An Innovative Concept to Manage GPS Reference Stations Network and RTK Data Distribution Globally

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Key words: GPS reference station network, Internet, Spider, data management, integrity monitoring, RTK, auto alarming, remote network monitoring

SUMMARY

National, state, regional and commercial organizations throughout the world now recognize the advantages and benefits of Continuously Operating GPS Reference Stations Network (CORS) for the replacement or the complement of conventional geodetic control network, providing homogeneous high-accuracy GPS data to users. The new development of telecommunication technologies and globalization of the Internet over the last decade has ushered a new era in data communications that few of us could have anticipated in the early years. A variety of languages and protocols have been developed to support the evolving communications infrastructure. Thus, the net result has been a convergence of the technologies underlying the Internet and GPS. In this paper, we describe an innovative approach of a new developed software solution – Spider and a web-based GPS data service interface which were introduced on the market early April 2003 for efficiently managing the entire operation of a GPS reference station network including remote GPS receivers connection, data collection and management, integrity monitoring, verification and auto alarming, remote network monitoring and real-time corrections distribution to users anywhere in the world by applying various telecommunication and information technologies available on the market.

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1. INTRODUCTION

National, state, regional and commercial organizations throughout the world now recognize the advantages and benefits of Continuously Operating GPS Reference Stations Network (CORS) for the replacement or the complement of conventional geodetic control Network. These infrastructures can be set up at convenient sites where needed to support all GPS user groups by providing them homogeneous, high-accuracy results over wide areas and eliminating the need for setting up temporary field reference station receivers. Thus, real-time GPS survey crews need only one rover receiver in the field for achieving high accuracy real-time positioning.

In order to further increase the efficiency and flexibility in system management, quality control and data distribution of a GPS reference station network, a research project has been initiated by Leica Geosystems AG. An innovative solution has resulted and was introduced on the market early April 2003. This solution deals with GPS data collection, verification, integrity monitoring, archives and distribution from GPS reference stations to end user groups by applying various telecommunication and information technologies available on the market.

Besides, web-based applications were also developed to gather and manage GPS data generating from different regional GPS reference stations and then provide different levels of data services to their users including GPS data files publishing, on-line GPS data-processing, remote system monitoring and real-time data stream broadcasting over the Internet.

This new approach fits really well the worldwide market needs and makes system administrators more efficient in controlling and monitoring these worldwide GPS infrastructures as well as their real-time data distribution strategies and charging mechanism.

2. DATA COMMUNICATION & REMOTE RECEIVER CONNECTION

As flexible and reliable communication is critical for GPS reference stations and networks, the new developed software solution - Spider can manage the operation of multiple GPS receivers and other external complementary devices such as meteorology sensors and tilt sensors located in different regions simultaneously via various communication technologies depending on the requirements and the available infrastructure:

- The GPS receivers can be connected to the Spider server by direct serial links (RS232). It is the most simple connection method and operating in the lowest cost. However, it is only suitable for linking GPS reference station located very closely to the computer

facility and usually be implemented in single-base GPS reference station application.

- The communication between the Spider server and the GPS reference station receivers can also be established by dial-up communications using the public switched telephone network (PSTN) and also wireless cellular network like GSM and CDMA. Besides, wireless radio can be another option for that application

There is no more need to have a computer in any GPS reference station site and the GPS receivers can be directly connected to a fax modem or a cellular phone with GSM, CDMA service.

Spider server is able to dial any pre-defined telephone numbers and establishes the connection to each GPS receiver simultaneously for:

- Remote system parameters and operations setting,
- Inspection of GPS receivers' status such as status of satellite tracking, data logging, real-time data distribution, etc
- Automatic data forwarding and verification
- Data downloading for centralized analysis and
- Data publishing on the Internet.

A number of communication devices have been tested including US Robotics 56K modem, Wavecom WMOD2 GSM modem and also Siemens M20 and TC35 GSM terminals. They are all being able to work in duplex mode and achieved stable performance.

This communication solution is also suitable for connecting multiple GPS receivers from different areas and not expensive in term of hardware, installation and running cost. However, the concurrent communication fee would be costly if a Spider server is connecting to all GPS reference stations continuously and especially for those reference stations locating abroad. Moreover, wireless communication network are likely to be interfered and signal is weakened in poor weather condition like heavy rainstorm and lightning.

