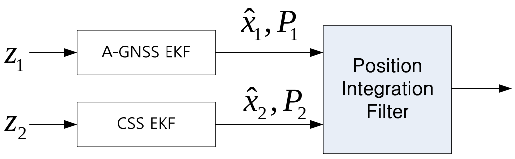


Fig. 3 Position domain integration filter

Each A-GNSS and CSS EKF is described by the following linear state model respectively:

$$
\begin{aligned}
x_{k+1} &= Fx_k + w_k, \quad w_k \sim N(0, Q_f) \\
z_k &= Hx_k + v_k, \quad v_k \sim N(0, R_f)
\end{aligned} \tag{1}
$$

w_k is a random disturbance input known as process noise. The measurements available for feedback are z_k and v_k is a random signal known as measurement noise. The process noise and measurement noise are assumed to be both white Gaussian and uncorrelated. Note that the description of the system and measurement noises is equivalent to that used in the Kalman filter problem. If the A-GNSS position estimation and the CSS position estimation are assumed independent. Note that the best combination of the each independent estimated value is described by the following equation.

$$
\begin{aligned}
P &= \left(P_1^{-1} + P_2^{-1}\right)^{-1} \\
\hat{x} &= P\left(P_1^{-1}\hat{x}_1 + P_2^{-1}\hat{x}_2\right)
\end{aligned} \tag{2}
$$

Range domain integration:

This method is actually a combination of pseudorange measurement of A-GNSS and range measurement of CSS. The observation of the CSS based position system is assumed that position is given the same the reference frame GNSS and CSS receiver's clock bias is absent to all AP and Tag is well synchronized to based station time system. The equation (3) is observation of the satellite positioning system, namely ρ_i, A-GNSS pseudorange and (4) is the CSS which is based on the ground positioning system, namely R_i, TOA observation of CSS that lead to the following functional model. To combine CSS into A-GNSS model given by equation (3), we have the following integrated observation equations (5).

$$
\rho_i = \sqrt{\left(X_i - x_u\right)^2 + \left(Y_i - y_u\right) + \left(Z_i - z_u\right)} + bu
$$

$$
\begin{bmatrix} \delta\rho_1 \\ \delta\rho_2 \\ \delta\rho_3 \\ \delta\rho_4 \\ \vdots \\ \delta\rho_n \end{bmatrix}
=
\begin{pmatrix}
a_{11} & a_{12} & a_{12} & 1 \\
a_{21} & a_{22} & a_{23} & 1 \\
a_{31} & a_{32} & a_{33} & 1 \\
a_{41} & a_{42} & a_{43} & 1 \\
\vdots & \vdots & \vdots & \vdots \\
a_{n1} & a_{n2} & a_{n3} & 1
\end{pmatrix}
\begin{bmatrix} \delta x_u \\ \delta y_u \\ \delta z_u \\ \delta b_u \end{bmatrix} \tag{3}
$$

α : Direction cosine vector

$$
R_i = c \cdot \tau_i = \sqrt{\left(X_i - x_u\right)^2 + \left(Y_i - y_u\right) + \left(Z_i - z_u\right)} + \delta\eta
$$

$$
\begin{bmatrix} \delta R_1 \\ \delta R_2 \\ \delta R_3 \\ \delta R_4 \\ \vdots \\ \delta R_m \end{bmatrix}
=
\begin{pmatrix}
\beta_{11} & \beta_{12} & \beta_{12} & 0 \\
\beta_{21} & \beta_{22} & \beta_{23} & 0 \\
\beta_{31} & \beta_{32} & \beta_{33} & 0 \\
\beta_{41} & \beta_{42} & \beta_{43} & 0 \\
\vdots & \vdots & \vdots & \vdots \\
\beta_{n1} & \beta_{n2} & \beta_{n3} & 0
\end{pmatrix}
\begin{bmatrix} \delta x_u \\ \delta y_u \\ \delta z_u \end{bmatrix} \tag{4}
$$

