THE FUNDAMENTAL CARTOGRAPHICAL TECHNOLOGY OF ANCIENT CHINA
— FORWARD INTERSECTION

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Most available ancient Chinese maps were not based on field survey but were compiled indoor using direct or indirect travel and exploration records. The map preparation process can be roughly divided into the following steps. Firstly, the position of a geographical object is marked on the sketch map using its orientation and distance. The orientation data is based on the 8-orientation system in which the circumference is divided into 8 parts. The distance data is mainly based on the Chinese distance unit “Li”, but a smaller unit “Bu” will be used for detailed description. Secondly, the rectification by “intersection” method is carried out in order to minimize the errors in the relative positions of a geographical object caused by the intrinsic “roughness” of the aforementioned spatial model. This “intersection” rectification method, which is similar to the “forward intersection” in modern survey technology, was analyzed in this article from three angles: (1) the simulation study of the 2nd century B.C. survey map “Mawang Dui Map”, (2) the analysis of the traditional survey theory recorded in Zhou Bi Suan Jing and Jiu Zhang Suan Shu (including Liu Hui’s annotation of the latter), and (3) the new interpretation of the Fei Niao model proposed by Shen Kuo. In addition, travel records of “intersection” observation and the technique and historical background of forward intersection were found in related historical and geographical documents. Finally, issues in the history of mathematics that are related to our topic were also discussed.

Key words: history of cartography forward intersection 8-orientation

THE RAISING OF THE QUESTION

Cartography based on field survey has been practiced since the very early period of Chinese civilization. The first typical record of cartography was found in an inscription on Ze Ren Pan, a piece of bronze ware dated 9th Century B.C. Some later examples include the Mawang Dui Maps of the Han

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Dynasty (ancient maps drawn on silk fabrics) dated 2th century B.C., the Emperor Kangxi’s Nationwide Map finished at 1718 A.D. and the Emperor Qianlong’s 13 Linee Map Series finished at 1760 A.D. In general, however, maps based on real field survey or documents recording this kind of survey and mapping practices are very rare in Chinese historical records.

On the other hand, most ancient maps available for current researchers were not the results of real field survey but were compiled from various secondary sources of information. Many single-frame or multi-framed maps from different historical periods belong to this category. In addition, maps encompassing small local regions were found in the appendixes of most of the chorography (approximately 8000 volumes in total), and these local maps constitute another major portion of this category. Examination of these maps revealed an intriguing fact that, although the mapping precision of the absolute orientation (factual orientation) of geographical object and geomorph are usually unsatisfactory, relative positions between neighboring geographic object and geomorph were mapped with surprising precision in most cases. This observation promoted us to investigate the survey and mapping techniques used in the preparation of these maps and our results suggested that the “intersection” method (which includes “forward intersection” and “resection”) may represent a major survey technique in ancient Chinese cartography.

“Intersection method” is a geometry-based survey technique originated from Europe between 16th and 17th century A.D. and therefore it has always been categorized as a “modern” technique. This technique is widely employed in modern survey practices. For example, intersection can be used to increase planar control network in a control survey. In addition, graphic intersection can be used to increase station points in topographic mapping with plane-table. However, in this paper we suggest that survey method similar to intersection method has been used in ancient China, which was actually consistent with the level of traditional mathematics and cartography at that time. Emphasis will be placed on the investigation of history of Chinese mathematics and the history of outdoor survey experience, which collectively served as the basis for the development of a mathematical model about space. This model occupies a unique position in the history of Chinese cartography. Since the map projection theory and the optical instruments in modern western survey can find no counterpart in ancient China, the “intersection method” discussed in this paper actually refers to a method based on Chinese ancient survey instruments and mathematical theory. This technique is primitive, simple and is in its early developmental stage. It is also apparent that, constrained by the historical background of the development of science in China, this method did not evolve into a mature survey technique in the modern sense.

