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# A Real-Time GPRS Surveillance System Using the Embedded System

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**As for data surveillance, the general packet radio service (GPRS) is the best candidate for always-on connection to any movement vehicles or individuals from the ground up to a few thousand feet above ground. Because of the inherent characteristics of the GPRS, the client circuit design requires a central processing unit (CPU) with an appropriate operation system (OS) to activate point-to-point protocol (PPP) as well as IP-addressed transmission control protocol (TCP/IP). This paper presents a system design for clients to carry out GPRS connection, and send GPS and other data to a server system. For surveillance purpose, a geographic information system (GIS) is applied to track the clients on the electronic map. The system architecture and design concept are discussed. Circuit implementation and real world tests are demonstrated and verified. The data transmission delay is estimated within 0.75 s, while the surveillance period can be controlled from 5 to 120s. The proposed system has been test in ground vehicles to ultralight aircraft at 1000 ft with most areas in Taiwan.**

## I. Introduction

Mobile communication has been developed from the first generation (1G) to the third generation (3G), from analog to digital technology, from voice only to wideband data transmission. Additional values from mobile communication service means the service accepts the voice communication, like mobile bank, mobile office, and mobile internet. Mobile communication can be defined as a good means for any moving individual to send or receive messages from anywhere within base station coverage. The application of data reporting for surveillance or real-time control is a rising demand where either GSM (Global System for Mobile communications, 2G) or GPRS (General Packet Radio Service, 2.5G) services are available. In most developing and developed countries, the mobile service infrastructure has been established under various adoptable technical support bases.[‡] [§]

In the GSM, data reporting for clients can be accomplished through a neat control using microprocessors. A client circuit design was successfully demonstrated to acquire GPS (Global Positioning System) data as well as other data to report to designate terminal using 8051 under PPP.[1] While GPS provides accurate positioning data in real time, the surveillance center can adopt the GIS to track the mobile terminals and display on its electronic map.[2,3] The data reporting and surveillance has become an acceptable means for Intelligent Transportation System (ITS). The integration of GPS, GSM or GPRS, and GIS for surveillance application is termed as $G^3$ technology in our development.

For surveillance application, all clients should always stay online. In the online surveillance solution, the most concern appears to be the GSM fare basis being applied based on connection time. Huge amounts of

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‡Data available online at http://www.comms.eee.strath.ac.uk/~gozalvez/gsm/gsm.html (cited Dec. 2003).
§Data available online at http://www.ee.surrey.ac.uk/Personal/L.Wood/constellations/tables/gsm.html (cited Dec. 2003).

communication cost are applied to the clients. When the GPRS system is activated, the GPRS solution is studied. The GPRS fare basis is charged according to actual data volume being transmitted.*

There are main advantages for developing GPRS technology. GPRS is more suitable than GSM in fare basis for always-on surveillance applications. GSM voice can also be added onto GPRS. Additionally, GPRS applies packet switching technology that multiple clients can share network resource simultaneously to connect the Internet using Transmission Control Protocol/ Internet Protocol (TCP/IP) protocol.

## II. Technical Background

### A. GPRS network structure

The GPRS network is established by imposing a GSN (GPRS Support Node) on the GSM base. GSN provides packet switching in the GSM network, connects IP or X.25 networks, and manages the packet routing. There is a Serving GPRS Support Node (SGSN) and a Gateway GPRS Support Node (GGSN) in operation.[4,†]

In the imposed system, the workload for voice communication stays in the original GSM structure. The new GSN deals with the GPRS system to connect onto Internet. In GSN, the SGSN is the primary component of cellular networks that employ GPRS. Through the radio network, the SGSN routes incoming and outgoing IP packets addressed to or from any GPRS subscriber physically located within the geographical area serviced by that SGSN.

The GGSN is also a primary component of cellular networks that employs GPRS. The GGSN serves as the interface to external IP packet networks, accessing external ISP functions such as routers and Remote Access Dial-In User Service (RADIUS) servers. In terms of the external IP network, the GGSN carries routes to the IP addresses of subscribers served by the GPRS network, and exchanges routing information with the external network.[4]

GPRS can provide more bandwidth than GSM network to connect to the Internet. Basically, it works on an IP network that follows the TCP reference model. But some behaviors are different from the traditional method accessing Internet, such as private IP.[5]

GPRS uses the method to transmit data packets like the Network Addresses Translator (NAT) structure in the Internet, as shown in Fig. 1. The NAT, an Internet standard, is a router that is placed between a public intranet, which uses private IP addresses, and the Internet, which uses public IP addresses. The NAT translates the private IP addresses of outgoing packets into public IP addresses. It also translates the public IP addresses of incoming packets from the Internet into private IP addresses

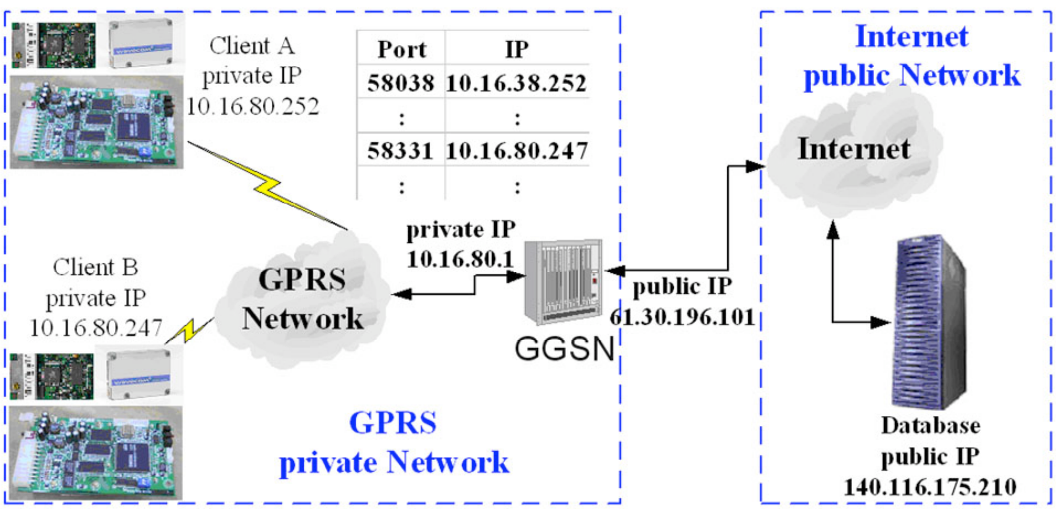


**Fig. 1 The proposed concept of GPRS to Internet connection.**

* Data available online at http://www.garmin.com/aboutGPS (cited Dec. 2003).