$\delta\eta$: Observation noise
β : Direction cosine vector

The state vector $x = \left[x \;\; y \;\; z \;\; b \;\; v_x \;\; v_y \;\; v_z \;\; f\right]^T$ chosen to describe the dynamic system consist of the following eight elements: WGS-84 ECEF x,y,z position and velocity, end receiver clock bias and drift. This is assumed to be constant velocity model with random walk disturbance and the dynamic model for the clock bias and drift is assumed to be a constant drift model with random walk disturbance.

$$
\begin{bmatrix} \delta\rho_1 \\ \delta\rho_2 \\ \vdots \\ \delta\rho_n \\ \cdots \\ \delta R_1 \\ \delta R_2 \\ \vdots \\ \delta R_m \end{bmatrix}
=
\begin{bmatrix}
\alpha_{11} & \alpha_{12} & \alpha_{12} & 1 \\
\alpha_{21} & \alpha_{22} & \alpha_{23} & 1 \\
\vdots & \vdots & \vdots & \vdots \\
\alpha_{n1} & \alpha_{n2} & \alpha_{n3} & 1 \\
\cdots & \cdots & \cdots & \cdots \\
\beta_{11} & \beta_{12} & \beta_{12} & 0 \\
\beta_{21} & \beta_{22} & \beta_{23} & 0 \\
\vdots & \vdots & \vdots & \vdots \\
\beta_{m1} & \beta_{m2} & \beta_{m3} & 0
\end{bmatrix}
\begin{bmatrix} \delta x_u \\ \delta y_u \\ \delta z_u \\ \delta b_u \end{bmatrix}
+
\begin{bmatrix} v_{1k}^{gnss} \\ v_{2k}^{gnss} \\ \vdots \\ v_{nk}^{gnss} \\ \cdots \\ v_{1k}^{css} \\ v_{2k}^{css} \\ \vdots \\ v_{mk}^{css} \end{bmatrix} \tag{5}
$$

$$
x_{k+1} = Fx_k + w_k, \quad w_k \sim N(0, Q_f)
$$

Where the transition matrix F is

$$F_c = \begin{bmatrix} 1 & 0 & 0 & 0 & \Delta t & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & \Delta t & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & \Delta t & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & \Delta t \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (6)$$

The process covariance of system noise w is calculated following equation.

$$Q = \begin{bmatrix} \frac{S_{px}\Delta t^3}{3} & 0 & 0 & 0 & \frac{S_{px}\Delta t^2}{2} & 0 & 0 & 0 \\ 0 & \frac{S_{py}\Delta t^3}{3} & 0 & 0 & 0 & \frac{S_{py}\Delta t^2}{2} & 0 & 0 \\ 0 & 0 & \frac{S_{pz}\Delta t^3}{3} & 0 & 0 & 0 & \frac{S_{pz}\Delta t^2}{2} & 0 \\ 0 & 0 & 0 & \frac{S_f\Delta t + S_g\Delta t^3}{3} & 0 & 0 & 0 & \frac{S_g\Delta t^2}{2} \\ \frac{S_{px}\Delta t^2}{2} & 0 & 0 & 0 & S_{px}\Delta t & 0 & 0 & 0 \\ 0 & \frac{S_{py}\Delta t^2}{2} & 0 & 0 & 0 & S_{py}\Delta t & 0 & 0 \\ 0 & 0 & \frac{S_{pz}\Delta t^2}{2} & 0 & 0 & 0 & S_{pz}\Delta t & 0 \\ 0 & 0 & 0 & \frac{S_g\Delta t^2}{2} & 0 & 0 & 0 & S_g\Delta t \end{bmatrix} \quad (7)$$

Where S_{px} , S_{py} , S_{pz} are spectral densities of the corresponding random walk disturbances and S_b and S_f are spectral densities of the random walk clock disturbances which are clock dependent. The covariance matrix of measurement noise is

$$R = \begin{bmatrix} \sigma_{gnss}^2 & & & & & \\ & \ddots & & & & \\ & & \sigma_{gnss}^2 & & & \\ & & & \sigma_{css}^2 & & \\ & & & & \ddots & \\ & & & & & \sigma_{css}^2 \end{bmatrix} \quad (8)$$

