Positioning Infrastructure and Indoor Positioning

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1 SUMMARY

The Positioning Infrastructure in Hong Kong has been evolved from a passive Geodetic Survey Control Network to Continuously Operating Reference Stations (CORS) to support high accuracy satellite positioning using GNSS anytime and anywhere in the past decades. While smartphones, smart sensors and Internet of Things (IoT) technologies can be found everywhere in a smart city, the demand and expectation of positioning have been expanding. As a result, the developers and managers of the positioning infrastructure must be fully aware of the trend to cater for the changing needs.

The Innovation and Technology Bureau (ITB) of the Government of Hong Kong Special Administrative Region has set up a TechConnect block vote to support Government departments in Hong Kong in planning and implementing technology projects, so as to enhance operational efficiency and improve public services by use of technology. In response to the initiative, a pilot project to explore, set up and test a ubiquitous positioning infrastructure covering both outdoor and indoor environments for potential smart city applications was proposed. The project aims to identify suitable and cost-effective Positioning, Navigation and Timing (PNT) technologies, to design, test and develop the infrastructure in a selected pilot project area, to evaluate the effectiveness and performance, to understand the limitations and concerns and to provide recommendations for review and consideration of the way forward if wider implementation is required in the future.

The project will start from a baseline study of the current situation of the development of various location-based applications, the technologies deployed, architectures of the supporting infrastructure, and the stakeholders involved. The project team will review the international standards and technological trends, as well as legal, social and ethical requirements by case study and stakeholder engagement. Based on the findings, a prototype infrastructure in a pilot project area would be designed, implemented, tested and evaluated. Demo applications would be developed to understand the effectiveness, limitation and potential of such prototype infrastructure.

From the experience of the pilot project, common standards, specifications and technological guidelines would be proposed to facilitate the potential applications or infrastructure developments. Last but not the least, the experience learned will be summarized, which will help the evaluation of the financial, technological, practical viability and constraints of various technical options.

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1 BACKGROUND

1.1 Positioning Infrastructure in Hong Kong

1.1.1 Traditional Geodetic Survey Control Network

The Survey and Mapping Office (SMO) of the Lands Department is the land survey, mapping and geospatial authority in Hong Kong. One of the major responsibilities of SMO includes the establishment and maintenance of the territory-wide geodetic control network and the satellite positioning reference station network. (Lands Department, 2020) SMO has been maintaining and densifying a network of accurate survey control points that covers the whole territory of the Hong Kong Special Administrative Region (Hong Kong SAR) for decades. This network provides the fundamental horizontal and vertical position reference for many vital activities, such as mapping, land boundary survey, town planning, land administration, building construction, infrastructure development, railway development, environmental protection, safety management of aerial and marine navigations, etc. (Lands Department, 2018)

1.1.2 The Hong Kong Satellite Positioning Reference Station Network (SatRef)

SMO makes use of the Global Navigation Satellite System (GNSS) to develop a local satellite positioning system, named as "Hong Kong Satellite Positioning Reference Station Network" (SatRef). The network consists of 18 Continuously Operating Reference Stations (CORS) including 16 Reference Stations and 2 Integrity Monitoring Stations evenly distributed in Hong Kong. The stations receive GNSS satellite data round-the-clock and send it to a Data Centre for further processing and analysis. The products are disseminated free-of-charge to users for high accuracy positioning applications. On the other hand, there is a Control Centre which is used for remotely control of the servers in the Data Centre. The whole SatRef system would be monitored in the Control Centre to ensure the services would not be interrupted.

The SatRef Reference Stations established an accurately surveyed control network to realize the local reference frame. The network provides a linkage between the local reference system and the global reference system. Spatial information can be effectively exchanged in the same spatial language. It provides various positioning products and services, including GNSS raw data in RINEX format, GNSS raw data streams in RTCM format, Network Real Time Kinematic (Network-RTK) data service, Differential GNSS (DGNSS) data service and GNSS data automatic computation service. These products and services provide significant improvements on accuracy, efficiency and productivity for various satellite positioning users; meanwhile, the cost of operation is therefore reduced. (Lands Department, 2018)

1.1.3 TechConnect Block Vote

The Innovation and Technology Bureau (ITB) of the Hong Kong SAR Government has reserved funding under the TechConnect block vote in mid-2017 to support Government departments in planning and implementing technology projects, so as to enhance operational efficiency and improve public services through the use of technologies.

