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# Telemetry and control system with GSM communications ☆

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**Abstract**

This paper describes an electronic system for telemetry and control applications of distributed systems. It consists of a portable electronic circuit (portable module) that can be connected up to various types of sensors depending on the application to be used in each case, together with a mobile-telephony communications system. Different portable modules can be used to build up a communication network governed by a central control unit (personal computer and communications system); communication can be established from the control centre with any portable module for sending or receiving information; it is also possible to modify the application programme executed in each portable module by the teleprogramming of the microcontroller system built into the latter circuit. Two applications of the network as set up are shown: analysis and transmission of a patient's electrocardiogram and the sending of a low-resolution video signal.



*Keywords:* Telemetry; Control; Mobile telephony; Machine-to-machine; Microcontroller; Electrocardiogram; Video

## 1. Introduction

Mobile communications have developed at breakneck speed in recent years. Mobile telephones today, with their various services [1] and types of network [2], are products of mass consumption, with very affordable prices, compact sizes and low energy consumption; the services that users may obtain from their mobile telephone depend above all on the operator supplying the service. Thus, apart from the typical telephony services (calls, SMS, voice mailbox, etc) there is also a trend towards incorporating new functions: geographical localisation of the mobile phone, news, advertisements to suit the user's geographical location, etc [3,4].

One of the applications that have not yet been sufficiently developed is the interconnection of industrial systems (telemetry and control). 'Telemetry' can be defined as the capacity of capturing, processing and sending system data, while 'control' is understood as the capacity of acting on the system in question, generally in accordance with the data sent by the system itself. Both concepts assume the existence of a two-way communication channel.

Machine-to-machine (M2M) communication between mobile, portable or stationary devices (clients) and centralised servers is estimated to get an exponential growth in the coming years and certain studies rate its growth prospects as being even higher than that of the voice market [5]. This will open for new ways to utilise the networks. To illustrate the possibilities for M2M communication, e.g. devices can be used for remote control, surveillance, tracking, localisation and telemetry. This type of communication device is today often made up of a wireless module, containing the mobile station (e.g. an ordinary mobile station without display and buttons), and additional application specific software added by a system integrator. The device can then be connected to the equipment that shall be controlled, for example a surveillance camera, the computer within a car or a soft drink machine.

Without doubt one of the fields that has most spurred the data-transmission use of mobile telephony is telemedicine. This is a field with enormous healthcare advantages and has therefore received generous aid from public bodies such as the european commission. Ref. [6] shows the state-of-the-art wireless telemedicine system; different systems are analysed based on GSM, GPRS, Bluetooth or LAN technology

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and work on several prototypes developed in various research projects is shown.

One of the problems that might crop up when setting up a telemedicine system is the bandwidth. The transmission of a radiograph image, for example, might take up as much as 40–50 Mbytes. In many of these systems it is therefore necessary to set up information compression systems, such as the JPEG standards, always without any appreciable loss of information. It would seem to be unfeasible to use a conventional telephony channel such as GSM for transmitting this type of information but it could indeed be useful for transmitting other physiological signals requiring a narrower bandwidth, such as the electrocardiogram (ECG), body temperature, blood pressure, oxygen saturation, etc [7].

The mobile telephony technique can be used for telemetry and control functions when the following obtains:

(i) there is coverage
(ii) the data transmission delay (SMS or call) can be random, even within very wide margins.
(iii) when service interruptions are tolerable, meaning that it cannot be used in critical safety tasks.

The advantages of the system are its affordable cost, the existence of a communications infrastructure covering most regions and the fact that the system to be controlled can be on the move.

In a telephone communications system the two-way transfer of information can be carried out in two ways:

- Setting up of a call and transfer of information in data mode. This possibility allows data to be transferred at the rate of 9600 bps in the GSM network. Theoretically the speed is higher in GPRS (115 Kbps dedicating 8 time slots to a single call and not activating any data protection) although the normal rates in practice are 56 Kbps [8].
- Transfer of information by short messages (SMS), with a maximum message length of 160 characters.

In the first case, once the call has been set up, the maximum data transmission delay between sender and receiver is likely to be about several ms; in SMS mode, however, this delay is unpredictable, as it depends on the message handling centre (normal values would be about 20 s).

