Digital reconstruction of the Song Dynasty Ganzhou drainage system based on AR technology and its' application in the new urban area planning and revision

H L. Cao[1]**, Y L. Chen**[2] **and T H.Tao**[3]

School of Architectural and Surveying Engineering, Jiangxi University of Science and Technology, 341000 Ganzhou, China

[1]634211660@qq.com, [2]34564594@qq.com, [3]250904570@qq.com

Abstract. Water-logging problem is a common problem in modern city. The urban built-up area of Zhangjiang new district in Ganzhou has the same water-logging problem, however, the old urban area of Ganzhou was praised as "Millennium no flood".The drainage system of the old urban area of Ganzhou—Fushougou, which is not flooded for hundreds years because of the perfect drainage system. It's valuable to be referenced to the modern city drainage and waterproof comprehensive planning. In order to explore the mystery of "Millennium no flood" of old urban area of Ganzhou, at the same time to provide directive opinion to the sustainability of Zhangjiang new urban area drainage system , this paper attempts to digital reconstruct the drainage system in old urban area of Ganzhou by augmented reality(AR). It will provide a new technological means and ways to evaluate the sustainability of urban underground drainage system under the surface feature changes in the landscape. On the basis of digital reconstruction of the drainage system in the old urban area of Ganzhou, the sustainability evaluation index of drainage system is studied by analyzing and contrasting with Zhangjiang new urban area drainage system, to guide the revision of comprehensive planning about city drainage and water-logging in the new urban area of Zhangjiang.

1. Introduction

In 2015, a total of 20.79 million residents in the 20 provinces (including autonomous regions and municipalities) suffered flood, which has caused 108 dead, 21 missing and 13461 displaced. The worst flood, which has ever seen in past years, brought about the direct economic loss of 35.3 billion Yuan, based in fact that it affected 1.717 million hectares of crops and left 44000 collapsed houses. The Intensity is rare throughout the years. According to the special investigation from Ministry of Housing to 351 domestic city,a total of 170 cities including 12 important cities, 33 secondary cities and 125 general city haven't developing the urban flood control planning. There are still 340 cities (53%) did not reach the flood control standards set by the state. The design of more than 70% of the urban drainage system construction in China heavy rains return period is less than 1 year. According to the national wide range of urban water-logging problem, the government has issued <The town drainage and sewage disposal ordinance>(No.641 decree of the state council), national standard <regulations on the urban drainage and wastewater treatment>, national standard <specifications for design of outdoor drainage >(2014 revision).[1]The Ministry of Water Resources published <the urban flood control planning outline> (revised). According to the flood control standards and specifications which have been revised, the local government are writing and developing the planning of flood control and

revision. How to solve the problem of urban water-logging, which is one of the important subjects to be studied and discussed.[2]

Ganzhou is located in the southern part of Jiangxi province ,where the new and old districts present totally different environment features .That is, the new district which is on the southern of the Zhangjiang river is often water-logging, while the old district which is on the northern of the Zhangjiang river is reputed for its stable environment conditions . This phenomenon has attracted the attention of scholars at home and abroad. In order to explore the mystery of old district of Ganzhou which is not suffering from a flood for a thousand year and provide guidance for the sustainable evaluation of the drainage system of the new district, this paper attempt to use the augmented reality technology(AR) to get digital reconstruction of drainage system of the old districts of Ganzhou .On the basis of digital reconstruction of the drainage system of the old districts, this paper studies the safety evaluation index of urban drainage system. A comparison between the drainage systems of Ganzhou old district and Zhangjiang new district is made, which provides favourable guidance for urban water-logging planning.

2. Drainage system of the old district of Ganzhou-fushougou

2.1 Fushougou Overview[3]
Ganzhou located in the southern part of Jiangxi province was built in 201 BC. Ganzhou surrounded by water on three sides. Zhangjiang and Gongjiang River flow across the city and they merge into Ganjiang River in the northern of the city. Ganzhou often suffered from floods from 201 BC to the Song Dynasty. Until AD 1068 - 1077 Song dynasty, Liuyi who is served as chief of a prefecture planned and constructed city street. According to the layout of the streets and topographic features, his team adopt the principle of partition drainage and then built two main drainage system. What they do make Ganzhou exempt from the flood for a thousand years and protect this city. The two main gutter ways are named as Fushougou because they look like "Fu" (good fortune)and "Shou" (longevity) of Chinese seal script.