In response to the TechConnect initiative, SMO submitted a number of funding applications to explore the viability and options of applying up-to-date technology and optimising human resources to enhance productivity and efficiency for survey and mapping. One of the proposals is to explore how the positioning services and infrastructure could cover the blind spots of satellite positioning, i.e. in the indoor environment. The TechConnect funding provided the opportunity and resource for SMO to evaluate the potential and limitations of developing a ubiquitous positioning infrastructure as a pilot project within a designated project area. The application of this pilot project was supported by the policy bureaux, i.e. the Development Bureau and the ITB.

1.2 Smart City Development

1.2.1 CSDI and 3D Digital Maps

Under the policies and initiatives of the Government of the Hong Kong SAR, the Smart City Blueprint for Hong Kong (Innovation and Technology Bureau, 2017) released in December 2017 set out the overall framework and strategy for developing Hong Kong into a spatially enabled smart city including the adoption of Building Information Modelling (BIM) and the development of Common Spatial Data Infrastructure (CSDI) and 3D digital map.

In the 2019-20 Budget, the Government announced its vision to press ahead with the setting up of the CSDI for the exchange and sharing of geospatial information to tie in with the development of various smart city applications by the community. Funds have been earmarked in the Budget to expedite the development of digital infrastructure as well as the 3D digital map, with a view to facilitate the dissemination, utilization and innovative application of geospatial data. (Chan, 2019)

A smart city requires accurate and reliable positioning not only for outdoor, but also indoor applications. Positioning is the key to connect the digital twins to our real physical world. It is essential to deliver accurate and reliable positioning information/ services to everyone, anytime and anywhere, for supporting smart city initiatives and various innovative location-based applications by the community and the government.

1.2.2 Indoor and outdoor positioning solutions

In Hong Kong, there were a number of indoor positioning applications respectively developed in various venues, including Mass Transit Railway (MTR) stations, some of the shopping malls, car parks, some university campus, etc. They adopt different sensors or techniques, with their

own positioning algorithms behind each application. Some of the infrastructures deployed might be application dependent. While some signals were publicly accessible or could be detected without much difficulty, the essential database required for positioning were kept private. Property owners would need to conduct their own survey or install their own devices for the venues.

Wi-Fi fingerprints were widely adopted in shopping malls where there were many Wi-Fi access points already installed by different parties. Bluetooth beacons were often deployed for centrally managed sites such as the Hong Kong International Airports and MTR stations.

To supplement the effectiveness and improve the limitation of satellite positioning in urban canyon area, advanced Bluetooth Low Energy (BLE) IoT network was developed for seamless positioning with the use of smartphone sensors by the Logistics and Supply Chain MultiTech R&D Centre Limited (LSCM) and the Hong Kong Polytechnic University in a Public Sector Trial Scheme project funded by the Innovation and Technology Commission. SMO has also worked with the Highways Department to install Geo-QR code tags with NFC on some conventional lampposts to provide reliable positioning information for various location-based applications of mobile device users.

The Jockey Club Smart City Walk Project initiated by Hong Kong Blind Union made use of the smart mobile devices to strengthen the connection with the external community for the visually impaired people and elderly, and enhance their independency of living. Through the application of Wi-Fi positioning and indoor wayfinding, the "Smart City Walk" mobile application (App) could provide graphics, audio and text navigation instructions to users in both outdoor and indoor venues, allowing anyone including the visually impaired and the elderly to walk around independently. The application now covers over 80 popular venues in Hong Kong. (Hong Kong Blind Union, 2019)

With the rapid development and deployment of 5G mobile networks in Hong Kong and worldwide, the positioning potential is expected to be significantly improved with a more direct line of sights and mm-wave signals available. It is expected that the applications of 5G for indoor and outdoor positioning could be a growing area.

1.3 Need for a ubiquitous positioning infrastructure

As discussed, there are different isolated, proprietary and customised solutions in the market to provide the users with effective positioning and wayfinding services in different sites, in particular for the indoor environment. The positioning performances of those methodologies vary so much in terms of efficiency, reliability and accuracy. Besides, users cannot perform seamless positioning from one point to another point continuously through various outdoor and indoor environments in order to achieve reasonable ubiquitous positioning for smart wayfinding purposes and other location-based applications. Furthermore, there are no standard specifications of positioning facilities and common data exchange requirements to facilitate system integration and data interoperability. Most indoor positioning systems and infrastructure set up by private entities are separate and non-interoperable.