† "Introduction to the GGSN Node, 2000-2001" by S. L. Inspira available online at http://www.netspira.com/ggsn.intro.en.pdf (cited Dec. 2003).

The GGSN works to provide the NAT and Dynamic Host Configuration Protocol (DHCP) service. When the GPRS user dials up "*99#" to an access point, the GGSN will allocate a private IP to the user, and will be responsible for transmitting the packets between the GPRS clients and the Internet Server.

In the proposed surveillance system, the clients use TCP/IP over PPP in the GPRS private network, and the communication protocol between the GGSN to the server is TCP/IP.[5]

## B. TCP/IP Network[5]

TCP/IP is a set of protocols developed to allow cooperating computers to share resources across a network. In the data surveillance applications, TCP/IP protocol provides a reliable connection between the server and the clients; while GPRS supports a wireless network environment to negotiate between the server and the clients without space limit.

The TCP/IP DoD (Department of Defense) Model, is a four-layer communication model in defined functions.

*Network interface layer.* This layer is responsible for placing data on the network medium and receiving data off the network medium. This layer contains such physical device as network cables and network adapters.

*Internet layer*. This layer is responsible for addressing, packaging, and routing the data that is to be transmitted. This layer contains four core protocols as IP, ARP, ICMP, and IGMP.

*Transport layer*. This layer provides the ability to order and guarantee communication between computers and passes the data up to the application layer or down to the Internet layer. The transport layer has two core protocols that control the method by which data is delivered. They are TCP and UDP

*Application layer*. This layer is the topmost layer in the TCP/IP stack. All applications and utilities are contained in this layer and use this layer to gain access to the network.

Figure 2 illustrates the adopted system protocol in this paper. In the Network Interface layer, the client adopts the GPRS network, while the server adopts the Ethernet to establish network connection. Both the client and the server use IP as the protocol in the Internet layer, and TCP in the Transport Layer. In the Application layer, the client application and the server application are programmed to process the communication between them.

TCP is a required TCP/IP standard protocol that provides a reliable, connection-oriented data delivery service between two devices. In connection-oriented communication, the connection must be established before data can be transmitted between the two devices. Two devices using TCP will establish a connection through a process known as a three-way handshake to provide the communication reliability. This ensures the data being transmitted to the server correctly and completely. IP helps to identify the location of the destination device in a network communication. However, IP is neither reliable nor capable to deal with addressing and routing packets between networked devices. TCP is a higher-layer protocol to acknowledge the packet delivery and recovery.

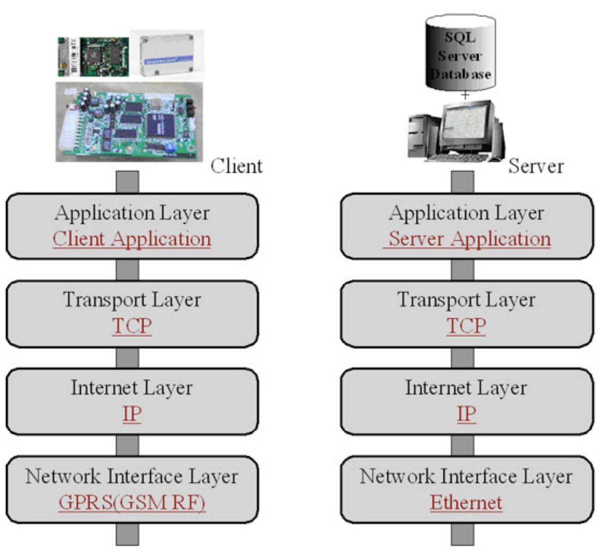


**Fig. 2 The proposed TCP/IP system protocol.**

To connect the clients through TCP/IP, the client hardware requires an operating system (OS) to activate the dial-up and connection process. In our earlier works, we use personal computer installing with Microsoft® Windows 98 to process GPRS connection. To meet the TCP connection requirement, a CPU with an appropriate OS was adopted to develop a handy hardware for the proposed idea. An ARM CPU with μCLinux is the most qualified candidate after surveys to develop miniature hardware.

### C. The Embedded System

In the embedded systems, there are several useful operation systems for use, such as VxWORKs, Palm OS, Windows CE, and Linux. Among them, Linux becomes the best choice to the proposed system design with the advantages as free initial code, easy and flexible to develop as a module platform, knowledgeable to promote kernel reliability, powerful Internet capability as UNIX system, and suitable to transplant with other system.[*†]

In the proposed client system, ARM/Linux is used to design the core system. ARM/Linux is to transplant ARM processor as its core machine and formulate μCLinux to become operation core. μCLinux (micro-control-Linux) is specially designed to construct an embedded Linux operation system using microcontrollers without memory management units (MMU). The adopted μCLinux is an extension of the Linux kernel 2.0 OS, with some simplification but the appreciated stability of the Linux operation system is maintained. [†]

The important characteristics of μCLinux might be focused on its memory requirements that μCKernel plus developing tools need only less than 900 kB (Ref. 6). The developing supports from the Internet are vast and easy to access. [*†]

To match with the client system hardware design based on ARM/Linux, the developing host system should install the Linux PC operation system to develop software. The developing procedures are

*Step 1*: Develop your programs.
*Step 2*: Write a make file.
*Step 3*: Build the binary code.
*Step 4*: Download the executable file.
*Step 5*: Execute the program.

The developing host system is connecting to the client hardware unit through RS-232 to download the program and execute the "minicom" program by setting it at 19200 bps in 8-bit data format at 1-bit stop without parity check. When the setting is ready, reset the client hardware unit to start program download.[6,‡]

## III. $G^3$ Surveillance System Architecture General Guidelines

In Fig. 3, the proposed $G^3$ surveillance system is an integration of GPS, GPRS, Internet, and GIS to monitor moving vehicles with real-time surveillance. The clients deliver the surveillance data to the Internet via the GPRS network and the data will be routed to the server by TCP/IP protocol.

The specifications for such an idea contain

*The clients*

1) activate an embedded system hardware and software to establish data conversion and transfer;
2) run software to establish GPRS communication in TCP/IP with continuing monitor functions;
3) update GPS data, store and send with proper format;
4) read and send required logic, analog and digital data; and
5) monitor and control the overall operation with watchdog for anti-spoofing, default, or lost connection.

