♣Steps towards the development of a portable and cost-effective system for human resources training in small satellite technology

Dr. Esaú Vicente-Vivas[1], Israel Nava[2], Victor Lomas[2], Jorge Morales[2], E. A. Jiménez[3], Z. Carrizales[3] and F. Gómez[3]

[1]Instituto de Ingeniería, UNAM, Cd. Universitaria Coyoacan, 04510, México DF., evv@servidor.unam.mx ,
[2]Student, Posgrado FI-UNAM, Cd. Universitaria, Coyoacan, 04510, México DF., israel_nava75@hotmail.com, vlomasb@yahoo.com.mx, jmorales@iingen.unam.mx,
[3]Student, FI-UNAM, Cd. Universitaria, Coyoacan, 04510, México DF., factore8@hotmail.com, zairalilian@yahoo.com.mx, paco_84df@yahoo.com .

Abstract. A detailed global description of a cost-effective portable system for training purposes in the satellite technology field is presented. The system might be employed in both: school laboratories and Mexican research centers. The former would allow attracting young generations to the world of Science and Technology, and the latter would employ it to generate and validate new satellite technology. The preliminary development steps towards the construction of a demonstrative prototype are described. The whole system consists of a small, fully instrumented and Portable Didactic Satellite (PDS), operations software for the didactic satellite, as well as executable software for personal computers which performs PDS supervision and control. Full information about each one of the PDS subsystems, comments regarding its envisioned operations, and the current development process to accomplish the first demonstrative prototype are described in this paper.

Keywords: didactic satellite, portable laboratory equipment, training system, cost-effective technology.

♣ **Research On Computer Science,** Control, Virtual Instrumentation and Digital Systems, Vol. 24, pp.117-130 , ISSN: 1870-4069, Centro de Investigación en Computación, IPN, México, DF, **November 2006.** Indexed in LATINDEX.

1 Introduction

Mexico has developed in the past a couple of small satellites projects, and currently is developing a couple more of them. Those projects are very important not only to stretch the enormous technological gap with industrialized countries, but also to launch a domestic satellite development and research program. The last could take us in the medium and long term to generate our own Remote Sensing and Communications satellites, according to the needs of the country. However, to conduct such a line of work, it is required the formation, qualification, and training of human resources in these technological areas.

According with our experience, it has been seen that the development of an experimental satellite in our country requires of 4 to 8 years of work, depending on the obtained financial support, as well as on the magnitude of the technological and scientific objectives.

We have also detected that this type of projects allows the participation of 25 to 200 people according to the challenges and the magnitude of the technological achievements faced by the satellite mission. Considering the cost of this type of projects (half million to 5 million US dollars) it is seen that the relation between the amount of participant personnel versus project cost is very low. In addition, if we consider how the young Mexican University people becomes attracted and motivated by satellite and space projects, it is observed an extremely low efficiency in the rows of participation and formation of new human resources in this field. By the way, this technology arena is related with the possibility to generate alternative solutions to national security problems from our country.

The analysis of the exposed scenario in México for the last 15 years, took us to elaborate the idea of developing a cost-effective training system for satellite technology employing commercial-off-the-shelf parts. The system is planned to be affordable enough to be used in laboratories with the intention to offer attractive, fast, and versatile training courses in the field. We plan to use the system in High Schools, Institutes, and Universities, with the intention of approaching new generations to the exciting world of space applications. Besides, the system will support the diffusion of Science and Technology activities in Mexico.

In order to carry out this project in a fast form, it was planned to be based on previous developments for satellite instrumentation elaborated by the Instituto de Ingeniería (IdeI) UNAM, [1], [2] and [3]. In this way, the paper describes the preliminary design of the PDS for human resources training in the satellite field. The PDS employs few satellite products already elaborated for the SATEX experimental microsatellite, [1], [2] and [3], as well as parts and systems of commercial use from the Automotive, Telecommunications, and Services industries.