The issue encountered at the moment was similar to the old days where there were many localised and isolated coordinate systems. A common coordinate system and standard are required to facilitate the exchange of spatial information and future infrastructure works projects.

In order to explore the potential of a proposed ubiquitous positioning infrastructure for smart city applications in Hong Kong, a pilot project at a small designated test area is firstly explored and evaluated before any wider area implementation could be considered. The pilot project plans to cover typical outdoor environment and indoor areas in the urban environment, and make use of the latest Positioning, Navigation and Timing (PNT) technologies to showcase an integrated positioning system for the provision of effective positioning services to potential users. The project could provide a sandbox to conduct experiments for comprehensive evaluation of the system, exploration of emerging technologies, formulation of the way forward, standardization of system requirements and data specifications, and understanding the constraints and limitations, which would be essential to explore whether any future wider implementation of the ubiquitous positioning infrastructure will be required and feasible in the long-run.

2 PROJECT OBJECTIVES

2.1 Introduction

With the support of ITB, the TechConnect project funding has been approved in 2020, and SMO is assigned the task to conduct the project. At the moment, SMO is preparing the consultancy brief to appoint a consulting firm to implement the pilot project. This paper will discuss how SMO work out the conceptual objective and scope, set out the basic project requirements, and identify the expected deliverables and outcome for the proposed consultancy study.

2.2 Objectives

The objective of this project aims to provide answers or insights into the following questions for the SMO:-

1. What is the current status of the development and implementation of different location-based applications in Hong Kong?
2. What is the latest international trend in PNT technologies development?
3. What are the public expectations and best practices of information security and personal data privacy in location-based applications?
4. What are the benefits, investments, limitations, concerns and pre-requisites for consideration of the way forward?
5. What additional works will be needed to facilitate ubiquitous positioning?

6. If a wider implementation in future is recommended, what is the proposed strategy and development road map?

The pilot project would also be a suitable opportunity to explore, propose, test and evaluate the potential solutions or the available technical options for the questions below:-

1. Where should the pilot project be conducted?
2. What should be the key expectation and design of the infrastructure prototype?
3. What are the major tasks involved in the pilot project?
4. How the risks and concerns encountered could be mitigated and minimized?
5. What are the policy to observe? What are the open standards to be followed? What are the new specifications to be established?
6. How could the effectiveness, performance and benefits of the prototype be demonstrated?

3 PROJECT SCOPE

3.1 Planning

3.1.1 Research and Review

As the very first step of the pilot project, a comprehensive research and review to identify the international state-of-the-art PNT technologies for developing a ubiquitous positioning infrastructure for outdoor and indoor environments of Hong Kong is needed. The research scope should cover a baseline study of the potential demand, if any, of the proposed ubiquitous positioning infrastructure, technological solutions currently implemented or to be implemented, service providers and experts available in the market, cost, performance and limitations, in order to provide a snapshot of the current market situation for Hong Kong.

The research shall also cover the technological evaluation and assessment of the global development trends, international standards and practices (e.g. ISO, OGC, W3C, IEEE, and etc.), with a fair evaluation and comparison of the cost, ease of deployment, common applications, constraints and achieved performance for the available options.

Apart from GNSS related positioning technology for the outdoor environment, a number of indoor PNT technologies have been deployed or implemented in various projects or applications. The popular ones include the use of Bluetooth Low Energy (BLE), e.g. iBeacon or Eddystone beacons, Wi-Fi fingerprints, 4G or 5G mobile phone network-based location algorithms, NFC and the use of visual markers such as Geo-Marker or QR code. Promising PNTs such as visual positioning by image or video recognition, geo-magnetic fingerprint positioning, visible light positioning or other radio-based positioning techniques such as Ultra-wide Band (UWB) should also be explored and reviewed.

The consolidated results should be presented in cases study of successful and failed experiences of implementation of ubiquitous positioning infrastructure in some advanced countries. To supplement the study, a matrix of pros and cons covering the cost implications (e.g. development cost and maintenance cost), technological performance (e.g. accuracy, reliability and availability), practicality (e.g. ease of deployment and maintenance effort required by operators and tenants), and level of privacy and data protection for each of the PNT technologies or solutions is to be prepared.

The review should not be a pure desktop study. The team should explore potential stakeholders in the community, identify and approach key stakeholders to collect views on what positioning application and performance are needed and how the infrastructure may be established.

