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Approaches to Census Mapping: Chinese Solution in 2010 Rounded Census

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Abstract: China still use sketch maps as control devices that guarantees consistency and accuracy of population counting in previous census. Although the rapid advancement of geospatial technologies provides many possible solutions of digital census mapping, existing researches do not answer which solution is suitable to China. Subject to many constraints originated from characteristics of China, a practical solution of census mapping based on remote sensing imagery and auxiliary geographic information was proposed and proved to be feasible through evaluation analysis and a three-stage pilot study. Imagery with 2.5 meters and higher resolution, innovative workflow of census areas delineation, easy-to-use census mapping software packages and training organization all together provide the all-around supports for the 2010 rounded census (the 6th census) mapping activities. A digital census geographic framework detailed at the level of enumeration area was established in the 2010 rounded census which fills in the gaps in the field of modern geospatial census in China. The spatially referenced digital census database, especially the detailed census units, is of great value in successive census, sampling survey and many other census-related fields. Future work including quality evaluation of census areas, census mapping solution in the Tibet Autonomous Region are also discussed.
Keywords: 6th census; census mapping; Chinese solution; geographic information system; remote sensing

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1 Introduction

Census is of critical importance for every modern country. Significant technical developments have benefited the census operations in recent decades. Geographic Information System (GIS) now plays a key role in census data collection, dissemination and in the analysis of population data. Most of the developed countries have population counted in geo-referenced census block for a long time and they start to optimize the geospatial infrastructure of census recently. In the United States of America, the TIGER (Topologically Integrated Geographic Encoding and Referencing system) (Robert, 1986) and its-related products are widely used in geo-demographic analysis like marketing, planning of social and educational, utility services, *etc*. since 1990. To improve the accuracy of the national census database for the 2010 census in the United States, the MAF (Master Address File)/TIGER Accuracy Improvement Project was initiated since 2000 (Frederick and Leslie, 2003). The MAF/TIGER system plus the Census Automated Map Production System (CAMPS) served as the geospatial infrastructure supporting numerous census operations and data collection, tabulation, and dissemination activities in the 2010 census of the United States (Beard *et al*., 2011). The Australian Bureau of Statistics (ABS) released the new Australian Statistical Geography Standard (ASGS) to improve the quality of small area time series data by extending the digital census framework to mesh block level in 2011 census. About

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1.5×10^6 basic statistical units were demarcated and their boundaries did not change as time evolved in Japan since 1990. In order to revolutionize traditional census, the Department of Economic and Social Affairs Statistics Division (2000) was promoting the use of Global Positioning System (GPS), digital imagery and GIS with census mapping in the new millennium. The geospatial census framework based on GIS, GPS with Personal Digital Assistant (PDA), and satellite images is established successively in developing countries. The territorial database for statistical purposes was constructed based on topographic maps, cadastral maps and existing paper maps in Brazil which holds 249 068 enumeration areas in total in 2007 (Department of Economic and Social Affairs Statistics Division, 2009). The statistics office of South Africa has prioritized the creation of a geo-referenced dwelling frame in preparation for the 2011 census operations, to ensure that all dwellings in the country are covered during enumeration (Sharthi, 2007). Even Fiji, a small Pacific island country, had used GPS technology to link census questionnaires with geo-referenced locations for all households in the country in 2007. Another most populated country India also delineated house listing blocks digitally in urban areas (Department of Economic and Social Affairs Statistics Division, 2009).

However, as there are no official geo-referenced boundaries at the level of townships, the geospatial census framework at more detail level does not exist in China before the 2012 rounded census (the 6th census). Using sketch maps or free-hand drawings of enumeration areas were the first attempt in support of the 4th census in the year of 1990 (Sun and Meng, 1992). Sketch enumeration maps showed detailed layout of buildings, roads, and landmarks and tried to ensure full coverage of the geographical area of the country, without any omission or overlapping. National Bureau of Statistics of China continued to use sketch maps in previous census in the year of 2000. The main progress of the 5th census in cartography aspect was the construction of digital township boundary database which was based on sketch census maps and the topographic maps at the scale of 1∶250 000 using GIS technologies. The numeration area maps of Pudong in Shanghai were digitized based on topographic maps at the scale of 1∶10 000 and developed the Pudong New Area Census GIS for further population data analysis (Wang *et al*., 2006). In order to delineate enumeration areas digitally and automatically, some scholars proposed some advanced delineating methods based on Voronoi diagram (Feng *et al*., 2009) and constraint Delaunay triangulation (Liu *et al*., 2011). There was still no digital and detailed census geographical framework at the level of enumeration area before the 6th census. Other census mapping practices focused on the census data dissemination. The population atlases of China based on successive census data were released in paper version (Population Census Office, 1987), electrical version (Yu *et al*., 2005) or on the web. According to cost-benefit analysis by Worrall (1994), investment in digital census mapping projects are heavily front-loaded. In order to benefit from the digital census geographical framework in terms of efficiency (cost savings or productivity gains) and effectiveness (impact of policies or programs that benefit from the new framework), it is imperative for us to explore the suitable solutions of census mapping for the whole China.