The question addressed in this paper stemmed from the observation of three related phenomena in ancient maps:

2 Research Team of the silk book of Ma wang dui Han Dynasty Tomb, (1975) The collection of the topographical map of the No.3 tomb of Ma wang dui Han Dynasty Tomb of Changsha, The Journal of Cultural Relic, (Beijing, P.R.China)No.2
A. Decent cartography theory has been proposed in ancient China, such as the Pei’s Six Principles about Geographic Description and Map Making, which was brought forward by Pei Xiu at 3rd century A.D. However, it appears that most ancient maps after 3rd century were not prepared according to these principles. B. The lack of precision in ancient maps is manifested by the distance and orientation deviation of the geographical object position, which can be partly explained by the lack of scientific theory about earth geometry and map projection in ancient China, but it is not clear why there is almost no precise maps even for small areas where the curvature of earth can be omitted. C. The method of “Ji Li Huang Fang” (drawing square grid with Chinese unit of length “Li”) was routinely used in ancient mapping practice. Several characteristics are obvious after the examination of most ancient maps: the map elements are relatively simple, the load of map content and the quantity of the geographical information included is small, and the encompassing area of a map is large. Judging from the overall low precision of these maps, it can be deduced that geographical object were drawn based on approximate graphic portrayal of orientation and distance. The marking of orientations was based on neither the 365 1/4 degree Fen Du Fa (the method used in the astronomical measurement of ancient China) nor the angular model designed by the 11th century scientist Shen Kuo, in which the circumference was divided into 24 orientations. According to the historical records about 8 geographical orientations, what was widely used instead was the angular model in which the circumference was divided into 8 orientations. In fact, the low precision of many ancient maps is consistent with the approximate orientation determination by the 8 orientation model. However, it is not clear how the actual map preparation process was carried out.

Acceptable precisions may be achieved in the orientation and distance determination of geographical object for small areas, where the curvature of earth can be omitted. However, how to maintain the correct relative positions of two neighboring geographical object can still be problematic. For example, suppose the there are two points A, B, which are located on a west-east oriented line, and there are another two points C, D, which are close to each other and are located at the south of the A-B line. According to the approximate model of 8 orientations, C is located southeast of A with a distance of 9 “Li”, and D is located southwest of B with the distance of 9 “Li”. As a consequence of this reasoning, C, D will merge together as a single point. If one wants to separate C and D on the map, then there arises a problem on how to determine the relative positions of C and D, or more explicitly, to determine whether C is located east or west of D.

Since most relative positions of geographical object in ancient maps are correct, rectification method must have been used. For example, if two sets of distance/orientation data input of an unknown point are obtained from two independent reference points, the positioning precision of this unknown point will be substantially improved when compared to the method using only one reference point and hence one set of distance/orientation data input. This improvement in positioning a single point will result in better distinction of the relative positions of two neighboring points. This proposed strategy is actually the “forward intersection” method which will be articulated in this paper. As mentioned before, except the very rare map based on field survey, most Chinese ancient maps were drawn by cartographers

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7 Xiaooyuan Jiang (ed.) (1996) Zhou bi suan jing (a book was written about the time around 1cn B.C) (Chinese), China Liaoning Province Education Press.
8 Kuo SHEN (Song Dynasty), Meng xi bi tan (reprint of a ancient book) (1997), P272
THE USE OF FORWARD INTERSECTION IN ANCIENT CARTOGRAPHY

The modern mathematical model for determining point positions using forward intersection is based on the determination of height datum, the measurement of baseline, and the map-making technique using projection geometry. Our research on the literature of ancient Chinese cartography led to the conclusion that the primitive concepts of these several key model components have been perceived very early in ancient China.

Horizontal measurement was discussed in the book *Zhou Li*, which was compiled at approximately 4\textsuperscript{th} -3\textsuperscript{rd} century B.C. According to this book, level surface of a small area was determined by the static water surface in a ditch, and the orientation was determined by using a Chinese version of the celestial azimuth coordinate system, with the Polaris as reference.\textsuperscript{9} In addition, a summary of the land measurement tools used in previous several centuries was preserved in *Han Shu Lv Li Zhi*, which was compiled at 1st-century A.D. According to this summary, the basic scale system used in length measurement at that time is “Fen”, “Cun”, “Chi”, “Zhang” and “Yin”. “Yin” (approximately 20 meters) is the length unit for long-distance measurement, and in practice the measurement of “Yin” was carried out by using the “Yin Qi” (equivalent of modern tape measure), which was made from a long bamboo strip and had the length of one “Yin”.\textsuperscript{10} The length units “Bu” and “Li” were also used in long-distance measurement. One “Bu” equals to 6 “Chi”\textsuperscript{11} and one “Li” equals to 300 “Bu”.\textsuperscript{12} “Li” is the most frequently used length units in ancient Chinese geographical travel. In the same book the application of the “Sheng” tool in long-distance measurement was also mentioned. This “Sheng” tool, when combined with the orientation-determining tool “Zhun”, can also be used to determine long-distance at a specific orientation.\textsuperscript{13}