The above research and reviews could provide the essential information for SMO to understand the needs, benefits, concerns and feasibility of a wider ubiquitous positioning infrastructure for Hong Kong.

3.1.2 Concerns on Privacy and Information Security

With the growing concern on personal privacy and information security in positioning and location-based applications, the project must cover a study on geo-privacy to meet the high expectations of the public. The pilot infrastructure must implement sufficient measures to ensure that all the information is securely and properly managed throughout the process. In order to gain the trust of the public, the study has to provide recommendations on the proper measures in the development, operation and management of the proposed infrastructure so that no personal data will be recorded in the infrastructure.

Therefore, the pilot project would have to cover a review of legal, social and ethical requirements, the concerns, risks and threats regarding personal privacy and data protection for implementation of the PNT technologies and applications, apart from technical considerations, should be addressed. The legislative and non-legislative regulations, guidelines, measures and best practice adopted or proposed in some jurisdictions will be valuable references.

Security Risk Assessment and Audit (SRAA) as well as Privacy Impact Assessment (PIA) shall be conducted by independent creditable third-party auditors or experts to detect any potential vulnerabilities of the IT system in the proposed infrastructure. Practical recommendations and suggestions from the auditors must be considered and properly implemented for the pilot project.

3.1.3 Project Area

As the sandbox for testing and evaluation, the project area selected for the pilot project should represent a typical urban built environment of Hong Kong as a metropolitan city. In Hong Kong, a mixture of buildings, shopping arcades, carriageways and inter-connected pedestrian footpath, transport interchanges, public open spaces such as parks and atrium, footbridges and subway connections could be easily found in many districts. In addition, there are many conventional lampposts along the streets to provide additional anchor through the installation of suitable

positioning devices for outdoor positioning. As such, the infrastructure should be able to handle the complicated urban streetscape and support positioning for typical use cases such as navigation along the routes from Building A to Building B, which may pass through one or more scenarios.

Since the innovative nature of the pilot project, it should be convenient and attractive for start-ups companies to test and explore with the prototype of the infrastructure.

3.2 Design

3.2.1 Infrastructure Design

It is preferable to implement different practical positioning approaches based on different technologies (or sets of fusion of technologies), together with different processing algorithms. Each of the proposed solutions has to be deployed in different indoor venues to provide meaningful demonstration and evaluation.

With sufficient background information, the system analysis and design exercise can be conducted to finalize the detailed technical requirements and specifications, methodology and tasks for the developments of each of the components of the infrastructure, including hardware, software and services requirements, communication infrastructure design, data specifications, and prepare for other necessary procedures and documents for the later stages of the pilot project.

3.2.2 Implementation and Test Plan

The study could provide the opportunities to brainstorm and list out all necessary and associated tasks which will be involved, including those to be performed by external parties (e.g. Privacy Impact Assessment, Information Technology Security Risk Assessment and Audit, Publicity Events Management Services, etc.), and the corresponding resources required for each task (e.g. estimated man-hour, team members involved, external specialist or specialist contractor to be employed, estimated budgets, etc.). The parameters relating to and affecting the project which includes justifications of the design proposed, cost, scope, schedule, quality, potential issues and risks, including personal data and privacy issue, with corresponding preventive and mitigation measures, baseline and the Key Performance Indicators (KPIs) for the project could be worked out from the experience gained during the pilot project.

3.3 Development and Test

3.3.1 Development and test

In the pilot project, it is necessary to execute the various defined tasks to develop the system components, including hardware, software, services, communication, data and procedure components of the proposed infrastructure solution. The design and development of the physical system of the infrastructure would then be worked out. It is also necessary to provide, install, commission and test the hardware components of the proposed infrastructure solution

in suitable outdoor and indoor locations in the project area. The hardware component to be developed shall include positioning devices, computing hardware and peripheral equipment for the development, provision, operation and management of the positioning services. The above components should be integrated into an integrated infrastructure, to be ready for demonstration and evaluation.

3.4 Review and Evaluation

3.4.1 Demo applications

To evaluate the performance and illustrate potential benefits and pitfalls, demo applications can be developed to illustrate a few use cases for technical evaluation of the positioning performance in terms of efficiency, effectiveness, availability, reliability, integrity, accuracy, and user experience.