*The server*

1) receives all clients data from Internet in real time,
2) controls surveillance data interval from 5 to 120 s,
3) maps and tracks all clients onto GIS,
4) communicates to each client individually, and
5) establishes database management software for server operation.

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[*] Data available online from http://www.uclinux.org/pub/uClinux/ (cited Dec. 2003).
[†] Data available online at http://www.uclinux.org (cited Dec. 2003).
[‡] For access to "Sockets (Part I)," by D. Z. Tabor, Jr., visit http://www.cs.njit.edu/~cis456/protected/lesson21/single21.html (cited Dec. 2003).

To accomplish the $G^3$ surveillance system, there are two major tasks to organize: 1) to build client hardware and software using embedded system technology to process the required functions and 2) to establish a PC-based server with powerful database management and analysis capability.

To test the developed $G^3$ surveillance system, both the client systems and the server system are tested in real-time operation as shown in Fig. 4. For the server system, 1) start the server system, 2) execute VB program, 3) wait and read the client data, 4) map data onto GIS. For the client system, 1) dial and connect GPRS, 2) acquire dynamic IP from ISP, 3) send data to the server in 5 s (or specified period from 5 to 120 s), 4) check connection status, and 5) reset.

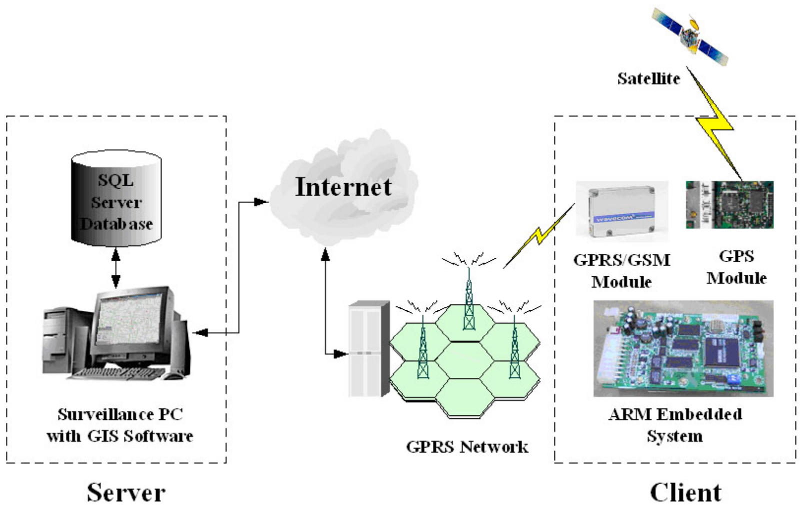


**Fig. 3 The proposed $G^3$ surveillance system architecture.**

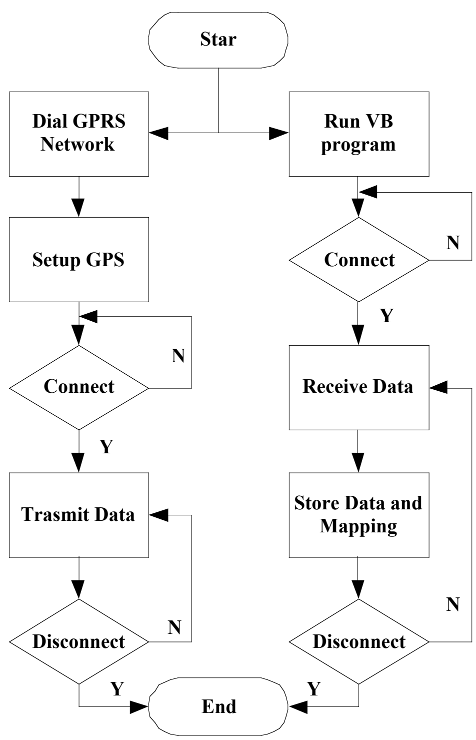


**Fig. 4 The proposed $G^3$ surveillance data flow chart.**

### A. The G$^3$ client system

To fulfill the specifications of the proposed G$^3$ client system, an embedded ARM system is designed to carry out the data transfer function. The G$^3$ client system hardware is shown as Fig. 5, where the embedded kernel to access data input and output is programmed. To the proposed surveillance application, GPS data as well as other data are processed in specific logic, analog and digital formats and sent through the GPRS module in controlled intervals, as shown in Fig. 6. The data packet is formed up in the ARM CPU from the peripheral sensors as well as GPS. Each data packet is activated by embedded Linux system.