Many developed and developing countries have established the geospatial census framework with different solutions. However, China still use sketch maps as control devices that guarantees consistency and accuracy of population counting in previous census. One of the aims of the 2010 rounded census of China is to establish a digital, highly-detailed geospatial census framework in rural and urban areas. The rapid advancement of geospatial technologies provide many possible solutions of digital census mapping. Which solution is suitable to census mapping in China? Are there special constraint factors and challenges for the statistical division during census geography design? How is the technical workflow of census mapping activities optimized? These questions were not answered by existing researches. In this paper, several solutions of census mapping are introduced and compared. The practical solution based on remote sensing imagery and auxiliary geographic information was proposed and popularized after pilot studies for the 2010 rounded census in China. The innovative workflow and software packages of census area delineation are discussed. A new digital census geographic framework detailed at the level of enumeration area was established which lay a foundation for the further census activities and geo-demographic research.

2 Solutions of Census Mapping

The key of the census mapping is the delineation of supervisor and enumeration areas (Cheng and Yao, 2000). During the census period, the whole country is subdivided into lots of pieces of land which are referred to as enumeration areas (EA) in support of population counting. Enumeration area is defined as the minimum census unit. Supervisor area is composed of several enumeration areas. Enumeration areas should be mutually exclusive (non-overlapping) and exhaustive (cover the entire country) and have boundaries that are easily identifiable on the ground (The 5th National Census Office of China, 2000). The size of an enumeration area is determined by the ten days workload of an enumerator. Generally speaking, the population size of an enumeration area ranges from 250 to 350 persons according to approachability within different geographic conditions (National Bureau of Statistics of China, 2009). The EA maps help the enumerators to easily identify their assigned enumeration areas and help the supervisors to monitor the census enumeration.

2.1 Alternative solutions of census mapping

Different countries may follow different approaches to census mapping according to their basis of existing geographic information, budgets, technical capabilities, time constraints and so on (Department of Economic and Social Affairs Statistics Division, 2009). In the following paragraphs, several alternative solutions are briefly introduced and analyzed.

Delineation of enumeration areas and collecting buildings based on remote sensing imagery is one of the solutions. The inventory of reference data with information on resolution, scale and coverage is an important factor to success of this solution. Marizette (2004) explored the feasibility using an automatic demarcation process on satellite imagery to identify settlement change for census purposes. This approach was used in 2010 rounded census in India for preparing a detailed digital geographic database of major towns. However, artificial interpretation and manual delineation are adopted in most of cases because of low accuracy of automatic classification. As the resolution of remote sensing imagery becomes higher, the cost and processing workload will grow in geometry class. Thus, in order to save cost of census mapping activities, the relationships between image resolutions and surface features need to be established in census areas.

The second solution is delineation of enumeration areas and extraction of buildings based on topographic maps. The basic geographic information includes map series at a wide range of scales. Small scale geographic information from 1∶10 000 to 1∶50 000 can be used as reference data for delineation in rural areas. Delineation of enumeration areas in urban areas depends on more detailed large scale topographic maps from 1∶500 to 1∶5000. If there are only topographic maps in paper format available, they should be digitized at first. A series of data processing steps like geometry correction, projection and transformation, map sheet match, extraction of block boundaries and buildings need to be specified as workflows. In most of the urban areas, the latest maps available from local authorities were used to delineate house listing blocks in 2010 rounded census in India.

Another solution is to derive the new census map database by updating the enumeration area maps in the previous census period. Since the geographic database is not available in digital format, free-hand drawings or sketch maps showing the layout of buildings, houses, roads and major landmarks as available from the previous census are used. In order to support construction of digital census geographic database, the solution needs other geo-referenced information like remote sensing imagery or topographic map. The sketch map also known as 'notional map' in India is used and stored as main sources for census activities in rural areas. As the sketch census map is not geo-referenced and the administrative boundaries change greatly through ten years, this solution is technically feasible but with great difficulty and low accuracy.