“Gui Yi” is among the earliest survey instruments of the world and its appearance was dated around the Zhanguo Era (6\textsuperscript{th} -3\textsuperscript{rd} century B.C.) or even earlier. This instrument is similar to the modern plane-table and it consists of two intersected straight arms, which can be rotated 360 degree. While one arm is used to determine the orientation of the table, the other arm is used as an alidade. Gui Yi can be used for leveling or for topographic mapping with plane-table,\textsuperscript{14} and the latter practice includes the focus of this paper: the forward intersection and resection.

\begin{itemize}
  \item \textsuperscript{10} Gu BAN (Donghan Dynasty), Han shu. Lv li zhi (reprint of a ancient book) (1975), Zhonghua Book Company, P966.
  \item \textsuperscript{12} Shi san jing zhu shu, Chun qiu gu liang zhuang zhu shu (reprint of ancient book) (1980) Zhonghua Book Company, P2415.
  \item \textsuperscript{13} Yucang, (ed.) (2002) The history of cartography in China, China Cartography Press, P78.
  \item \textsuperscript{14} Keling WANG (1992), A ancient cartographical instrument in Pre-Qin of ancient China- Gui Yi, The Journal of History of Natural Science (Chinese), No.3.
\end{itemize}
Mathematical precision assessment of the Mawang Dui Maps (2nd century A.D.) revealed some intriguing facts that may give insight into the aforementioned issues. This map encompasses a region of around 10,000 km² and is prepared with a 1:170,000 scale, and the geographic complexity of the mapping region is manifested by the variation of heights above sea-level from 100 m to 1000 m. Surprisingly, in the central region of the map, the relative position and distance of some important geographical object were found to be very precise, and some particular point pairs have zero deviation when compared with modern map. In addition, among the survey routes (vary in length from 38 km to 114 km), one (91km) has zero deviation in azimuth angle and merely 2 km deviation in length.

Some scholars proposed that “Chong Cha Fa” was used in the survey process of ancient maps. Chong Cha Fa is a survey method in which observation tower was set up more than twice to obtain multiple data sets, and then the Principle of “Gou Gu” (the Principle of Pitagoras) was applied to carried out calculation. In essence Chong Cha Fa is an indirect method to measure and calculate inaccessible points. The analysis of these scholars was based on the book Zhou Bi Suan Jing and Jiu Zhang Suan Shu (both dated 2nd century B.C.), and the book Hai Dao Suan Jing (appeared as an appendix to Jiu Zhang Suan Shu) by a 3rd century A.D. mathematician Liu Hui. It was Liu Hui who summarized previous survey techniques and brought forward the theory of Chong Cha Fa in his Hai Dao Suan Jing. Re-examination of the distance and orientation precision of some points in the Mawang Dui Map generated several surprising observations. Initially, 22 survey lines on the Map, which may have been subjected to real survey in ancient time, were chosen. These survey lines go through the points of settlement (represent military castles and community centers of the rural population) and some salient geomorphological points (such as the intersection points of hilltop and river). Then, azimuths and horizontal linear distances of selected points were measured and compared to the results obtained from modern maps, and a series of deviation data were obtained.

After this we tried to find the highest point of the most salient mountain Jiu Yi Shan. The Jiu Yi Shan area on the map was represented by a series of fish-scale like lines with similarity to the modern contours. In an effort to find out the hint for the highest point from the fish-scale pattern using archeological method, we proposed several possible candidate points, and then draw a triangle using one candidate point and two other salient geomorphological points (two river intersection points with dense population around). The sides of the triangles vary from 26 to 30km. Comparison with modern map revealed that the deviation in the azimuth or the length of the three sides were all close to zero. Examination of the other candidate points also generated very small deviations. Such a high level of precision was probably not achieved by using Chong Cha Fa because the distance between different points are quite long and the complex geomorphology between the points made the application of Chong Cha Fa very difficult. The fact that direct visualization was possible between the points

16 Xiaoyuan Jiang (ed.) (1996) Zhou bi suan jing (a book was written about the time around 1cn B.C) (Chinese), China Liaoning Province Education Press, P75-76
18 The paper Forward Intersection—The Chinese Surveying and Mapping Technology 2000 Years Ago. by Zilan WANG, was presented in British Society for the History of Science Annual Conference, Liverpool, 25-27 June 2004. The paper will be published shortly.
promoted us to propose that “forward intersection” was probably used in the survey process and the knowledge of projection geometry (or comparable practical experience) was used in map preparation.