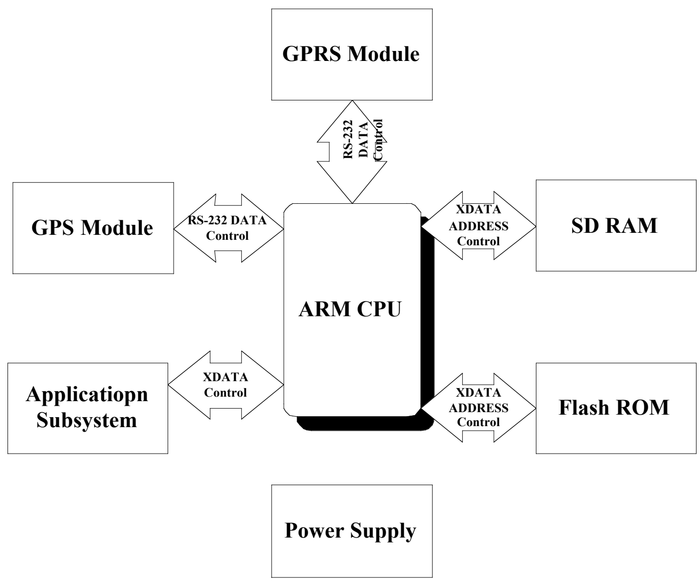


**Fig. 5 The client system hardware design using ARMCPU.**

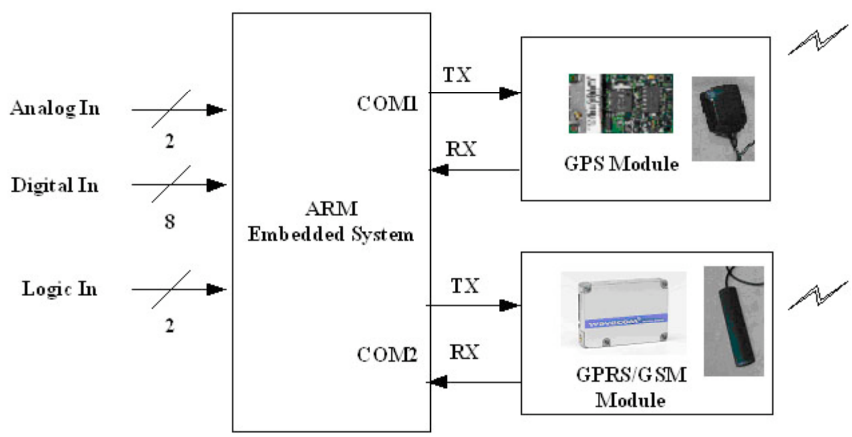


**Fig. 6 Data input in the G$^3$ client system hardware.**

The client system hardware design results in specifications such as a Samsung Electronics' S3C4510B network processor running at 50Mhz a 2MB Flash (1M x 16bit); a 16MB SDRAM (2 x 4M x 16bit); one RS-232C serial console port, COM1; one full RS-232C electricity serial port, COM2; two programmable output LEDs; one GPRS/GSM signal LED; a 20 pin signal input port; and one program download switch. The RS-232 ports are used as COM1 for GPS module to capture positioning data, and COM2 for GPRS module to transmit data to mobile communication system.

**B. μCLinux Embedded Program**

The $G^3$ client system establishes the operation system software and the application system software, as shown in Fig. 7. The operation system software is inherently a μCLinux OS under ARM/Linux infrastructure, and contains "Bootloader" and "Linux" programs. Bootloader is like BIOS in PC to initialize hardware and peripherals, and transfer their control to μCLinux operation system. μClinux is the operation system to allocate system resources and negotiate among all programs.

The application system software is developed with pppd, chat, socket, and talkphone for use. The pppd carries out point-to-point protocol designation, completes dialing and connection, forms and deforms data packets. Chat is a program called by pppd, to command dialing and send user ID and PIN after ISP being connected, and assist pppd to complete dialing and connection. Socket controls data ports to collect input data and GPS data, opens the communication channel to the server system, then transmits all data to the server IP. Talkphone carries out voice signal detection, and recovers to data transmission after a fixed period (1 min) or voice termination between the servers to the clients.

Because GPRS cannot operate voice and data simultaneously, the application program talkphone is used to pause data transmission before the server can send a voice call to the clients. As the proposed applications are focused on surveillance data transmissions, only the server can call the client with limited time, 1 min in our test. This simplifies communication fare to be straight on data only.

The client system is startup by the following steps, as shown in Fig. 8.

1) Install GPRS SIM, initialize GPS, GPRS and ARM/Linux.

2) Use COM2 to connect GPRS module, start PPP dialing, and command GPRS to connect to the server system.

3) Use COM1 to connect to GPS module, and command time interval for each data packet, say 5 seconds in the test.

4) Check connection or wait to connection.

5) Send data packet to the server system; continue or interrupt depends on the server system request.

6) Watchdog reset.

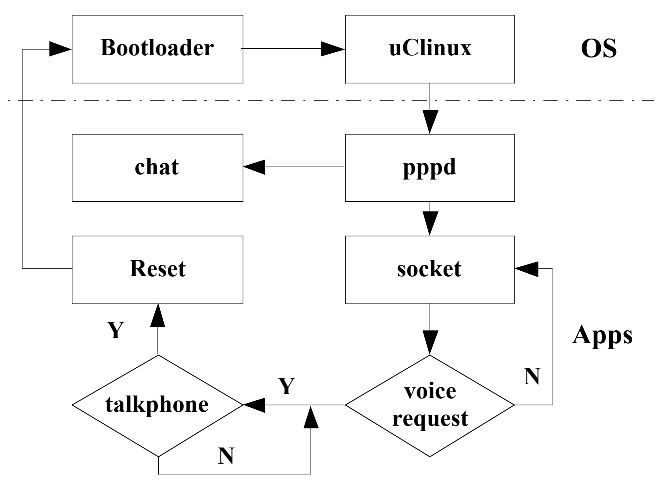


**Fig. 7 The flow chart for the embedded software in $G^3$ client.**

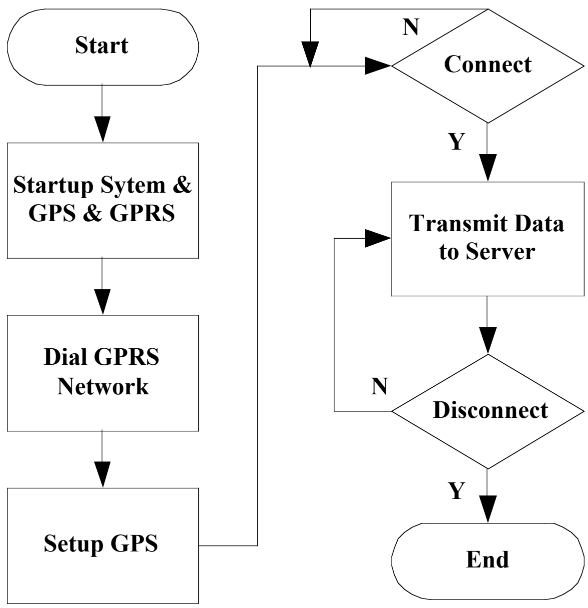


**Fig. 8 Flow chart to startup the client.**

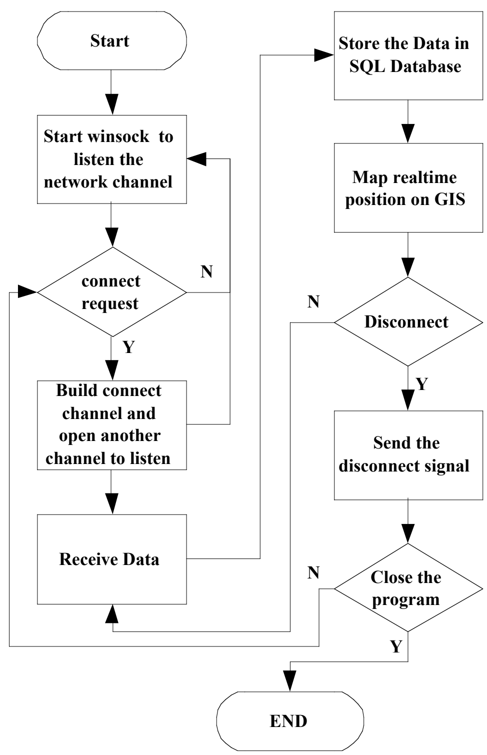


**Fig. 9 Flow chart of the $G^3$ server system.**

### C. The $G^3$ Server System

In the proposed $G^3$ surveillance system, the server is designed using a personal computer installing with Microsoft Windows 2000 Sever and Microsoft SQL Server 2000. To process GIS data mapping and tracking, a Visual Basic (VB) software is programmed in conjunction with MapX electronic map database under execution of the Winsock program. The Winsock program is used as the interface to connect Internet. The server system will receive all client data from Internet, and display all data onto GIS electronic maps. To maintain the surveillance data, a database is established for permanent storage and further analysis.

