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An embedded control and acquisition system for multichannel detectors

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Abstract

We present a pulse counting multichannel data acquisition system, characterized by the high number of high speed acquisition channels, and by the modular, embedded system architecture. The former leads to very fast acquisitions and allows to obtain sequences of snapshots, for the study of time dependent phenomena. The latter, thanks to the integration of a CPU into the system, provides high computational capabilities, so that the interfacing with the user computer is very simple and user friendly. Moreover, the user computer is free from control and acquisition tasks.

The system has been developed for one of the beamlines of the third generation synchrotron radiation sources ELETTRA, and because of the modular architecture can be useful in various other kinds of experiments, where parallel acquisition, high data rates, and user friendliness are required. First experimental results on a double pass hemispherical electron analyser provided with a 96 channel detector confirm the validity of the approach. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The recent availability of third generation synchrotron radiation sources is opening many new opportunities in the field of experimental physics. These opportunities, however, can be exploited only if suitable new acquisition hardware [1] is developed. A fundamental acquisition improvement is given by the use of parallel readout which strongly increases the efficiency of detection systems in many kinds of spectroscopies [2].

For example, in photoelectron spectroscopy experiments, where an electrostatic energy analyser is used to disperse photoemitted electrons with different kinetic energy [3], the high intensity and brilliance of the source makes it possible to perform fast data acquisition [4,5]. The present limit, however, is the time required to scan the kinetic energy. Were "snapshot" data acquisitions possible, the

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time scale of the surface phenomena to be studied would be decreased by at least one order of magnitude. However, to reach this result, it is necessary to be able to acquire several energy channels simultaneously (typically 100 is a good number of points in a core level spectrum to resolve 2–3 peaks), and with very large data rates; as a consequence, specific electronic instrumentation is to be developed, in order to solve problems such as channel crosstalk, poor integral nonlinearity [6], and in order to deal with the increased number of channels in comparison with the detector systems at present available [1]. Another important issue is related to the system ease of use and flexibility so that: (a) users do not have to worry about the details of control and data acquisition, and (b) the system setup can be easily changed or updated according to the needs of the experiment. Moreover, the use of state-of-the-art technology allows to significantly reduce the nonrecurring engineering costs with respect to previous conventional setups and in comparison with solutions based on expensive and complex crates.

In this paper, the multichannel acquisition system under development at the Elettra laboratory is described. This system has been tested on a double pass hemispherical analyser [7,8] incorporating a multidetector of 96 discrete anodes which is going to be installed on the SuperESCA beamline [9], where it will be used for fast XPS experiments [4,5]. However, it must be kept in mind that its modular and embedded architecture allows it to be used in a large number of physics experiments, in those cases where position sensitive detectors are used.