2.2 Planning and Design Features of Fushougou
(1) Districted Draining System Adaptive to Terrain
"The Shou Gutter way takes in water from the northern city and the Fu Gutter way from the southeastern city." Starting from the South Gate, the Fu Gutter way passes by the middle part of Jianguo Road, Junjing Alley, Pangaopu Street and stretches to Bajing Road. The Shou Gutter way starts from the new Gannan Road and goes along the two Xinkai Roads, Xijin Road, reaching the Weat Gate. After the completion of the two main ditches, a number of sub-ditches have been built, presenting a systematic and ordered draining system in the ancient Ganzhou city.
(2) Natural Draining Availing of Elevation
The Fushougou makes full use of urban terrain elevation, using the natural flow to make the city rainwater and sewage goes into the river.
(3) Reasonable Selection of Material and Large Cross Sections
The cross sections of the two drainage systems are rectangular in large size, made of masonry. According to historical records, the gutter way is "about 0.6 to 1 meter wide and 1.5 to 2 meters deep, built firstly by bricks and then stones". Although having been maintained and improved for several times, the gutter way still keeps its structure of brick walls and stone shields.
(4) Intact Draining System
The old urban district of Ganzhou city has a drainage system dating back to the Song Dynasty. It is composed of five parts: the Fushougou, reservoir, city walls, ditches and water windows, consisting an intact drainage system. The Fushougou is connected with the dozens of ponds inside the city, constituting a reservoir with large capacity. This system can regulate the flow quantity of rainstorm and reduce the flow of sewer system. Once the rainfall intensifies and the water in the Fushougou floods, the water will go into the ponds to be regulated. Twelve water windows are built at the outlet to prevent the river water in Zhang and Gong Rivers rises beyond the outlet and thus floods into the inner city. Water windows consist of inner gate at the inlet, ditch and outer gate at the outlet. Because of sharp gradient, water will form a strong flow after entering water windows, taking away dirt and other solids, opening the gate and flowing into the river. The rule underlying here is that when river

water is below water window, it opens windows with the force of sewer water and then drains out; when river water is above water windows, it closes windows with the force of river water in case of backward flow.

3. Augmented reality technology in Fushougou digital protection application

3.1 Digitization of Fushougou

The walls were demolished and the water windows were ruined during the Cultural Revolution in China (1967-1977). Then the pond and moat were filled after the Reform and Opening up. This paper is based on the platform of ArcGIS 10.1. According to the urban map of Ganzhou city in Tong Zhi dynasty and recorded Fushougou condition in combined with field research, we get digital reconstruction of Fushougou and draw the Ganzhou Fushougou digital map.See Figure 1 for details. This study attempts to restore the Song dynasty's Fushougou drainage system in Ganzhou city with the use of modern technology, which provides reference for today's drainage planning.[4]
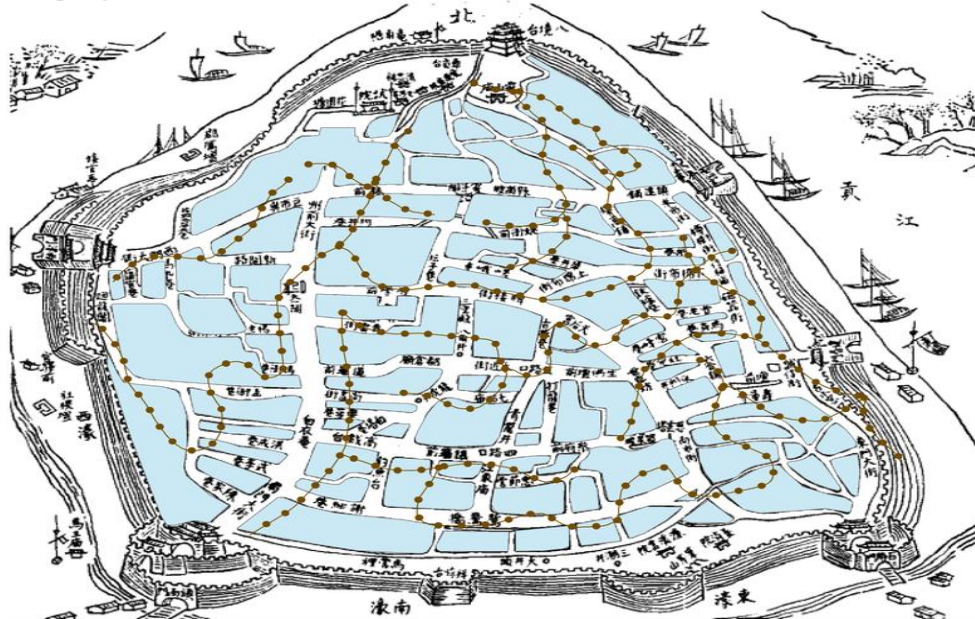