THE GEOMETRICAL BASIS OF THE FORWARD INTERSECTION

When Liu Hui was annotating the book Jiu Zhang Suan Shu, he attached his own work Hai Dao Suan Jing, which is mainly about survey and calculation using the Principle of “Gou Gu”. The first question in Hai Dao Suan Jing is about how to determine the relative height and linear distance of an island from a remote place. Briefly two observation towers with identical height were set up, and the distance between them is 1000 “Bu”. These two observation towers were positioned in such a way that the island, the observation tower in the front, and the observation tower in the back were located on a straight line.

The original text to describe this arrangement read as “San Xiang Zhi”, and this sentence can be traced back to another book Mo Jing, which was dated 5th-4th century B.C. and was compiled by Mo Zi and his pupils. In this book it was said that “A natural example of a straight line can be found in the San Constellation, in which there are three stars on the same direction”. The San Constellation is actually the Secunda Constellation, in which three small stars line up on a straight line and the line is in an east-west orientation. This celestial straight line was also used by Chinese ancient astronomer to represent the horizontal line perpendicular to the surface of the earth. In addition, several other important concepts in geometry, such as “Ping” and “Xiang Guan”, were also discussed in Mo Jing.

Both Jiu Zhang Suan Shu and Hai Dao Suan Jing were written as collections of sample questions. In the opinion of Dr. Joseph Needham, these two books were considered to represent some kind of “empirical 3-dimentional geometry”, and he also pointed out that the annotations written by Liu Hui were “the greatest explanation” to the empirical 3-dimentional geometry described in Jiu Zhang Suan Shu. It is worthwhile to mention that Mo Zi was originally an artisan, and the knowledge in Jiu Zhang Suan Shu and Liu Hui’s work was extracted from applied techniques. It is obvious that in real land survey and map preparation, spatial geographical data have to be analyzed by geometry and then projected to 2-dimentional plane. This is the essential concept of “projection geometry” and it served as the mathematical basis for the survey and mapping procedure using intersection method.

Among the six key points of cartography proposed by the ancient cartographer Pei Xiu (3rd century A.D.), three of them (“Gao Xia”, “Fang Xie” and “Qu Zhi”) were thought to represent such a mapping process: indirect length data of the inaccessible points and accessible points were obtained, after that these set of length data were transformed to linear distance on a horizontal plane, and in the end the distance and orientation of the inaccessible points can be marked on the map. In terms of the methodology to transform indirect length data into horizontal distance, Pei Xiu proposed that the aforementioned cartographical parameters “Gao Xia”, “Fang Xie” and “Qu Zhi” have to go through (1) Jiao (rectification), (2) “Can (Hu) and Kao (Jiao)”(comparison and rectification) with the six kep

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19 Xiaoyuan Jiang (ed.) (1996) Zhou bi suan jing (a book was written about the time around 1cn B.C) (Chinese), China Liaoing Province Education Press, P343
20 Jiefu TAN (1981), Mo jing fen lei yi zhu, Zhonghua Book Company, P18, 37, 39
points of cartography and (3) calculation to give reasonable data on orientation and distance. “Kao Jiao”, “Jiao He” and “Can Hu” are three types of indirect survey approaches, and they actually means “to measure one unknown point from two accessible points”. We believe that this is intrinsically consistent with the survey, measurement and mapping technique using forward intersection.

Scientist Shen Kuo (11th century A.D.) carried out a leveling measurement of more than 800 Li and he also had personal experience in the preparation of map and model map. Based on the cartography theory by Pei Xiu and the empirical experience of his own, Shen Kuo pointed out that “Hu Tong” and “Bang Yan” should be carried out for the indirect measurement of “Gao Xia”, “Fang Xie”, and “Qu Zhi”. Most scholars thought that what Shen Kuo actually referred to is the calculation of horizontal linear distance. Through our research we concluded that the “Hu” in “Hu Tong” means intersection and the “Tong” means the same point, so collectively “Hu Tong” means measuring the same point from different orientations. Similarly “Bang” has the meaning of “side, multiple orientations”, so “Bang Yan” can also mean measuring the same point from different orientations. In addition, the “Qu Niao Fei Zhi Shu” in his work means the determination of horizontal linear distance and direct orientation. All these are clear evidence for the existence of intersection and forward intersection method, or, more explicitly, the technique to measure the spatial data of an inaccessible target, in ancient China.