The fourth solution is to generate enumeration areas automatically based on address matching. The basic principle of the solution is to redistrict the Voronoi polygons created around the geo-referenced address point according to the pre-defined population number. The algorithm needs to deal with the effect of administrative divisions thus the generated blocks contain the addresses in the same divisions only. Other considerations include preferring to choose address points which are easily accessible in terms of topographic condition. This solution can set up links between the address information and census blocks. This link information is very important in subsequent geo-demography analysis. For example, the MAF/TIGER system integrates the address data and census blocks to support better decisions of population-related analysis. However, there is no uniform specification or fixed model for address names in China so far (Sun *et al*., 2010). Meanwhile, few of the geocoded address databases is complete even in modernized cities like Beijing, Shanghai, *etc*. The solution is not applicable in most places in China.

The fifth solution is collecting data using the GPS-enabled PDA. With the adoption of PDAs, the field data to be displayed on the screen could be stored in internal storage or transmitted to a specified server for further treatment. GPS collected data may include the boundary lines as well as the internal points of census areas, the point locations of different buildings. To facilitate later EA map interpretation by enumerators, the location of landmarks in the village (places of hospital, schools and so on) may be recorded by handheld PDAs. In many places, enumeration areas can be recorded using vehicle-based GPS in stream-mode. In this sense the navigation maps in most of cities can be one of important data sources for census mapping. The technological innovation introduced in Brazil′s 2007 census operation is the use of PDAs integrated with GPS (Alicia Bercovich, 2007). Fiji, founded by the United Nations Population Fund, geo-referenced every single housing unit occupied by a household using GPS devices in 2007 census (Department of Economic and Social Affairs Statistics Division, 2009). The GPS devices were shared with other Pacific island countries to conduct the geo-central census. This solution can provide sufficient accuracy for census mapping activities with or without differential correction although multi-path errors exist in dense urban areas. Collected data can be read directly into GIS databases, making data conversion steps unnecessary. Although the cost of each GPS-enabled PDA can be kept in a reasonable low price by mass customization, a very large number of GPS units may be required for only a short period of data collection, making widespread implementation of GPS potentially very expensive. Meanwhile, whether the coverage and up-to-date state of navigation map database in China can provide enough support for census mapping or not is still an open question.

These solutions can be combined and decomposed to make up more possible approaches. If not requiring the unification in the whole country, different solutions can be adopted in different places where local conditions permit. For example, the first two solutions can be combined to better support census area delineation based on imagery and topographic maps. If the imagery data and vector data of topographic map are loaded in the GPS-enable PDA, the data collecting process becomes easier with the help of map navigation capabilities.

2.2 Characteristics of digital census mapping in China

China has its own characteristics and needs to address following issues in census mapping activities. Firstly and most importantly, China has a vast territory with various geographic conditions and a huge population about 1.37×10^6 according to the Communiqué of the National Bureau of Statistics of People's Republic of China on Major Figures of the 2010 Population Census[1] (No.1) (http://www.stats.gov.cn/was40/gjtjj_en_detail.jsp?searchword= census&channelid=1175&record=3). A large amount of manpower, materials and capital are to be devoted to the census work. Thus, cost-saving solution is preferred. Secondly, the population is unevenly distributed throughout the county thus the size of enumeration area varied greatly. There are many large uninhabited lands like Hoh Xil in Tibetan Plateau as well as many densely populated urban areas like Luwan district in Shanghai with population density larger than 40 000 per square kilometer. Thirdly, the boundaries of administrative divisions are very complex and change frequently. For example, the number of townships decreased by 40% from 503 to 315 in Wenzhou City, Zhejiang Province in 1992. The new readjustment program of administrative divisions in Wenzhou merged half of townships in the year of 2011. Fourthly, capabilities of geospatial infrastructure in support of census activities varied greatly in different parts of China due to uneven economic development. There is still a large area without maps at the scale of 1∶50 000 in the west of China where the program ′Western Mapping Project′ is underway. The national map coverage includes map series at a wide range of scales with different update frequency. Taking Beijing Municipality as an example, the fundamental geographic information databases cover whole territory at a scale of 1∶10 000 as well as areas within the Fifth Ring Road at a scale of 1∶2000. Generally speaking, the latest updated data lagged two or more years in urban areas and five or ten years in rural areas behind the actual conditions. Fifthly, in order to get the census area delineated all over the county, technicians from the census office need to be trained. In the previous census, China relied heavily on the masses of technicians and enumerators who participated in drawing sketch maps during pre-enumeration phase. The technicians and enumerators with different level of education lack professional knowledge in GIS-related fields and experiences of interpreting images and maps. How to explore new solutions of man power configuration in digital environment and effective training systems is of great importance. The last and also important constraint factor for census mapping is the inflexible administrative structure of the census office from top to bottom and the incompleteness of formal mechanism on data sharing among government departments.