This paper presents a telemetry and control system for mobile-telephony interconnection of several elements of diverse functions; it therefore harnesses the advantages of the mobile telephony transmission network. The general system architecture is shown in Fig. 1; the aim is to set up a communication network formed by an indeterminate number of nodes (Portable Modules, PM), controlled by a personal computer in which the network control application is run (Control Centre, CC). Communications between the network elements is by way of mobile telephony data transfer using SMS or by setting up a call in data mode. Mobile telephony provides a two-way communications channel, with access to any point with cover and at a cost that depends mainly on the amount of data to be transferred.

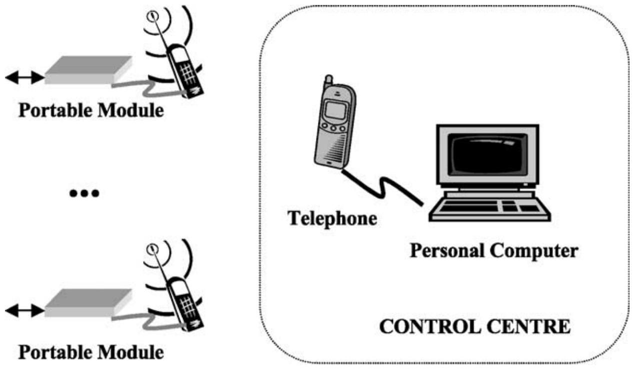

Fig. 1. General Architecture.

The Control Centre is made up by a personal computer and the suitable communications system (normally one or more mobile telephones). The CC software obviously depends on the network characteristics, but it must in any case be able to handle communications (calls and SMS messages) and also provide for the following functions: allowing authorised users to add to or remove a PM from the system, allocating the telephone numbers, making operational queries, teleprogramming of the application software in each PM, fixing the alarm levels, etc.

The electronic system making up each one of the portable modules consists of a microcontroller-based electronic circuit, thus providing an open system that can be reconfigured at software level; the system can be adapted to the characteristics of the environment to be monitored and/or controlled. Another of its advantages is the possibility of modifying the application software that is running in the microcontroller (teleprogramming) by sending the appropriate command and software via the communications system.

The range of possible applications is vast. By way of example this system could be used for controlling a set of vending machines, lift machinery, tracking a fleet of vehicles on the basis of the cell that gives coverage to the mobile, low-speed image transmission and even telemedicine applications, such as the analysis of certain parameters and the sending of a patient's ECG to a control centre. The limitations of the system, based on the current limitations of the transmission channel, are determined by the amount of data to be transmitted per time unit. It will only be viable, therefore, when said amount is not very high.

The aim of this research work is to create a hardware platform for implementing M2M services, including telemedicine services. The success of the platform will be determined by the flexibility and capacity of the portable modules. It is vital for the system to have a high number

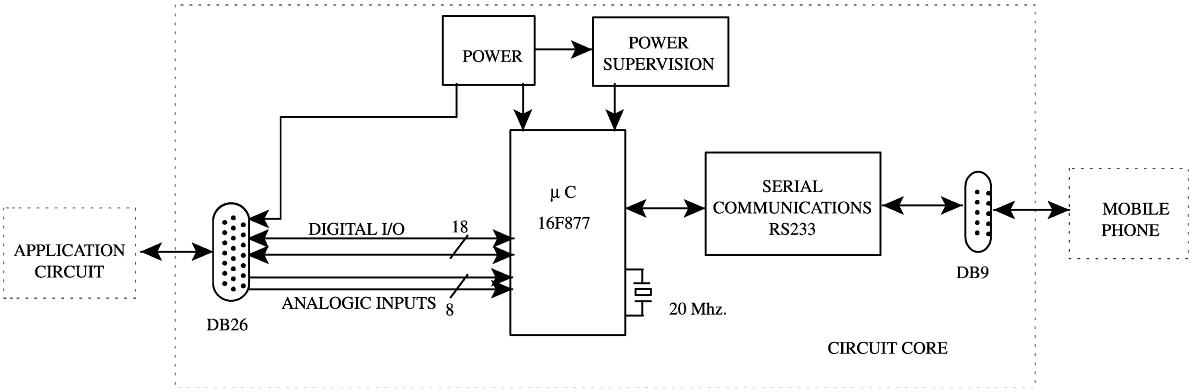


Fig. 2. Hardware of the portable modules (core).

of inputs/outputs and to be reprogrammable. It also needs to be economical in cost and consumption and re-scalable so that it can be used in a great variety of applications with the minimum modifications.