The main progress we achieved in this paper compared to previous research is that, by using the modern cartography term “forward intersection”, we bring new interpretation and definition to the ancient cartography theory. Apart from the aforementioned comments of Dr. Joseph Needham on Chinese geometry (which suggest the existence of traditional 3-dimentional geometry), and our analysis about the ancient projection geometry technique, research on ancient literature also revealed multiple evidence to suggest the empirical concept and mental basis for forward intersection, which was mainly summarized from the experience and observation of ancient travelers.

In his work Shui Jing Zhu, the geographer Li Dao Yuan (6th century A.D.) described the visual impression of the Heng Shan (in the current Hunan Province) based on some travel diaries from 4th century B.C. to 4th century A.D. According to him, Heng Shan was located at both sides of the Xiang River, and the three main peaks of Heng Shan were so high that they looked like the cloud in the sky. If from Changsha one traveled towards upstream by boat, one could always see Heng Sha during the 700 km journey. Within the flexual route, one would face Heng Shan for 9 times and also face the opposite direction of Heng Shan for 9 times. This is actually a typical “forward intersection” experience in which one “observes” the same salient target from multiple orientations.

Similar scenario was also found in the travel documents about the Three Gorges of Yangzi River. There was a Huang Niu Shan in the Xi Ling Gorge (one of the Three Gorges). The rapid current went around the high mountain and it took three days to pass the mountain if one traveled from downstream to upstream. During these three days, the Huang Niu Shan could be viewed from different angles, which

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23 Kuo SHEN( Song Dynasty), Meng xi bi tan (reprint of a ancient book) (1997), P360
24 Ci yuan, China Commerce Press (1979), P246
made it another suitable example for the empirical experience of “forward intersection”.  

Jiu Yi Shan (south Hunan Province) has been a famous sacred mountain even before the 1st century A.D., and the mountain was described in the book Shan Hai Jing (compiled at 3rd century B.C.), and also in an even earlier poem Jiu Ge, which was written by the great poet Qu Yuan of Chu Kingdom. By quoting the diaries of early travelers, Guo Pu (3rd century A.D.) described the visual impression of Jiu Yi Shan in his annotation for Shan Hai Jing. According to him, there were 9 brooks in Jiu Yi Shan with similar appearance, and it was difficult to distinguish them from a remote place.  

Intriguingly, in the Mawang Dui Map, there are 7 column marks on the east of Jiu Yi Shan, and there are 9 column marks on the south of Jiu Yi Shan. We favor the interpretation that the 7 column marks means that 7 peaks could be observed on Jiu Yi Shan from west, and the 9 column marks means that 9 peaks could be observed from north. This clearly indicates that the same mountain was observed from two different orientations, which made it a very typical example of “forward intersection”. While the above examples are related to travelers, this example is probably related to the cartographers who prepared the map.  

Our interpretation of the Liu Hui’s “measurement of an inaccessible target by multiple use of observation towers” gives theoretical support to our conclusions about the cartographical significance of the Jiu Yi Shan fish-scale pattern and the column marks on the Jiu Yi Shan area. The survey techniques developed by Liu Hui was given special attention in the preface of his Jiu Zhang Suan Shu annotations: (1) he established the method of multiple use of observation towers and he pointed out that “direct visualization should be available between the target and the survey station” (2) For those survey routes where indirect measurement has to be carried out, he suggested that “the target should observed from the other side” and sometimes one may need to “observe and measure the target three times ” or even “four times”. These statements essentially point out such a mapping strategy in which the geometrical relationship between the target and the observer is established from multiple orientations and the information obtained can then be used for geometrical calculation and map preparation.

Although we can not be absolutely sure whether the Jiu Yi Shan on the Mawang Dui Map was indeed drawn by the method similar to that of Liu Hui, we do believe that, those column marks on the two perpendicular orientations “indicate” or “clearly show” that they are “orientation lines” resulting from “intersecting” observations from two different orientations. If this is indeed the case, then one can say that Jiu Yi Shan on the Map was based on forward intersection survey, and it was drawn using projection geometry method.  

