

## Concepts of Comprehensive PNT and Related Key Technologies

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**Abstract.** The core idea of comprehensive positioning, navigation and time (PNT) is the technique that uses all the available resources to provide PNT services in the whole area, including inside and outside door, air, space, under water and underground, which does not solely on the GNSS. The definition and basic concepts of the comprehensive PNT are presented. The possible signal sources are listed. The core technologies related to the comprehensive PNT are analyzed, including the integration of multiple sensors and adaptive data fusion for multiple PNT signals. It is emphasized that the information of the comprehensive PNT should be from “multiple sources based on different physical principles”, the user terminals or sensors should be “deeply integrated” and the PNT information should be “adaptively fused” and serve mode might be based on cloud platform. The comprehensive PNT system should meet the robust availability, continuity, high accuracy and reliability with unified geodetic datum and time datum.

### Introduction

The development of satellite navigation and positioning system has completely changed people's life style. Changing the combat style of troops, especially the battlefield awareness style; it also changed the mode of government management, especially the mode of government management. The regional of BeiDou satellite navigation system (BDS) built by China has also played an important role in China's traffic management, emergency command, Marine fishery and national defense construction. But BDS, like the American GPS, the Russian GLONASS and the European Union's Galileo, has natural vulnerabilities: weak signals, poor penetration and vulnerable to interference.

GNSS is generally composed of three parts: space segment, ground segment and user segment. Firstly, there are potential risks in the safe and stable operation of space segment satellite. Secondly, satellite signals are very weak and vulnerable to interference and deception, affecting core business groups such as defense, power and finance. In addition, satellite ephemeris are generally provided by ground tracking station an operation control system, and PNT service of GNSS cannot be guaranteed. Finally, the PNT service of GNSS cannot benefit the underground, underwater and indoor areas. In the cities with high-rise buildings and special areas with dense forests, the signal is easily blocked, and the availability, continuity and reliability of PNT service cannot be guaranteed.

As early as 2010, the US department of transportation and department of defense began to plan the US national comprehensive PNT architecture to build a new national PNT system by 2025[1]. This PNT system can provide more capable and efficient PNT services. The US uses PNT as the infrastructure that the US economy and national security depend on. The gulf war and confederate war have put GPS PNT to the test. American policymakers also have realized, however, American's defense action to rely too much on the GPS, so they began to worry about the fragility of GPS PNT, security and robustness, and plan to build new PNT alternative system[2], the department of defense and the ministry of communications combined more than 40 research institutes and enterprises begin to research and development, based on different physical techniques, different principles and new theoretical system of PNT[3]. Professor Parkinson was proposed in 2014 by PAT concept[4]: protect, toughen and augment. Its core is to protect the PNT of GPS signals from attack, and has the tenacity. He proposed a star and local enhancement methods improve GPS service ability, increase availability and reliability, while the other scholars emphasize the development of GPS as the core, and

compatible with other means of PNT system, including the micro navigation and positioning and Timing technology (micro PNT), quantum aware of PNT technology and other is expected to improve the physical field sensitivity and precision of the sensor technology, high stability and high reliability technology such as atomic clock[5].

This paper tries to start with the basic concepts of comprehensive PNT, basic information source and core correlation technology to describe the future development of comprehensive PNT, as so as to provide references for the system construction, equipment development and technology development of comprehensive PNT.

### The Basic Concepts of Comprehensive PNT

Here we give a comprehensive PNT definition: multiple PNT information sources based on different principles, controlled by cloud platform, highly integrated multi-sensor and multi-source data fusion, generate basically unified spatiotemporal and spatial information with anti-interference, anti-spoofing, robust, available, continuous and reliable PNT service information. The information flow diagram of comprehensive PNT is shown in figure 1. The above definitions actually include the compatibility and operability of the GNSS PNT services<sup>[6-8]</sup>.

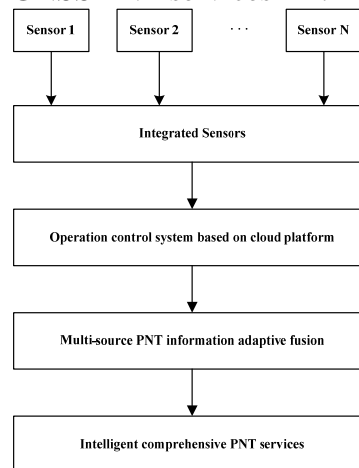


Figure 1. information flow diagram of comprehensive PNT

In fact, comprehensive PNT has hybrid and autonomous properties, some people call it “Hybrid and Autonomous PNT System, HAPS”<sup>[2]</sup>, HAPS also emphasizes multi-type PNT information sources based on different principles, integration of multiple technologies and functions, and multi-type information fusion services. HAPS emphasize collaboration, group, integration and fusion. As a result, PNT services provided by multiple system combinations are more available, continuous and reliable than PNT services provided by single system. For example, multiple types of GNSS integrated navigation, GNSS/radio communication combinations, GNSS/gravity matching/INS integration, etc. all belong to this type of comprehensive evaluation service system.