Figure 1. Study area

By using ArcGIS statistical analysis function and combining with historical data, we can obtain the statistical data of the Song dynasty's Fushougou drainage system in the old districts of Ganzhou. These data include watershed area(2.7 km^2),main channel length (12.78km),average cross section area of drainage ditch(1.4m^2),sub channel length(44.56km), average cross section area(0.032m^2),the number of the pond for water storage(79), capacity(110600 m^3),city wall length(8.126km),ditch and pond length (3.78km),average cross section area(18.67 m^2) and water windows' number(12). [5]

3.2 The Application of Augmented Reality Technology in the Digital Protection of Fushougou

The basic idea of AR Technology is to combine the 3D model of the virtual object generated by the computer with the real world.AR technology enables virtual and real images to become an organic whole and enhances the users' perception and understanding of the real world. In augmented reality system, the main task is to match the virtual objects around the users with the real world and display them in real time. Therefore, virtual reality alignment and display are the key technology in the Augmented Reality Technology.[6]

(1) System framework

We use ARToolKit to develop the augmented reality system of outdoor 3D pipe network. The video tracking database of ARToolKit can calculate the position and direction of the camera relative to the mark point in real time because it is based on computer vision. While it cannot be directly applied to the development of the outdoor system, this paper has improved the ARToolKit. The system frame diagram is shown in Figure 2.

(2) The main functions of the system

The system functions are as follows:

a) Virtual information enhancement

The users can see that the images generated by the computer are overlapped on the video image in reality.

b) Query of attribute information

Pop up the corresponding attribute information of the pipe ditch when a pipe ditch was selected.

c) Navigation

The two-dimensional digital map can be embedded into the system and switched at any time. Users can get real-time observation of their current location. The system can display the relevant information automatically according to the user's line of sight direction.

d) Spatial analysis

Three-dimensional pipe ditch can be carried out buffer analysis in order to determine the distance between the different types of pipe trench meets the safety requirements. Besides, tube bursting analysis and plug tube analysis of pipe network can also be carried on.[7]
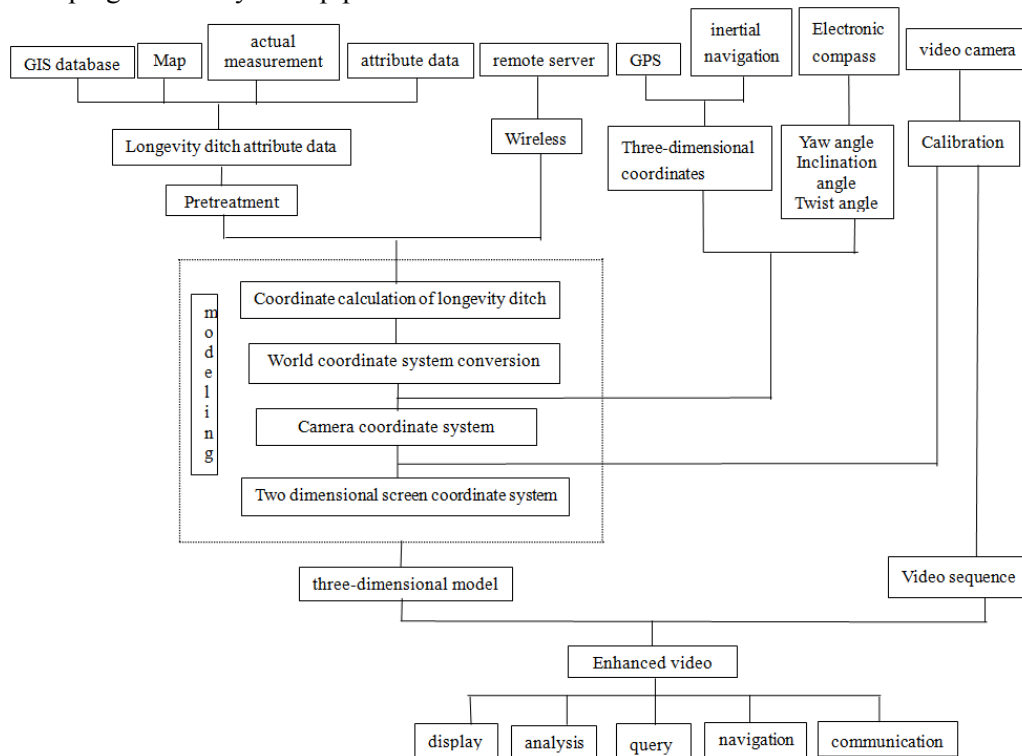