In the modern intersection mapping procedure, the first step is to establish appropriate “known points” from which observation can be carried out. Direct visualization should be available between these points and the target, and appropriate intersection angles should be maintained between the known  

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27 Research Team of the silk book of Ma wang dui Han Dynasty Tomb, (1975) The collection of the topographical map of the No.3 tomb of Ma wang dui Han Dynasty Tomb of Changsha, The Journal of Cultural Relic, (Beijing, P.R.China)No.2  
28 Xiaoyuan Jiang (ed.) (1996) Zhou bi suan jing (a book was written about the time around 1cn B.C) (Chinese), China Liaoning Province Education Press, P4-5
points. The intersection angle should be somewhere between 45 degree and 90 degree, since intersection deviation will increase if the angle is too small. In the next step, the horizontal distance between known points are measured to establish data sets for them. After that intersection measurement of the target can be carried out, and the position of the target can be directly marked on the map by intersecting orientation lines from known points. This is the most convenient method to map the position of an inaccessible point since the calculation of similar right-angled triangle (as discussed in *Zhou Bi Suan Jing*, *Jiu Zhang Suan Shu* and Liu Hui’s work) is not required.

In summary, we found appropriate geomorphological points, routes with direct visualization, and good intersection angle by carrying out multiple simulation trials and comparing the results with modern maps. Therefore we concluded that forward intersection method was used to map Jiu Yi Shan. (Please see the reference No.17)

**THE ORIENTATION SYSTEM IN ANCIENT CHINA AND ITS CONNECTION WITH FORWARD INTERSECTION**

According to the history of ancient Chinese mathematics and cartography, angle measurement was not used for the preparation of most ancient maps except the national maps prepared during the Reign of Emperors Kangxi and Emperor Qianlong. The standard method used in most cases is “Ji Li Hua Fang” (Drawing square grid with Chinese “Li”). Although angle calculation appeared very early in ancient Chinese astronomy (the whole circumference was divided into 365 1/4 degrees), the concept of spherical trigonometry was not formed in China and the development of trigonometric functions claimed its start in Europe after the Renaissance Era. However, the Chinese astronomer Xu Guang Qi (17th century A.D.) pointed out that the Gou Gu Xian theory in ancient China contained some kind of “nomenclature” with intrinsic similarity to trigonometric functions, and Dr. Needham also considered the “Chong fu li chan biao ce liang fa” of Liu Hui as an empirical substitute for trigonometry functions.29

The situation of the angle calculation in ancient map preparation is similar to what happened in ancient astronomy: In both cases concrete experience is a dominant feature. For example, the relative orientation and distance between geographical object was simply “described” but not quantified by angle calculation; in other words, angle calculation was not necessary for the traditional mapping method such as “Ji Li Huang Fang”. The lack of angle calculation may have something to do with the fact that control survey was not emphasized (or was simply unknown) in traditional survey practice.

As a consequence, direct description of the cartographical object’s position using orientation and distance in a 2-dimensional planar system became the core method in traditional cartography. When interpreting his six principles on cartography, Pei Xiu pointed out that enough attention should be paid to distinguish the relative orientation and distance between geographical object and “the spatial relationship of geographical object on a map should agree with the real situation”. This view was further articulated as “the position relationship between different geographical object should be correct in a 8 orientation spatial system” by Hu Wei (17th century A.D.) after studying the cartography theory

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The 8-orientation system mentioned here is the most commonly-used spatial model in the geographical description and mapping practice in ancient China.

Shi Pan (dated before 1st century A.D.), which was originally used in augury, is the earliest instrument for the division of relative geographical orientation in a circumference. In the book *Huai Nan Zi Tian Wen Xun*, the whole circumference was divided into 24 orientations using 8 “Gan” out of the 10 “Tian Gan”, the 12 “Di Zhi”, and 4 “Gua” out of the 8 “Gua”. The 1st century A.D. Shi Pan excavated from Korea is the oldest Shi Pan found in archeological work. This Shi Pan is composed of a “Tian Pan” and a “Di Pan”, and on the circumference of the Shi Pan there are 24 orientations and 28 constellations, the latter of which are located around the equator circle of the celestial sphere in traditional Chinese astronomy. The scale on the Shi Pan was similar to that on the circle of a compass.

