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# AUTONOMOUS VIBRO-ACOUSTIC MONITORING SYSTEM

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***Abstract.*** *This paper presents a low cost multi-purpose monitoring equipment, developed at Laboratory of Dynamics and Instrumentation – LADIN, from EPUSP. Its design specification was based on the previous experience of our team in several multidisciplinary research projects: Magnetic Non Destructive Testing (NDT), vibro-acoustic fault monitoring in industrial plants, ecological acoustics, bioacoustics, underwater acoustics and geophysical phenomena monitoring. In many of these projects, there is the need for a long term monitoring system, going from some hours to several months in autonomous manner, or else powered by solar panels. The main characteristics of the present system are: low-cost, long life autonomous recording, high storage capacity, frequency band from 10 Hz to 20 kHz and two analogue input channels. As it is a computer-based system, it is possible to specify the duty cycle and to implement algorithms for automatic detection and classification. It can be powered by an external 12V source, or by an internal pack of batteries. The case that encapsulates the system is designed to endure harsh environment, including underwater deployment up to 100m. For terrestrial applications and with at least two units, it is possible to have the units deployed in a network array, and use GPS time source for time synchronization. A variety of sensors can be used with this platform: accelerometers, microphones, hydrophones, geophones, and magnetic sensors, among others.*

***Keywords:*** *autonomous system monitoring, acoustic, noise, vibration*

## 1. INTRODUCTION

Around the world, there has been a considerable increase in investments in vibration and noise monitoring, not only in industrial plants (Mello Junior, 2010), here included power plants (Bastl, 1974), but also in the monitoring of large civil construction sites, entertainment and sports events, road traffic (Chakrabarty, 1997), ports (Darbra et al., 2009) and mines (MSHA, 2012). The main objective is to proactively invest in predictive maintenance and environmental quality, to take account of concerns in the areas of both ecology and human health (Stapalfeldt and Manvell, 2011; Taylor and Griggs, 2011 and McBride, 2004).

According to Bracci and Stollery (2011), permanent, field-based, noise and vibration monitoring has been established since 1970, but only in the 90's did the first fully digital noise monitoring systems begin to be available. Also, these systems were big, high cost, limited by analogue to digital rate, slow computer performance and slow data transmission rate systems.

Advances in information technology have helped to improve instrumentation and numerical methods to automatically detect, localize and identify vibro-acoustic events. Both instrumentation and signal processing methods allowed increased functionality and lower instrumentation costs (Mennitt and Fristrup, 2012; Bracci and Stollery 2011). This progress has thereby made hardware no longer a limitation factor in order to develop very effective monitoring systems (Filipponi et al., 2008; Kanjo, 2010; Taylor and Griggs 2011). The challenge is, nowadays, dislocated to software development. Advances in monitoring are not just related to what we measure and what we can achieve with these measurements, but also change the approach to long term monitoring. Therefore, very sophisticated solutions for event detection, identification and localization can be much more effective, with lower costs. Additionally, for industrial plants, the building and analysis of large historical and spatial database can provide important information regarding plant functionality, health and environmental impact. .

In order to be effective, monitoring systems should have some critical characteristics, such as continuous and remote monitoring capability, which provides real time information, thereby allowing viable solution and intervention to be quickly undertaken. Additionally, in case that long term, large areas of monitoring are necessary, the need of personnel on site, carrying on measurements, can be avoided by the use of autonomous equipment which is an additional factor for costs reduction and increased effectiveness.

The present work proposes a low-cost vibro-acoustic monitoring system that can handle the following tasks:

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- multi-sensor monitoring,
- remote environmental noise measurement,
- remote predictive maintenance monitoring,
- noise data processing,
- large data storage capability,
- real-time or user-defined download data,
- data transmission via TCP/IP or USB,
- GPS data handling.

These characteristics, allied with the low-cost, multi-sensor and open system modularity, allow the configuration of network sensing, and the monitoring of long term, large-scale areas. Although the hardware is based on components found on the market, the integrated solution is very effective and robust.

Therefore, this paper describes an Autonomous Vibro-Acoustic Monitoring System (from now on named AVAMS), its hardware and software characteristics having been developed in accordance with an open source philosophy. Additionally, the paper also describes some examples of applications and presents a unit installed at Poli/USP campus. Although the system can be used for several other types of monitoring, this paper focuses on vibration and acoustic applications.

## 2. AVAMS HARDWARE

The hardware was developed to be a low-cost computer-based system. Figure 1 shows the hardware scheme. It is a simple, modular and customizable platform, composed basically by one or two Sensors (microphone, accelerometer, hydrophones, geophones, magnetic sensors, among others) connected, via an analogue to digital interface (A/D), to a Computer that records data in a Storage Unit, processes the data and sends it over via LAN or Internet through a Communication Unit. Several types of energy sources can power this system.