1.1 Further Applications of PDS Computer and Related Work

With the intention to increase the applications of the equipment and subsystems generated by our group, we planned to develop a small sized single board computer to be used not only in the PDS, but also in 1 kg picosatellites (PICOSATs) like the one projected to be developed jointly by IdeI UNAM and IPN.

1.1.1 PICOSATs Around the World

The PICOSAT concept was developed by Stanford University and California Polytechnic State University in San Luis Obispo under the name of CubeSat in 1999, [4]. Since then a great amount of universities from all over the world are developing, are planning to build, or have developed a PICOSAT project to enter the space activities. Among the countries involved in CubeSats projects are: USA, Canada, Germany, Japan, Denmark, Netherlands, Norway, Switzerland, Australia, Korea, Malasya, Argentina and Colombia, [5]. The cost of this type of projects depends on the country that makes it, and go from <100,000 to 1,500,000 US dollars including the costs of inception, launch, operation and end-of-life.

PICOSATs are launched in groups as secondary payloads on rockets from different countries. However, Russian rockets are often selected for launching purposes because of its attractive cost. Even the Space Shuttle has opportunities to launch important groups of them. In 2006 the launching cost for orbiting a PICOSAT with a group of CubeSats through a Russian rocket was 40,000 US dollars. There are a couple of companies in USA that commercialize the fundamental subsystems to construct PICOSATs. They charge 6,000 US dollars for every subsystem such as: structure, communications, electrical power, attitude determination & control, and on board computer. Nevertheless, it is important to notice out that additional investment has to be considered for experiments, development of operations software, hardware environment testing, launching services and ground station. In this sense, the cost required to develop not only a PICOSAT but even the acquisition cost of every PICOSAT commercial subsystem is still a problem for many universities from developing countries. Besides it has to be taken into account that low-earth-orbit CubeSat missions have a typical lifespan of 3-9 months. In other words, for a University from a developing country means an important investment to place a small spacecraft in orbit for a very short period of time.

Another important point to highlight refers to the widespread trend in the PICOSAT field to use commercial-off-the-shelf (COTS) electronics parts, must of them even without protections for space operation. For this purpose few universities perform laboratory testing on parts being subjected to heavy ion testing, vacuum, and temperature extremes to select those parts with inherent capabilities to survive harsh environments, [6]. In order to determine the expected amount of radiation in space, specialized Radiation simulation software from the US navy is available through the web, [7]. When COTS parts are taken to space orbit and when they behave well, then they become referred to as space proven or flight tested. When those parts are published in papers other PICOSAT builders with less resources take advantage of that information and decide to employ them (power electronics, computers, communications, sensors, solar cells, etc) in their small satellites. Some times PICOSAT parts are successfully tested in space even without previous testing in laboratory, those parts are also referred as space proven or flight tested.

CubeSat missions are attractive and demanded around the world because they are employed for technology demonstrations, proof-of-concepts, scientific experiments and human resources training, [8], [9], [10], and [11]. However, because of financial problems most of the Universities from developing countries are impeded to participate in this strategic technology field. This scenario along with our experience in the small satellite field took us to develop the PDS with the goal to provide Universities from our country with a portable and cost-effective system for human resources training in the small satellite field.

On the other hand, the development of a PICOSAT has extremely severe restrictions in several issues, one of them related with the maximum dimensions every subsystem can reach. For these reasons the size of the PDS computer was projected to fulfill the size restrictions of a PICOSAT. Later, the size of the PDS computer defined the dimensions of the complementary PDS subsystems. It should be highlighted that the PDS is not intended for space use but for educational purposes in terrestrial laboratories.

