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SAMOS Switching Antenna Monitoring System Applied on Tailings Reservoir On-Line Monitoring Project

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Abstract:

Tailings reservoir has become the 19^{th} state-level danger source of China government, which could cause permanent damage to the local environment and kill hundreds of thousands of people if the dam earthen made collapse.

SAMOS, Switching Antenna Monitoring System, is derived from GNSS, Global Navigation Satellite System (GPS, GLONASS and COMPASS/BEIDOI), which enables a single GNSS receiver to monitor more than just one monitoring point according to the specified accuracy requirement. This method helps to save lots of GNSS receivers while always keeping the high performance of accuracy and online monitoring features.

This paper introduces how Beijing iSpatial experts deployed that technology for a tailings reservoir dam online monitoring application and the practical performances of SAMOS and the software in a slow-deformation project.

Key Words: Tailings reservoir, online monitoring, SAMOS, Switching Antenna, GNSS monitoring, software, Kalman Filtering

1 ONLINE MONITORING SYSTEM FOR TAILINGS RESERVOIR

Tailings reservoir is a large pool which is usually built at the foot of mountain with long earthen dam to collect the waste material of metal ore dressing industry. There are more than 7 thousand normal tailings reservoirs, and nearly 5 thousand abnormal tailings reservoirs still running across the whole China.

This huge danger source has already been recognized and paid great attention by the China State Administration of Work Safety(SAWS) since 2006. Online monitoring system became an important technical support and handle for detailed administration measures It took years of technical investigations and pilot project, such 9 GPS for 700 meters Zhejiang Litie tailing reservoir and 44 GPS for 4.5km earth dam of Anhui MaSteel tailing reservoir, to finally qualify the concept.

GNSS monitoring system became then the indispensable online monitoring method to check the displacement of the earthen dam because of three important features of such system, all-weather supported, continuously operational 24/7 and high accuracy in displacement monitoring.

But due to the high cost of the high performance GNSS receiver and communication system to support huge amount of GNSS raw data transmission, GNSS online monitoring system is still nowadays an expensive technology considering the equipment for 12 thousand tailings reservoir dams. In fact the huge cost of the traditional GNSS installation is preventing the authority to invest and fulfil their obligations.

2 SAMOS – THE PARADIGM SHIFT IN GNSS MONITORING

SAMOS is an abbreviation of “Switching Antenna Monitoring System”, a professional GNSS monitoring system with innovative GNSS signal processing technology, which is specifically designed for high performance low cost GNSS monitoring solution, such as Hydro Power Dam, landslide, bridge, subsidence areas and high-rise building GNSS monitoring application to only cite a few.

In tailings reservoir dam monitoring case, the continuous processed observation represents every day a 3D displacement value for each monitoring point since the deformation of earthen dam is rather slow motion with total deformation range that can reach few centimetres.

Based on such application requirement, SAMOS offers a solution where there is no need to setup at every monitoring point a full pair of GNSS receiver and antenna but only one antenna per point of interest connected to a switch where only one GNSS receiver is attached. Using a timer, the switch can connect the GNSS receiver to a particular antenna and log the corresponding observations. When the quantity of observation has been reached, the switch disconnects the antenna from the GNSS receiver and automatically establishes the connection to another antenna. After a complete cycle, the switch is re-addressing again the entire antenna network. This solution can greatly mitigate the cost of the installation by reducing the number of high performance GNSS receivers.

3 THE ARCHITECTURE OF SAMOS

SAMOS system is selected for monitoring projects where a large amount of GNSS receivers is needed. The reference station remains mandatory but can easily doubled as the budget allows that.

SAMOS hardware system is designed with a number of GNSS antennas, a GNSS receiver connected to the switch, the switching hardware, the coaxial antenna cabling and at least one GNSS receiver base station. In that architecture, several switches can be placed for addressing specific group of GNSS antennas in a common project. The system is very scalable and modular. If monitoring points cannot fit with cabling connection, we can still setup the GNSS receiver and antenna pair like traditionally.

Fig 1: an example of SAMOS architecture

The length of the coaxial antenna cable can be extended up to 500 meters with special GNSS signal amplifier placed every 90 meters adding 29db signal gain each section.