5. Experiments and Result

To evaluate the proposed system and algorithm, the field test area is selected to the Konkuk University's engineering building. This building has simple structure and easy access to an open outdoor environment. We have measured four points of outdoors and four point of AP coordinate and five point of trajectory in indoors were surveyed by a total station so that their absolute positions would be known and could be used to compare the integrated solutions. We have carried out two different experiments. In the first experiment, we have received GNSS signal and IEEE 802.15.4a CSS signal for three minute on the point to point which is surveyed point by total station. AS represented in the Fig.4 integrated system moved point to point from outdoor to indoor point.

Fig. 4 Test bed of Konkuk University's engineering building

The aim of experiment is to gather integrated data set from A-GNSS and a couple of CSS indoor position system and including below,

- An assessment of the initial aiding to CSS position sensor.
- An assessment of the basic performance of the integrated A-GNSS and CSS in the position domain and range domain.
- Show that a position solution can be maintained seamlessly from outdoors to indoors

nanoLOC Development Kit:

Nanotron Technologies' nanoLOC TRX Transceiver were used for the experiment as for IEEE 802.15.4a CSS sensor. This chip has built-in precise ranging ability of 2m in indoors and 1m in outdoors. This transceiver operated in the ISM band of 2.4GHz and data rates are selectable from 2Mbps to 12kbps. Also, maximum RF output power is 0 dBm and receiver sensitivity is up to 97 dBm.

Fig. 5 IEEE 802.15.4a CSS nanoLOC Development Kit

u-blox ANTARIS4 GPS Evolution Kit:

For all of the tests done, u-blox LEA-4T receivers were used. This receiver support precision GPS timing and raw measurement data for positioning applications provides high sensitivity, exceptionally low power consumption and USB connectivity. This receiver supports A-GPS which is provided aiding information such as almanac, ephemeris and initial position.

Fig. 6 u-blox AEK GPS Evaluation Kit

Open sky

The first experiments of integration A-GNSS and IEEE 802.15.4a CSS test was performed in front of the Konkuk University's engineering building. The four of IEEE 802.15.4a CSS Access point were set up in the entrance and were mounted high on extension poles on top of tripods, so that integrated system's tag achieved the best reception of signal. Fig 7. show that the number of satellite and performance of ranging domain integration in the open sky. GNSS signal was received for 2minute and CSS signal too. Fig 8. Show that performance of the position domain integration.