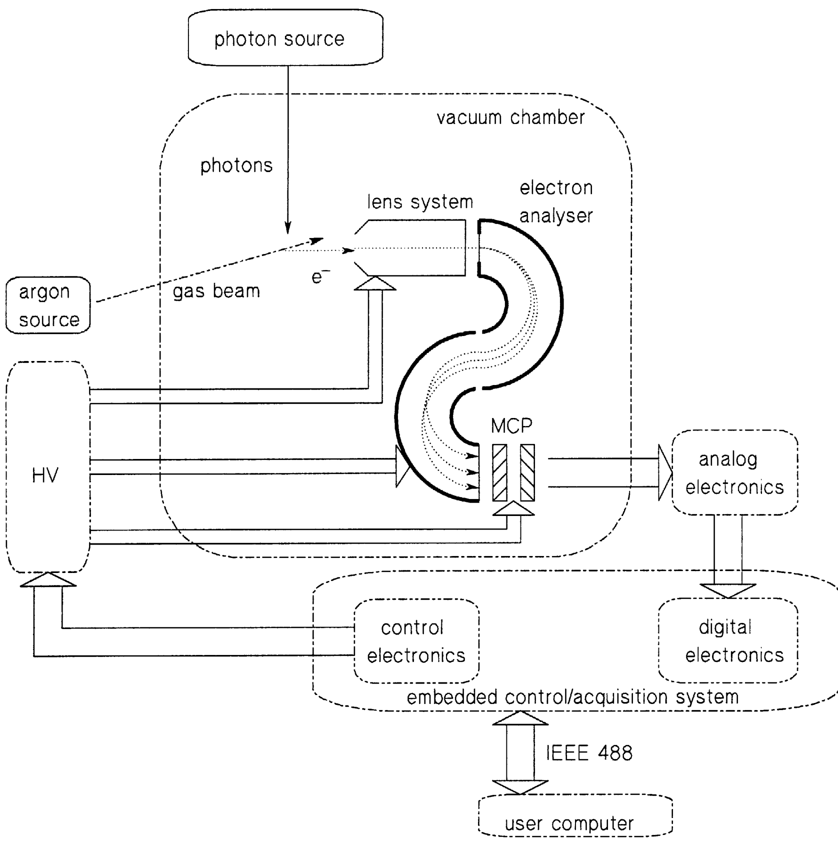

Fig. 1. Block diagram of the control and acquisition system. The setup for the preliminary test is shown, with a UV lamp as radiation source.

In the following, we first give a general description of the overall experimental setup, with reference to the SuperESCA experiment; then we analyze in more detail the experimental chamber, the analog electronics for acquisition, and the digital electronic section with the counters and the embedded controller. Finally, some preliminary experimental results with the new system are reported.

2. General description of the system

The block diagram of the system is presented in Fig. 1. Electrons emitted by the sample, either by photoelectric effect or by electron excitation, are energy-dispersed by an electron energy analyzer (Fig. 2), then they are collected by a detector, which consists of two microchannel plates (MCPs) in chevron assembly, and proximity focused onto 96 discrete gold anodes evaporated on an Al_2O_3 substrate. Each anode of the detector is connected via ultra high vacuum feed-throughs to a preamplifier/thresholding unit. The maximum input rate is higher than 20×10^6 counts/s/channel, well above the microchannel plate limit; the time window can be as short as 70 ns, or, due to the considerable depth of the counters, as long as 400 s at the highest input rate.

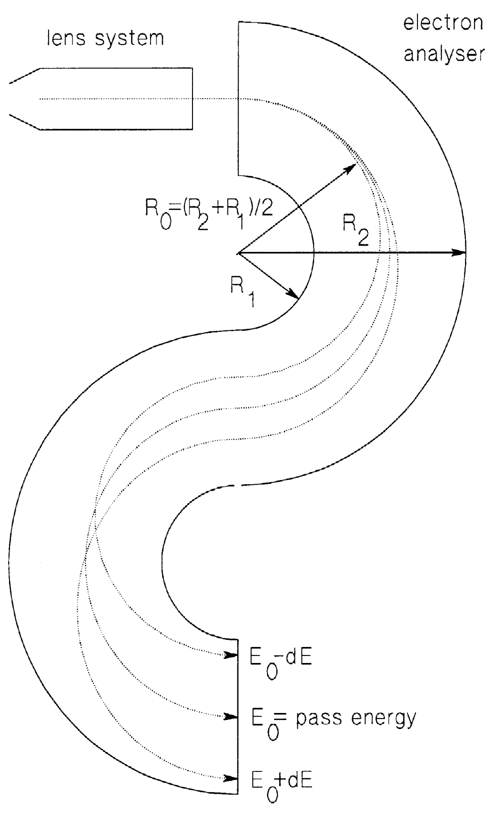

Fig. 2. Energy separation of the electrons according to their energy in a spherical electron analyzer.

The embedded control system supervises the measurement and takes care of the counters management. It is interfaced with the user computer via a standard interface (IEEE 488) and/or by an Ethernet connection. Through these links, the user can specify the experiment parameters (number of channels, counting time window, energy range, etc.). The embedded control system can also take control of the experiment by setting the polarising voltages of the electron analyser. In this way the system manages data acquisition autonomously and retains the acquired data until the user downloads them.

The digital electronics section (i.e. counters and controls) has been implemented on PC/104 cards, thus obtaining a compact, lightweighted system. Moreover, it is based on the ISA bus, which has been chosen for its simplicity, low cost, and widespread availability of hardware and software. Another advantage of the IEEE PC/104 standard is given by its large bus driving capability, which allows the connection of a large number of expansion cards, thus ensuring a very high flexibility of the system.