The servers should establish the Internet connection through the following steps as shown in Fig. 9.

1) The server system should be PC capable to connect to a fixed IP address.

2) User will start VB program, set its port, open two channels by using Windsock program, one channel is used to "listen" to the clients with connection requests, the other channel should be ready to establish a connection.

3) At receive and accept, the client's request for connection, the reserved channel will read the client's data, and switch the other channel as reserved for next connection. Otherwise, continue to "listen" to the client's requests.

4) Once the connection is established on-line, the client data will be read and display on the GIS, and write into database.

5) The server system will determine its connection state or interruption. In general, the server system is an always-on system in the proposed surveillance application.

### D. The Data Format and Database Design

While the client is connected, client data can be sent according the predefined time interval and data format to a destined IP address. In the proposed applications, we require positioning data from GPS, logic, analog, and digital inputs from the client. The data format from the client systems will appear like:

$GPRS-KGT$GPRMC,082908,A,2259.6952,N,12013.3550,E,37,309,050103,05,2.4,14$62A60FFF

| ID | Log | Lat | Spd | Course | Alt | UTC | Sat | In3 | In2 | In1 | In0 | Time | Date |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | |

Details of the data format are described as follows:

ID = GPRS-KGT,

Longitudinal = 120+13.3550/60 = 120.2225833 degrees,

Latitude = 22+59.6952/60 = 22.99492 degrees,

Speed = 37x1.852 = 68.524 km/h,

Course = 309 degree,

Altitude = 14 m,

UTC = 082908 time,

Receiving Satellites = 05,

In3 = 62(hexadecimal) > 98(decimal),

In2=A6(hexadecimal) > 166(decimal),

In1=0F(hexadecimal) > 15(decimal), = "0" reserved, and next four logic inputs of 1100, terminals one and two are high, and terminals three and four are low.

In0=FF(hexadecimal) > 255(decimal), = 8-bit digital input of11111111,

Time = local time to write data, hhmmss.

Date = local date to write data, ddmmyy.

The reporting data are read from the 20 pin input port: four pairs of "0 or 1" logic inputs (8 pins), two pairs of analog inputs (4 pins), and one set of 8-bit digital input (8 pins). After analog to digital conversion, the two analog inputs become 16 pins input to CPU data bus. This occupies the overall 32-pin data bus in the CPU. The GPS data string contains a lot of information. We have only to select the necessary data for vehicle surveillance purpose to read and send. The real data for surveillance purposes is estimated from 140~150 bytes depending on GPS conditions. This data size is just right to some system providers to fit into data packet basis of 160 bytes in Taiwan.

## IV. Implementation and Verification

The proposed $G^3$ system is implemented in two parts. The first part is to accomplish the client system hardware design and fabrication. At the same time, the second part is devoted to developing a server system on a personal computer. During the breadboard circuit phase, tests have been made including topology and software to verify dialing and transmitting reliability. The circuit hardware is designed by surface mount technology (SMT) to miniaturize the overall printed circuit board (PCB), and also to improve its production quality. Fundamental tests are carried out to verify the proposed concept in the system design as demonstrated previously.

There is a key parameter to test. The data period is dependent on the surveillance requirements. In our verifications, the data periods are tested from 3 to 120 s. For periods below 5 s, the client data might be congested during base station handover; while for periods longer than 90 s, the Mobile System Provide might shut down GPRS connection. Under congestion, the client system hardware will hold the data to the next available time slot, and send. The client system hardware has a watchdog function that will activate the re-dialing process for GPRS connection recovery. In aviation surveillance applications, the data period is suggested to be 5 s, as compared with the radar period. In ground vehicle surveillance applications, the data periods may vary from 30 s to 120 s, to avoid huge data processing or Internet congestion.

## A. Transfer Time Test

Because GPRS is connecting to the Internet to transmit data, data transmission is tested to examine the packet delay. Figure 10 shows the packet transfer time test for 3925 samples. In the test, a client system sends data to the Internet and reads it into the server by a computer. We record the data sent and receipt time difference. The average transfer time delay is statistically about 750 milliseconds, as shown in Fig. 11. The Internet condition and GPRS base station handoff have caused certain influence to data transmission to cause delay variations.