Thus, the Spider solution also provides communication possibilities based on the Internet.

A Spider server is able to connect multiple GPS reference station receivers through local or wide area networks (LAN or WAN) using TCP/IP protocol. It is only required to have a permanent communication line established with a fix static IP address at each site such as a data leased line (e.g. 64K or 128K leased line), high-speed data line (e.g. T1 or E1 line) and also a broadband Internet connection. A Spider server can therefore connect individual GPS receiver in a network via a dedicated IP address and port number. The data communication flow is set on a higher speed and becomes more stable.

The monthly communication fee should be usually fixed and the network operator can maintain an open permanent connection between the Spider server and each GPS reference station site without paying extra cost. It is the best way for managing a long-term large area

or even a global GPS reference station network due to its high efficiency in connection speed and stability in a relatively low cost.

In addition, for GPS receivers having only serial RS232 interface for remote connection, a ComServer and a router for converting RS232 signal from the GPS receiver to IP protocol for transmitting to the Spider Server in the central facility need to be installed. There are many various devices available on the market and user can select the suitable one according to the number of port necessary to be map to a given IP address.

Readers please refer to the diagram 1 for the overall data communication and GPS receiver connection strategy in this solution.

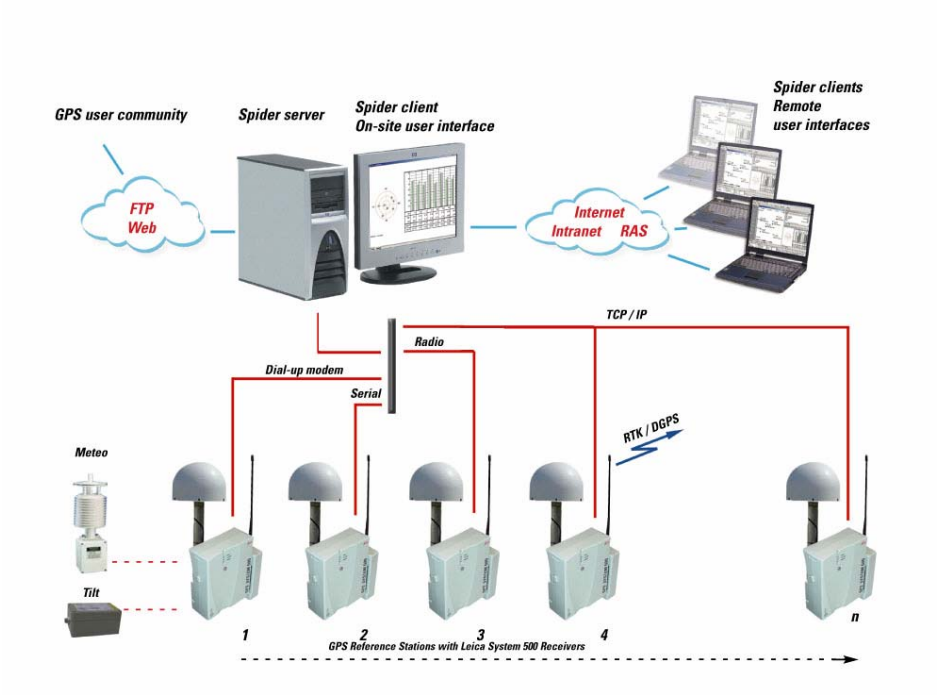

Diagram 1: Data communication and GPS receiver connection strategy

3. DATA MANAGEMENT

Spider makes use of Microsoft SQL Database Server Desktop Engine to manage the configuration, operational parameters settings of GPS receivers and other external devices in the stations. Multiple software modules and components in the system can then access the data from the database simultaneously and this open architecture allows the user customization and flexibility for future expansion in the network.

Moreover, the Spider server and the Microsoft SQL Database run automatically and continuously as a Windows™ service, so the software modules and database can be automatically launched once the computer server is started and the whole system can run in normal operating condition according to predefined operational parameters even if Windows™ is not logged or the Spider software interface is closed. In case of a total power failure, the software will restart as the computer reboots in order to provide full reliability.

At the start of the system, the network operator will define the basic GPS station parameters such as station name, coordinates, GPS receiver & antenna model, antenna height offset, data logging rate of GPS receiver as well as other external sensors, data communication ports, automatic data polling intervals and the storage path in the computer server.