3. Experimental chamber

A very simple experimental setup was adopted for preliminary tests of the system (see Fig. 1): it consits of a cell containing the gas of interest (the target, Argon in our case) and a UV lamp; the photon beam is passed through the cell orthogonally to the lenses axis of the electron analyser. A gas cell is used rather than a gas beam because of the longer interaction path and the resulting increase in signal. The ionization zone in the gas cell is imaged by a suitable electrostatic lens system on the entrance slit of a 150 mm double pass electron analyzer [8].

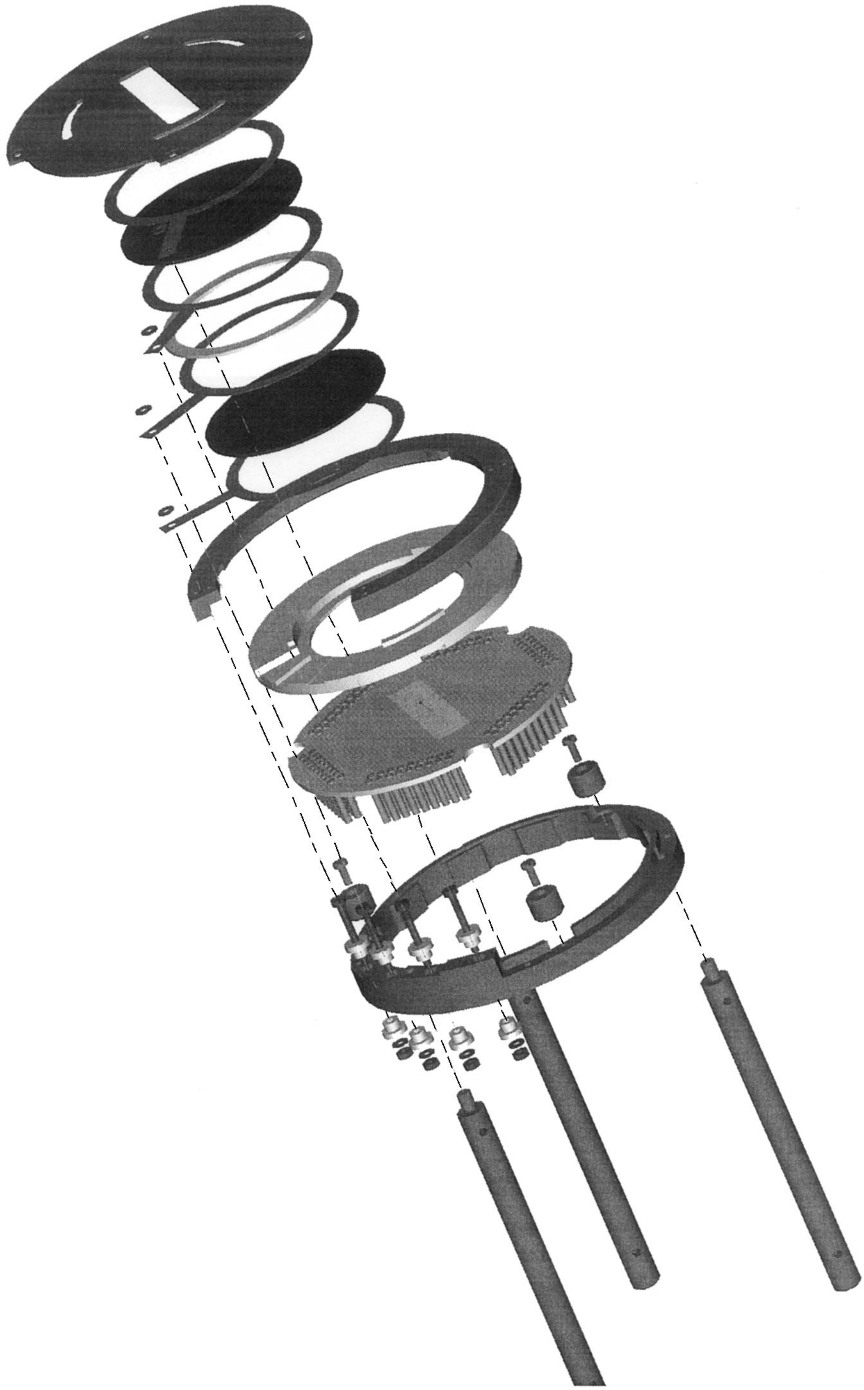

Fig. 3. View of the 96 channel detector assembly.

