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SPIRAL: A MICROPROCESSOR-BASED TELEMETRY AND TELECONTROL SYSTEM

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Abstract

This paper presents a microprocessor-based system for remote control and measurements through a local CSMA transmission network with star topology. Every remote station has its own control and measuring program and is also subject to the orders of a central station. This is a general-purpose system, since it can be programmed for use in various telemetry and telecontrol applications.

Key Words

Local-networks, telemetry, telecontrol, microcomputers.

1. Introduction

In both scientific and technical fields, it is often necessary to make periodical real-time measurements of certain parameters and to act on control elements.

This is not always easy to do, especially when control and observation sites are distant or difficult to access. Moreover, the constant presence of a human observer is often required by circumstances such as the frequency of sampling or the unexpected moment at which control actions and measurements become necessary. Again, this is not always possible.

Currently, computer technology [1–4] provides the means for managing control and measurement processes from a distance through microcomputers linked via communications networks to a central computer located in the data processing center under human supervision [5–7]. Furthermore, such systems mean that stations may be located at the very source and destination of the information, regardless of accessibility. Therefore, the frequency of sampling and the times at which controls are to be carried out may be set without the presence of an observer. A further advantage of telemetry and telecontrol networks is that systems may be achieved with a totally integrated infrastructure to support all the tools required for effective operational management systems [8].

Our system, with the above mentioned characteristics, has been used in several applications and complies with the specifications detailed in the following sections.

The present paper includes (in Section 2) a general description of the system hardware detailing the constituent elements. As well, further details are provided on the design of the non-standard conventional elements, i.e. the communications control board (Section 2.1) and the remote stations (Section 2.2). The following section (Section 3) deals with control software and the transmission frames used in the CSMA access method applied to our system. The last part of the paper gives possible applications of the system (Section 4) and the conclusions of this work (Section 5).

2. Hardware Implementation

The telemetry and telecontrol network (called *Spiral System*) comprises a Central Station (CS), and a group of Remote control and measurement stations (RS) linked to the central station by star topology (see Figure 1). The system uses CMOS circuits for low power consumption.

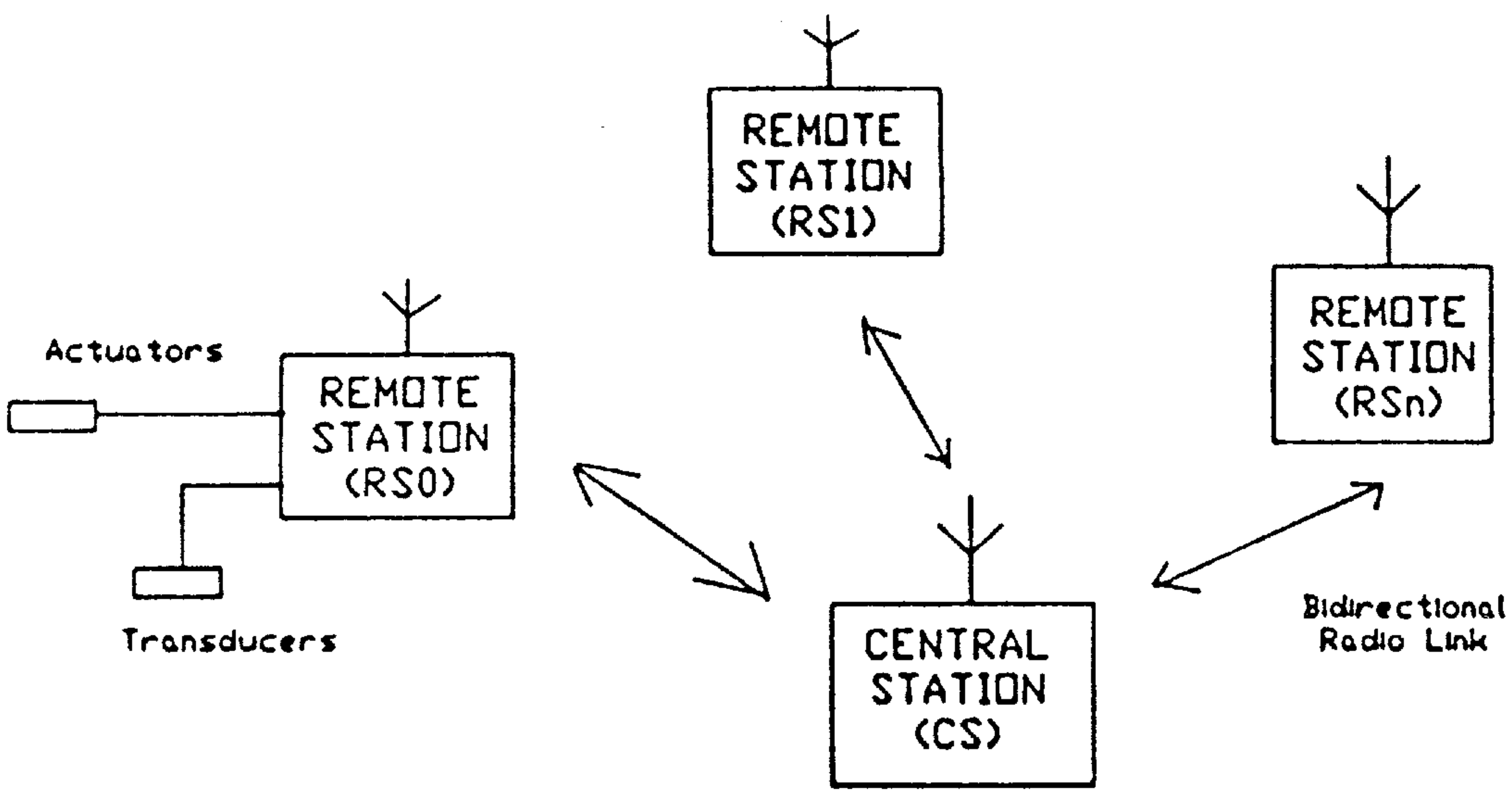

Figure 1. SPIRAL System diagram.