Figure 2. Based on ARToolKit 3D augmented reality system diagram

4. Drainage system of the Ganzhou old district in the Song dynasty and safety evaluation of storm-water system of the new district

4.1 Construction of index

The security of the system includes physical security and social security according to the theory of VPM (vulnerability of place model) model proposed by Cutter.[8] The reason why we focus on the physical security index is because this paper mainly analyzes the significance of the Song Dynasty drainage structures to the modern drainage system planning. On the basis of the safety evaluation index, this paper optimized the actual situation of the song drainage system in the old district of Ganzhou constructed the following 9 indexes as the safety evaluation index of the drainage system:

a) The rain mouth relative height(ha), b) Grid spacing(qa), c) Diameter of pipe(da), d) Unit of the catchment area of pipeline capacity(ra), e) Pipe slope(ia), f) The unit of catchment area building storage capacity(ga), g) Water outlet(Oa), h) Runoff coefficient(αa),i) Emergency facilities(ja).

4.2 The Determination of the index weight

Because each index is different in the security of the rain water system and has different importance, the weight of each evaluation index should be determined before the evaluation.According to the

composition and operation characteristics of the rainwater system, this study used the analytic hierarchy process (AHP) to determine the weight of each index (W).
see Table 1.

Table 1. Water drainage system safety evaluation index weight value

W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_8	W_9
0.1081	0.0624	0.1513	0.1697	0.1249	0.1009	0.0729	0.1649	0.0448

4.3 Security evaluation model
We use the Delphi method and direct calculation method to evaluate the performance of the above mentioned safety evaluation index in the drainage system. According to the weight value of safety evaluation index in the system, the mathematical model for calculating the safety of drainage system is established:[9]

$$V = haW_1 + qaW_2 + daW_3 + raW_4 + iaW_5 + gaW_6 + OaW_7 + \alpha aW_8 + jaW_9 \qquad (1)$$

The *V* in formula (1) represents security degree.

4.4 Determination of safety level
Data so in this study, we use the return period P and the safety degree V as the basic index, the water depth and the water time as the apparent index in view of the return period P which is the most direct indicator of urban storm water system .This article made urban rainwater safety rating scale (Table 2) based on the characteristics of China's city water-logging in recent years. The water depth, water time and the safety evaluation level of the rain water system may be obtained under different rainfall intensity according to the P value of the rainwater safety degree.[10] See Table 2.

Table 2. Safety assessment of urban storm water system

Safety degree V	Characterization description	system performance	Security level
[0.9,1.0]	P≥50 year,h≤0.10m,t＜0.5h,	very good	Very high
[0.7,0.9]	50＞P≥10 year,h≤0.15m,t＜1.0h	good	high
[0.5,0.7]	10＞P≥5 year,h≤0.20m,t＜1.5h	secondary	commonly
[0.3,0.5]	5＞P≥1year,h≤0.30m,t＜2h	difference	low
＜0.3	P＜1year,h＞0.30m,t≥2h	Poor	Very low

4.5 Drainage system of the Ganzhou old district in the Song dynasty and safety evaluation of storm-water system of the new district
According to the above mathematical model, we can calculate the token value of each index element and comprehensive safety evaluation value of drainage system of the old district and storm-water system of the new district. See Table 3

Table 3. Token value of drainage system of the Ganzhou old district in the Song dynasty and the new district