Two Philips G12-46/A MCPs in chevron assembly at the exit of the monochromator sense the energy-dispersed electrons (Fig. 2). Each MPC is biased with 900 V, voltage which is sufficient to cause a saturated pulse height distribution. The bunches of electrons at the exit of the second MCP are collected by a multiple anode which consists of 96 gold strips 0.32 mm wide deposited onto syntherized alumina. The anodes are 0.15 mm apart from each other, without any grounded guard line in between; tests have shown that grounded guard lines increase cross-talk between adjacent channels, this being probably due to the large value of the impedance between ground and guard lines, given the small cross-section of the latter. The strips are slightly bent according to the theory [10]. A view of the detector assembly is presented in Fig. 3.

4. Analog electronics

The analog part of the acquisition electronics is shown in Fig. 4. It is hosted in a box immediately outside the vacuum chamber, and consists of bias, coupling, and protection circuits, and of a preamplifier and thresholding unit.

The signals are extracted from the vacuum chamber using custom 50 pF capacitors, which provide AC coupling and HV (up to 4 kV under UHV conditions) isolation for the following circuitry, kapton insulated shielded cables, and two 50 channel ultra-high vacuum feedthroughs. The use of shielded cable, instead of a coaxial one, has been forced by the high rigidity of the latter, which made the bunch of cables extremely difficult to manipulate. Each line has been loaded using a 51 Ω resistor, in order to set the input impedence of the module to 50 Ω.

It has to be noted that the choice of adapting the transmission line from one hand avoids signal reflections, from the other significantly reduces the signal amplitude. This fact does not degrade the performance of our system, because of the high sensitivity and low noise of the following stage, which is described below. In turn, the possibility of signal reflection has to be carefully considered. Indeed, if we consider a transmission line length of, e.g., 1 m, the propagation delay turns out to be about 5 ns, too long for the short (less than 1 ns) pulses coming from the MCPs. Another advantage of the low input impedence is the reduction of noise pickup.

Each signal is suitably amplified by one channel of a 16 channel Microchannel Integrated Charge Amplifier (MICA) integrated circuit [11], which also converts the pulses into digital signals. Each MICA input is protected using two BAW13 diodes and a 100 Ω resistor, and is operated with tail cancellation mode disabled, due to the very short duration of the pulses to be detected. A threshold may be adjusted to change the input sensitivity.

This circuitry has been included in a set of hybrid circuits (CHYBA, Charge Hybrid Amplifier). Each CHYBA has a metallic case, is 46.5 × 33.8 × 4.0 mm large, and processes 16 channels. Results of bench

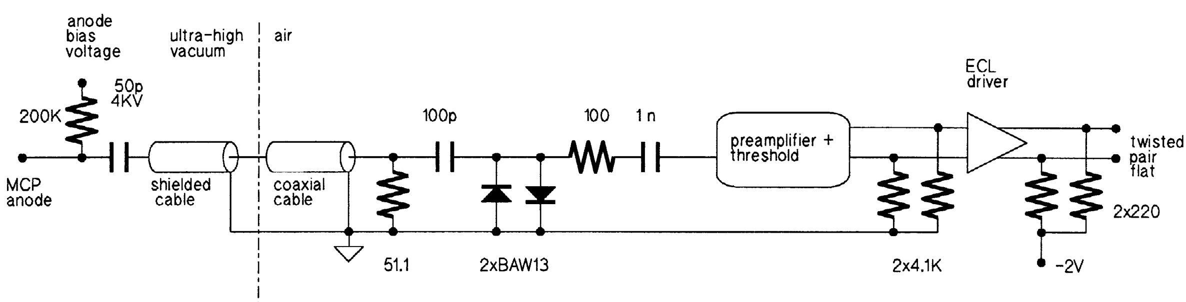

Fig. 4. Analog electronics (for one channel) for anode bias, AC coupling, protection, preamplification, and thresholding. Preamplification and thresholding for 16 channels are performed by a single MICA [11] integrated circuit.