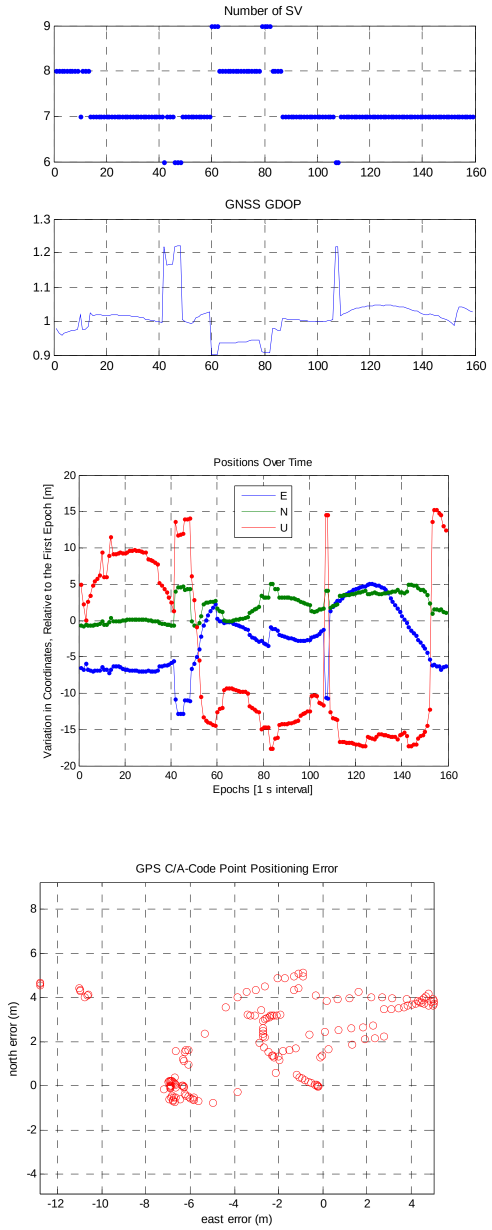


Fig. 7 Number of SV and the performance of range domain integration in open sky (RKF)

Range domain integration is slightly better than position domain integration because range domain integration is better GDOP than position domain.

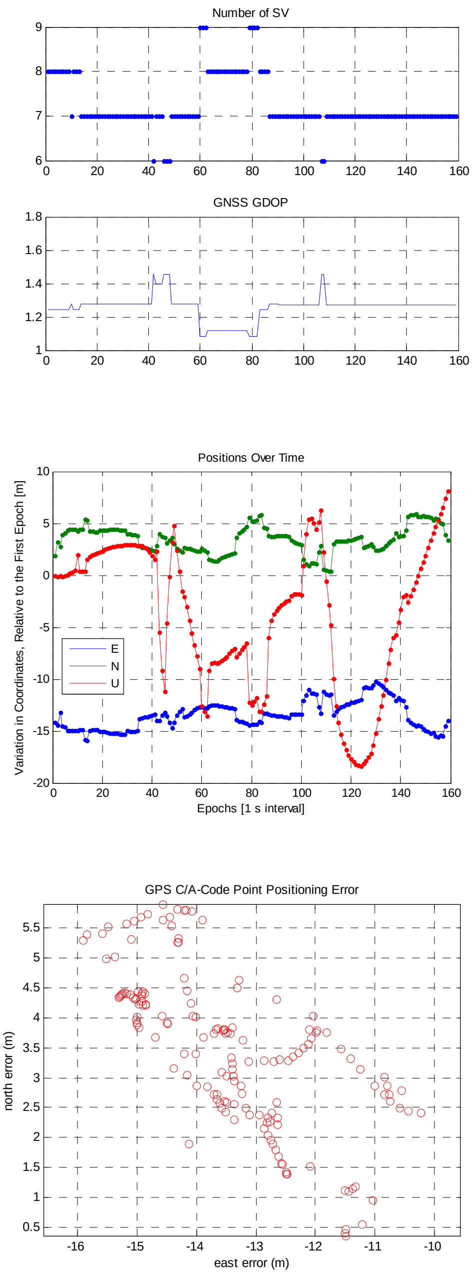
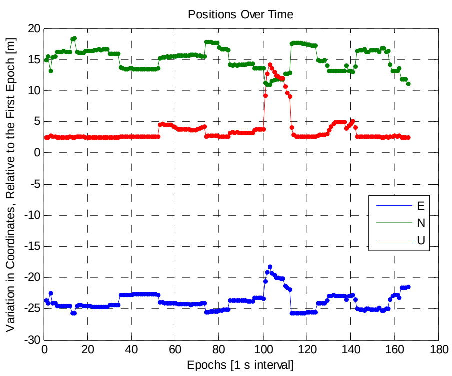


Fig. 8 Number of SV and the performance of position domain integration in open sky (PKF)