Serial number	index	weight	Drainage system of the Ganzhou old district in the Song dynasty		Zhangjiang new rainwater system	
			Token value	Comprehensive value	Token value	Comprehensive value
1	h.	0.1081	0.91	0.098	0.61	0.066
2	q.	0.0624	0.86	0.054	0.35	0.022
3	d.	0.1513	0.96	0.145	0.65	0.098

4	r.	0.1697	0.95	0.161	0.32	0.054
5	i.	0.1249	0.91	0.114	0.58	0.072
6	g.	0.1009	0.97	0.098	0.25	0.025
7	O.	0.0729	0.92	0.067	0.42	0.031
8	α.	0.1649	0.93	0.153	0.47	0.078
9	j.	0.0449	0.81	0.036	0.73	0.033
Total		1.0		0.927		0.479

By comprehensive evaluation, the safety degree of drainage system of the old district was 0.927 and the safety degree of the rainwater system in the new urban area was 0.479.The system performance of the old district is "very good" and the safety level is "very high", but the system performance of the Zhangjiang new urban rainwater system is "poor" and the level of safety is "low". We can get the interpretation of the mystery "Millennium no flood" of the old district and "the reality of frequent water-logging" of the new district.

5. The advice of rainwater system planning of the new district of Ganzhou

In order to ensure the safety of the rainwater system planning of the Zhangjiang new district, we need to optimize the existing planning from the following aspects based on the the digital results of Fushougou and safety assessment analysis:

(1) Increasing the design return period of drainage system of the new district of Ganzhou

At present,the new district of Zhangjiang often emerges water-logging phenomenon as drainage pipe network design return period of drainage system of the new district is one year.Therefore,the thesis proposed that the design return period should increase up to 30 years.

(2) Rational use of pipe materials

Reasonable selection of pipeline materials can ensure the effective long-term operation of the urban drainage system. Standard reinforced concrete structure was widely used in pipes of rainwater drainage system in Zhangjiang district. Without preservative treatment, the endurance of the reinforced concrete structure is about 50 years old, and culvert pipes with such structure can rarely be replaced. While the use of masonry structure is extensively available in drainage pipeline in Fushougou, the structure owns its merits: it is easy to repair and its economic endurance is longer than that of reinforced concrete structure. As a result we recommend that masonry structure should be applied to the rainwater system in Zhangjiang district of Ganzhou city.

(3) The determination the reasonable section form

At present, the main water pipe diameter is basically above 1000mm in the new district of Ganzhou, while the branch pipe diameter is 150-400mm.It is too small to collect and discharge.Therefore, this paper suggests that we should increase the diameter of the branch pipe.

(4) Rational use of paving materials

In the construction process of the new district of Ganzhou, an army of concrete structures covered the ground, which increase the pressure of urban drainage system by reducing the ground water permeability and increasing the urban rainwater runoff .

(5) Zoning plan according to terrain

The new district of Ganzhou which has 1833.27 hectares set up six water drainage area to drain away water, but merely four partitions were carried out at the old district which only has 2.7 square kilometers. Obviously the setting number of the water drainage area of the new district is too small. So, the new district rainwater system planning should be based on the actual situation of the gap between high and low terrain area and subdivises drainage area scientifically and reasonably.

(6) Increasing the outlet

The new district of Ganzhou which has 1833.27 hectares set up six water drainage area to drain away The catchment area of the new district is 1800 hectares and the number of outlet is 4 at existing planning. While the old district is only 2.7 square kilometers, which has built 12 water outlet. So it is necessary to greatly increase the outlet to reduce the emission intensity of the existing water outlet.

(7) Strengthening the combination of water storage and drainage

Strengthening the combination of urban rainwater storage and drainage can enhance the ability of city water-logging. At present, the new district has built 1002 acres of Urban Central Ecological Park, of which the lake area is more than 600 acres. The lake is connected with Zhangjiang River through a 2 kilometers water Creek. The lake can play a role in flood storage and flood drainage by saving a lot of rainfalls and discharged into the Zhangjiang River through the river system. Reference Fushougou design concept, this paper aims to form ecological system which combines water storage and drainage by proposing a substantial increasement for the storage pond and connecting the pond to the urban underground rainwater system under construction data source.

Acknowledgements

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