Table 1
Results of bench tests on the CHYBA hybrid circuit

Channel input impedence	1540 Ω//4.2 pF
Maximum input sensitivity	3×10^4 electrons
Input sensitivity tolerance	10%
Crosstalk between channels	− 23 dB
Temporal resolution	50 ns

tests on the CHYBA are reported in Table 1. In particular, pulses of 10^5 electrons may be distinguished when they are at least 50 ns apart.

The thresholded pulses are available at the output of the MICA as ECL pulses. Each MICA output is then buffered using a Motorola 100314 ECL line driver, which is connected using a twisted pair flat cable to the digital electronic section, which is described in the following.

In all the analog section, particular care has been given both to ground quality and to bias voltages and power supply filtering, in order to avoid false counts due to noise and/or channel cross-talk. In particular, the supply of each module has been filtered using a double π cell RLC filters; ground loops have been avoided at each system level and a solid metal plane has been used in the box containing the CHYBA circuits.

5. Digital electronics for data acquisition and system control

In Fig. 5, the block diagram of the digital electronics part of the acquisition system is shown. It is hosted into several PC/104 cards. The ECL signals coming from the analog module are first translated into TTL levels using Motorola 100325 ECL to TTL converters; all the subsequent digital logic is implemented in TTL logic.

The counting section consists of 3 sets of 32 asynchronous 32 bit counters; each set occupies a PC/104 card. Each counter has its own buffer, in order to implement a double buffered counting process. Consequently, after the end of a time window, pulse counting can be immediately started for the following time window while transferring the data of the previous one. This is of particular importance when the data acquisition time is comparable to the readout time. For 96 channels, e.g., 384 bytes have to be transferred for each time windows, which requires approximately 0.2 ms if a 2 MB/s channel bandwidth is available: this would be a 20% overhead if using a 1 ms time window.

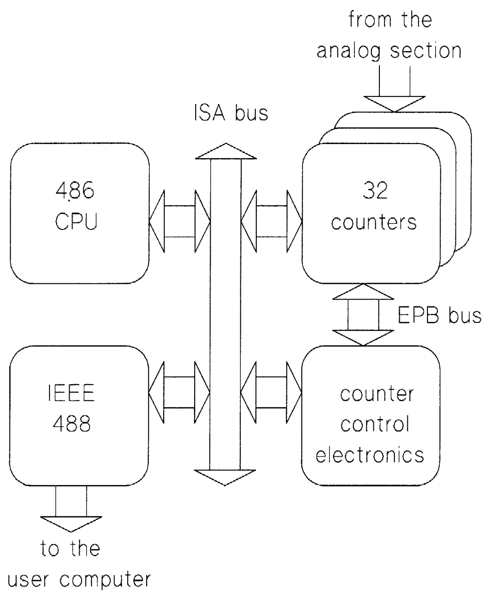

Fig. 5. Block diagram of the digital electronics part of the control/acquisition system.

It is worth noting that, due to the structure of the system and to the fact the counters are asynchronous, it is possible to trigger the time window on any event, such as synchrotron radiation pulses.

The counters have been built using several FPGAs, in order to reach the best compromise between performance, size, ease of upgrading, and cost. In particular, we used twelve pASIC2 2009 FPGAs by QuickLogic, which have been chosen because of their very high speed given by the "antifuse" technology[1].

The chips have been programmed using Verilog HDL. Bench tests have shown a maximum count

[1] The antifuse technology actually does not allow to re-program the chip, so that in case of upgrading it is necessary to use a new one. In our case this is not of concern, however, due to the low component cost and the low number of chips involved.

rate higher than 20×10^6 counts/s. In a fourth PC/104 card there is some additional electronics, which has been similarly implemented using an FPGA. This part controls the data transfer between the counters and the system processor. More precisely, the tasks of this FPGA are the following:

- counters management (e.g., time window length);
- interfacing between counters and system processor; e.g., it takes care of counters address management (i.e., if a 'counter read' instruction has been issued by the processor, the FPGA recognizes the address and enables the corresponding counter to write onto the data bus);
- notification to the CPU that new data are available; this can be done using either a flag, which is polled by the processor, or an interrupt.