The main aim of this paper is to give a detailed description of the characteristics and possibilities of the portable modules. They have been designed with the idea of developing a basic hardware system, which could be used to solve a host of problems, with the minimum number of modifications or alterations to the original structure.

This paper has been broken down into the following sections: first of all a description is given of the hardware architecture of the portable modules; Section 3 shows the characteristics of the software that can be run on the microcontroller and explains how the application is remote-loaded. A description is then given of two applications that can be based on this platform: an application of the system for the analysis (Heart Rate Variability (HRV)) and transmission of a patient's ECG (Section 4) and another for the low-speed transmission of video images (Section 5). The article ends up by recapitulating the main ideas developed therein.

## 2. Hardware of the portable modules

The overriding idea in developing the portable modules was to keep them small in size and economical in energy consumption but with a high flexibility in terms of adapting them to various applications and also with ease of communications.

To this end a basic architecture has been designed (core) that is invariable in all portable modules (Fig. 2); the core has the minimum requisites of an autonomous system: power supply, a microcontroller and the mobile telephony communications channel. An 'application circuit' will be connected thereto, the type depending on the application to be used in each case. The core of each PM is based on a microcontroller, a power supply system of $+5$ V with a power supervision facility, a serial communications block for the two-way transmission of information through a mobile telephone using a DB9 type connector and a set of digital and analog inputs/outputs and analog inputs, allowing the system to receive information and act on external elements. These inputs and outputs, plus the power supply lines, are fed into a connector (DB26) for connection to the core of the appropriate application circuit.

A PIC 16F877[1] microcontroller is used (although another of the same family might be used with the same pin number and greater capacity). It is an 8-bit RISC circuit with 8 A/D converters, 3 timers, PWM signal generators, serial and I2C communication, working with a clock frequency of 20 MHz; the latter can be upped to 50 MHz if a superior version such as 18F452 is used. Its internally implemented RISC architecture gives an instruction runtime of between 80 and 200 ns depending on the oscillator chosen. The cost and capacity of this microcontroller, in terms of the number of A/D converters, digital inputs/outputs, timers, etc, make it suitable for a great number of applications.

Communication between a mobile telephone and the platform is effected via a serial channel (needing only the lines Tx, Rx and GND). The board has a serial channel prepared for it and the telephone will need a connection cable running from its control terminals to the PM, one end of the cable being a DB9 connector. Communication between the μC and the mobile phone is effected with AT commands defined by the manufacturer [9] (configuration of the telephone, reception of calls or SMS, sending of SMS, etc) at 19.2 Kbps.

The core of the hardware system is the same in all the different PM configurations. The appropriate application circuit will be used to suit the application's characteristics; both will be connected by the DB26 connector.

The core serves to activate or receive data from remote systems that emit the right signals: digital signals with levels of 0 and 5 V and analog input signals which can be digitised by the AD converter of the μC. If the input signals or

[1] http://www.microchip.com

the outputs to be worked with are more complicated, an application circuit has to be used, as in the case of the two applications examined in this article.

## 3. PM software

The microcontroller programme has been structured in two parts (Fig. 3):

- *application*: This is the programme that is run for the functions of telemetry and control (normal system application). It is housed in the microcontroller's internal FLASH memory. Its ability to write in the memory on line (without needing to stop the microcontroller) makes it possible to reprogramme the application. This part of the code is loaded by a data mode call with a suitable key for that purpose. An special application is needed in the CC to generate a machine code of the microprocessor and send it in a suitable format.
- *resident*: This is the part that controls the interruptions and reprogrammes the application. It is hence not usually activated and is brought into action only by a predetermined event. One of these events will be the reconfiguration of the application. The resident part of the programme will allow communications to be effected only by means of a call; if the application needs to handle SMS, therefore, the message handling functions will have to be programmed into the application.