GNSS signal is collected by GNSS receiver through the antenna switch from each antenna periodically under control of antenna switch timing system.

The raw GNSS data can be logged onto the SD card inside the GNSS receiver attached to the switching hardware in a survey campaign mode (for one or two days) and data post processing will be handled manually afterwards. The other possibility is the capacity of the system to transmit directly to the central monitoring software the data using any communication possibilities. IS-MonNet, runs on a PC server and access the data through serial com port or Ethernet LAN port the data to perform real-time or post processing automatically online with several parameters that the user will control.

Fig2: GNSS antenna switch

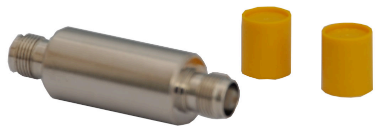


Fig 3: GNSS signal amplifier

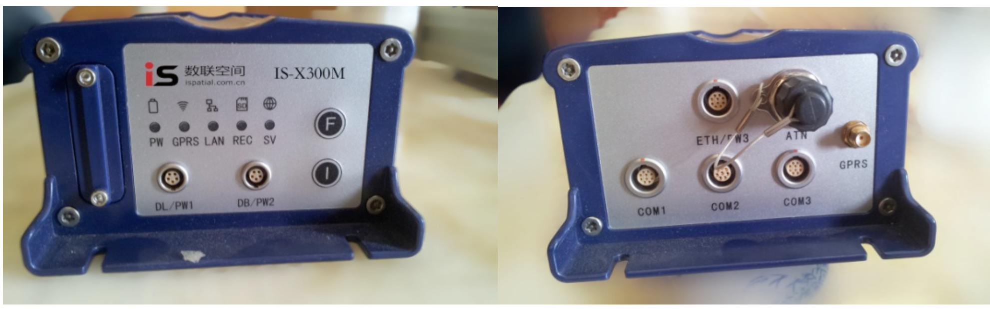


Fig 4: IS-X300M GNSS receiver

4 GNSS MONITORING SOFTWARE

SAMOS MonNet software is advanced GNSS kinematic positioning software developed by Shanghai iSpatial Co., Ltd., processing short to medium baseline length within millimetre level of accuracy and coping with switching antenna scheme.

The software uses epoch data to distinguish which data is from which antenna to organise the raw data's transmitted by the switch.

The ASW (average sliding window) method is applied.

The key for achieving high accuracy performances is to fix the ambiguities and for carrier-based relative positioning between a rover **r** and a base-station **b**, the following double-differencing measurement equations for **carrier phase Φ** and **pseudo range P** are used.

$$\phi_{rb}^{ij} = \rho_{rb}^{ij} + \lambda(B_{rb}^{i} - B_{rb}^{j}) + \varepsilon_{\phi} \qquad (1)$$

$$P_{rb}^{ij} = \rho_{rb}^{ij} + \varepsilon_{P} \qquad (2)$$

Where $()^{ij}$ and $()_{rb}$ represent a single-difference between satellites and between receivers, respectively, ρ is the geometric range, λ is the carrier wave length and ε is the measurement error of the observables. B_{rb}^{i} is the single-difference of carrier phase ambiguities in cycle.

We settle the unknown vector as:

$$x = (r_r^{\ T}, B_{L1}^{\ T}, B_{L2}^{\ T})^T \qquad (3)$$

$$B_{Lj} = (B_{rb,Lj}^{1}, B_{rb,Lj}^{2}, \ldots, B_{rb,Lj}^{m})^T$$

Where r_r is the antenna position expressed in the ECEF frame.

The measurement vector y_k at epoch t_k is:

$$y_k = (\phi_{L1}^T, \phi_{L2}^T, P_{L1}^T, P_{L2}^T)^T \qquad (4)$$

By using standard EKF (extended Kalman filter), the state vector **x** and its covariance matrix **P** can be estimated by:

$$\begin{aligned} \hat{x}_k(+) &= \hat{x}_k(-) + K_k(y_k - h(\hat{x}_k(-))) \\ P_k(+) &= (I - K_k H(\hat{x}_k(-)))P_k(-) \\ K_k &= P_k(-)H(\hat{x}_k(-))(H(\hat{x}_k(-))P_k(-)H(\hat{x}_k(-))^T + R_k)^{-1} \end{aligned} \qquad (5)$$

Where $h(x)$, $H(x)$ and R_k are the measurements vector, the matrix of partial derivatives and the covariance matrix of measurement errors, respectively.