The *Central Station* consists of a standard PC with an EGA video-controller, hard disk, printer, and an RS-232 series interface connecting the PC to a Telecommunications Central Unit (Figure 2). In turn, this unit comprises a communications control board (which will be described in Section 2.1), a power source and a radio-transmitter-receiver (FM-VHF).

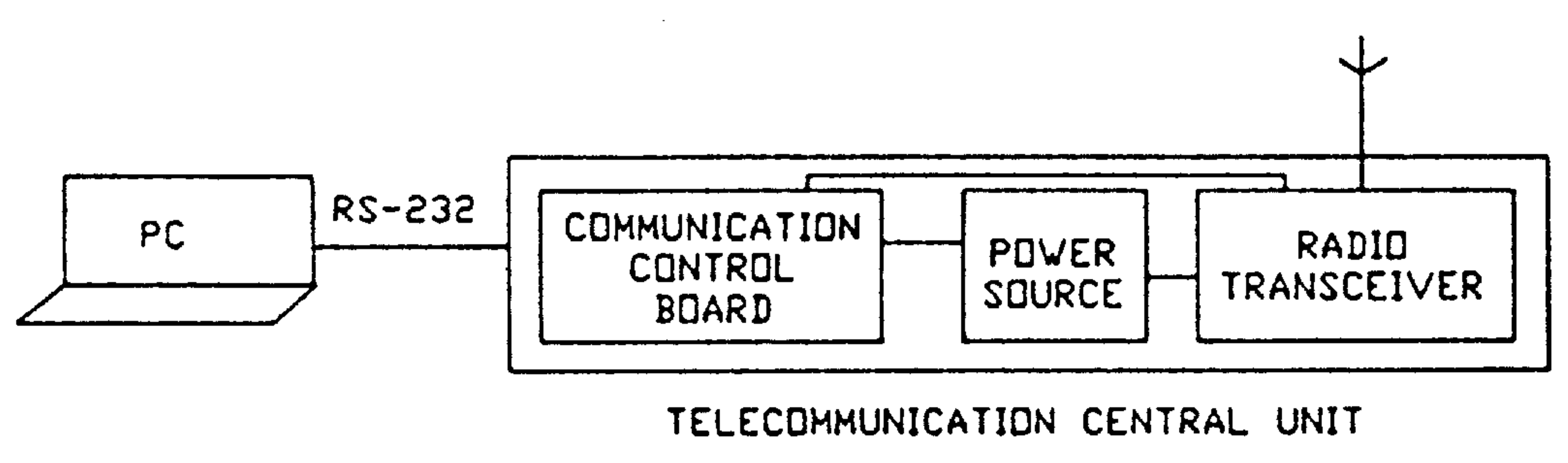

Figure 2. Components of the central station.

The *Remote Control and Measurement Stations* (see Figure 3) linked by radio to the central station are equipped with the following elements (as described in Section 2.2):

1. A processing board (microprocessor, RAM, EPROM, etc.).

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2. A/D converter boards with 8 transducers connected to each one.
3. Digital I/O interface boards each with 8 optocouplers as inputs and 8 relays as outputs.
4. A communications board ("communications controller," in the figure).
5. A VHF radio transmitter-receiver.
6. A keyboard with numeric and function keypads and a 16-character liquid crystal alphanumeric display.
7. Built-in power source with DC-DC converters. Input voltage is taken from a battery charged with photovoltaic cells.