1.2 Availability of Commercial Educative Satellites in the International Market

It must be stated that commercial availability of similar products to the PDS is rarely seen in the global market. Right now the only PDS like commercial product detected by the authors is the Eyasat educational system developed initially by the US Air Force and since February 2006 commercialized by Colorado Satellite Services, [12]. The Eyasat basic equipment starts at 8,000 dollars. However, this price is difficult to be afforded by Mexican schools, and in general difficult to be afforded in developing countries. This is why the PDS is planned to be developed and offered for an under 3,000 US dollars cost in order to be attractive for different domestic schools, universities, and so on. This goal shaped the design and the main characteristics of the PDS in order to achieve a cost-effective development. To accomplish the referred objective all the PDS PCBs will be manufactured in only two layers, the power subsystem was achieved with rechargeable batteries and an external battery charger, 1-wire sensors were preferred, and the PDS structure was chosen according with cost-effective commercial available products. In addition, few cost-effective auxiliary interfaces such as the command execution visualization subsystem, orientation determination sensors, serial and USB expansion ports, as well as expansion cards for user defined interfaces are aggregated in the PDS to be perceived as a friendly device with growing capabilities.

2. Portable System for Human Resources Training in the Satellite Technology Field (POSTSAT)

The POSTSAT is basically formed by the PDS, the PDS operations software, and executable software for personal computers. The PDS will contain an operations control software to carry out, among other functions: 1) The communication with the personal computer software, that will perform as the Ground Station Software (GSS) for Telemetry acquisition and Command Shipment, 2) the functions requested by the GSS, 3) the capture of requested telemetry, 4) the pack up of telemetry to be transmitted by a wireless mean, 5) the manage of GSS required protocols, 6) the simulation of orbital times for the didactic satellite, 7) real time operations with the didactic satellite, 8) the stabilization functions, etc.

As shown in figure 1, the POSTSAT contains a PDS with a cylindrical shape of 12 cm in diameter and 17 cm as maximum height. In addition, it contains the Ground Station Software (GSS) that executes itself in a PC. This carries out the functions of telemetry acquisition and command transmission to the PDS. Besides, this software allows uploading new operation software to the PDS by wireless means.

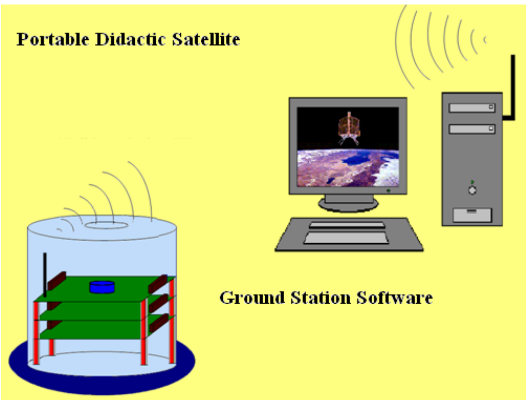

Figure 1. Fundamental parts of the POSTSAT.

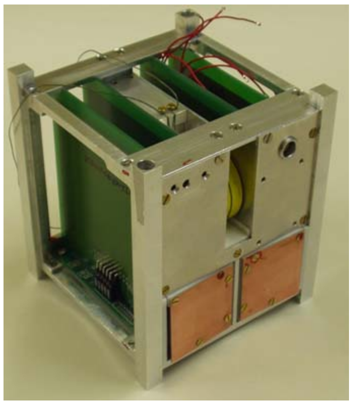

Figure 2. One Kg mass PICOSAT

The whole POSTSAT software will be recorded in a compact disk (CD) which will also contain the user and the operations manuals. For these reasons, the POSTSAT final version will consist only of the PDS and a CD. This is the system we expect to share with educative institutions from our country.
In addition to the system that is described in this article, it will be elaborated later a laboratory practice manual. This will allow carrying out training practices with the satellite system in a simple and friendly way, in order to teach the satellite system operation to the user. This manual will be carefully elaborated by another work team. It will emphasize the clarity of concepts, as well as the progressive transference of information, besides of reinforcing the learned knowledge, the questioning of treated

subjects, as well as the comparison of learned concepts with the operation of commercial small satellite systems. The organization, development, and implantation of this learning and training methodology will appear in later publications.