For the standard deviation σ of carrier phase or pseudo range error, SAMOS employs an elevation-dependent model with user-defined parameters:

$$P = 2(a \cdot a + b \cdot b / \sin(e) / \sin(e) + c \cdot c \cdot bl) + C \cdot sclk \cdot dt \qquad (6)$$

Where the elevation angle of satellite is e, bl is the base-line length, C is the speed of light, dt is the time period. $a, b, c, sclk$ are user defined parameters.

Time update of the state vector and its covariance matrix from epoch t_k to t_{k+1} by EKF is expressed as:

$$\begin{aligned} \hat{x}_{k+1}(-) &= F_k^{k+1} \hat{x}_k(+) \\ P_{k+1}(-) &= F_k^{k+1} P_k(+) F_k^{k+1^T} + Q_k^{k+1} \end{aligned} \qquad (7)$$

Where F is the transition matrix and Q is the system noise covariance matrix.

By solving the EKF formulas, the estimated rover antenna position and the single-differenced carrier-phase ambiguities are obtained. Then the float carrier-phase ambiguities should be resolved into integer values in order to improve accuracy and convergence time. The well-known efficient strategy LAMBDA and its extension MLAMBDA are used by the software. After the validation by the simple ratio-test, the fixed solution of the rover antenna position is provided.

5 THE YUANPING TAILINGS RESERVOIR IN SHANXI PROVINCE

SAMOS technologies has been used to connect 9 GNSS monitoring points as well as 9 Osmometer (An Osmometer is a device for measuring the osmotic strength of a solution, colloid, or compound) along a 2000 meters earthen dam length, which belongs to “Shanxi Aluminum Co. ltd, China Power Investment Corporation(CPI)”, in order to monitor both the displacement of dam and the water level inside the dam.

Z0 is the base point of the system and Z1 up to Z9 are monitoring points. Z0 and Z1 use common single antenna paired with one GNSS receiver. Z2 up to Z9 points are controlled by two data collection cabinet, with 4 GNSS points and osmometer devices for each. The data are transferred by RS232 or RS485 serial interface and then mapped into Ethernet signal to be transferred via optical fibre cables up to the central monitoring room.