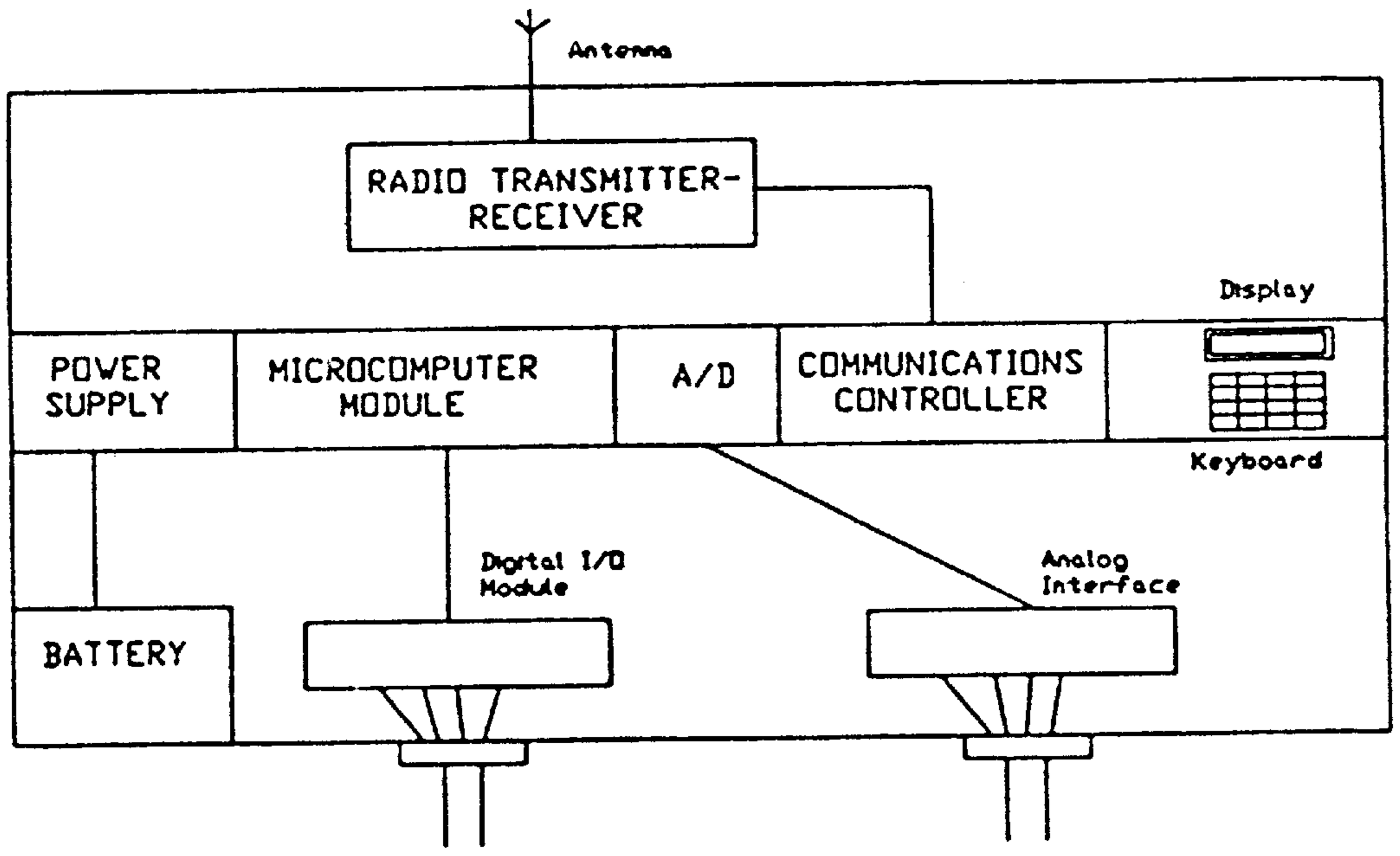


Figure 3. Arrangements of modules at a remote station.

The high-end configuration of each remote station has n=8 converter boards (for 64 transducers) and m=4 I/O boards for digital signals (32 inputs and 32 outputs). The system can operate with 1 to 16 remote stations.

A wide variety of sensors can be connected to the analogical or digital inputs of the remote stations to measure magnitudes such as liquid level, temperature, conductivity, air humidity, pH, pressure, water depth, wind speed and direction, rainfall, flow, strength, linear and angular position.

The devices required to manage control elements, such as motors, pumps, electrovalves, etc. may also be linked to remote stations, and the remote stations may control such elements, either by commanding the station itself (by program) or the central station. Every remote station has control programs for its input and output devices.

The hardware elements specifically designed for the SPIRAL system are described in the following section.

2.1 Communications Control Board

This board operates as a Data Circuit-terminating Equipment (DCE) and acts as an interface between Data Terminal Equipment (DTE) (remote and central processor) and a standard radio transceiver/receiver equipment with a VHF frequency range carrier.

The aim of this board, used both at the central station and the remote stations, is to implement an RS-232C interface for the transmitter/receiver equipment.

The radio transmitter/receiver equipment (Figure 3) has 4 input/output lines (TXA, RXA, SQT and PTT) with the following meaning:

- TXA Transmission signal input.
- RXA Reception signal output.
- SQT Active output (L) when the radio is receiving.
- PTT Input to order the radio module to switch on the transmission mode.

The RS-232 lines used are as follows:

- TXD Data transmitting line (DTE to DCE).
- RXD Data receiving line (DCE to DTE).
- DSR Active line (L) when the power is on, i.e. when DCE is ready.
- DCD Active line (L) when there is a carrier in the data reception line.
- CTS Active line (L) during transmission.
- DTR Shows that DTE is ready to transmit (it must be active to allow the transmission).
- RTS DTE requests a transmission from DCE with this signal.

The communications control board, among other elements, contains a 74HC943 FSK modem and two 74HC123 monostables (M1 and M2). The transmission rate is 300 bps, enough for the signals required to measure or control.

A CSMA (Carrier Sense Multiple Access) transmission protocol [9] is used. This method is applied to our system as described below and in Section 3.3.

If a station wishes to transmit, it activates the RTS control signal. Transmission is not established until a long "silence" is detected during a T1 time. In fact, when the SQT signal is not active, it shows there is no reception. A transmission can therefore taken place. To avoid collisions between possible messages transmitted at the same time by different emitters, there is no transmission until the T1 contention slot is finished. This period is equal to the M1 monostable pulse width.

The transmission stops (PTT becomes inactive) when DTR or RTS are inactive or when a T2 contention slot, imposed by the time necesary to transmit a frame that is physically imposed by the M2 monostable, is finished. Once the T2 time has elapsed, the transmission is cancelled so as to avoid any of the stations transmitting indefinitely through some fault.

When the transmission has finished, no further frame may begin during a recovery time period (contention slot), T3, given by: T3 = T1.

The transmission system described has many operational alternatives. The central station provides total control of the transmission, thus avoiding any possibility of collisions. The system also lets the remote stations start communications. In such a case, the communications program could manage several channel access strategies to increase channel efficiency [9]. We have proved that the simple communications hardware protocol used is very useful for our system, because it has been designed for a small number of stations.

2.2 Remote Stations

Each remote station, as stated in Section 2.1, comprises a processing board, from 1 to 8 A/D converter cards, from 1 to 4 digital I/O interface boards, the communications board and the radio transmitter-receiver.

Figure 4 provides a diagram of a processing board block. Basically, it has a microprocessor, 8 KBytes RAM (4364), 8 KBytes EPROM (27C64), a "watch-dog" circuit (H6006), 2 I/O digital interfaces (VIA 65C22), display and keyboard interface circuits, and a serial interface (ACIA 65C51).