3. Architecture of the Laboratory Didactic Satellite

The PDS architecture is basically defined by its computer dimensions, which were fixed according with the dimensions of a PICOSAT, [11], [13], and [14], figure 2. The PICOSAT is a 10cm x 10cm x 10cm aluminum frame cube, which admits the installation of 8.5cm x 8.5cm printed circuits boards (PCBs). In this way, the same PCB size was fixed for the PDS electronic cards, whereas its complementary subsystems will reside in printed boards of the same size in a tandem assembling, figure 1.
The complementary PDS subsystems are: Power, communications, sensors, inertial wheel stabilization, magnetic torquer coil stabilization, visualization of satellite answers to commands, and a card for new developments.

3.1 Computing subsystem

The PDS has a single board operations computer, which integrates lateral connectors in a bus way to interconnect cards in tandem. The electrical connector offers the required mechanical subjection among the printed circuit boards. In addition, each PCB contains screw holes in each one of the corners, which allows screwing the whole printed board array to the PDS structure.

When using bus type connectors, all the electrical signals are available for all the assembled cards, thus it is possible the card interconnection without caring the order of them. Therefore, the order mentioned in the next paragraphs is just with the intention to have an order in the article writing. Besides, it is important to notice out that all the bus type connectors in the cards are male type in their superior part, whereas the inferior part looks like a wire-wrap connector. This allows the interconnection of cards in tandem as much by the superior side as by the inferior.

Considering that the PDS computer will be used as well in Picosatellites to be placed in space orbit, the computer design included hardware to eliminate the latch-up effect. This effect is generated by cosmic radiation in commercial electronic parts when they are taken to space orbit. The latch-up prevention hardware will be installed exclusively in computers elaborated for PICOSATs, whereas the PDS computers will not install such electronic parts because they will be employed only in terrestrial environment. The goal is to generate a single PCB computer for both applications to increase the applications of this computer, as well as lowering the development cost of our small satellites projects. Figure 3 shows the block diagram for the PDS computer.

It should be highlighted that the remaining cards exposed in following paragraphs will be used only in the PDS and are not intended for use in space orbit. However it is also important to mention that the world-wide philosophy to develop PICOSATS is based on the extensive use of commercial-off-the-shelf parts and systems. Where must of the projects even excludes the use of latch-up protection electronics. In this way PICOSATS have attractive development times (six months in some cases) which make them useful to validate state-of-the-art technology in space. In addition, they can be manufactured with very small budgets. This philosophy has taken the PICOSAT field to the Faster, Cheaper and Better approach. As can be deduced, the expected life for this type of spacecraft is low but at the same time enough to test and validate new technologies in a short period of time.