It was also suggested that primitive compass “Si Nan” might have been put on the Shi Pan since record about Si Nan can be found in the book *Han Fei Zi You Du*, which is dated 3rd century B.C. On the other hand, practical magnetic compass, which includes compass for “Feng Shui” and for navigation, was invented in 12th century A.D. Magnetic compass was not mentioned in Shen Kuo’s *Meng Xi Bi Tan*, but he did discuss the way to draw a map using 24 orientations. He mentioned that, in the situation when the map is lost, one can precisely reconstitute the map without any real land survey if one still have the “book” which records the positions of geographical object (cities) in the 24 orientation system. It is obvious, from the description of Shen Kuo, that the “map” he mentioned is a “complicated” map rather than a survey map, and the “book” should be some kind of travel essay or geographical investigation report which record the positions of cities and other geographical object using 24 orientation system.

Compass with 24 orientations should have been used if the positions of geographical entities were indeed recorded using 24 orientations, as described by Shen Kuo. However, the 8 orientation system is what was actually used in most ancient geographical documents. In addition, the maps in the appendixes of most chorography are very sketchy and were probably prepared using the 8 orientation system. The 8 orientation system is easy to distinguish and describe and is suitable for the making of sketchy reconnaissance maps.

Most scholars believe that the *Yuan He Jun Xian Tu Zhi*, compiled at 8th century A.D by Li Ji Fu, represents the start of a common practice in which the major geographical object in a particular local region was observed according to the 8 orientation system and the resulting map serves as the framework for the chorography of that region.

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30 Xiaoyuan Jiang (ed.) (1996) Zhou bi suan jing (a book was written about the time around 1en B.C) (Chinese), China Liaoing Province Education Press, P257
31 Er shi er zi, Shanghai Ancient Books Press (1986), P1216
32 Zhenduo WANG (1989), The collection of the papers of Scientific Archeology, China Cultural Relic Press, P107, P111, P119, P175 and P182
33 Kuo SHEN (Song Dynasty), Meng xi bi tan (reprint of a ancient book) (1997), P272
34 Jipu LI (1983), Yuan he jun xian tu zhi, China Book Company, P3, it said they use 8-orientation to describe the counties and other important geographical objects near the capital of Tang Dynasty.
35 Wei HUANG (1993), The research of chorography, University of Fudan Press, P334
In fact, in ancient Chinese texts before 1st century A.D., evidence has been found to indicate (1) the combined use of the 8 orientation system and route distance to describe geographical positions and (2) the “forward intersection” method in which one target was observed from multiple orientations. For example, the combination of the 8 orientation system and route distance is the standard format to describe geography in the book Shan Hai Jing, which is the earliest regional geography book in China. The Shan Jing section was finished at approximately 5th-3rd century B.C., and the Hai Jing and Huang Jing sections were finished several centuries before or after the 1st century A.D.

The format used in Shan Hai Jing was also employed by the author of Han Shu Di Li Zhi (finished at 1st century A.D.), the earliest geography gazetteer in China. In addition, in Han Shu Xi Yu Zhan, the location of one geographical object was described not only according to the 8 orientation plus route distance, but also from several different orientations. "6820 Li [southeast] of Qie Mo (a city in the current Xinjiang Province) is Chang An, and 2258 Li northwest of Qie Mo is the headquarter of Du Hu. Wei Li is located north of Qie Mo, and it takes 3 days to travel by foot to Xiao Wan, which is located south of Qie Mo. …… 2000 Li west of Qie Mo is Jing Jue (The currently Minfeng County of Xinjiang Province).” This is a very precise “intersection” description because it involves the descriptions of a single target from 5 different orientations. Similar “intersection description was also found in Yue Jue Shu (1st century A.D.), which was thought by many scholars as the earliest chorography in China. It says “Bai Lu Shan is located at the south of Quan Shan and is 29 Li from the County centre.”