Autonomous PNT system contains two meanings: One is that a single PNT system can independently complete or maintain PNT services without the support of other external systems, such as autonomous orbit determination of satellite based on inter-satellite link and PNT services provided by INS. Secondly, a certain system is combined with other functional components to realize the system’s autonomous PNT service to supplement the fidelity and robustness of the single system PNT service<sup>[2]</sup>. GPS/INS deeply integration system is such kind of autonomous comprehensive PNT.

While it is not difficult to define comprehensive PNT, it is relatively difficult to build a national comprehensive PNT system and provide comprehensive PNT services. First of all, service user needs of PNT are different, such as anti-interference and deception of high security user demands, and it is required to have underwater and underground PNT service functions, integrated PNT service functions of indoor and outdoor and integrated PNT service functions of ordinary users, and PNT services of high dynamic, continuous and free from obstacle occlusion required by transportation users. Special groups also need PNT service wearable, miniaturization, low power consumption and

intelligence. Obviously, the construction of comprehensive PNT system inevitably involves the high integration, miniaturization and even miniaturization of service terminal, and the integrated PNT system also involves intelligent information fusion.

### **The Information Sources of Comprehensive PNT**

To meet robust availability, robust continuity and high reliability, Comprehensive PNT need have redundant information sources based on different principles. This is because if information based on the same principle is subject to interference and occlusion, no amount of information source is available.

#### **Space-based Radio PNT Information**

Space-based radio PNT information is still the main source of comprehensive PNT in the future. China's comprehensive PNT system must be based on BDS, which is compatible with GPS, GLONASS, Galileo and other regional satellite navigation system<sup>[2-4]</sup>. To enhance the service ability of GNSS, especially improve landing aircraft flight safety and security, many countries respectively established stars enhance system and enhance the system of foundation, in addition, some scholars put forward also use low-cost Leo satellite and communications satellite supplement space-based GNSS signal and enhancement. First of all, Leo satellite and all kinds of communication satellite orbit is low, the signal power is relatively strong, are generally not susceptible to interference, Leo satellite and communication satellite in PNT service can greatly increase the visible satellite number, enhance the satellite observation geometry, and signal strength is improved, it is useful to improve the performance of space-based PNT service.

But it is important to note that even if the sky is full of all kinds of PNT satellite, the signal is sheltered, the space-based PNT service will be interrupted, and space-based PNT service susceptible to interference or intentionally deceive, cannot ensure the safety of PNT service. Moreover this kind of space-based PNT service need the support of the ground movement control system, once the system is damaged, space-based PNT service

#### **2.2 Ground-based radio PNT information.**

Ground-based PNT include ground-based enhance GNSS, pseudo-satellite systems, and a variety of other ground-based radio PNT services. In fact, a variety of ground-based radio navigation and positioning technologies were available before GPS, for example Doppler navigation radar, ROLAN, TACAN, Omega, VOR and Alpha<sup>[6]</sup>. These ground-based radio navigation systems have a small range of function, but can be used as a supplement to regional PNT services. In recent years the rapid development of mobile communication and wireless network system can be as an important source of new ground-based PNT.

#### **INS Information Sources**

INS is electromechanical optical and mechanical navigation system. INS has the advantage of strong autonomy, and it can be calculated by independent equipment without photoelectric exchange. The microcomputer electrical system MEMS has the features of low cost and easy integration. INS can provide the position, speed and acceleration information of the carrier, which is suitable for the navigation and positioning of underwater, underground, deep space. However INS cannot provide high-precision time information, the error accumulation is obvious. Therefore, INS usually needs to integrate with other PNT information source, that is, it needs to integrate high-precision time information, and also needs high-precision external position information for cumulative error correction.

#### **Matching Navigation Information Sources**

Matching navigation information sources usually store information with unified geographic coordinates first, then obtain corresponding feature information through various sensors, then match the premeasured and stored information, so as to obtain local information. There are mainly image matching, gravity field matching and geomagnetic field matching. Such matching navigation

information for underground, underwater and indoor navigation<sup>[7,8]</sup>. The positioning accuracy depends on the spatial resolution of the measurement information in advance and absolute positioning precision, also depends on the sensor precision real-time perception. The geomagnetic field information is too sensitive, and physical environment disturbance of geomagnetic field information will cause larger change. In addition, matching navigation generally does not provide time information, so it also needs to be integrated with time information sources and other PNT information staff.

### **Other PNT Information Sources**

Photoelectric astronomical observations, extragalactic pulsar signals, laser navigation information, underwater sonar beacons and so on can be used as comprehensive PNT information sources<sup>[9]</sup>.