2.3 Primary solutions of census mapping in China

One of the aims of the 2010 rounded census of China is to establish a digital, highly-detailed geo-referenced census framework. The digital EA database is to be established in the whole country. In urban areas, the database of precisely located dwelling units like apartments and flats should be created.

The choice of census mapping solutions is affected by many factors like existing digital or analog map products, available financial and human resources, technical capabilities in the statistical office, size of the country and so on (Department of Economic and Social Affairs Statistics Division, 2000). According to the best practices of census mapping design in other countries, characteristics of China and requirements of the National Bureau of Statistics of China, several principles for choice of alternative solutions were identified. Firstly, relevant data used in the solution should be available and be guaranteed. This will ensure the full coverage of enumeration areas database. Secondly, the solutions should balance the accuracy and workload of census mapping. Thirdly, the selected solution should be technologically advanced while being simple to technicians and enumerators, which will reduce the difficulty of training. Lastly, the economic cost of the solutions should be financially secure at a reasonably acceptable level.

The evaluation matrix of different census mapping solutions is presented in Table 1. According to the above principles and the evaluation results, the combination of census mapping solutions based on imagery and small-medium scale topographic map is preferred. Listed inventory of remote sensing imagery and geographic information in the first stages of solution test in the following paragraph show the complete coverage all over the country of relevant data. The census area with high accuracy can be acquired through medium workload. The technological aspects of the adopted solution are not so advanced that limited training time is enough for technicians with high level of education. What's more, imagery used in this solution is expected to be shared by the Ministry of Land and Resources through good coordination, thereby saving the cost greatly.

3 Pilot Projects and Popularization Nationwide

In order to test the feasibility and guarantee the operability of the primary solution, a series of solution test work and pilot projects were conducted in different places. The whole process can be divided into three stages: preliminary tests, pilot project of census mapping, and pilot project of overall census process. Different pilot areas were carefully chosen according to local geographical and population characteristics in each stage. Figure 1 shows the location of the pilot areas.

3.1 First stage: indoor experiments and on-the-spot investigation

The first stage was preliminary tests including indoor experiments and on-the-spot investigation. The aim of the preliminary tests is to investigate the capabilities of

Table 1 Evaluation matrix of census mapping solutions

Solutions	Technological advancement	Data availability	Workload/accuracy	Consistency with statistical business	Cost
Delineation based on imagery	Medium	Full cover	Medium/high	High	Medium
Delineation based on topographic map	Low	Full cover at small scales; partially at large scales	Large/depends on map scales	High	Medium
Updating previous census map	Low	Full cover	Large/low	High	Medium
Address matching	High	Partially	Medium/medium	Low	Low
GPS-enabled PDA	High	Works without data	High/high	Medium	High

geospatial infrastructure, imagery interpretation of potential technicians and of the remote sensing imagery with different resolutions in support of delineation of census areas based on available data in different areas.

The chosen test sites are Yiwu City, Nanchong City, Huidong County, Changping District, and Haidian District (Fig. 1). Yiwu City is located in the central area of Zhejiang Province. Yiwu is mostly plains and hills with high population density and high level of economic development. Thus, most of data related to census mapping are available and the capabilities of potential enumerators are good enough to interpreter images. Nanchong City belongs to hill areas in the Sichuan Basin, located in the northeast of Sichuan Province (Fig. 1). Its characteristics are medium population density and medium level of economic growth. The obstacle for census mapping here is the foggy weather in winter which prevents the optical sensors capturing the surface features. Huidong County, located in the south of Sichuan Province, is a typical mountainous area with low level economic development. The average educational level of the people in Huidong County is very low, compared with countries or regions in other places of China.

The methods used in the indoor experiments are combination of survey of available data and interview. The survey results in an inventory of remote sensing imagery and geographic information. The complete coverage of imagery with resolution higher than 3 m and geographical information at small scale is guaranteed. The imagery data with different resolutions come from different sources of different organizations. The geographical information at the scale of 1∶250 000 comes from National Administration of Surveying, Mapping and Geoinformation since the year of 2000. Both of these data are available with different time stamps. Other auxiliary data sources include geographical information at medium scale (1∶50 000 or 1∶10 000) in eastern developed areas and digital map in support of city planning at large scale (1∶1000 or 1∶500) in urban areas. The interview tested the image interpretation ability of potential enumerators using image maps in paper format or on computer screen in these sites. The staffs from local Planning Bureau or Land and Resources Bureau often have good experience in interpre-