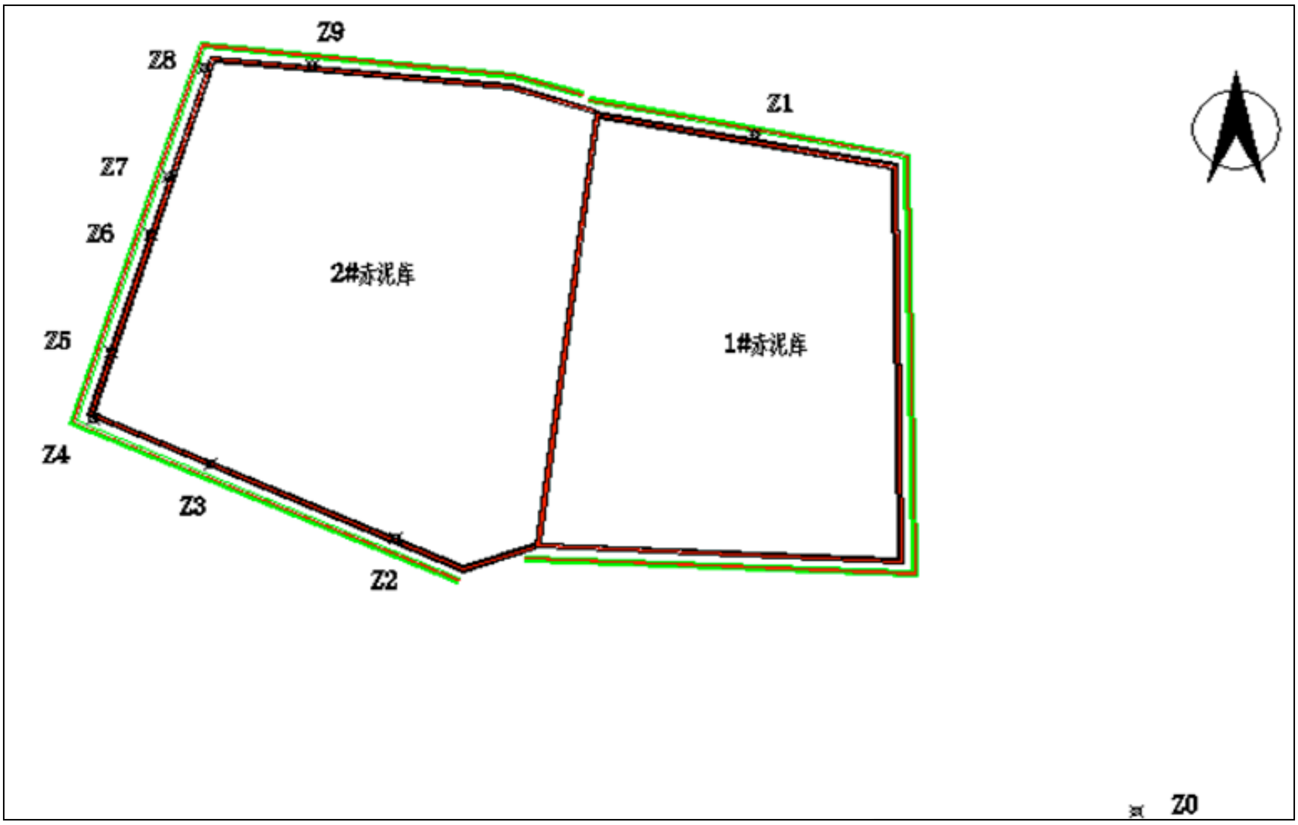
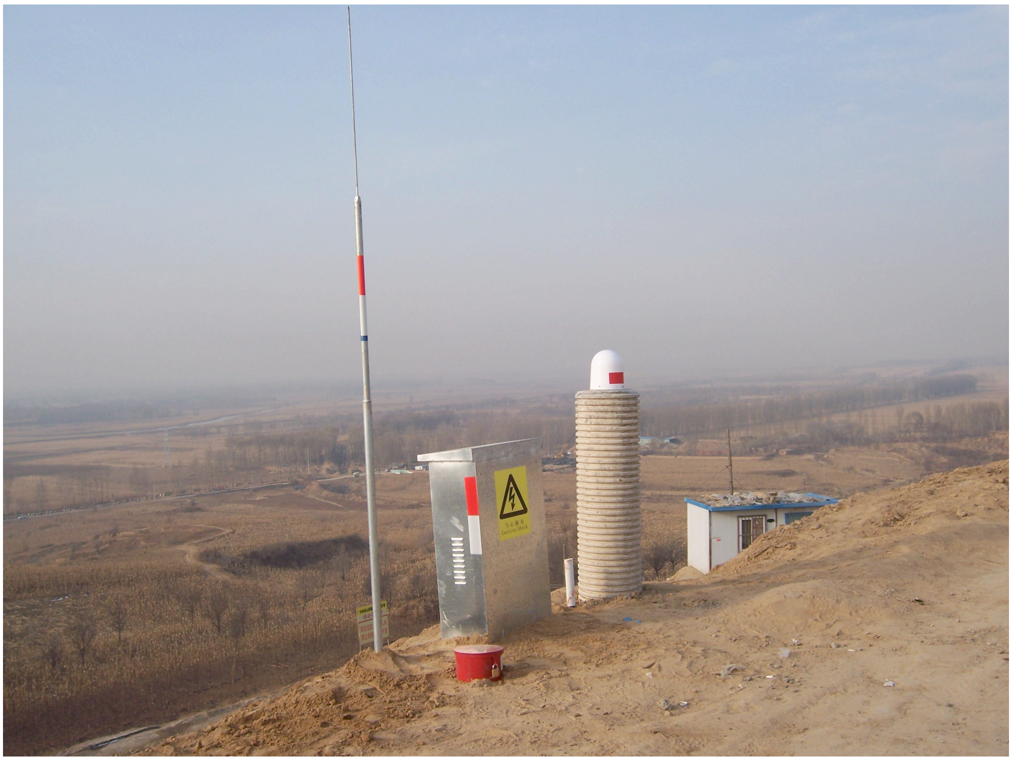