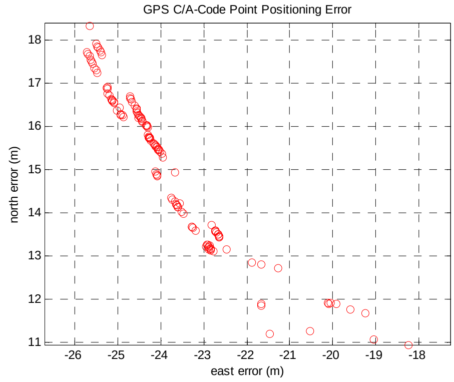
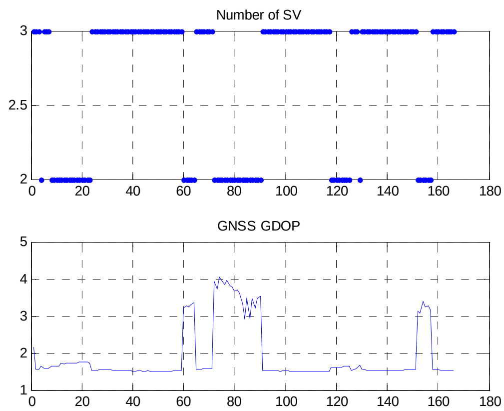
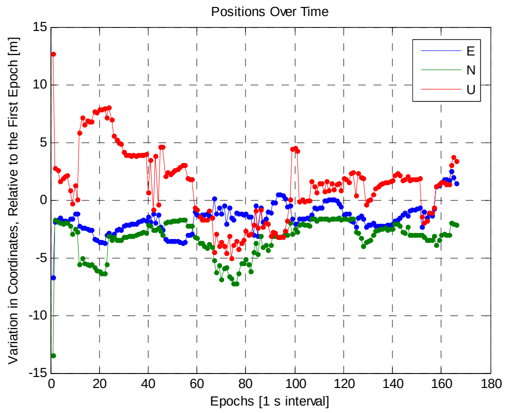


Fig. 9 Performance of the IEEE 802.15.4a CSS in open sky (CSS only)

Transition region

This test is performed in front of the entrance of the building. In this experiment we have received GNSS signals and CSS signals about 2 minute. The result is show that there are shadow effects of satellite in front of the entrance. Thus, position domain integration is bad GDOP. Range domain integration is better than that. But refer to the Table 2, the RMS value is similar to each other.





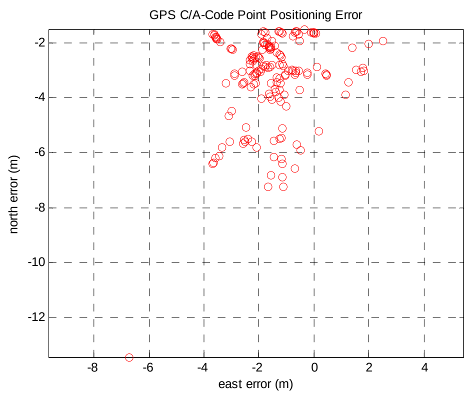
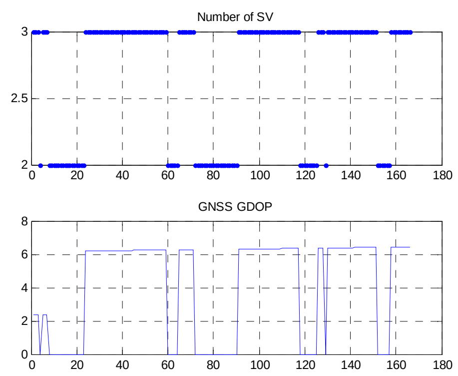
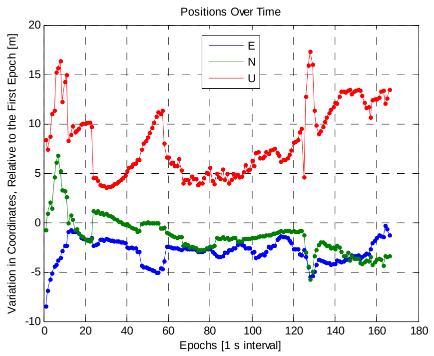


Fig. 10. Number of SV and the performance of range domain integration in transition region (RKF)