The Spider server will automatically be linked to each GPS reference station during a predefined interval (e.g. every 10 minutes, 30 minutes, 1 hour, etc) via different communication strategies as previously discussed and will download the data files stored in the memory of GPS reference station receivers.

Besides, the Spider server will then convert the raw data source to produce various data files in different data rates, data file lengths and data formats such as Leica MDB proprietary format, RINEX format and GPS Hatanaka compressed format to finally store into different user assigned locations in the computer server. In case of having GPS reference station receivers and Spider server connected by PSTN or wireless dial-up communication, the Spider server can be automatically disconnected the communication line once the data files are completely downloaded and thus save the communication costs. Furthermore, if the communication link is not stable and fails to complete the data downloading, the software will automatically re-download that missing data files in the next downloading interval.

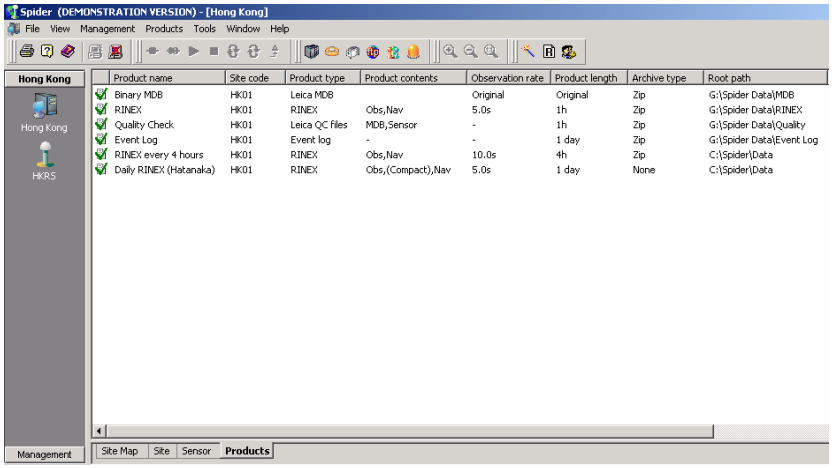

Diagram 2: The software interface for generating different types of data file in different formats

In addition, the network operator is able to define a FTP server or a Web server address, so Spider server will transmit raw data, RINEX files, and other associated files such as quality checking files and event log files immediately when available or at specified time intervals to one or multiple FTP or Web servers for an easy access by the GPS users community. Different files can be pushed to different FTP servers. The users can share and distribute these data files by the Internet.

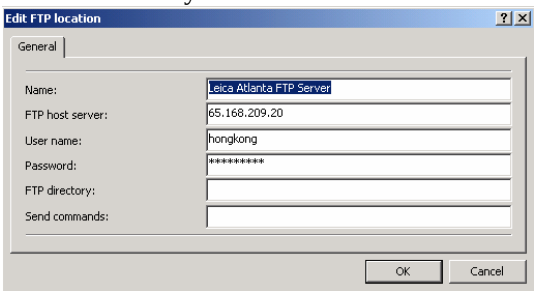

Diagram 3: FTP data forwarding interface

4. SYSTEM MANAGEMENT CONSOLE

The console management control of the whole GPS reference station network is illustrated by the diagram 4.