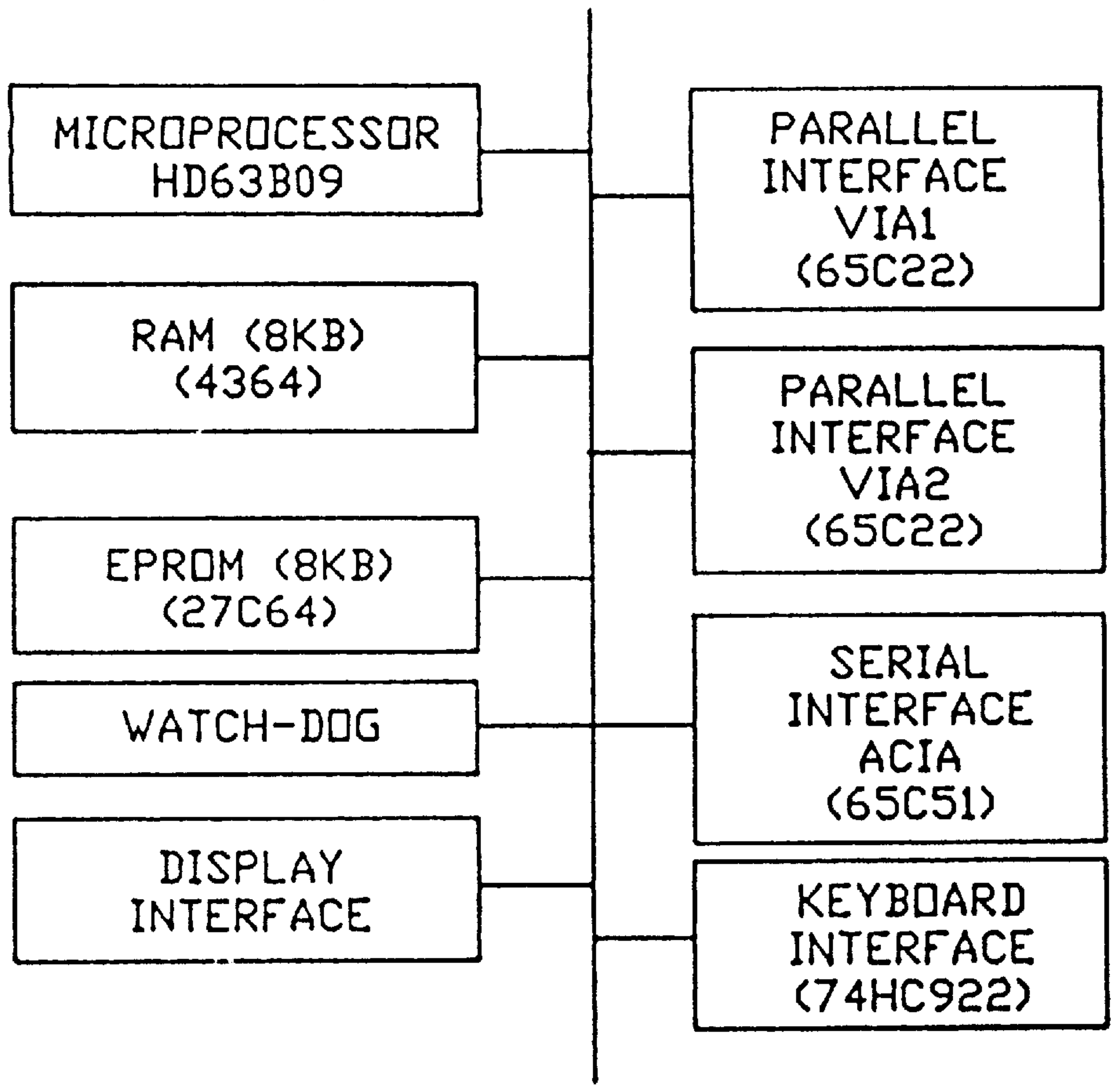


Figure 4. Block-diagram of the remote station processing board.

The Data Acquisition Board consists basically of a 12-bit A/D converter (AD7572) with a 12-microsecond conversion time. With an LF13508 analogical multiplexer, there are 8 analogical channels (AD0, AD1, ..., AD7) with inputs that can be selected in current (0-20 mA, 4-20 mA) or voltage mode.

The digital I/O interface board has 8 optocoupler digital inputs and 8 relay outputs. An integrated Darlington circuit (ULN2803) has been used to increase current to active relays. This board is directly connected to a VIA (65C22) on the processing board.

3. System Software

This section provides a brief description of the functions performed by both the remote control software (at the central station) and the measurement supervision software (at the remote stations). The format of the software-generated frames for communications control is also provided.

Under normal operating conditions, every remote station waits for an information request or control order from the central station. Once orders emitted by the central station have been executed, the related remote station returns to the waiting state.

To achieve reliable intercommunication, every station has its own identification code and checksum field, which means that mistakes among stations and transmission errors may be easily detected.

All of the following operations may be performed from the central station:

1. To effect a periodical and automatic polling of every station connected to the network, acquiring and saving data.
2. To request measurements from every remote station.
3. To switch on or off any control element connected to the digital outputs of a remote station.
4. To process the data received according to application specifications, with alarm responses or with an automatic control order at the remote station.
5. To display processing diagrams of every network station showing real-time data.
6. To make dynamic graphics of any variable.
7. To provide periodical printed information on different events.
8. To save the evolution of every remote station on a historic file.

3.1 Central Station Software

Figure 5 shows a flowchart of the main program at the central station. This program is interrupted by a series of periodical or non-periodical events that apply to different services, which are described below.