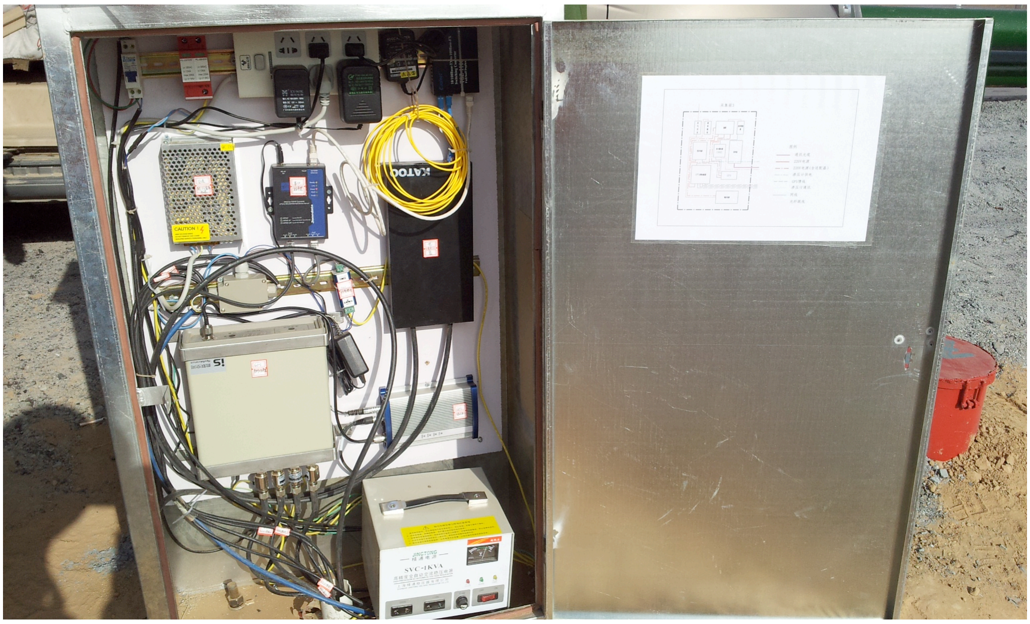
Fig 5: Overview of the point deployment

Picture 1: A view of this 2000 meter reservoir dam

Picture 2: Base point and the central monitoring room behind



Picture 3: A typical switching antenna monitoring point with data collection cabinet and osmometer(red cylinder is the cover of osmometer pipe)