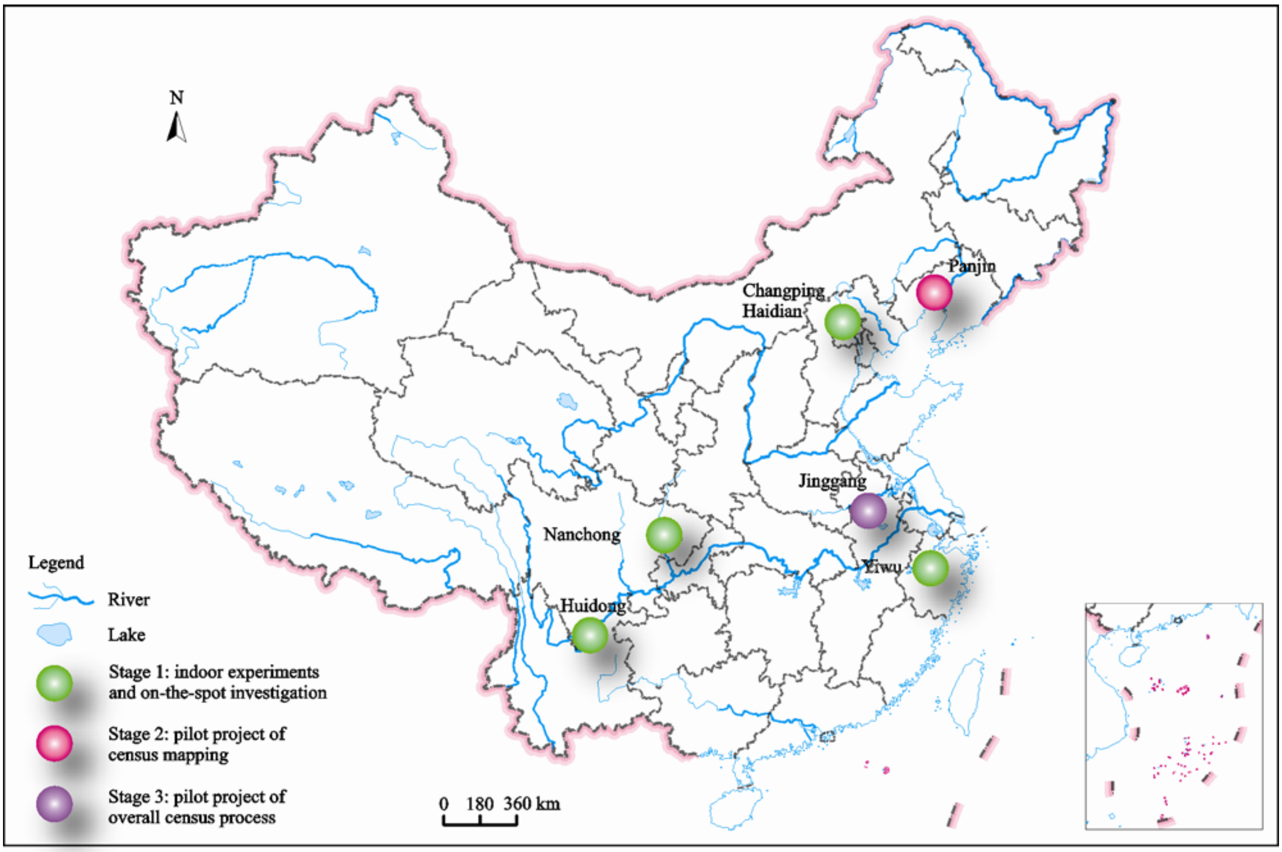

Fig. 1 Location of pilot areas

tation of remote sensing imagery as well as digital aerial photo especially in developed areas like Yiwu City. They also have some skills about GIS data processing and will have capabilities to delineate enumeration areas with little training.

Urban and rural areas with diversified population densities as well as distinct geographic conditions may need different imagery with different resolutions. On-the-spot investigation in typical areas is a prerequisite for establishing the relations between the image resolution and surface features and further the choice of remote sensing products. Imagery with resolution 2.5 m (CBERS-02B, IRS-P5, Spot 5) and 0.61 m (Quickbird) are chosen to investigate their capability of aiding enumeration area delineation in Changping District, and Haidian District, Beijing, China. The two districts cover different types of areas including rural mountainous areas with sparse dwelling, plane village area, urban fringe area with shanty and densely populated urban areas.

The accuracy and usability of satellite imagery were evaluated during on-the-spot field survey. Some conclusions are listed in Table 2. Quickbird imagery allows every operation of census mapping but with high cost. The imagery with resolution of about 2.5 m can support delineation of supervisor area in most areas except shanty towns, old towns and areas with low factory buildings. The delineation of enumeration area is guaranteed by combination of imagery and topographic maps. IRS-P5 imagery is superior to Spot 5 imagery while Spot 5 imagery is superior to CBERS-02B imagery in support of census activities. Similar results on optimal imagery resolution for census area division have been reported by Ma *et al*. (2011). As the second land survey depends mostly on satellite-aerial photographs of which resolutions are equal to or higher than 2.5 m, the results further stabilize the feasibility of primary solution of census mapping.