The counters are connected to this card by a simple proprietary Extensible Parallel Bus (EPB), which is used to control them and to address them during the reading phase. The EPB may be easily extended in order to communicate with other devices, by using several spare lines which already connect all the FPGAs. E.g., instead of controlling the voltages of the electron analyzer voltages, it would be possible to program the FPGA to perform other kinds of operations to fulfill the needs of different experiments (see Fig. 1). The system is therefore capable of autonomously performing a complete measurement, taking care, e.g., of both energy sweep (in the ESCA experiment case) and data acquisition and memorization.

A PC/104 card equipped with an Intel '486 processor, the IDEA AT/32-4 by Eurotech, provides general control over the whole system. More specifically, the microprocessor takes care of system configuration and test at boot time, experimental data download from the counters and storage into its memory, communication with the user computer. The x86 processor architecture has been chosen for its ease of programming, the large amount of available software tools, and the low cost.

The system is interfaced with the user computer via the standard communication protocol IEEE 488, using the TNT4882 card by National Instruments. This protocol has been chosen due to its present widespread use in physics laboratories. In any case, if in another version the Ethernet protocol is to be used, it will only be necessary to replace the interface hardware and software. Of course it is possible to use both protocols at the same time.

6. The software for the digital electronics

For a system like the one described here, which is dedicated to experimental activities, a modular and real-time Operating System (OS) is to be chosen in order to correctly perform both the acquisition and the control tasks. We have chosen the QNX OS, because of its characteristics of scalability and very low context switching time; furthermore, it provides multitasking support and permits to directly address up to 4 GB of memory without memory extenders.

The control and acquisition software has been written in ANSI C and x86 assembly language. We also wrote the software driver for the IEEE 488 card, which was not available within QNX.

One of the advantages of QNX is that, due to its modularity, it may be very compact if only the needed modules are loaded. In our system, the CPU board has 8 MB of main memory; the OS and our software require approximately 0.5 MB, so that there is large space available to store experimental data, without the need to frequently download them into the user computer.

7. Experimental results

Preliminary results have been obtained acquiring the spectrum of gas phase argon $3p^{1/2}$ and $3p^{3/2}$ using as excitation source a UV lamp. In a traditional "energy scan acquisition" the photoelectrons are collected at the exit slit of the analyzer by a single channel detector (usually a channeltron) and the different energies are selected by varying the voltage potentials of the hemispheres; in this way the acquisition takes several seconds (sometime minutes) due to the necessity of changing the voltages of the hemispheres and of the other electrostatic lenses of the analyzer for each energy of the spectrum. In order to overcome this limit it is possible to take advantage of the natural energy dispersion of the electrons at the exit plane of the analyzer and to collect the electrons by means of