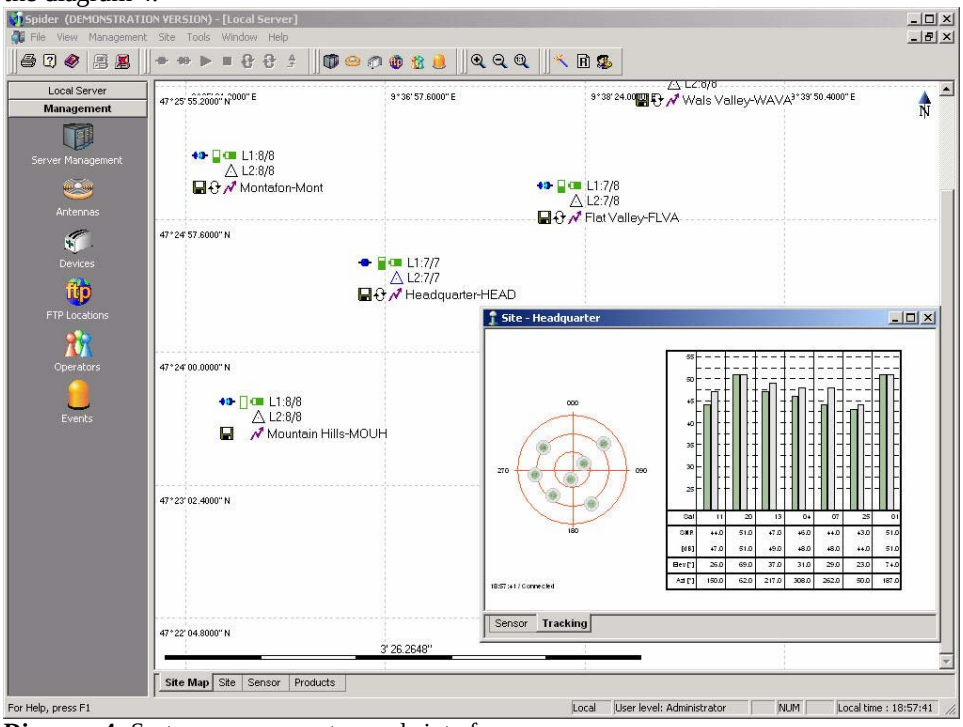

Diagram 4: System management console interface

The network operator has a full operational status view of each GPS reference station of the whole network through the system management console interface. It displays the entire network operation status including connection status, receiver operation status such as power level and memory status of the GPS receiver, data logging and real-time data broadcasting status, satellite tracking status such as the number of tracking satellites on L1 and L2, signal-to-noise ratio, azimuth and elevation angles of each satellite; and external meteorology and tilt sensor data status.

In case of abnormal behaviors happening in GPS reference station such as communication failure, receiver's power low, low memory space, data logging failure or RTK data output failure, then the color of the corresponding functions icons will change and error messages will be displayed in order to clearly notify the network operator.

5. INTEGRITY MONITORING & ERROR REPORTING MECHANISM

A Spider server produces quality check report file automatically every time it completes the GPS raw data files downloading and the quality control procedure checks the completeness and consistency of all data downloaded, monitors the various communication links and the operation status of the entire system. These quality check report files can also be automatically forwarded to another server or a web platform for any operators' inspection.

In order to be more efficient and faster response in tackling system and data quality problems, the network operator can define a range of inspection criteria and tolerance values. The diagram 5 shows the checking criteria and tolerance values defined as:

- *GPS receiver's related issues***:**
  - Receiver's power voltage, free memory space and internal temperature
  - Receiver start up failure
  - Receiver data logging status
  - Receiver data downloading status

- *Communication link related issues:*
  - Communication between Spider server and GPS receivers
  - Upload / Download status
  - FTP data forwarding status
  - Event and alarm sending status

- *Data quality related issues:*
  - Number of actual observation epoch logging on L1 and L2
  - Actual satellites logging status
  - Code and phase observation status on L1 and L2
  - Loss of lock on L1 and L2
  - Observation data gap
  - Ephemeris summary, etc

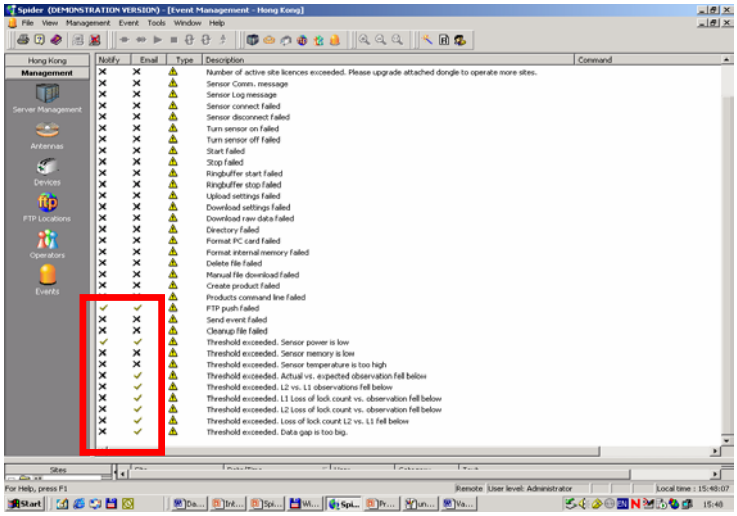

Diagram 5: Criteria for issuing warning messages

In case of any abnormal behavior happening in the GPS data and also in the GPS receiver operations that exceed the predefined tolerance values, the Spider server will send out an alarm message describing the problem via emails and will display messages on screen. It also keeps those alarm messages into a daily event log file for history.