The historical period between 1st century A.D (Dong Han Dynasty) to 7th -10th century A.D (Tang Dynasty and Wu Dai Era) witnessed the appearance of a lot of “Tu Jing”, which are geography books with attached maps. Although very little of those books and maps were preserved, research on those precious surviving fragments suggest that the use of the 8 orientation system for geographical description was very popular through the period and some books even included details about geomorphology. For example, in Han Yang Jun Tu Jing (dated 6th -8th century A.D.) there is a geographical description of Chi Bi, a famous ancient battlefield (the battle happened at 3rd century A.D.), “Chi Bi, also known as Niao Lin, is located 220 Li northwest of Han Yang, 80 Li west of Han Chuan County, and it encompasses both the north and the south side of the Han River.” In this description the orientation and distance of the target was elucidated by two intersecting information sets from east and southeast, and its spatial relationship with the natural environment (Han River) and the neighbouring city (Han Chuan) were pointed out. This paragraph is not only a vivid account of geographical observations, but presumably also a precise record of intersection observation practices used in the accompanying map. Many more examples of this kind can be found in ancient Chinese documents.

Guang Xu Shun Tian Fu Zhi (the end of 19th century) is excellent chorography which comprehensively recorded the local history and geography of the 5 boroughs and 19 counties within the border of Shun Tian Fu (Beijing being its administrative centre). In the preface to the Di Li Zhi. Jiang Yu, there is a discussion about the principles and methods to compile the Di Li Zhi section in a chorography, “The Yuan He Jun Xian Zhi of the Tang Dynasty contains detailed description on the distance and orientation

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36 Zhongmian Zeng(ed.) (1981), Han shu.Xi yu chuan di li jiao shi, China Book Company, P29
37 Weiyi LIU(1997), Han tang fang zhi ji yi, Beijing Library Press, P422
(according to the 8 orientation system) of geographical entities, and this body of geographical information can be used for error-checking and for assessing the advantages of geographical elements and their surrounding environment. Famous experts in chorography, such as Wang Cun and Yue Shi, all follow this format in their works, and the methodology and theory of this format is considered as an excellent standard by people in the geography field. 38Wang Cun (11th century A.D.) is the author of Yuan Feng Jiu Yu Zhi, and Yue Shi (10th century A.D.) is the author of TaiPing Huan Yu Ji. These two books are outstanding works of magnificent chorography and have far-reaching influence on the history of Chinese civilization and geography.

From above analysis one can conclude that the combined use of the 8 orientation system and route distance to describe the spatial position of geographical object is one of the classical methods to compile geographical record and maps in ancient China. It should be pointed out that the “map” mentioned refers to a map based not on real survey but on data from geographical investigation and travel experience. One good example on the application of this method by military leaders at 1st century B.C. was found in the story of Zhang Yan Shou, which is an attachment of Han Shu. Zhang Tang Zhuan. It says “… The General in Chief Huo Guang asked General Zhang about the landscape of the battle area and corresponding military strategy. Upon this request General Zhang made a map immediately according to the available data, and then reported the situation of army and the strategy to the General in Chief using this map.”39

The aforementioned method to record geographical entities by the combination of the 8 orientation system and distance is reminiscent of the preliminary phase in modern map preparation, which includes reconnaissance and sketching. In other words, the ancient method is suitable for preliminary survey but not final survey. In fact, it is very easy to generate a series of problems in the indoor map preparation process using data from such a method. For example, as discussed in the beginning of this paper, the relative position of neighboring geographical object is difficult to establish, and sometimes distortion or even perversion will happen. Because of this, rectification from “the other side” is required, and this requirement is met by the “forward intersection” method discussed in this article.

As discussed before, “forward intersection” method was probably used to determine the position of Jiu Yi Shan in the 2nd century A.D. Ma wang Dui Map. It is important to point out that the concepts of “forward intersection” and the “Measurement of an inaccessible target by repeated use of observation towers” are deductions based on case analysis, and clear articulation of the theoretical concepts used in these cases could not be found in historical records. There is also no example for the explanation and elucidation of these theories. We reasoned that, since the discovery and accumulation of empirical knowledge has always been the emphasis in traditional Chinese cartography, its constraint on people’s mind may have prevented the development of a mature theory. In fact, the lack of logical reasoning is one of the cultural characteristics in the history of Chinese traditional science and technology. Nevertheless, one can never underestimate the historical significance of such a rich body of adventurous experience whose implications have touched the frontier of the contemporary science and technology.

38 Ci yuan- Volume 2, China Commerce Company (1980), P1061
39 Jiamei ZHOU(1987), Guang xu shun tian fu zhi, Beijing Ancient Books Press,P603