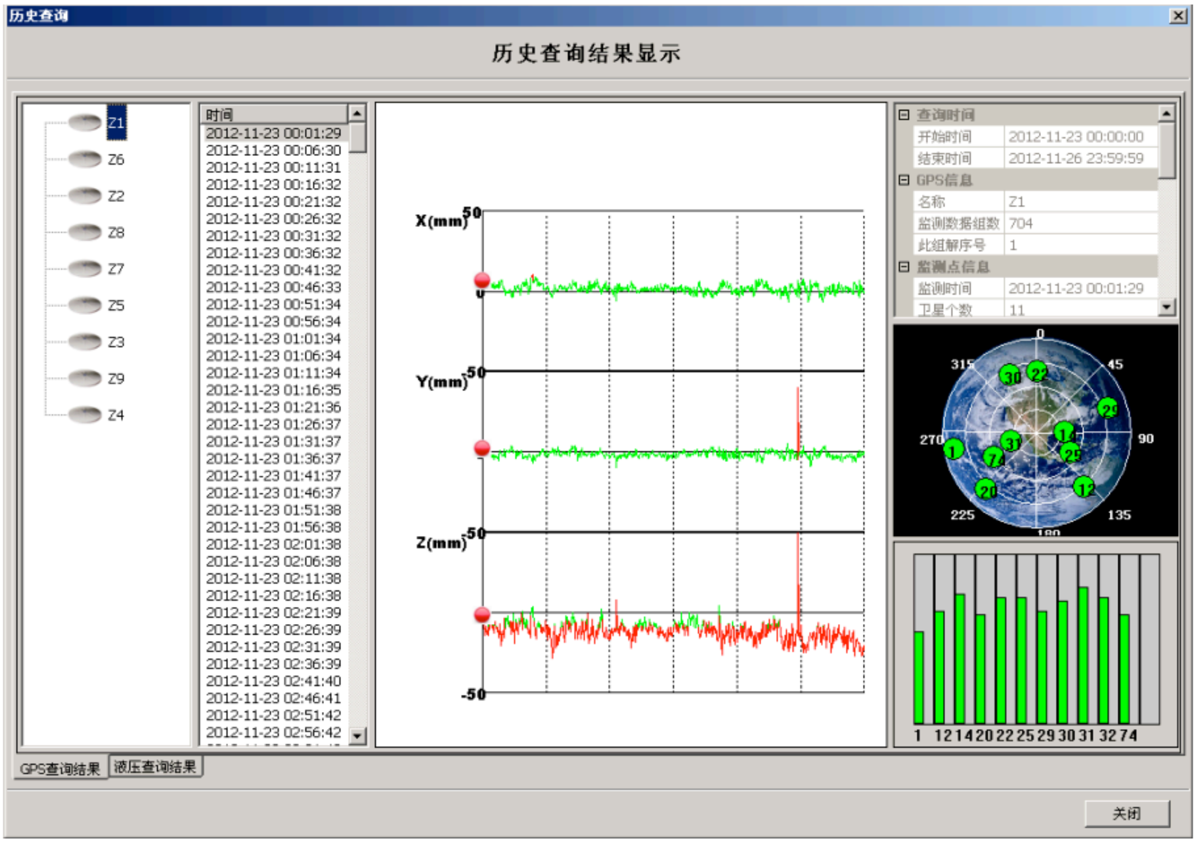


Picture 4: Data collection cabinet with antenna switch and all data communication, power supply, lighting protecting devices

Picture 5: Central monitoring room

	点名	属性	GPS类型	通讯方式	通讯参数	X	Y	Z	对应基站
1	Z1	流动站	Hemisphere	TCP客户端	.1.231:10001	1930059.773	4590193.831	3973669.524	Z0
2	Z2	流动站	Hemisphere	TCP客户端	.1.233:10001	1929774.540	4590694.056	3973228.218	Z0
3	Z3	流动站	Hemisphere	TCP客户端	.1.233:10001	1929536.126	4590725.453	3973307.268	Z0
4	Z4	流动站	Hemisphere	TCP客户端	.1.233:10001	1929383.693	4590745.576	3973356.933	Z0
5	Z5	流动站	Hemisphere	TCP客户端	.1.233:10001	1929382.235	4590681.456	3973431.589	Z0
6	Z6	流动站	Hemisphere	TCP客户端	.1.232:10001	1929388.665	4590569.125	3973558.057	Z0
7	Z7	流动站	Hemisphere	TCP客户端	.1.232:10001	1929391.155	4590514.680	3973619.082	Z0
8	Z8	流动站	Hemisphere	TCP客户端	.1.232:10001	1929395.770	4590409.000	3973737.790	Z0

Picture 6: Sensor management GUI



Picture 7: History data of Z1 monitoring point

6 CONCLUSIONS

SAMOS technology and software have been designed and developed to meet the expectations of managers and engineers in charge of maintaining engineering infrastructures situated in risky environments with the need to have a full picture of the movements to feed deformation models and take appropriated decision accordingly to the feedback of the system.

The “Switching Antenna Monitoring System” namely SAMOS has been developed with the highest quality of technology and know-how and by specialists in GNSS hardware and firmware technology. The software that is part of the complete system has proven to deliver on a 24/7 rate the best linear unbiased estimators using advanced filtering techniques on mm level of accuracy.

Without any comprise on accuracy, the switching antenna system has demonstrated on many other projects such hydro power dams, landslides and subsidence areas that monitoring solutions can and must be affordable when respect to human live and environment are the concern.

The authors have no doubt that more and more engineers involved or confronted to permanent monitoring of their infrastructures will consider SAMOS as the most appropriated solution to get high accuracy results at an affordable budget level.

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