In some countries, there is also an e-mail's service to pager forwarding, so this alarm e-mail message can also be shown on the operators' pager for immediate problem solving. Moreover, the network operator can make use of "Command line processing" advanced feature to launch automatically another application script which will launch for instance a SMS messaging program.

In addition, this command line processing feature can also be used for performing an integrity monitoring by running other applications such the Teqc +QC developed by UNAVCO. The new release of the Leica processing software SKI-Pro can also be invoked automatically for computing the GPS baselines in a network adjustment. By this way a comparison can be made immediately against the known values of the baselines coordinates for a continuously and automatically station stability checking which is definitively mandatory for such services.

6. REMOTE CONTROL & SECURITY

The software is designed in a modern Server / Client architecture and provides a remote GUI client interface that can be installed on any remote computer. Therefore, using Internet, TCP/IP networks or dial-up connections, the network operator with this GUI client interface can connect from anywhere to a Spider server which has a fixed IP address assigned. The network operator can remotely monitor the entire GPS network performances and also configure and control a Spider server anywhere in the world which control all connected

receivers and external sensors. Users without proper administrator privileges can also have a view on the network operations.

When there are multiple remote clients logging into the same Spider server, any of them with the proper administrator's privileges can modify and update the configuration database in the Spider server and any updates will be synchronized for every remote computer connected. The diagram 1 illustrates that mechanism.

The software has in summary two different levels of user access right – Administrators and Viewers. The network operators can define every remote client's level of accessing privileges by the user management interface.

As an Administrator, the client logged has full control over the Spider server and the GPS receivers. He can start and stop the various operations, create and change the configurations, set parameters and modes, etc. This access right is usually only granted to network supervisors and operators. However, if the client has only the Viewer privileges, he can only inspect the system and receiver status but not control the operation of the software and configuration parameters setting.

7. REAL-TIME DATA BROADCASTING

The software supports both RTK and DGPS data broadcasting on each networked GPS reference station to be used by RTK and GIS GPS rover users. The real-time data stream can be broadcasted in various formats such as the compacted Leica proprietary, RTCM v2.x, CMR and CMR+ through different communication solutions including radio, GSM, ISDN and PSTN network and also Internet. The real-time data can be either transmitted directly from the GPS reference stations in the field or it can be routed back and centralized in the Spider server to be re-distributed to the GPS rover users. Other sophisticated data distribution facilities such as Access Servers, web application services and charging mechanisms can complete the solution.

A list of common use communication devices including various brands of radio modems, GSM terminals and fax modems are already defined in the device interface and the network operator can select the suitable one and configure two streams of real-time data of any networked reference station in different formats and output rates via different communication devices simultaneously. This is a flexible solution to meet different users' needs and area coverage. It can also work in time-slicing mode for different real-time data streams broadcasting of different GPS reference stations in different divided time intervals by using the same radio frequency channel without signal interference or jamming problem.