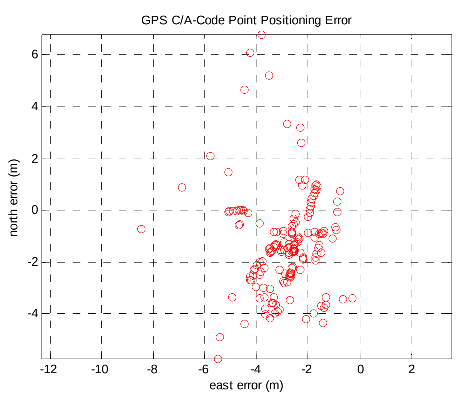
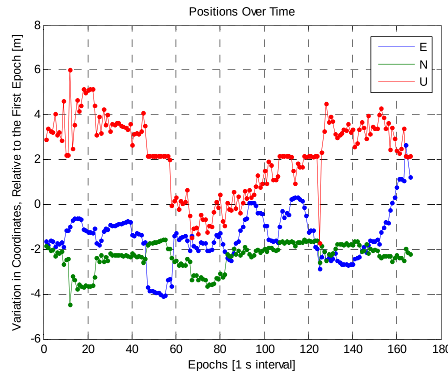


Fig. 11. Number of SV and the performance of position domain integration transition region (PKF)



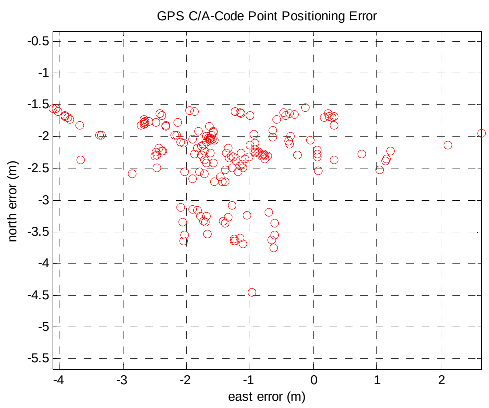
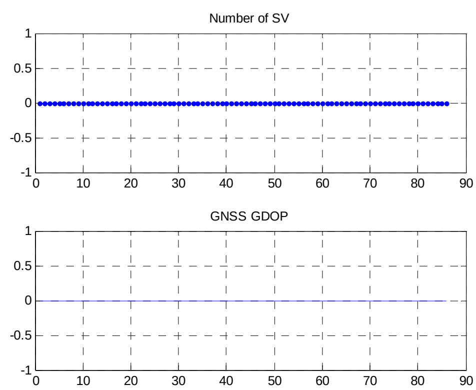


Fig. 12. Performance of the IEEE 802.15.4a CSS in transition region (CSS only)

Indoor environment

This test is performed inside of the building. The general trend is showed that as the number of GNSS pseudorange is decreased and the CSS range is increased. So that there are similar result of Fig 13, Fig 14, Fig 15. Because there are no pseudorange measurement of GNSS and then used only CSS range and position measurement.



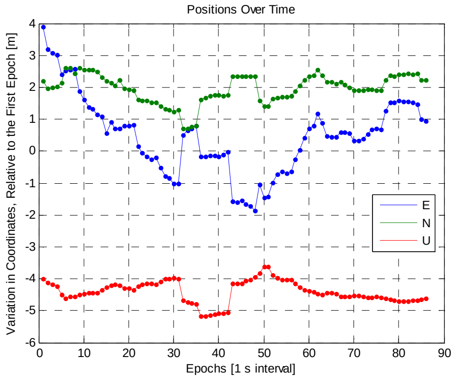
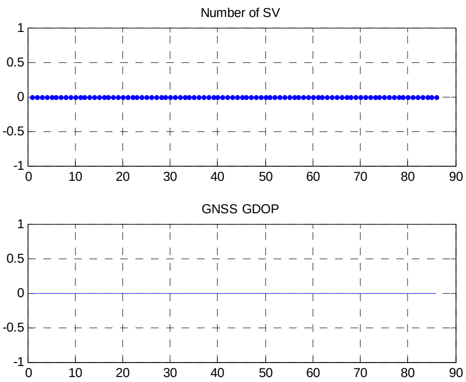
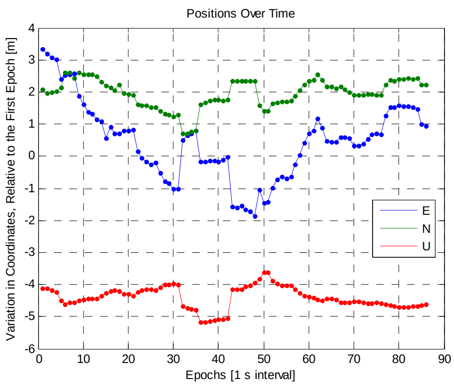