The resident programme starts in the 0004 h position of the programme memory map (interruptions vector) and sees to the following functions: control of interruptions, communications between the PM series port and the mobile telephone (reception of a call in data mode), decoding and processing of the commands received via the communications channels and recording the application programme in the programme memory. A protocol is established to find out how much the new application occupies: initially only a header is sent with information on the application characteristics. This information includes the size occupied by the application so that the resident programme can keep track of bytes received and correctly run the microcontroller's memory map. In these circumstances the application programme may be received by mobile telephone and may be modified in the same way as many times as may be deemed necessary.

To set up a call the microcontroller generates the suitable AT commands; the telephone number to be called is stored in the EEPROM of the PIC (small 64 byte auxiliary memory); should the number dialled be engaged or go unanswered, the system automatically dials another alternative number, stored in a circular, totally reprogrammable list. Once the call has been set up the programme controls the sending of data and the reception of information sent from the CC.

The system has the capacity of sending SMS and receiving them at any moment by suitably manipulating the telephone's AT commands. When the telephone receives an SMS it sends a command by its serial port, tripping an interruption in the microcontroller; in the attention subroutine the SMS content is passed to the microcontroller's memory. The SMS is erased from the telephone's memory and the microcontroller decodes the SMS received and acts accordingly.

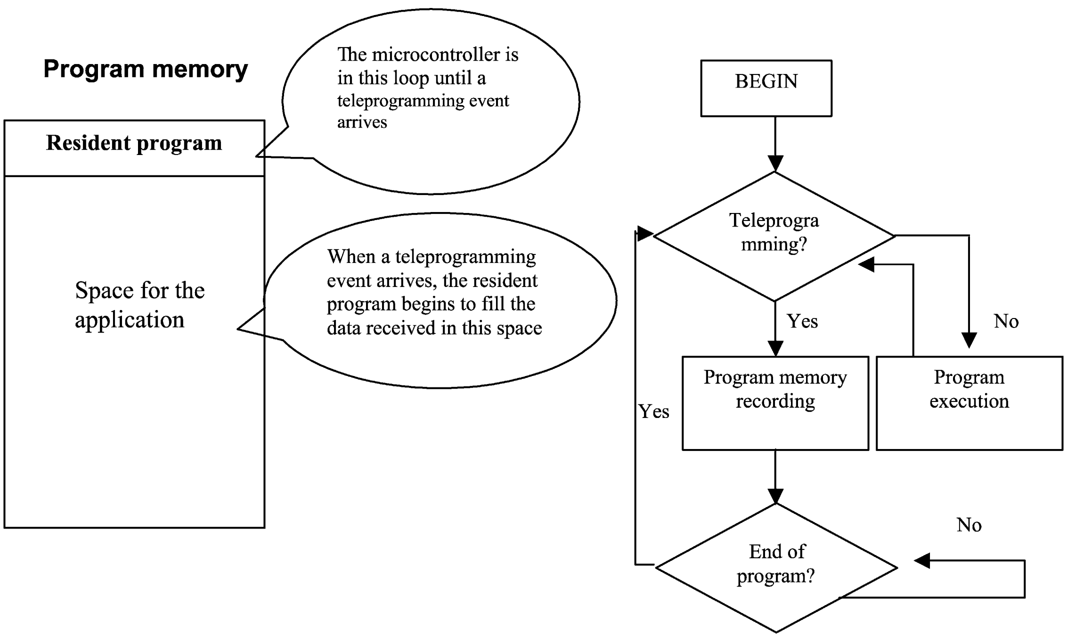


Fig. 3. Flow diagram of the microcontroller programme.

To send an SMS the microcontroller generates the corresponding frame and sends it to the telephone through the RS232 communication.

The application programme depends on the function to be given to the PM; in the following sections examples are given of two practical applications. The first deals with the implementation of a system for capturing ECGs and processing them to find out the time between R waves and set up communication with a CC according to the data processed. The second harness the system's ability to send images from a remote site to a CC.

## 4. Implementation of an ECG pickup and processing system

The remote capture and analysis of physiological signals is a field of great interest, since it would significantly improve many patients' quality of life. There are several portable systems that perform that function, using radio-frequency links [10], mobile telephony [7,11], Internet [12] or satellite communications [13] as the means of communication.