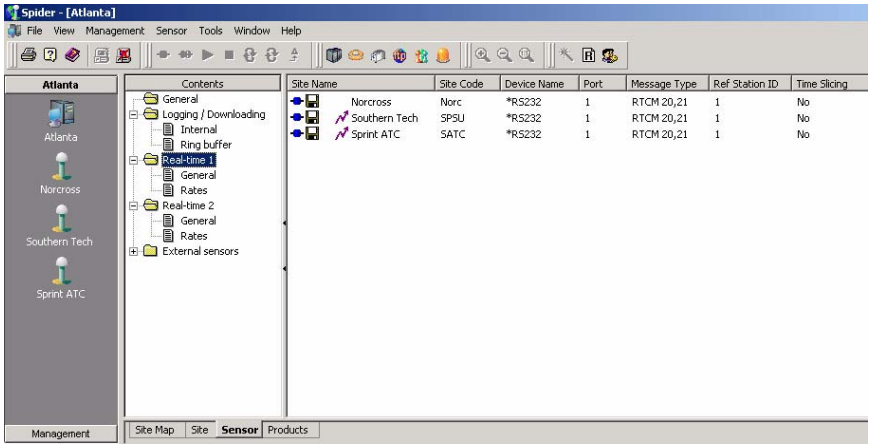

Diagram 6: Real-time data setting interface

On the other hand, a solution of distributing real-time data to multiple users located in a wide area or even worldwide has been developed over IP and the multiplexing of the streamed data through a centralized web server is another service example, which enables simultaneous rover clients to benefit from these corrections directly through the use of wireless Internet connection in the field by using CDMA, GPRS technologies and future 3G-communication network by using a daisy-chain approach where an internet-enable relay site is used to retransmit the corrections by radio to the local area is also perfectly feasible. This technique decreases the reliance on expensive line-of-sight radios to broadcast the data over large areas. In support of these new applications, the RTCM committee is now working on a new standard based of the RTCM message transmission through the Internet (NTRIP).

To broadcast any real-time data over the Internet, the data stream from each GPS reference station needs to be routed to the Spider server and converted and forwarded to a unique static IP address and port number of a web server which has a permanent Internet connection. The real-time data stream is continuously available on Internet.

Multiple rover users can connected to this Internet Web server by using a Pocket PC with a CDMA or GPRS PCMCIA modem, and then access the real-time data stream from the specific IP address simultaneously. People can receive real time data corrections from any GPS reference station located in the world for real-time positioning where the wireless CDMA or GPRS signals are available without any geographical distance restriction on corrections transmission. The success of achieving high precision real-time positioning over long baseline length is however still dependent on the resolving integer ambiguity algorithms implemented on the GPS rover receivers.

According to the result of a RTK field test done in Beijing PRC in August 2003 by using the Leica SR530 GPS receiver, which accessed real-time data stream from two GPS reference stations in Beijing via Internet, the horizontal accuracy for a short baseline of around 10 km was on the 2 cm level (1 sigma); and for the long baseline test of around 55 km was on the 4

Comment [M1]: HI Vincent Beijing – Hong Kong is more than 55 km ???

cm level (1 sigma). The RTK initialization time was successfully achieved in approximately 10 seconds for the shortest baseline and approximately 1 minute for the long baseline.

In addition, we tried to fix the coordinates of a point located in Beijing by receiving the RTK corrections from the Hong Kong GPS reference station via Internet - the GPS baseline was nearly 2000 km - and a 50 cm horizontal precision was achieved well suitable for a DGPS position.

It has been proved that Internet is an efficient solution for transmitting real-time data stream from one point to multiple rovers simultaneously and the cost of receiving the corrections on the rover side is the lowest: This is mainly due to the data communication charge on CDMA or GPRS network based on the volume of data packets received but not on the connection time duration. The GPS corrections data stream size being very small, the RTK/DGPS positioning by receiving corrections via Internet is then the most economical solution.

Diagram 7: RTK position fixed over Internet for 55740m baseline

8. WEB-BASED GPS DATA SERVICES

In this research project, Leica Geosystems AG has also developed a worldwide-centralized web-based server and a data archiving center, which use a set of GPS reference stations located in each Leica worldwide representative. This is part of the “Leica Nets the World” initiative.

The objective of this initiative is to take advantage of our worldwide representation to create a sparse network of GPS reference stations linked together by the Internet and then provide different kinds of data services to the worldwide GPS users through various communication medias. This initiative will also help Leica Geosystems AG to gain a much better understanding of the emerging communication technologies and will enhance the expertise we have to manage large-scale networks.

New GPS data online applications such a Web based Coordinate Generator and a data service charging mechanism is now available but can be also deployed locally for the user who expresses his interest in those applications.