### **The Key Technology of Comprehensive PNT System**

#### **The Terminal Technology of Comprehensive PNT**

With the increase of PNT information source, the development of user PNT service terminal is bound to be a challenge. In the future, the comprehensive PNT service terminal can realize chip integration, so as to realize miniaturization and low power consumption. It should include such devices as radio navigation, INS, micro-atomic clock frame, and there is no systematic deviation to meet the characteristics of interoperability. At present, the easiest thing to realize is to integrate chip-level atomic clock, micro-electro-mechanical systems and GNSS, or to embed the IMU and hip-level atomic clock into the GNSS receiver, there are many research achievements in this field<sup>[7-11]</sup>. This is a relatively ideal and relatively simple system, but due to the significant error accumulation of INS, in the case of long-term absence of GNSS signals, there are still problems in comprehensive PNT service.

The other PNT terminal integration is all kinds of matching navigation sensors, integrated atomic clock and MEMS. Although the accuracy of various types of matching navigation is not high, but no obvious systematic error accumulation. That can be used to correct INS error of long distance navigation. In addition, the ultra-stable miniature atomic clock unit can provide synchronization time information for all kinds of matching navigation and INS.

The comprehensive PNT terminal may include pulsar information sensor, optical radar sensor, etc. Multi-source information perception of sensitivity, anti-jamming, stability is the key to the integration PNT sensor, the future comprehensive PNT system development, should first solve the problem about small or micro-stable clock, the second is the development of super stable and cumulative error INS unit without external information support for long-endurance carrier. Should develop the depth of integration technology of sensors, chip rather than simple bundles of all kinds of sensors, so as to meet the miniaturization, portable, low power consumption, long-endurance PNT service needs.

#### **The Fusion Technology of Multi-source Information**

Comprehensive PNT is not the integration or synthesis of single PNT information, but the fusion of multiple types of information, so the normalization of spatial benchmark and unified time benchmark should be carried out. China comprehensive PNT should use China 2000 coordinate benchmark and China Beidou time<sup>[7,10]</sup>. Information fusion of multi-source PNT should unify the function model of observation information. The function model of PNT service system and PNT service component based on different backgrounds and theories is different. All kinds of observation information may also contain their corresponding important physical parameters, geometric parameters and time-varying parameter. In order to realize the comprehensive PNT service, all kinds of PNT observation the function model of information, should be represented as the same position, velocity and time parameter, it should also include all kinds of PNT sensor or the system deviation parameters of all kinds of PNT information source.

Information fusion of multi-source PNT should have a reasonably optimized random model. Different types of PNT observation information have different uncertainty and different error distribution<sup>[8,11]</sup>. The variance or weight of all kinds of observation information should be determined in real time during multi-type PNT information fusion. Comprehensive PNT information should adopt rational and efficient calculation method of multi-source information parallel computing is the important means to realize efficient PNT information fusion. In order to avoid repeated information using, dynamic model should be used<sup>[6]</sup>. In order to control all kinds of abnormal observation of PNT parameters, the influence of poor resistance to information fusion should be used<sup>[8]</sup>. In order to control the abnormal influence on comprehensive PNT parameter estimation, dynamic model adaptive kalman filtering can be used<sup>[11]</sup>. Information fusion of multi-source PNT is shown in figure 2. Information fusion of multi-source PNT should be based on information compatibility and interoperability in order to ensure the interchangeability of PNT results, not only the availability and continuity of PNT should be improved, but also the robustness and reliability should be significantly enhanced.

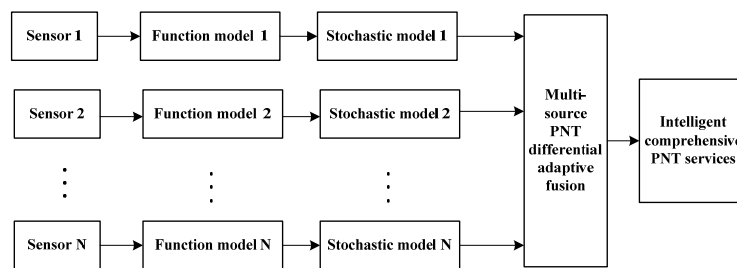


Figure 2. Information fusion of multi-source PNT

## Conclusions

Comprehensive PNT is the future development direction of navigation, positioning and timing, shows PNT information source, the height of the sensor integration and miniaturization, normalization of comprehensive PNT space-time datum, control means of the cloud, multi-source information fusion from specialization, and eventually to implement the intelligent of the PNT service model, Due to emphasize PNT principle of diversity and the redundancy of information, its fault tolerance, system error compensation ability, exception error influence of control ability and poor resistance will be significantly enhanced, and availability. Both integrity and reliability will be improved. The key technologies of comprehensive PNT development include micro ultra-stable clock, ultra-stable inertial unit or autonomous navigation sensor, chip integration of multi-source sensor, adaptive fusion theoretical model of multi-source PNT information and rapid computing methods.

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