One of the signals that furnishes a great deal of information on the physical state of a patient is the ECG; the ECG signal has amplitudes in the range ±2 mV and a bandwidth of no more than 50 Hz; it is hence a low-frequency signal suitable for telephony transmission.

Heart rate variability (HRV) is a parameter of great interest in cardiology [14]; this system involves detecting the patient's ECG and measuring the time interval (the time between R waves, for example). This variability is caused by functioning of the circulatory control system plus external influences. Under normal conditions the heartbeat rate is higher by day than by night. The existence of a lower variability might be indicative of some sort of heart disorder. This test is conducted over periods of time of 24–48 h, so the patient has to be fitted with a portable system to store the RR interval signal in a suitable recording medium. The recording is then analysed by the doctor with semiautomatic methods.

The electronic system we have developed performs the following:

(i) continually digitises the patient's ECG.
(ii) Automatically measures the RR interval.
(iii) Should the reading obtained stray from certain preset margins the signal is sent by mobile telephone to a medical attention centre (CC).
(iv) It is also possible for the CC to ask the system to transmit the patient's ECG in real time.
(v) At any moment, by means of an SMS, the PM can receive a message to change its operational parameters, the telephone numbers it sends data to, sampling frequency, thresholds, etc.

The main advantage of this system is that the patients' data are shown in real time, so these patients can then be attended at any moment; this can be of great interest in the follow-up of out-patients. Data collection protocols at home or care institutions can be carried out for data logging purposes.

The hardware of the application circuit of this application is shown in Fig. 4; the object thereof is to modify the ECG signal so that it can be digitised (the sampling frequency is a parameter that ranges from 50 to 250 Hz.) by the microcontroller's internal AD converter (dynamic range between 0 and 5 V) (Fig. 5). The circuit consists of an amplifier (formed by an instrumentation amplifier-INA111- and a non-inverting amplifier) with a bandwidth of from 0.01 to 50 Hz and gain control and off-set control digitally adjustable by two programmable resistors X9C103, on the basis of commands generated by the microcontroller: the signal to be digitised is thus brought into line with

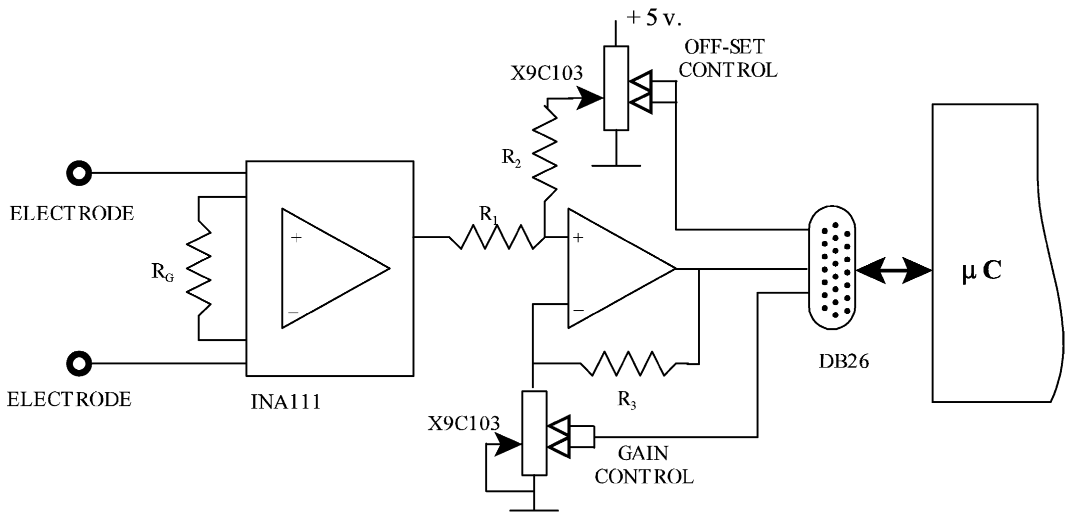


Fig. 4. Electronic diagram of the ECG amplification stage.