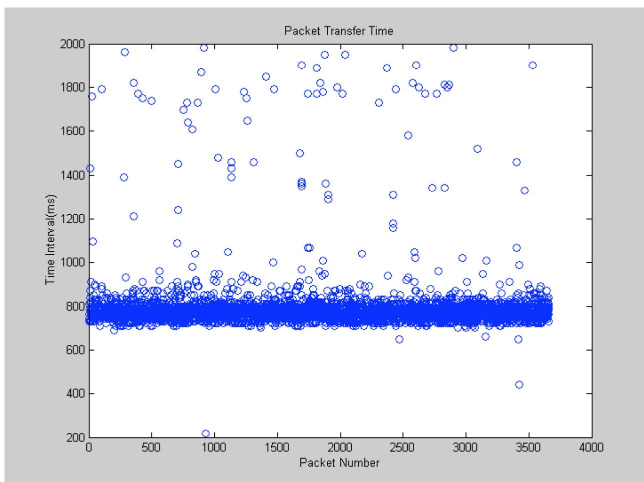


**Fig. 10 Real-time data transfer tests.**

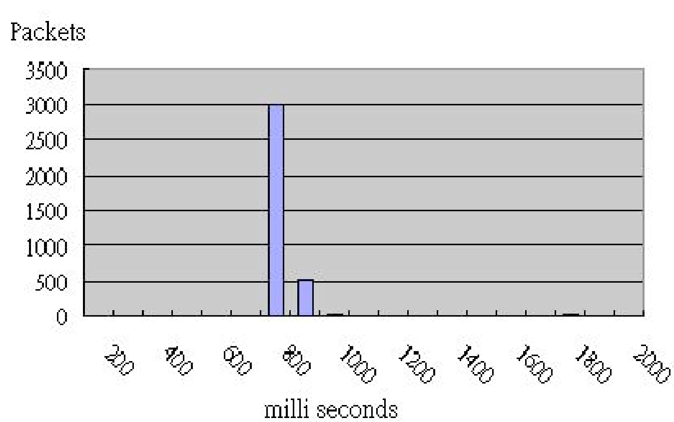


**Fig. 11 Transfer time statistics.**

## B. The Server System

In real-time surveillance, the server system is designed to track all client data from the Internet. At least 20 functions to track multiple clients, real time display, historical replay, data statistics, warnings, one-way voice calls, etc., are created in the server system software, and are tested to verify the system capability. Figure 12 shows the real-time surveillance display for multiple inputs in a small region. On the top of screen, all functions are displayed as tool blocks. At the bottom of screen, all clients (vehicles) and their input data are displayed. In Fig. 13, a historical data replay is shown. We can show a vehicle moving in the past time interval. In Fig. 14, a vehicle is tracking on freeway from north to south in Taiwan. Figure 15 shows the client data in the server computer database. All reported data are stored into the database for further analysis. Figure 16 shows a vehicle moving around an industrial park.

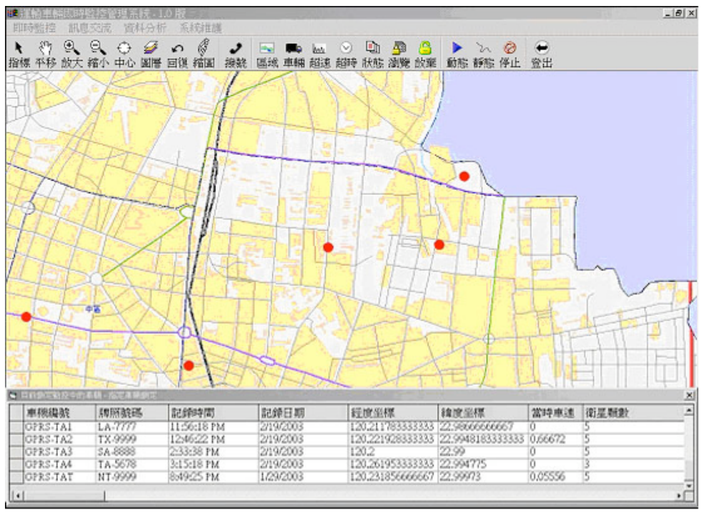

**Fig. 12 Ground vehicle surveillance in city with client data.**

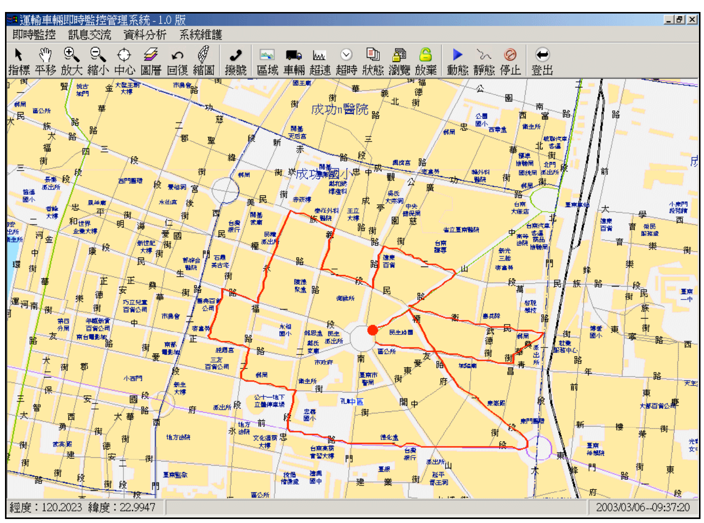


**Fig. 13 Ground vehicle surveillance in historical data replay.**

From the tests in Figs. 12 –16, we can instantly receive the client data under surveillance. The results verify that the proposed $G^3$ technology is effective to establish a real-time surveillance system for ground vehicles. In the tests just mentioned, we set a 30 s data period in the client system.

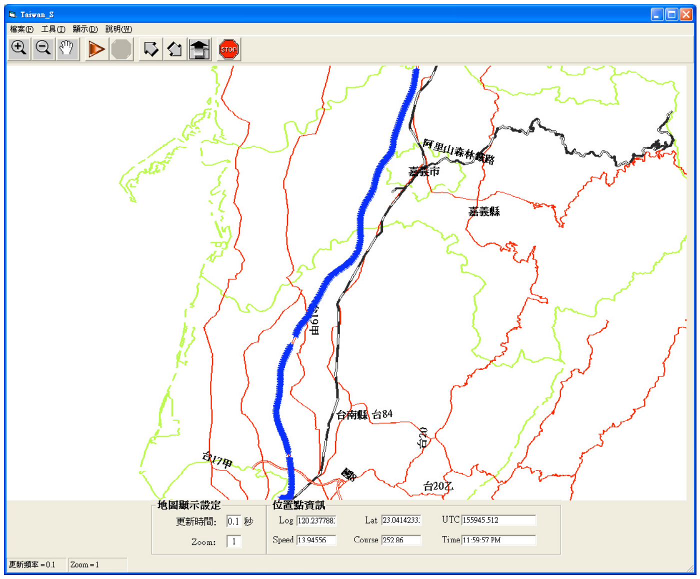


**Fig. 14 Ground vehicle surveillance track along freeway.**

SQL Server Enterprise Manager - [2:資料表 'GPRSBTB' 中的資料 (在 'DTcarDB' 中) 於 'AERO']