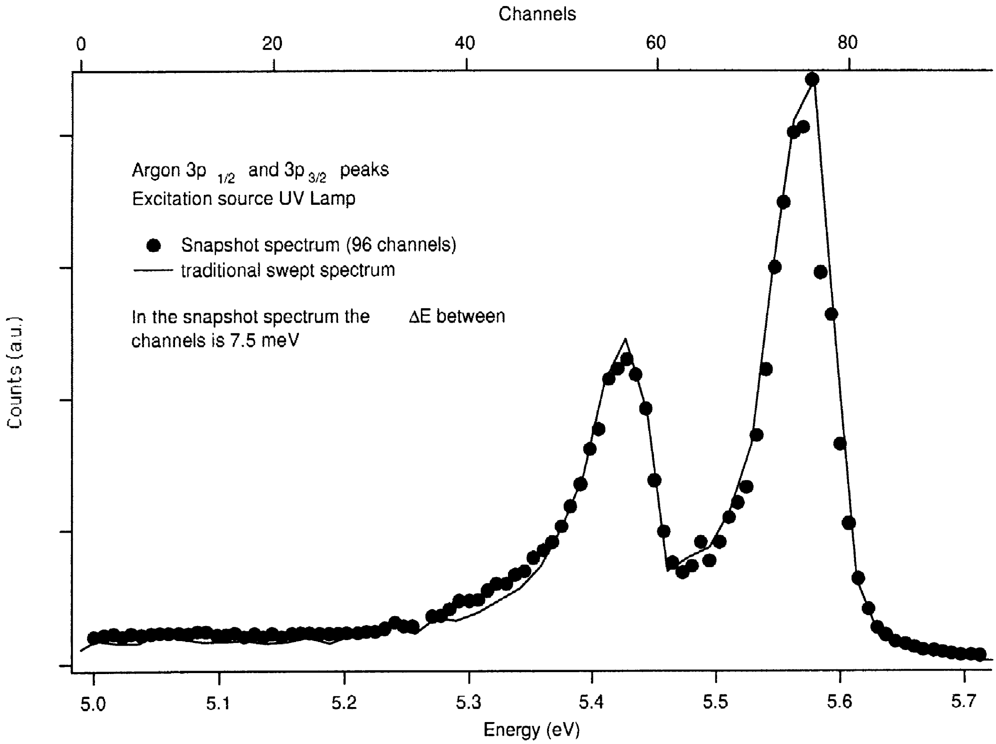

Fig. 6. Spectrum of gas phase argon $3p^{1/2}$ and $3p^{3/2}$ using as excitation source a UV lamp.

several acquisition channels; this kind of measurement is called "snapshot experiment" because all in one go you have the spectrum without moving the analyzer voltages: of course, to perform this kind of experiment, you need a number of channels high enough to resolve 2–3 peaks. At present there exist some electron analysers that have more than one single channel at the exit slit, either using an array of channeltrons (generally less than 10) or adopting a chevron MCP system followed by an anodes array. However, in both cases, the great difficulty to work out a UHV compatible multi-anode detector and to develop the preamplification and acquisition system for more than 10–20 channels has limited the maximum number of channels available so that it was impossible to have well resolved snapshot peaks[2].

[2] In any case in this "few-channels solution" there is still the advantage that in one energy scan you have n times (n is the number of channels) the information you would have with a single channel.

These problems have been overcome in our system, thanks to the accurate design of the detector assembly, the analog electronics part, and the embedded control system. This may be appreciated in Fig. 6. where we report the 96 channels snapshot spectrum acquired in less than 1 s and the "traditional" swept spectrum acquired in about 30 s; for both spectra the pass energy was 10 eV. (The pass energy is the energy of electrons that enter the analyzer orthogonally to the entrance slit (see Fig. 2) and at $R = R_0$, where R_0 is the mean radius of the analyzer, so that their trajectory is a circle of radius R_0.) The energy dispersion at the end of the analyzer is a function of the pass energy [7], and the measured energy separation between anodes is 7.5 meV, when the pass energy is 10 eV, as predicted by the theory. Each snapshot channel was previously calibrated in order to compensate for the different sensitivity of different areas of the channelplates.

8. Conclusions

In this paper, a multichannel acquisition and control system has been presented. Its main characteristics are the high number of fast acquisition channels, which allows to get 'snapshots' to perform time resolved experiments, and the embedded control architecture, which frees the user computer from data loading and experiment control, and guarantees system modularity and portability. The system is being tested in the SuperESCA experiment at the Elettra Laboratory. Preliminary results have demonstrated the validity of the proposed approach.

The number of channels, presently 96 for the SuperESCA experiment, is somehow limited by the UHV feedthroughs and by the flexibility of the wires[3] in case some mobility has to be allowed to the analyzer like it could be required in angle resolved measurements. We are presently developing a multichannel integrated counting section which will be put directly in ultra high vacuum in close proximity of the anodes, and which will be connected to the outside using a fast serial port. In this way, the number of acquisition channels can be increased, and bidimensional detectors can also be utilized.

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[3] It has to be remembered that 50 Ω kapton shielded cables are used to connect the anodes to the analog electronics. These cables are rather stiff, so that a bundle of, say, 100 of them can seriously limit the movements of the analyzer.