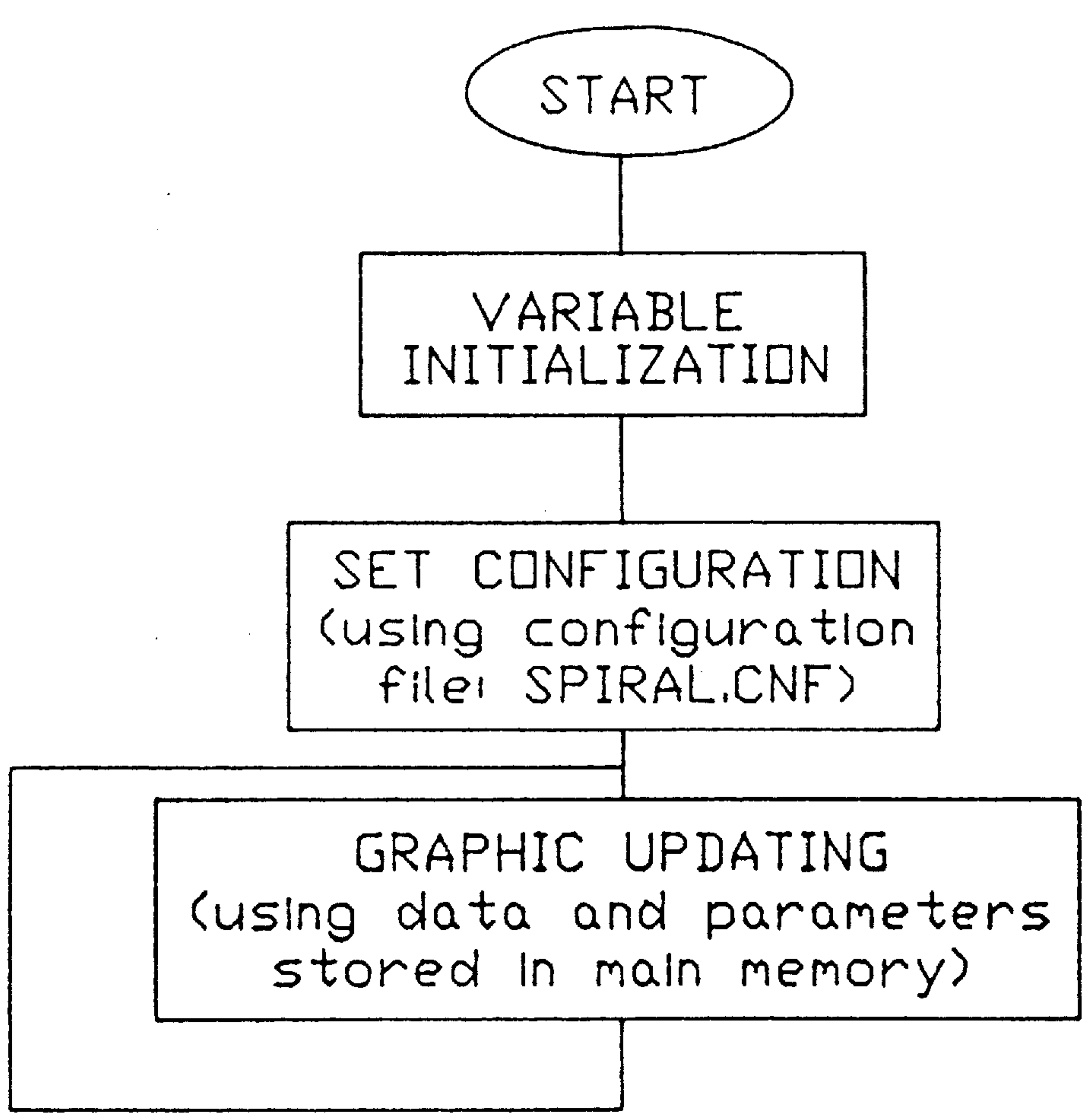


Figure 5. Flow-chart of the main central station program.

Real-time timing. This generates different periodical interruption signals for the following purposes:

(i) Periodical register service. This writes updated main memory data on a disk file. The data is put into memory by other services.

(ii) Periodical data request from remote stations service.

The request periods are user-programmed according to the specific application being carried out on the network.

(iii) Transmission timing service. This generates the time sequences for CSMA transmission management (Figure 6a). Initially, the transmission system is waiting for a message to transmit (State A in the figure) and, when a message is ready, it enters a carrier detection state (B in the Figure). Channel occupation is detected approximately every second. If the channel remains occupied after a certain length of time, a "time-out" occurs and the transmission system returns to State A. If, however, there is no carrier (i.e. the channel is free) then a transmitter stabilization wait state (State C) occurs, which takes between 0.5 and 1 seconds to stabilize the emitter after its electrical start. It then goes into State D, or a "message transmit" state within the message-transmission service, in which the frame is transmitted. Should the transmission be interrupted (the CTS signal disappears) or completed, then it returns to the "awaiting message" state (State A).