| SerNo | ID | Lon | Lat | Speed | Course | Att | UTC | Sat |
|---|---|---|---|---|---|---|---|---|
| 22317 | AEZN-009 | 120.220605 | 23.007525 | 33.00264 | 236.81 | 52.8 | 3205.999 | 5 |
| 22318 | AEZN-009 | 120.22025 | 23.00732 | 31.68772 | 244.52 | 53.1 | 3210.999 | 4 |
| 22319 | AEZN-009 | 120.219878333333 | 23.0071783333333 | 28.85416 | 250.12 | 52 | 3215.999 | 5 |
| 22320 | AEZN-009 | 120.219473333333 | 23.007035 | 31.947 | 250.7 | 50.7 | 3220.999 | 5 |
| 22321 | AEZN-009 | 120.219068333333 | 23.006905 | 30.96544 | 250.37 | 50.5 | 3225.999 | 3 |
| 22322 | AEZN-009 | 120.218688333333 | 23.0067533333333 | 30.31724 | 254.15 | 50.6 | 3230.999 | 4 |
| 22323 | AEZN-009 | 120.2183 | 23.0066483333333 | 28.76156 | 246.27 | 50.8 | 3235.999 | 5 |
| 22324 | AEZN-009 | 120.217988333333 | 23.0065316666667 | 18.20516 | 250.28 | 49.8 | 3240.999 | 5 |
| 22325 | AEZN-008 | 120.217878333333 | 23.0064883333333 | 17.66808 | 248.49 | 43.9 | 3243.999 | 4 |
| 22326 | AEZN-009 | 120.21777 | 23.0064533333333 | 18.39036 | 251.1 | 49.9 | 3245.998 | 5 |
| 22327 | AEZN-008 | 120.217743333333 | 23.0064616666667 | 7.09316 | 225.02 | 53.7 | 3248.998 | 4 |
| 22328 | AEZN-009 | 120.217611666667 | 23.0064133333333 | 12.4084 | 256.69 | 53.3 | 3250.999 | 5 |
| 22329 | AEZN-008 | 120.217666666667 | 23.0064883333333 | 16.59392 | 204.92 | 63.7 | 3253.999 | 4 |
| 22330 | AEZN-009 | 120.217526666667 | 23.00635 | 10.85272 | 205.82 | 57.1 | 3255.999 | 5 |

**Fig. 15 Surveillance data format.**

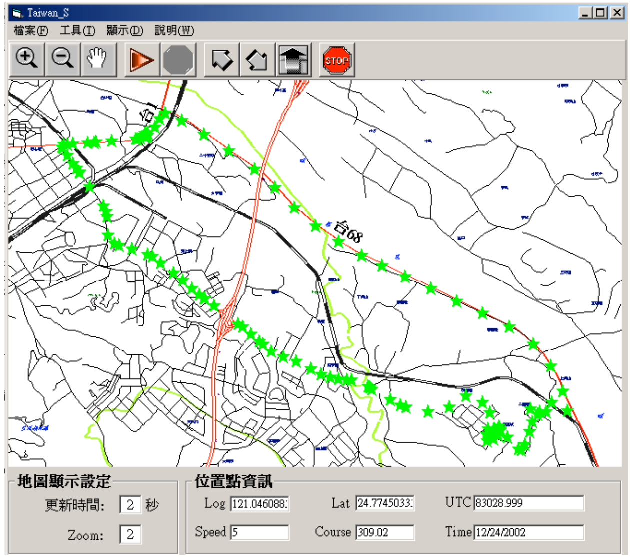


**Fig. 16  Ground vehicle surveillance track.**

### C. Aviation Test

Although mobile communication is developed for ground users only, it is possible that a client at a few hundred feet above ground can still receive base station connection. As a result of the Earth's curvature, a remote base station can transmit signal up to higher altitude under line-of-sight effect. For helicopter or ultralight aircraft, the cruise flight is operated below 5000 ft above ground level (AGL).

Figure 17 shows an ultralight flight operating at about 1000 ft AGL in southern Taiwan. In the aviation tests, we use a 5 s data period as compared with radar period. The reason for flight surveillance is focused on safety to prevent the ultralight from intruding into nearby Ping-Tung Airport (PTN). The Civil Aviation Administration (CAA), Taiwan, is planning to place all ultralight flights in Taiwan under appropriate surveillance. The proposed $G^3$ technology is tested to meet the demand. There are shortages at present, e.g., the surveillance altitude should reach higher. The KGT system provider proposes feasible solutions to enhance this application.

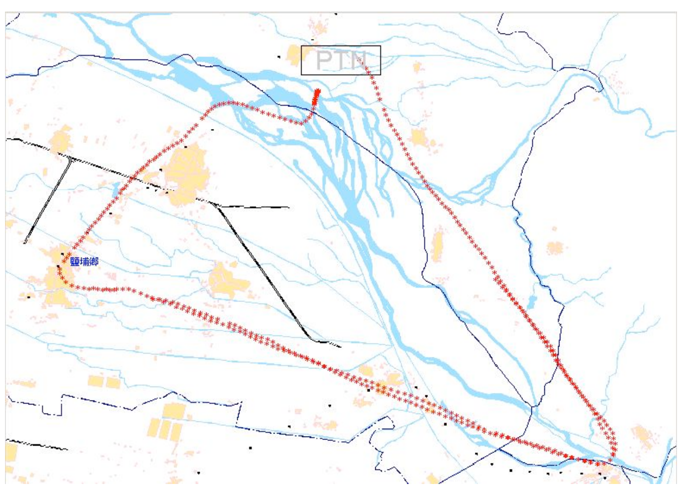


**Fig. 17 Ultralight aircraft flight surveillance around 1000 ft.**

## D. Airspace Surveillance Test

The ultralight flights near PTN may possibly intrude into the surveillance airspace. In ATC issue, aircraft approach to or departure from PTN should pay attention to those ultralight flight activities. The flight surveillance and warning system is constructed to demonstrate the capability of the proposed $G^3$ technology for this application.

From the test results in Fig. 18, the proposed $G^3$ technology is applied into an ultralight surveillance system for this area of ultralight sport flights. Two surveillance ranges of 7 and 8 n miles are created for this demonstration in Fig. 18. The ultralights may conflict into the PTN surveillance airspace to initiate warning signal from the "PTN Airspace Surveillance System." Figure 18 shows ultralights flying under surveillance in a specified operating airspace. In Fig. 19, once the ultralight enters the surveillance range, a warning signal is activated. Further design consideration with suitable display, warning, and process can be studied under acceptable ATC requirements.

Without surveillance, the ultralights may threaten the flight safety of any controlled airspace. The test result and demonstration in Figs. 18 and 19 fulfill the surveillance demands to ultralights in approved airspaces using the $G^3$ technology. Referring to Fig. 19, constrains can be designed depending on airspace requirements. Ultralights under surveillance can be operated inside any defined approval airspaces, or constrained to nearby surveillance airspaces.

By the same concept, if mobile communication can cover higher altitudes, the proposed concept for low altitude surveillance application can be applied to general aviation or civil aviation in the future.