3.4.2 Evaluation

With the demo applications, the next tasks could be the planning and design of the testing and technical evaluation for the proposed infrastructure solution in the project area. The technical evaluation can cover accuracy, reliability, availability, system efficiency, and user experience of the infrastructure against the defined baseline quantitatively. In addition, user interview and questionnaire survey can be conducted to collect test data and feedbacks for further analysis. The results should be reflected in a project report illustrating the objective, technical performance, merits and deficiencies, potential benefits and limitations, and relevant suggestions for further improvements.

3.5 Standards and Documentations

3.5.1 Standards and Documentations

During the project, there may be some technical standards adopted and defined for evaluation. These standards and guidelines would be a new starting point for future implementation of positioning infrastructure if considered appropriate in future. The API/SDK developed in the pilot project could be released as open-source code for free-of-charge testing use during the project trial period. The documentations such as recommended data standards, specifications, and implementation guidelines developed in the pilot project could also be released for the publics' reference and update for future improvement.

3.6 Way Forward

After reviewing the process, deliverables, plans, design and implementation efficiency of the project, a report can be prepared to summarize the findings, observations and lesson learnt, identify issues and recommend solutions and improvements.

Based on the findings, the way forward, the feasibility or suitability of developing a wider area ubiquitous positioning infrastructure could then be explored. The findings would be useful before making a recommendation of whether the infrastructure should be further expanded as a wider area infrastructure can be made.

The roadmap shall echo the findings and essence from the research report and evaluation results, and outline the conceptual design of any wider area infrastructure, scope and requirements, resources implications and dependency, benefits, the implementation workflow and strategies, and publicity plans. From the experience gained in the pilot project, the report can also cover any other suggestions which could facilitate the development and promote the potential applications of the ubiquitous positioning infrastructure.

The pilot project would provide the opportunity to collect and work out creditable contents and practical recommendations covering the conceptual design, scope and requirements, and potential technological solutions of the territory-wide infrastructure. The costs implications for future development, operation, maintenance as well as promotion should be properly estimated. The expected benefits should be highlighted and quantified as cost-saving or revenue generation. Intangible social benefits should also be elaborated. The personal data and privacy concerns, prevailing legal requirements, social and ethical considerations, and the corresponding or proposed regulations, guidelines, measures and best practice to be adopted with reference to the international experiences and standards have to be addressed properly when making the recommendation. These should be further elaborated in the proposed strategies, workflow and time-frame for subsequent implementation if it is considered to go ahead.

4 CONCLUSION

The pilot project is intended to be the sandbox to prove and showcase the potential benefits of the proposal, as well as to experience the difficulties and challenges in technical, legal, social and ethical aspects before any wider area implementation is to be considered. It could provide an objective source to facilitate consideration of the way forward.

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6 BIOGRAPHICAL NOTES

Mr. Kenny Chi-hung CHAN is a Land Surveyor in the Survey and Mapping Office, Lands Department of the Government of Hong Kong Special Administrative Region. He received his BSc(Hons) degree in Surveying and Geo-informatics in 2002, and his MSc degree in Construction and Real Estate in 2007, from the Hong Kong Polytechnic University. He has more than 10 years of working experience in the Geodetic Survey Section of the Lands Department, with extensive involvement in the development of positioning infrastructure, as well as the establishment and maintenance of survey control network in Hong Kong. He was a core team member for the implementation and on-going development of the Hong Kong Satellite Positioning Reference Station Network (SatRef), and many pioneer projects such as designing smart positioning sensors for Multi-functional Smart Lampposts Pilot Scheme. In 2015, he was sponsored to take the MSc course in Positioning and Navigation Technologies at the University of Nottingham, United Kingdom, and awarded the degree with Distinction. He has received the Outstanding Graduate award by the Royal Institute of Navigation (RIN) for graduating top of the course. He is a Member of the Hong Kong Institute of Surveyors (HKIS) and the Royal Institution of Chartered Surveyors (RICS). He was elected as the Chairman of the Young Surveyors Group of the HKIS in 2012.

Mr. James Ying-kit WONG is a Senior Land Surveyor in the Survey and Mapping Office, Lands Department of the Government of Hong Kong Special Administrative Region and is responsible for developing and maintaining the positioning infrastructure of Hong Kong. He attained his Postgraduate Diploma in Geo-information Systems and MSc in Geomatics from the Hong Kong Polytechnic University in 1998 and 2004 respectively. He is a member of the Hong Kong Institute of Surveyors (HKIS) and the Royal Institution of Chartered Surveyors (RICS).

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