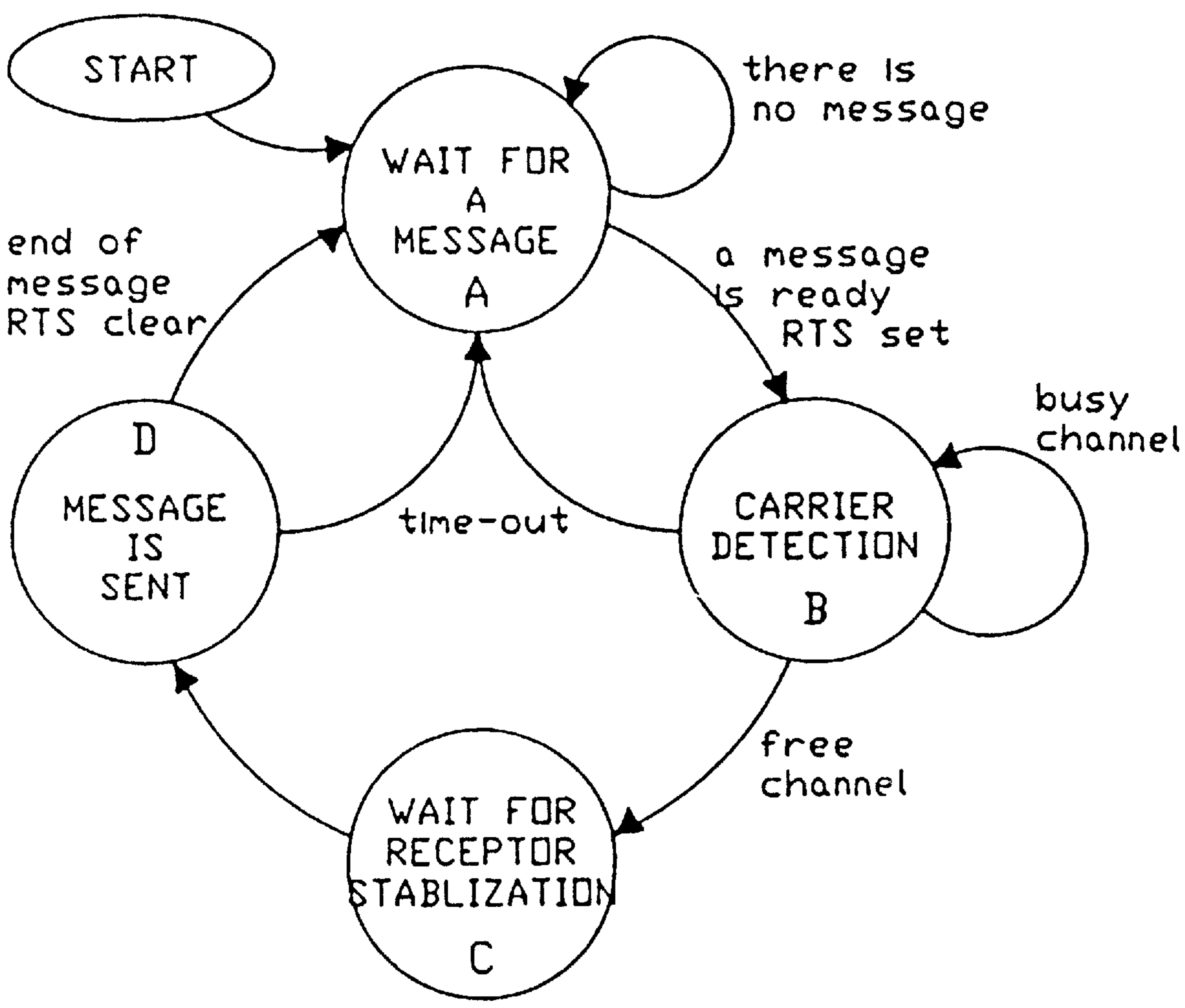
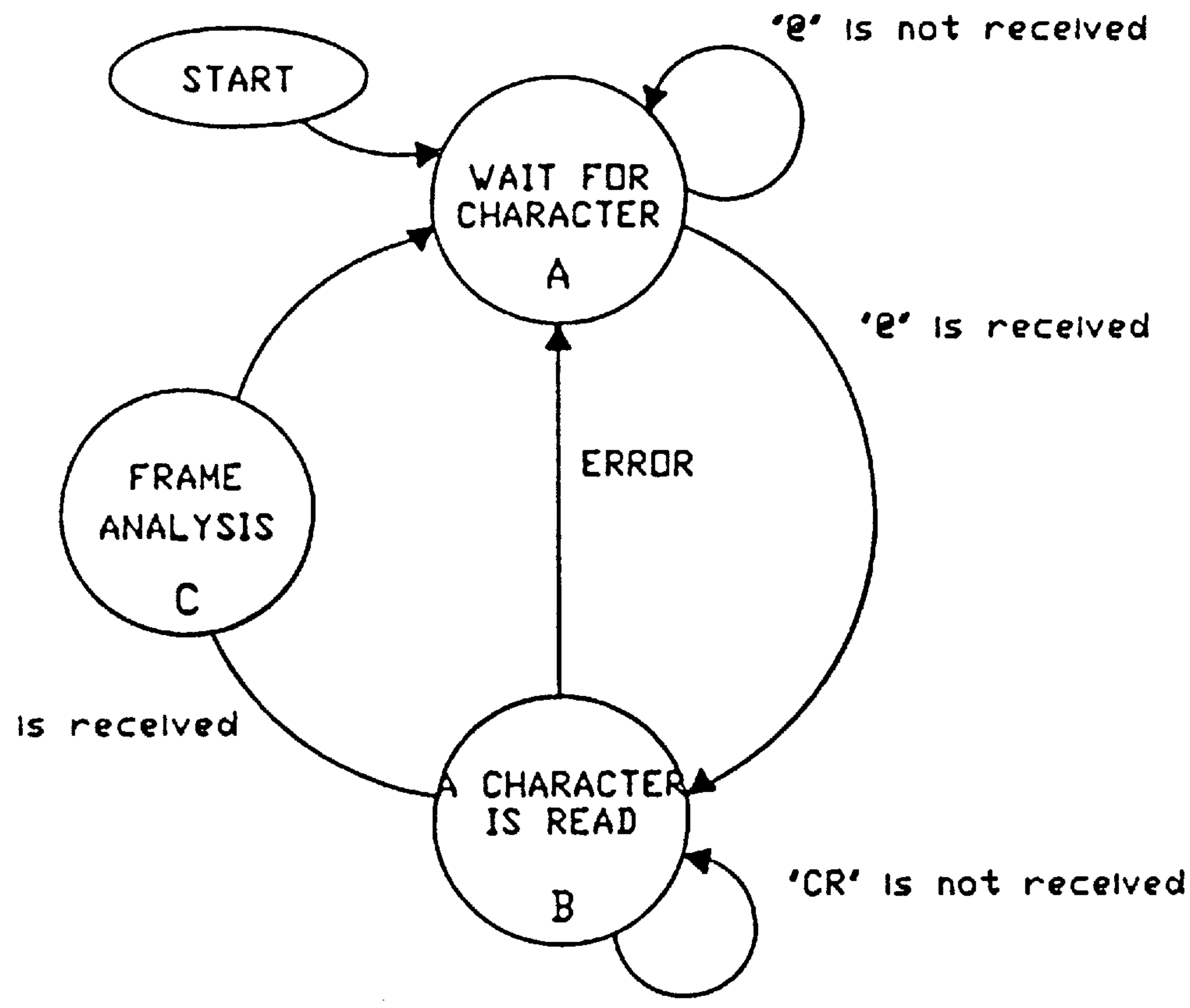


Figure 6. Diagram of state transition: a) of the transmission process; b) of the reception process.

Receiver Service. This service comprises two modules, as follows:

(i) Receiver and frame analysis service. Figure 6b shows a diagram of the transition states of the receiver system. Initially, the receiver is in a waiting state ready to receive the head character of a frame (@), State A in the figure. When it receives this character, then the receiver passes to State B or the "character read" state. All the characters are read and recorded in the main memory one by one, until the "CR" end-frame character is received. Control then passes to the received frame analysis routine and reception switches to the waiting State A.

(ii) Data updating service. An array with the different



secondary stations is defined in the main memory. The data updating service updates the array according to the information contained in the frames received (Section 3.3). The graphic updating procedure of the main program (Figure 5) consults this array to produce a graphic representation of the data.