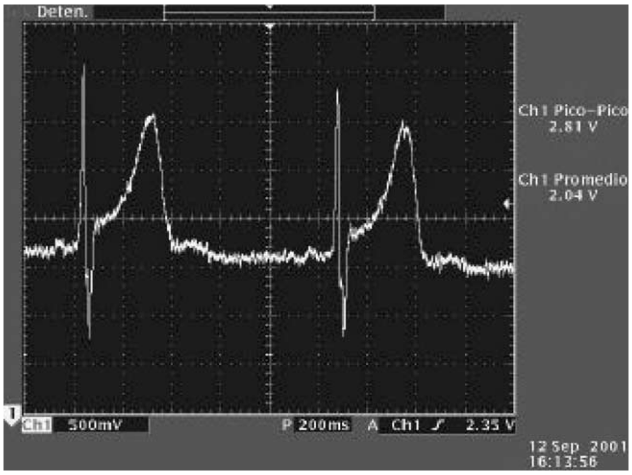


Fig. 5. ECG at the output of the amplification stage.

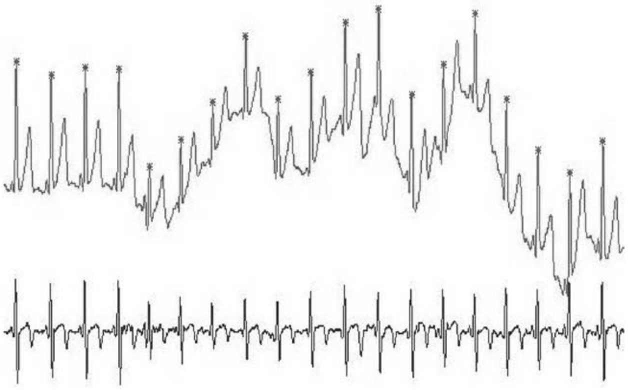

Fig. 6. Example of the detection of the RR time interval in an ECG. (a) ECG signal. (b) First derivate.

the characteristics of each patient (heart-electrode impedance, electrode displacement, loss of electrode properties, etc.).

The μC software controls the signal digitalisation process and checks that the R wave reading is trustworthy; the digitised signal is filtered by software to improve its characteristics [15] and the R wave readings are detected from sharp changes in the ECG. Fig. 6, for example, shows the behaviour of the R wave detection algorithm when there are great variations in the baseline of the digitised signal. The system then measures the time interval between R waves; should these not fall within a given margin as indicated by the CC, an SMS message is sent indicating a possible alarm in the patient. Normally in this case the PM will receive a message from the CC telling it to send the ECG to a prefixed telephone number by setting up a call in data mode, so that the ECG can be seen by a medical specialist.

Microcontroller commands can be used for varying the gain and off-set of the ECG signal's amplification stage, so the system can be adapted to the characteristics of different patients. To do so a signal transmission is requested from the CC and displayed on the monitor; by means of an interface, commands are sent to adjust the gain and off-set until the signal has the required dynamic margin. With this function it is possible to adapt the system to different persons or correct the effect of a loss of electrode properties with use.

## 5. System for transmission and/or analysis of video images

Another of the applications that can be carried out by a PM is the transmission and/or analysis of video images. The main limitations in this case are:

- the images have to be transmitted at low speed.
- if the algorithms are implemented in the μC, the automatic analysis of the images has to be very simple due to the computational load.

The image capturing system used is the 128 × 128 pixel artificial retina M64283FP (MITSUBISHI) [16] with analog output. One advantage of this integrated circuit is that it can itself carry out basic processing operations of digital images, such as mask filtering, edge detection, etc.

In this case it would not be worthwhile using the microcontroller's AD converter as the signal digitalisation

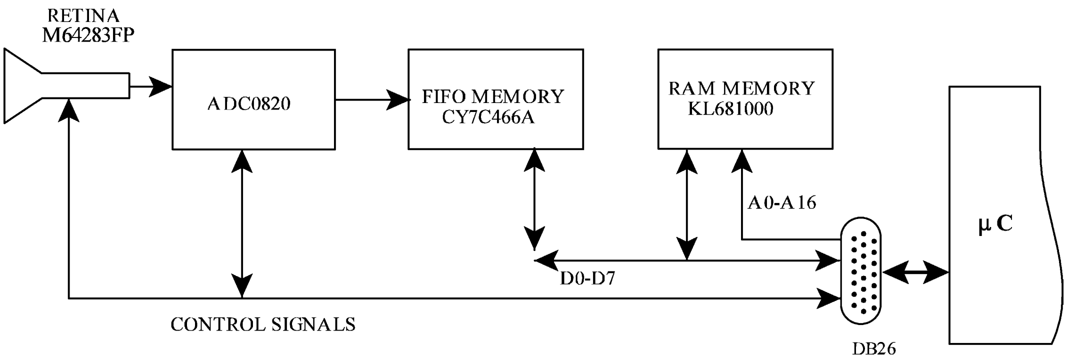


Fig. 7. Block diagram for video capture.