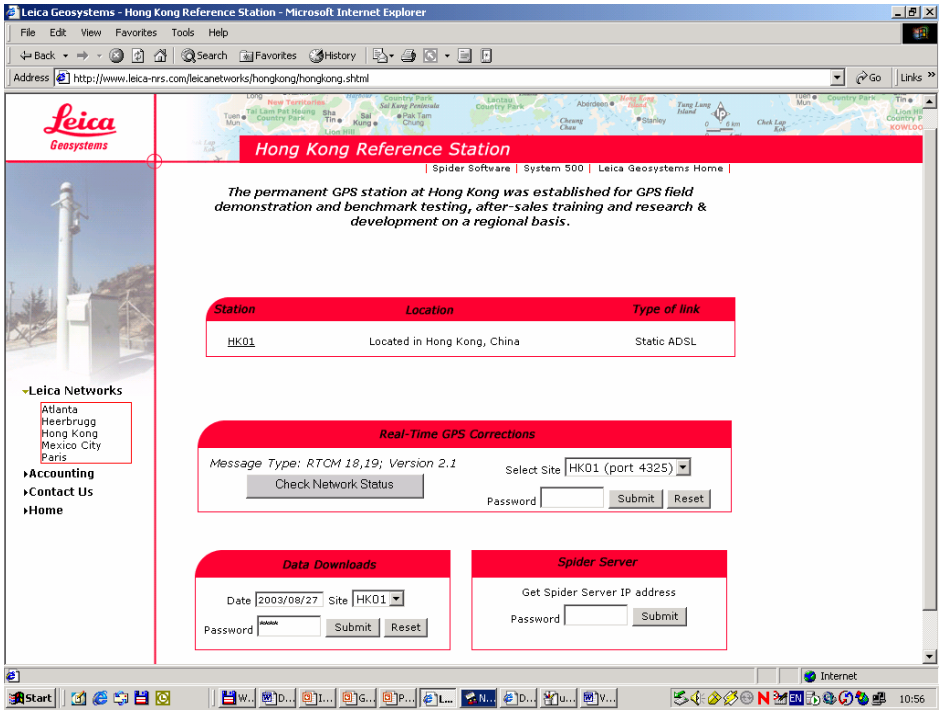

Diagram 8: Layout of web-based GPS data services solution

9. CONCLUSION

Thanks to this project research, Leica Geosystems AG has now a complete suite of solution available for helping the GPS Network supervisor in his daily tasks as shown in diagram 9. The importance for a region to build such a modern geodetic infrastructure is now definitively well accepted.

Those developments aim to contribute to these efforts by providing an appropriate and useful solution.

We strongly believe that the today surveyors and engineers will rely more and more to those kind of services provided by a GPS Network to improve the quality and efficiency of their works for customer's satisfaction.

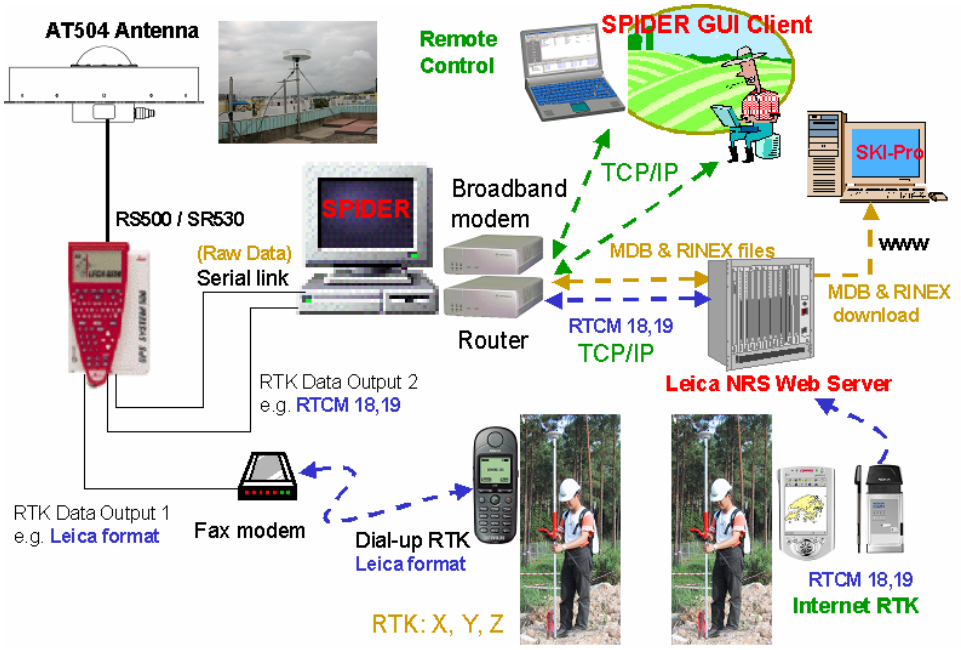

Diagram 9: A sample solution of GPS reference station configuration for providing data files, RTK corrections and remote server access services through Internet

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