Keyboard Service. The user may program the system from the central station by means of a set of branch-type menus. The keyboard service is carried out by two modules. A menu control interprets the options selected by the user, i.e. the module detects whether the selected option corresponds to a further submenu or is a terminal option. In the latter case, the module goes to the order-generating procedure for transmission to the remote stations.

Error management service. The central station software also provides an error management service with error report and error treatment segments.

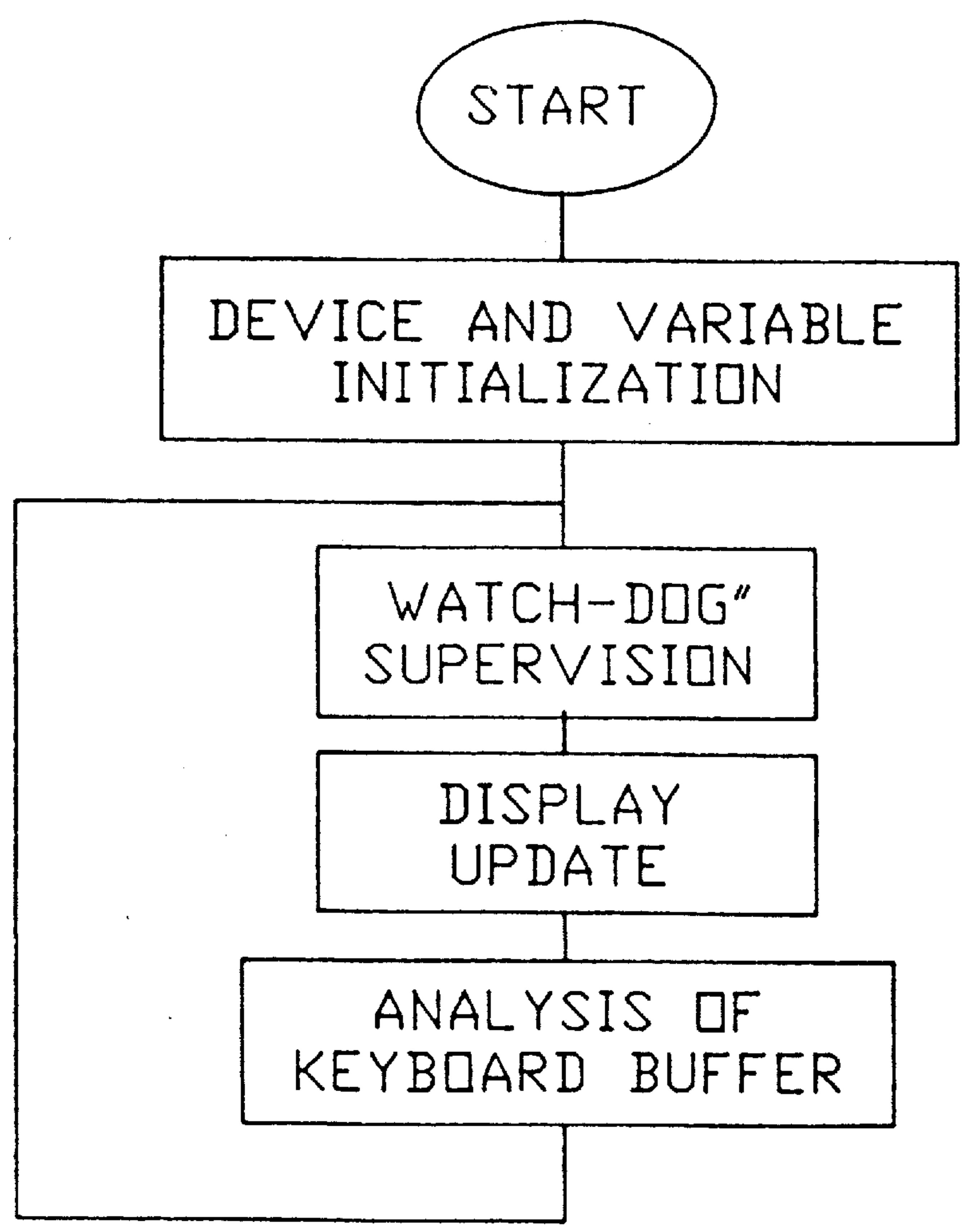


Figure 7. Flow-chart of the main secondary station program.

3.2 Remote Station Software

The remote station software is recorded on EPROM memory. The flowchart of the main program for each secondary station is shown in Figure 7.

Three basic functions are performed in the main loop:

"Watch-dog" Management. In this procedure, if this point of the loop is not passed within a specified period of time, the system automatically goes to a reset position.

Display Updating. Information shown on the display is updated with existing data at specific positions in the memory. The values and positions to be displayed will change according to the keyboard analysis and the changes in memory content effected by the different services.

Keyboard Analysis. This segment is responsible for the management and interpretation of information input in the main memory buffer by the keyboard reading service.

The main interruption services of the remote stations are as follows:

Real-time Timer. This is associated to the following services:

(i) Transmission Timing Service. This generates the time sequences required for CSMA transmission management (Figure 6a). This service is analogous to that of the same name at the central station. It ensures calls to the message transmission service (in State D, Figure 6a) which fills up UART when it is empty.

(ii) A/D conversor data service. This service acts at programmable moments in time marked by the real-time timer. It also ensures that the converters receive the conversion control signal, and that the data read are introduced in an array, defined previously in the main memory. The data in the array are read by the message transmission service, to be sent to the main station, or by the display updating procedure in the main program loop (Figure 7).

Reception and Frame Analysis Service. This is the same as the central station service (Figure 6b). Once the meaning of the frame has been interpreted, the conditions required to carry out the order are set. In the case of an information request, the corresponding response frame is generated.

Keyboard Reading Service. This service captures the code of the key pressed and stores it in the corresponding memory buffer. The analysis of this buffer content is carried out within the main program (Figure 7).