3.2 Second stage: pilot project of census mapping

The second stage was a pilot project of census mapping. The pilot project was carried out to test the feasibility of technical procedure as well as the usability of desktop and web-based tools for delineation of census areas. The pilot area is located in Panjin City, Liaoning Province (Fig. 1). It covers two counties, Dawa County (rural area) and Xinglongtai urban district, for delineation of supervisor area and township. The delineation of enumeration area and collected building data were tested in Youyi subdistrict office in Liaoning Province.

For the purpose of the census, China is divided into seven hierarchical levels, i.e. country, province, city, county, township, supervisor area (villages or neighborhood committees), and enumeration area. The enumeration area has no actual administrative roles. As there are authorized boundary lines above county level only, the boundaries of township, supervisor area and enumeration area need to be demarcated before census taking.

The proposed workflow integrates a top-down delineation approach and a bottom-up verification approach. The top-down approach is used for delineating census area while the bottom-up approach is used for verifying the correctness of census areas. Detailed workflow of delineating census areas is shown in Fig. 2.

The delineating process of census areas may be classified into two methods: a decomposition method and a merging method. One county level boundary polygon is split into several townships in the decomposition method. The township polygon is split into supervisor areas while the supervisor area polygon into enumeration areas. However, the philosophy of merging method is to acquire the lowest level census areas first and then merge them into higher level census area, e.g., several enumeration areas may make up of a supervisor area

Table 2 Capabilities of different imagery for census mapping based on on-the-spot investigation

Imagery	Resolution	Rural mountainous area	Plane village area	Urban fringe area	High density urban area
CBERS-02B	2.36	◎○○	●⊙○	●⊙⊙	●●◎
IRS-P5	2.50	●⊙○	●⊙○	●⊙⊙	●●●
Spot 5	2.50	◎○○	◎○○	●⊙⊙	●●◎
Quickbird	0.61	●●●	●●●	●●●	●●●

Notes: Different symbols represent supporting capabilities of remote sensing imagery, i.e. in ●each part, ◎most part, ⊙little part, ○ none of area, the operation is guaranteed by imagery. The order of symbols in each cell is as follows: the first symbol represents capabilities supporting delineation of supervisor area, second and third ones represent capabilities supporting delineation of enumeration area and building markup, respectively