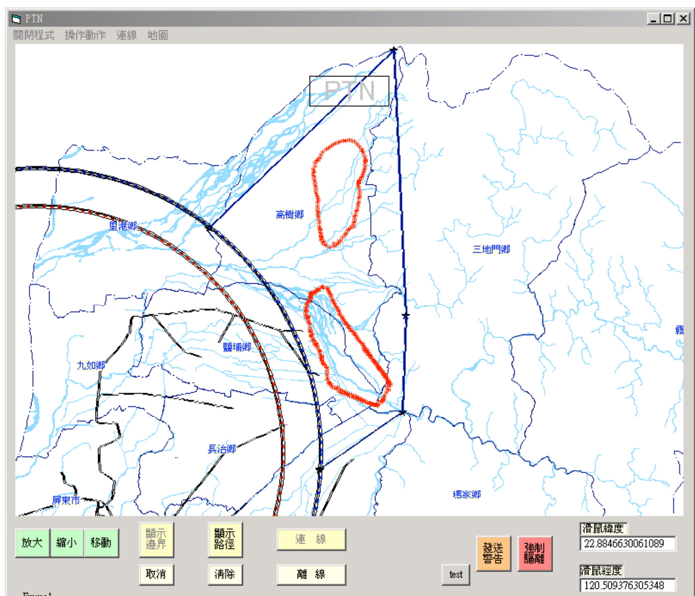


**Fig. 18 Ultralight surveillance near PTN below 1000 ft on GIS display.**

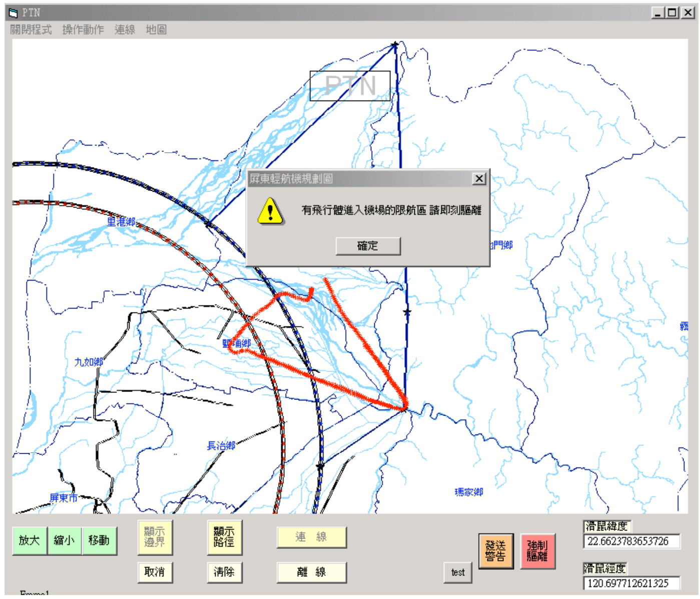


**Fig. 19 Activation warning in the PTN Airspace Surveillance System.**

## V. Discussions

From the flight tests, the proposed surveillance system is viable using $G^3$ technology. The test results show that the GPRS data surveillance is useful to ground vehicles and low altitude flights. Several issues have arisen to discuss.

*Service coverage*. In Taiwan, six system providers have made GSM and GPRS service in very good coverage except mountain areas. To most vehicle surveillance applications, the GPRS coverage can offer good service to the clients.

*Altitude coverage*. The tests failed above 1000 ft AGL, because the coverage of GSM or GPRS is designed typically for ground operation only. The tests showed that the connecting base stations were remote from the field under line-of-sight signals. All nearby base stations cannot cover higher altitude of more than 15 deg above ground. Four possible solutions are proposed by KGT system provider: 1) lift up the antenna angle for higher coverage in nearby base stations inside the airspace; 2) add the fourth sector antenna to cover higher altitude users; 3) increase the power level of the remote base stations outside the airspace; 4) establish a base station for ultralight flight service at the center of the approved airspace. The following tests are conducted in the future.

*Internet capacity*. The $G^3$ clients report data into a designated IP address through GPRS. Theoretically the capacity of each IP address is unlimited, but actual conditions need to be verified. Each IP address can possibly handle as many as 1000 clients at the same time under Map-X developed software infrastructure. For a larger amount of clients under surveillance, the Internet condition is a great concern to its overall performance and efficiency.

*Congestion limits*. Each base station is designed typically for 30 uplinks and downlinks for GSM and GPRS. At the same time, each base station can offer 15 to 30 GPRS data exchanges out of GSM service. As the vehicles are moving dynamically, the proposed surveillance system can accept reasonable numbers.

*Communication fare*. GPRS communication fare basis is charged per megabyte of actual data transmission. The $G^3$ client hardware will carry 150 bytes for each data packet. If the ultralight is operating 6 h a day in a 5 s data period, the daily data volume is 150x12x60x6/1M = 0.648 MB. If a vehicle is operating 18 h in a 30 s data period, the daily data volume is 150x2x60x18/1M=0.324 MB. System providers in Taiwan offer the GPRS fare varying from NT$50~100/MB, on different bases. Communication cost for the proposed surveillance system is fairly acceptable.

*Lost data statistics*. The proposed $G^3$ technology might have chances to lose data. On lost connection, the $G^3$ client systems take about 10~20 s (or 2~4 data packets duration) to recover the GPRS connection, if the base station signal is good. Lost connection might happen over altitude limit or at base station handover. During handover, statistically, there is possible to lose 1 or 2 data packets at a chance less than 1% chance, or 0.1% to lose connection. During normal connection, there is possible to lose 1 data packet at 0.05% chance.

## VI. Conclusion

In this paper, a real-time surveillance system based on the GPRS and Internet data interchange is proposed, designed, implemented, and verified. The client system hardware designed using an embedded system with μCLinux is fabricated for tests. A server system is designed and established as an infrastructure for general applications.

In the client system hardware design, the embedded system using μCLinux has been verified with very high reliability for GPRS to Internet connection. In the tests, the client system hardware and sever system real-time software are verified with perfect match for data acquisition and access. The proposed $G^3$ technology is a good solution as a real-time surveillance approach for intelligent transportation system as well as flight surveillance in low altitude. Applications for any moving vehicles along a wide area can be adopted. Service coverage is excellent in Taiwan to initiate GPRS surveillance service to any kinds of trucks and cars.

The test results in this paper have verified the feasibility and effectiveness of the proposed $G^3$ technology in vehicle surveillance using GPRS data communication.

## Acknowledgments

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