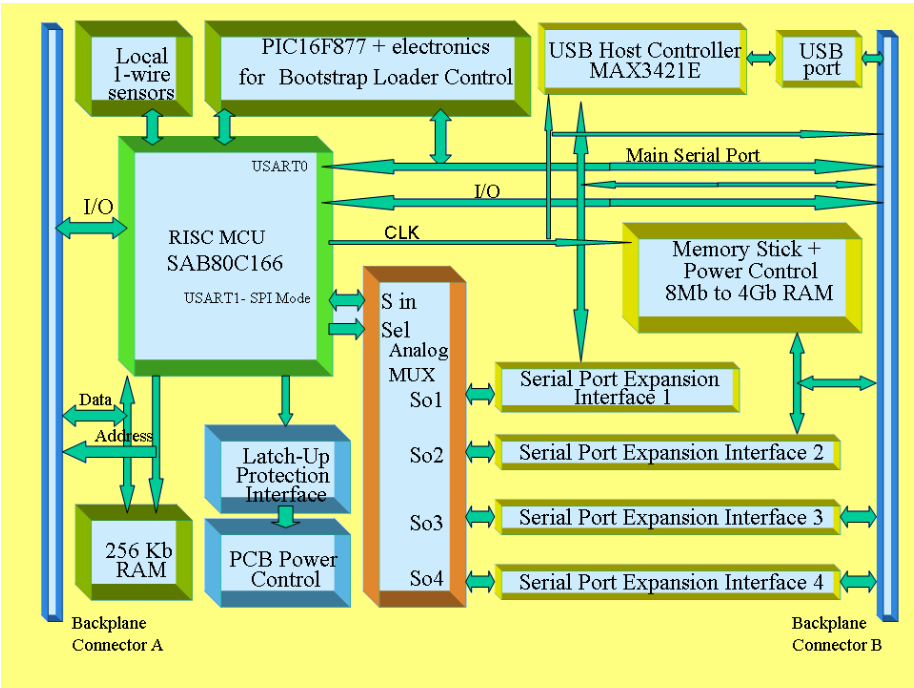

Figure 3. Preliminary block diagram for the PDS computer.

The PDS single board computer is built around the 16 bit RISC SAB80C166 processor from Siemens, industrial version with extended temperature, 40 Mhz oscillator, 256 kb of RAM memory where the PDS operations program will be loaded, hardware for automatic uploading of new programs to the computer and a total of 5 serial ports. The lasts support full-duplex asynchronous communication up to 625 Kbaud and half-duplex synchronous communication up to 2.5 Mbaud. The synchronous mode is employed in serial port So1 to gain access to a USB port on one side, and on the other side serial port So2 allows the communication with a Memory Stick card, [15]. The last will be used to add as much memory as required in order to store several types of PDS telemetry. It should be highlighted that the design of the computer hardware is already finished, however software development is required to validate the communications with both the USB port and the Memory Stick interface.

On the other hand, the 100-pin SAB80C166 microcontroller internally contains important resources as follows: a watch dog timer, interrupt controller, 16-bit timers, 10-channel 10-bit A/D converters, two serial channels and several 16 bits I/O ports, with a total of 76 I/O lines.

The SAB80C166 allows the uploading of new programs in external RAM memory, however it is required to control few electrical signals according with specific feedback responses from the processor. For this purpose a small PIC microcontroller was integrated in the PCB which will also be connected to the communications channel with the Ground Station. In this way, when the GSS software sends the "downloading new program" command to the PDS, the PIC16F877 microcontroller takes over the control of the SAB processor for both to achieve and to supervise the uploading process.
Regarding the software development for the SAB80C166 it is written in standard "C" language, programs are compiled using the BSO Tasking family of tools for the SAB80C166 microcontroller.

3.2 Power Subsystem

The second PDS card is the power one, where reside 4 AA-sized lithium rechargeable batteries and the electronics that admit its recharge by means of an external battery charger. In this way, it constitutes a simple, small, and economic power subsystem. Batteries are located in the lower part of the PCB, thus this card has to be the first one in the PDS tandem array, in such a way that mechanical separators allow the positioning of batteries.

3.3 Communications Subsystem

The third card constitutes the wireless communications system. Taking into consideration that this PCB will include a commercial wireless device, it means the PDS will raise its cost when it includes the wireless system, since its intention is the PDS to become a commercial system. However, this subsystem confers a great operative versatility to the didactic satellite. We are considering the integration of a Stand-Alone RF radio modem from MaxStream, Inc., particularly the XStream-PKG-R RF Modem, operating in the 2.4 GHz band, indoor range of 180 m, 2.1 dB dipole antenna, throughput data rate from 9,600 to 19,200 bps, serial communications, 7 to 12 V operation, spread spectrum, FSK modulation, 7x14x3 cm size and 200g weight, see figure 4.