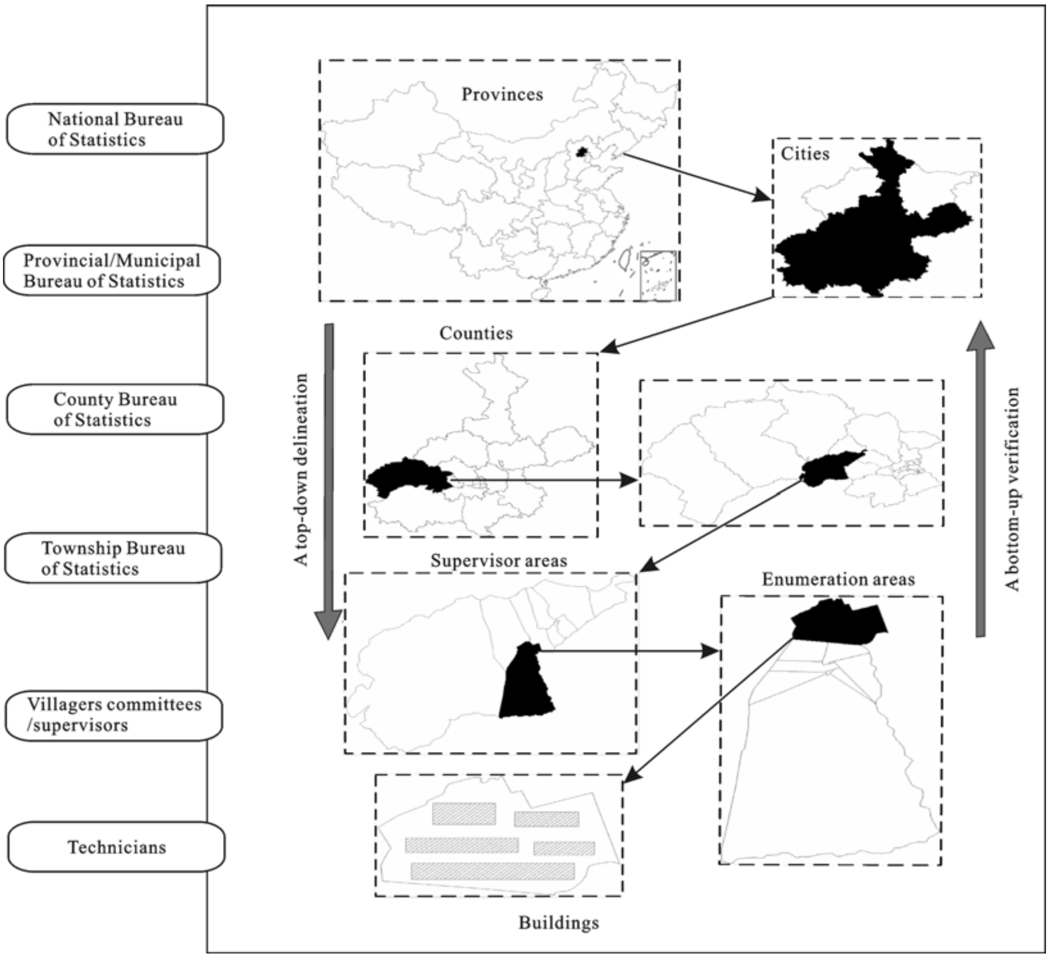

Fig. 2 Workflow of census area delineation

while several supervisor areas make up of a township polygon successively. The first method is in line with the people's mode of thinking. Thus, this method is adopted in the pilot study for census mapping. What's more, if some areas have difficulties in delineating enumeration areas for reasons of low resolution of imagery, delineating supervisor areas would be the next-best thing.

A bottom-up verification approach is proposed to guarantee the correctness in topology and other aspects at different levels according to the administration hierarchy within statistical department. The enumeration areas should be exclusive and exhaustive which means the topological correctness between the boundaries of the census areas at the same level. Other information collected by subordinates like one to one correspondence between the code and name of census areas, classification of urban or rural areas and so on are also need to be verified by superiors.

When talking about the specified technical steps, there are also two methods for census area delineation: polygon-based method and polyline-based method. In the polygon-based method, two new polygons are clipped by a split line (Chang, 2010) from the high level boundary polygons based on imagery and geographic information. One of the two new polygons is ready for adding attribute information like census code, area name, *etc*. More polygons need to be further clipped out by new split lines. The operation is repeated until each census area in the high level boundary polygon is attributed. In the polyline-based method, boundary lines of census area are drawn by technicians based on their interpretation of imagery. At the same time, one point which is often referenced as internal point is dotted in the census area and attributed with necessary information. The boundary polygon can be constructed from the boundary lines and internal points through topological operation. The polygon-based method is straightforward and easy to implement. But the usability test in the pilot program does not support this approach. The polyline-based method is complicated for reason of topological operation especially in the context of overshoots and undershoots of polyline segments (Chang, 2010). However, the workflow of this method can be easily decomposed into several steps using wizard, thus the usability test in the pilot program shows that this method is more easily accepted by technicians.

The pilot project shows the feasibility of the workflow design for census mapping. The integration of the top-down delineation and the bottom-up verification was proved to be necessary and practical. Taking the delineation of township boundary line as an example in Panjin, there are overlapping area as well as areas left out as shown in Fig. 3, which need verification and further revision from high level Municipal Statistic Office during census mapping.

Fig. 3 Overlapping and omission areas during delineation of townships in Panjin, Liaoning Province

The pilot project also shows the usability of the web/desktop-based census cartography system. More information on the design and implementation of the web-based census cartography system can be found in Luo *et al*. (2009). The web-based census cartography system is a prototype system designed for the pilot study. It supports online editing of census areas, import of GPS data and uploading of sketch maps et al. The desktop-based census cartography system is designed for production use. The philosophy of user participatory design and test driven development is reflected during the software design and development. The main principle is to make the software as simple as possible while keeping the completeness and stability of the function. The name and code of the census areas are built-in beforehand. The software is wizard-based in order to guarantee success in census area delineation by stepping users through a series of dialog boxes. The desktop-based software is robust, bug-free as well as with user-friendly interface.

About 250 technicians with higher education background from local statistical office, planning bureau, land and resources bureau were trained to participate in the pilot project. Thanks to the Google Map/Earth and web 2.0 technologies, which make geographic information very popular to all internet users (Li and Shao, 2009) in a more persuasive way (Goodchild, 2007), about a half of the technicians have basic knowledge of geographic information system and remote sensing imagery. There were 33 townships and 281 supervisor areas/villages delineated in Dawa County and Xinglongtai District. Meanwhile, there were 56 enumeration areas subordinated to 4 supervisor areas delineated in the pilot study. Each building in Youyi subdistrict office was collected during the period too.