time would be very high. The following system was therefore decided on: once the image pickup order has been received, the image is digitised as quickly as possible and stored in a FIFO memory (Fig. 7); while this process is underway the microcontroller can carry out other functions. Once the image capturing process is over, it is then sent by mobile telephony.

The retina's analog signal is digitised with the ADC0820 converter, with a resolution of 8 bits and a maximum conversion time of 2.5 μs. Once obtained, the digital code is then stored in the FIFO memory.

The CY7C466A memory of YPRES is used to store the data before the subsequent processing and/or transmission thereof. This is a FIFO of 64K words by 9-bit wide with full and empty flags to detect overrun and underrun. The storage capacity of images and/or data is amplified by means of a RAM (KL681000) of 128 Kbytes; this is used mainly for image processing and when access is required to the value of any of its pixels, a process that is more difficult in the FIFO memory.

The image processing level is limited by the memory available in the system (in the system as developed, the 64K FIFO memory can store up to 4 images and the RAM memory 9 images) and the programme that can be run in the microcontroller; the system can therefore be applied in those cases that can be solved by simple algorithms, such as the detection of changes in certain parts of the image, detection of movement, etc. The aforementioned hardware system is used for detecting scene changes in a telemonitoring system; to solve this problem the image, once captured and stored in the FIFO memory, is sent to the RAM, where it is possible to accede arbitrarily to those areas of the image (Region of Interest) that it might be necessary to analyse; in this case a comparison is made between the levels of grey in several areas of the image in consecutive images. Should a change in image characteristics be detected, the system can

Fig. 8. Image transmitted.

immediately send the video signal to the CC or send an SMS for the CC operator to act accordingly. Fig. 8 shows an example of an image sent by the system; the time needed for capturing, digitising and storing the image is 160 ms.

The limitations of the implemented system for the transmission and/or analysis of video signals are the following:

(i) Capture, digitisation and storage time in the FIFO memory of the image.
(ii) The implementable algorithms must be simple and quick to run so as not to increase the time between image captures.
(iii) The image transmission speed is 13 sg.
(iv) The low image resolution ($128 \times 128$).

A new version is currently being designed and tested to improve on these characteristics. This new system has the following features:

(i) A webcam is used as the sensory element; these are low-cost systems that deliver a digitised signal via a USB bus, also augmenting the image resolution and thereby solving limitations (i) and (iv).
(ii) Problem (iii) can be solved by working on two fronts: carrying out an image compression before transmission or using a transmission channel with a greater bandwidth. The image compression can be carried out by software or by hardware. The latter method has been chosen, using an FPGA for implementing the MPEG-1 compression algorithm. As for the possibility of increasing the bandwidth this will be determined by the use of new mobile telephony terminals: GPRS, UMTS, etc.

The system described can be used for control functions. Once the image has been transmitted, an SMS command or data mode call can be sent from a supervising centre for the hardware system to act on one or several digital outputs.

## 6. Conclusions

This article presents an electronic telemetry and control system with a communications system based on GSM technology. Used in conjunction with a microcontroller-based system and the remote-loading of the application, this system can be adapted to a host of applications. Results are shown of a system for the capture, analysis and transmission of a patient's ECG and another system for the transmission of video signals.

The use of other microcontrollers of the same family will allow the system to work with larger application programmes and will also speed up the data processing.

The implemented architecture provides great versatility in system application. At hardware level it is a modular system in which the core remains invariable and only the application circuit is changed to suit system needs. As for the software, it can even be remotely downloaded, considerably increasing the flexibility of the system developed.

Commercial GSM terminals are used for data transmission but the system can be updated to new versions, such as GPRS, UMTS or other systems such as personal handyphone system (PHS).

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