It is necessary to point out that the PDS can be used also without the wireless communication system, in which case, this PCB holds only an RS232 line driver to accomplish the RS232 voltages for a PC serial port. Under this configuration, the communications channel among the educative satellite and the PC is just a wire. In this way, the PDS has two operative options from the communications point of view, which will significantly influence the cost of the didactic satellite.

(a) (b)

Figure 4. RF radio modem being considered for the project, a) For a PDS PCB and, b) For ground station.

3.4 Platform and Orientation Sensors Subsystem

The fourth card integrates the satellite telemetry sensors. Although, each one of the described cards has at least a pair of local sensors (current and temperature), we have planed to include in this card a tilt sensor and a digital compass for PDS orientation determination purposes. Both of them will be very useful to visualize the PDS telemetry in real time. It has to be noticed that most of the PDS sensors are 1-wire technology, they were selected to significantly reduce the number of traveling signals through the PDS bus. As can be found in [16], the 1-wire sensors let the microcontroller, by means of only two wires, to access an important amount of sensors. This contrasts with conventional sensors, which require two wires for each included sensor.
Regarding the tilt sensor and the digital compass, will be used in the PDS under a real time telemetry acquisition mode requested by command, which will allow the GSS software to generate 3D real time animations in connection with the satellite manipulation generated by the user in laboratory environment.

The PDS will employ the 1490 digital compass from the Robson Company. It is a solid-state Hall effect cheap device, 12 pin component, with cylindrical shape and requires 5 V supply, [17]. When rotated it senses the position of the four cardinal points on a compass, North, South, East and West. As well as the intermediate directions: North East, North West, South East, and South West.

For the tilt sensor a low cost SQ-SI-360DA solid-state MEMS based Inclinometer which provides both an analog voltage output and digital serial output corresponding directly to a full-scale range of 360º of pitch angle (single axis range) or ± 80º of pitch and roll angle with (dual axis range) will be employed, [18]. The device offers 0.1^0 resolution when the digital serial output is used. On the other hand, when analog output is utilized a 2^o resolution is obtained.

3.5 Inertial Wheel Stabilization Subsystem (IWSS)

A fifth card will lodge a DC motor and its associated electronics, which will be employed as an inertial wheel for PDS stabilization control effects. We are currently validating the electronic control scheme for the DC motor and making arrangements to generate a card together with an inertial mass located in the rotation axis of the motor. It is necessary to point out that under laboratory validation testing the didactic satellite will be suspended in the laboratory ceiling by means of three strings, as shown in figure 5. Once in a suspended position, a command will be sent through the communications system, and then will be received by the PDS computer, then, as an answer action, it will actuate the motor in the rotation direction and at the RPMs indicated by the command. Under these circumstances, the didactic satellite will experience reaction forces that will generate the PDS movement. This will allow the user to carry out several dynamic experiments for satellite stabilization control in a cost-effective fashion.

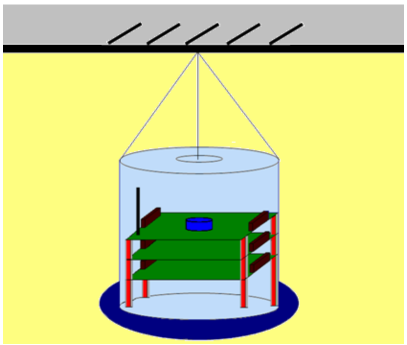

Figure 5. PDS suspended from the ceiling. Stabilization testing procedures.

Figure 6. Ground station software for the PDS will be inherited Satex microsatellite project.

The IWSS operation will be autonomous from the PDS computing system to allow the continuous control and supervision of the PDS stabilization subsystem. For this purpose a PIC processor 18F4431 will be integrated in this board, while the Microchip MPLAB C18 C compiler will be employed for software development. The communication among PDS computing system and PIC microcontroller will be made through the serial port expansion interface 3 shown in figure 3.