Fig. 13. Number of SV and the performance of range domain integration inside building (RKF)





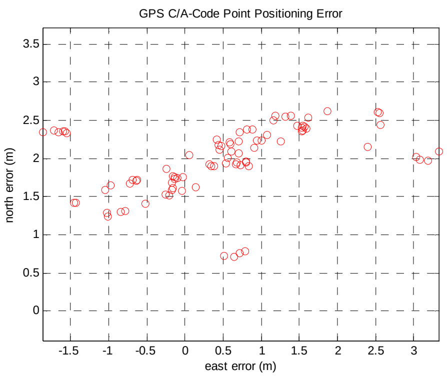
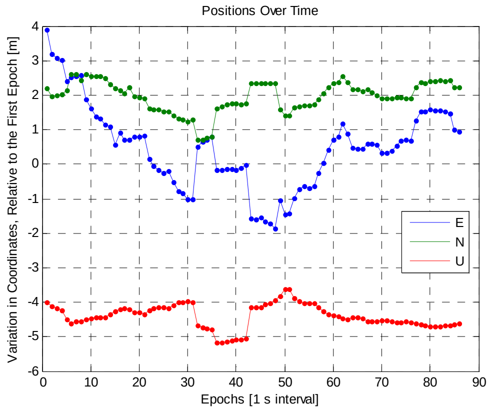


Fig. 14 Number of SV and the performance of position domain integration inside building (PKF)



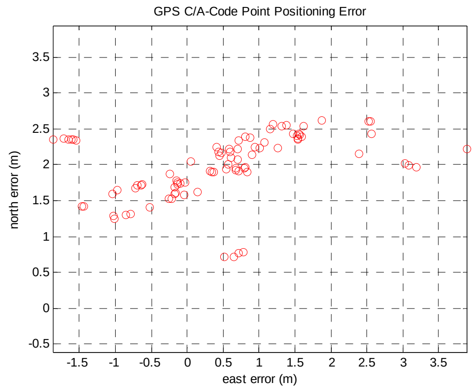


Fig. 15. Performance of the IEEE 802.15.4a CSS inside building (CSS only)

Table.2 RMS error between GNSS, CSS only and integration of A-GNSS and IEEE 802.15.4a CSS integration

	Open-sky	**Transition**	**Indoor**
GNSS only	**4.9128**	**523807.2**	**N/A**
CSS only	**3.0145**	**3.0042**	**2.2909**
PKF	**14.020**	**3.9050**	**2.3866**
RKF	**5.7805**	**4.1968**	**2.3978**

Conclusion

The objective of this paper was to integrate the A-GNSS and the CSS positioning system for the seamless location. In this paper, the initial aiding which is provide A-GNSS using IEEE 802.15.4a Chirp Spread Spectrum

Data-link to be sufficiently close to the user position. The integration of A-GNSS and CSS that is position domain integration and range domain integration method is proposed in the transition region to steady location output in case of limited availability of positioning resources and poor geometry. Positioning is jointly determined by integrated A-GNSS pseudorange and CSS range observation or position result. The proposed method is better accuracy or reliability than only GNSS or only indoor sensors because CSS augmentation is both beneficial a complementary to GNSS.

Acknowledgments

This work has been supported by the BK21 program.

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