3.3 Third stage: pilot project of overall census process

The third stage was a pilot project overall census process including the house listing, delineation of census areas, building data collection, trials of census questionnaire, and control of data quality. The aim of this pilot project was to test the popularization overall solutions of census. The pilot area is located in Jinggang Township, Shushan District, Hefei City, Anhui Province (Fig. 1). The scope of pilot area covers 18.34 km^2 with three neighborhood committees, two villages, and one open economic zone.

Important documents for digital census mapping were drafted like the scheduling of the census project, detailed rules and regulations on house listing, delineation of census areas and coding. According to the trial census, there are 11 396 permanent resident households and 34 796 permanent resident population in the pilot area.

3.4 Popularization of digital census mapping solution

The pilot projects have proved the correctness and feasibility of proposed digital census mapping solutions. On the basis of summarizing the experience gained in the pilot phases, specifications and regulations on census mapping were revised. Meanwhile, the usability of software tools was improved. The popularization plan including training and software deployment was then implemented.

The snowballing training approach was adopted. More than 500 technicians from 31 provinces (autonomous regions or municipalities) were trained from 19 to 27 in April, 2010 in Beijing. About 40 000 people are successively trained in their own provinces in May and June, 2010. The digital census mapping work were initiated in June 2010 and finished in December 2010. There are about 40 000 townships, about 690 000 supervisor areas and 5.5×10^6 enumerations areas delineated all over the country (statistics are crude and should not be cited anywhere). As the census mapping solution was applied nationwide, it is the first time that China has established the digital geospatial census framework.

4 Discussion

The rapid advancement of geospatial technologies provides many possible solutions for digital census mapping. This paper provides feasible solution for census mapping for the 6th census in China through evaluation analysis and a three-stage pilot study. The approaches to census mapping in China in the 2010 rounded census has at least two innovative points. Firstly, considering lots of above-mentioned constraint factors, a feasible census mapping solution based on remote sensing imagery and geographic information was proposed and popularized almost all over the country. A digital geospatial census framework was established for the first time. About 40 000 technicians and millions of enumerators become to know more about GIS-related technologies and to think spatially for census purpose. Secondly, a new and innovative workflow integrating a top-down delineation approach and a bottom-up verification approach of census areas was proposed, evaluated and popularized. The workflow improved the precision and quality of census mapping in the 6th census greatly. The solution and experience of the census mapping activities is a good reference for other developing countries.

The significance of the digital census mapping achievements of the 6th census can be summarized as follows. Firstly, the digital products of census areas can provide basic support of successive census and population sampling. If the update mechanism of census areas especially enumeration areas is established, the mapping activities of pre-enumeration or pre-sampling stage will be much easier than before through saving large amount of manpower, material and financial resources. Secondly, the new digital geospatial census framework makes the construction of basic unit of population statistics to be possible for the first time. Steady, minimum and effective basic units of population statistics are fundamental in census, sampling, analysis and data aggregation. Thirdly, the digital census database with high-quality spatially referenced information for small geographic units is of great value in many census-related fields. Some examples of applications for such data include emergency planning and humanitarian response, urban planning, flood plain modeling, planning of social and educational services, poverty analysis, utility service planning, labor force analysis, marketing analysis, epidemiological analysis, and so on.

5 Conclusions

From this study, it is concluded that the census mapping solution based on remote sensing imagery and geographic information is feasible for China. Imagery with 2.5 m and higher resolution, innovative workflow of census areas delineation, easy-to-use census mapping software packages and snowballing training approach all together provide the all-around support for the 2010 rounded census mapping activities. The census mapping practice during the 2010 rounded census demonstrates that China has established a digital, highly-detailed geospatial census framework in rural and urban areas. Linking census data with geospatial framework lays a solid foundation for subsequent censuses and many census-related applications.

There are still some unsolved issues to be addressed in the future work. Firstly, the quality of the geospatial census framework data needs to be evaluated from several aspects like accuracy, consistency, topographic correctness and so on. Secondly, the digital census mapping work in the Tibet Plateau, where the natural condition is quite serious-arcticalpine and anoxic, is still rare. Practical solutions in such a special alpine-cold zone need to be further explored. Georeferencing sketch map of enumeration area with other digital geographic information like 'Western Mapping Project' database seems a practical solution and needs further analysis. Thirdly, the updating mechanism of enumeration areas based on dynamic demographic process needs further research. The change detection approach based on remote sensing imagery of multiple time series may provide possible solutions.

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