3.6 Stabilization Subsystem based on Magnetic Torquer Coils

The PDS has also been planned to include an electronic card lodging a number of small magnetic torquer coils (MTC) that will generate small forces to affect its control dynamics. These will be operated in diverse modalities with the momentum wheel interface to implement different stabilization procedures with the satellite training system.

3.7 PDS Command Execution Visualization Subsystem

The seventh card will integrate a display device which is currently under definition stage. This will provide visual feedback to the users whenever the PDS receives a new command from the GSS executed in a personal computer. Among the interface possibilities hexadecimal displays, led stack lights, sound interface and a Digi-Talker interface (to provide talking capabilities to the PDS) are found.

3.8 New Developments Subsystem

The PDS will offer one or few expansion boards (as required) with access to the resources (computer, power, communications and command visualization) of the satellite training system. This is achieved by the PDS back plane type connectors provided at any one of the development cards. In addition, the card will have a proto-board layout to ease the placement of passive and active components, as well as to allow wire-wrap connections.

3.9 PDS Structure Subsystem

In order to define the didactic satellite structure two different choices were considered. The first one was constituted by a rectangular prism shaped acrylic structure, and a second one conformed by a cheap commercially available cylindrical container manufactured with plastic. When it was considered the manufacture cost, the manufacture time and the acquisition of materials, it was decided to go for the commercial cylindrical container. In addition, the last solution allows the POSTSAT to be produced at a lower cost through the reduction of manual labor. The chosen structure is light, cost-effective and will shape the PDS to render a satellite appearance. Once a set of PCBs are plugged together, the stack will be fixed to the plastic structure with screws.

4 Ground Station Software for Remote PDS Control and Remote PDS Supervision

The GSS software executes in personal computers and interacts with the PDS software to achieve both the demonstration and the training functions of the didactic satellite system. In fact, great part of the friendship attributes for the whole POSTSAT system (simplicity and clarity of use) are generated by this software. For these reasons, it was decided to develop the software under the bases of a previously developed software for the Satex microsatelite project [3]. This software performs similar functions to those planned for the PDS, we have access to the source code, and importantly, it was tested during the development stages of the referred project. The software written in Visual Basic employs enough visual resources so that the user may easily identify the satellite status from telemetry data. The visual resources are generated from AutoCad drawings and the animations are rendered with Flash Software, figure 6.

Despite GSS software will be based on the Ground Stations software developed for the Satex project, it will be a modified version according with particular characteristics of the satellite training system. However, the software will have similar functions to those employed to control small satellites launched into space orbit, among them: 1) Immediate answer commands, 2) Task commands to define assignments according with programmed times defined by the command itself and which will have delayed answers from the PDS, 3) Telemetry request commands in agreement with time intervals specified by the user, 4) Real time telemetry requests to allow on-line PDS supervision with the help of 3D animations, 5) Time programming (scaled) required by the PDS to simulate orbital timings in agreement with user requirements, 6) Satellite stabilization control commands, etc.

4.1 Communications Subsystem for the PC

As already mentioned, the communication between GSS and the PDS software will be allowed either by cable or by wireless means, so that the POSTSAT system will be used in agreement with financial resources available in many laboratories. Figure 4b shows the equipment being considered for these purposes. It will be directly connected to the serial port of the personal computer where the GSS will be executed.

5 Current State of the Project and Planned Activities

So far we have important advances in every PDS subsystem that is why we expect to assemble a preliminary prototype and get it available this year. However, following activities will be required to be developed in parallel fashion to reach the goals of having a full demonstrative and useful system: 1) development of PDS operative software, 2) development of ground station software, and 3) Elaboration of manuals for the whole system. It should be highlighted that the success of the exposed system will also be indeed in the planning, in the methodology and in the content of the system manuals.

Once the first complete and functional prototype is finished, few copies will be assembled to use them in a pilot training program in the Engineering Postgraduate course titled "Design and construction of small satellites", given by the first author at the Posgrado de Ingeniería, UNAM, since year 2004. With the feedback of the participant students and with the results of use and evaluation, the necessary adjustments to the manuals and program course will be made. Then a diffusion stage will be started to incorporate the POSTSAT system to specific programs from Schools interested in the exposed system.