3.3 Transmission Frames

Inside the network, the frames used to link the main station and the secondary stations have the following format:

@	DESTINATION	SOURCE	INFORMATION	CHECKSUM	CR

where:

1. The characters @ (ASCII 100 0000) and CR (ASCII 000 1101) are the flags defining bordering the frame,
2. DESTINATION is the station code which will capture the message,
3. SOURCE is the station code emitting the message,
4. INFORMATION is the information field which may contain orders or response data, and
5. CHECKSUM is a field which depends on the DESTINATION, SOURCE and INFORMATION fields, and corresponds to the 2 LSBs of their sum. CHECKSUM is calculated again in the receiver with the values from the received frame, then this value is compared with the received CHECKSUM field; the frame will only be accepted if both values coincide. Moreover, the individual parity of each character is tested during communication.

The INFORMATION field may contain the following messages:

From Central Station to a Remote Station:

* R A

Analogic data request

* R P

Digital data request

* W X	uu	dd

writing in the relays connected to the X port (where X = A,B,C,D). Each bit "1" in byte uu (2 hexadecimal characters) switches on the corresponding relay connected to the port. Each "1" in byte dd switches off the corresponding relay.

From a Remote Station to Central Station:

* S A	AD0	AD1	AD2	AD3	AD4	AD5	AD6	AD7

The remote station sends analogic samples. The information for each converter is the sum of the last 16 samples of 12 bits read (16 bits or 4 hex characters), thus representing the average value of these 16 samples.

* S P	A	B	C	D

The remote station sends digital data (2 hex characters for each port).

4. Applications

The proposed system may be applied to any process within which measurement or control of distances of analogic magnitudes which are slowly variable in time is required. The following are some of the possible fields of application:

Communal Irrigation Systems. Starting and stopping well pumps, flow measurement, irrigating times, aquifer levels, salinity in water, and so on.

Hazard Prevention. Measurement of rainfall and flow in hydrological basins, measurement of landsliding.

Centralized Alarm System. Fire and trespasser detection with radio warning to central station.

Electric Power Network Supervision. Electric measurements: voltage, intensity, potential, cos (Φ), remote regulation [10–12].

Agriculture. Measurement of humidity and temperature in greenhouses and automatic action on electrovalves and heaters.

Meteorology. Regardless of accessibility, stations can be installed for measurement of rainfall, temperature, wind speed and direction, solar radiation, humidity, etc.

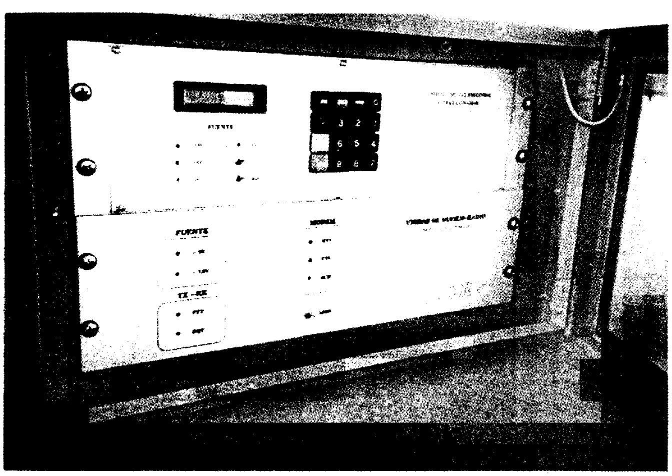
Hydrology. Piezometric measurements and hydrochemical control of underground water with measurements of levels and conductivities.

Environment. Atmospheric and hydrological studies by means of electrodes for pH, specific conductivity, and dissolved oxygen measurements.

Remote Control Water Heaters. Control of the heating elements for residential customers in towns or residential districts [12].

Water Supply or Treatment. Remote supervision of tank levels, pipe pressure and flow, free chlorine, valve position, and action on pumps, valves, chlorine dosers, etc. [7, 13–16].

Our system is currently being used with highly satisfactory results by EMASAGRA, the municipal water company in the city of Granada (Spain) for remote control of water treatment and supply stations. Figure 8 shows photographs of the Secondary Station and Telecommunications Central Unit built to date.



The main functions of SPIRAL in this application are as follows:

1. Remote action on control elements (doser pumps and valves).
2. Processing of data received, with immediate response on warning systems when alarms are given in situations such as excess chlorine content, low levels in storage deposit tanks, excess turbidness and pump failure.

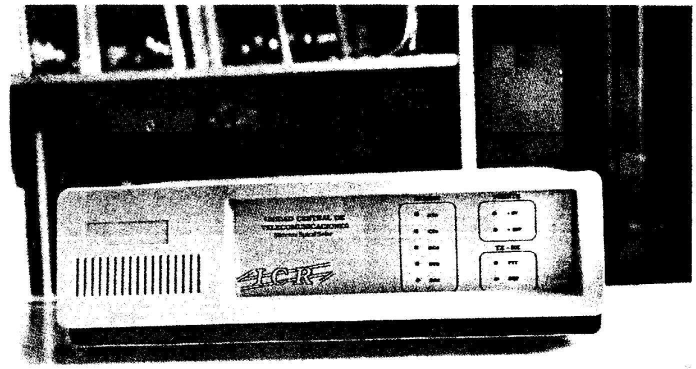


Figure 8. Photographs of the system built (Remote station and Telecommunications Central Unit).

3. Presentation of schematic diagrams for each station in the network with real-time display of changes occurring. It displays the most significant elements of each installation and their changes on a high-resolution colour screen.
4. Graphics of the temporal evolution of each variable.
5. Periodical, written reports of events and actions taken.
6. Storage on a disk file of the historical evolution of the variables measured and actions taken.

6. Conclusions

A system designed and developed to carry out telemetry and telecontrol functions has been described. Its main characteristics include simple station architecture and communication interfaces and protocols and great versatility.

This system provides for the possibility of implementing measurements and remote actions automatically and in real time at low cost and power consumption. The system may also be linked to any kind of commercially available sensor in intensity, voltage or pulse output.

The main advantages of the system include its overall conception and construction, its specific design of the communications board and the remote stations, and its configuration of the software for both central and secondary stations. The simple and useful application of the CSMA transmission method for the system is another advantage.

SPIRAL has multiple application possibilities and is currently being used successfully for the remote control of water supply and treatment by a water supply company in the city of Granada (Spain).

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