6 Concluding Remarks

We have presented the preliminary design, the development advances, the global architecture and the projected operations for a portable and cost-effective system to train human resources in the field of small satellite technology. The equipment was planned and based on 15 years of experience and work in the area. The PDS also considers the attraction of young people from our country for the satellite and the space fields. On the other hand, we expect the project will be affordable for many Institutes, Technologic Schools and Universities, and hence will represent an open gate for the new generations to participate in a field of work perceived to be far away from the academic possibilities of developing countries. In addition, the exposed system will attract young people to the world of Science and the Technology.

In this way, the exposed project tries to generate a whole portable training system, attractive and friendly, with capabilities to be adopted as a partner to access the world of science and technology, satellite technology or towards other technological fields such as Electronics, Telecommunications and Informatics.

7 References

1. Esaú Vicente-Vivas, Fabián García-Nocetti and Francisco Mendieta-Jiménez, “Automatic maintenance payload on board of a Mexican LEO microsatellite”, Acta Astronautica Journal, Elsevier Science,, Volume 58, Issue 3, Pages 149-167, February 2006.
2. E. Vicente-Vivas y D.F. García Nocetti, “Computadora de Vuelo Triplex de Diseño y Manufactura Mexicana para el Microsatélite Satex”, Revista Iberoamericana Información Tecnológica, ISSN 0716-8756, Vol. 17, No 1, pp. 69-76, Enero 2006, Chile.
3. E.Vicente Vivas, A.Espinoza M., C. Pineda F., J.R. Tórres F. Y A. Calvillo, “Software de Adquisición de telemetría y control de operaciones para microsatélites”, 4º Conferencia Internacional en Control, Instrumentacion virtual y Sistemas Digitales "CICINDI 2002", Pachuca, Hidalgo, México, Agosto del 2002.
4. CubeSat Origins, http://directory.eoportal.org/pres_CubeSatConcept.html .
5. CubeSats Running Projects, http://en.wikipedia.org/wiki/CubeSat#Current_running_projects .
6. Y.Tsuda et al, "University of Tokyo's CubeSat "XI" as a Student-Built Educational Pico-Satellite -Final Design and Operation Plan", The 23rd International Symposium of Space Technology and Science, Matsue, Japan, 2002.
7. Nav Cosmic Ray Effects on Micro Electronics, https://creme96.nrl.navy.mil/ .

8. The Stensat Group, http://www.stensat.org/ .
9. H. Heidt et al, "CubeSat: A new Generation of Picosatellite for Education and Industry Low-Cost Space Experimentation ", 14th Annual/USU Conference on Small Satellites, August 2001.
10. Montana Earth Orbiting Pico-Explorer, http://www.ssel.montana.edu/merope/ .
11. Miyamoto K. et al, "Tokyo Institute of Technology Small Satellite Projects", 7th University Space Systems Symposium, Waikoloa, Hawaii, November (2004).
12. Eyasat home page: http://eyassat.com/tiki/tiki-index.php?page=ContactUs .
13. The Stanford University CubeSat concept, http://cubesat.info/ .
14. CUBESATS - CanX-1 PicoSat – at University of Toronto, http://www.utias-sfl.net/nanosatellites/CanXProgram.html .
15. Memory Stick Standard, Memory Stick PRO Specification Summary, Sony Corporation, December 2004.
16. Maxim, http://www.maxim-ic.com/1-Wire.cfm, (2005).
17. Digital Compass from Robson Company, http://www.imagesco.com/articles/1490/03.html .
18. Inclinometer%20Datasheet_3.4c.pdf, http://www.signalquest.com/SQ-SI-360DA_ Solid-State%20MEMS %20Analog%20and%20Digital%20