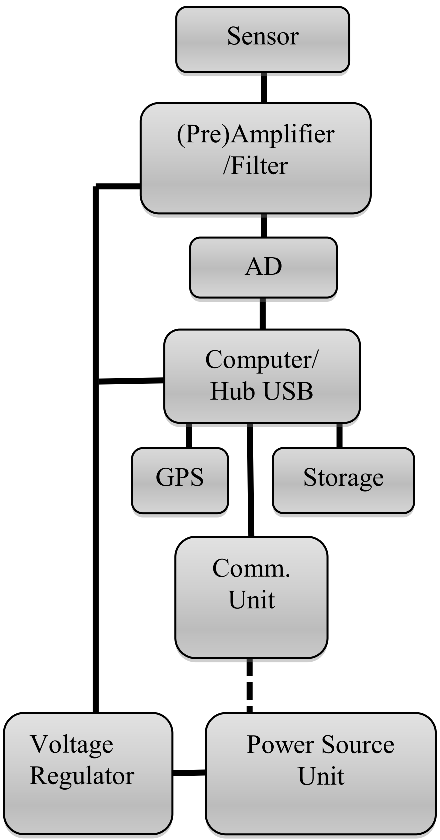


*Figure 1. Hardware Scheme of the AVAMS*

Following the strategy of using, at maximum, components found on the market (in order to lower costs and universalize usage), the hardware platform is built by using an open source hardware as Computer Unit, USB audio

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interface as A/D Unit, pen-drives or hard disks as Storage Unit, GPS dongle and data transmission devices, also available on the market, as Communication Unit.

### 2.1 Computer plataform

Two computer platforms were tested, both low-cost ARM-based GNU/Linux open source hardware, the BeagleBone Rev A6 (BeagleBone, 2013) and the Raspberry Pi Model-B (Raspberry, 2013). Due to the similarity between both (although Raspberry Pi price is lower than BeagleBone's), the AVAMS will be detailed only for the Raspberry Pi version, which specification follows:

| | |
|---|---|
| CPU | 700 MHz ARM1176JZF-S core (ARM11 family) |
| GPU | Broadcom VideoCore IV[74], OpenGL ES 2.0 (24 GFLOPS) |
| Memory (SDRAM) | 512 MB (shared with GPU) |
| USB 2.0 ports | 2 |
| Video outputs | Composite RCA, HDMI |
| Audio outputs | 3.5 mm jack, HDMI |
| Onboard network | 10/100 Ethernet |
| Onboard storage | SD / MMC / SDIO card slot |
| Low-level peripherals | 8 × GPIO, UART, I²C bus, SPI bus |
| Power ratings | 700 mA (3.5 W) |
| Power source | 5 volt via MicroUSB |
| Size | 85.60 mm × 53.98 mm |
| Weight | 45 g |

Table 1: Hardware specification of the Raspberry Pi Model-B

Raspberry Pi is a good choice for its support to a full Linux Operating System and several I/O ports: two USBs 2.0, Ethernet and GPOI (which can be used to interface several kinds of sensors like accelerometers, temperature, humidity, barometric pressure, movement and infra-red sensors, etc.) In order to increase the number of USB ports, a USB Hub can be added to the computer unit.

### 2.2 Sensors, Data acquisition and storage

Taking advantage of the Raspberry Pi flexibility, a variety of sensors can be used with this platform: microphones, hydrophones, geophones, magnetic sensors, accelerometers, temperature, humidity, barometric pressure and movement sensors, among others.

These sensors are connected to an Analogue-to-Digital Interface (AD), which is connected to the computer via USB. Nowadays, audio interfaces, with sampling rates up to 192 kHz, 24 bits of digital resolution and dozens of analogue channels, can be found on the market. The audio interface used in this work presents digital resolution of 16 bits, two analogue input channels and frequency response of 10 Hz to 22 kHz (+-1dB) at 48 kHz sample rate, or 10 Hz to 20 kHz at 44.1 kHz sample rate, or else 10 Hz to 15 kHz at 32 kHz.

A GPS dongle can be connected via USB and it is used to sync the system time/location, so that it is possible to employ a network of AVAMS, as mentioned before.

To storage all this data, the system uses a High Capacity Pen Drive or Hard Drive connected to the computer via USB. After the Embedded Software processes and saves the data, it can also be transmitted to the server, according to the user specification in the initial setup procedure.

### 2.3 Communication and Data Transmission

The computer uses the Communication Unit (Figure 1) to send the recorded data and to receive user commands through LAN or Internet. This can be implemented via, mainly, three different standard technologies, Power Line Communication, Power Over Ethernet (POE) or Wireless network.

Power Line is a technology that uses electric power wiring to transmit both AC electric power and data over the same power cable. With this, the AVAMS is powered with AC, and a suitable power conversion/regulation powers the AVAMS components. The communication part of the Power Line is connected to the computer via Ethernet cable. With this type of connection, it is possible to reach distances up to 300 m between the AVAMS and the LAN or Internet facility.

The POE Technology allows data and power transfer through just one Ethernet cable. With POE, the system is powered by direct current (DC), in the interval 5V to 12V. It is possible to reach distances up to 100 m, between the AVAMS and the LAN or Internet facility.

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The third technology is based on a Wi-Fi available network. In this case, a USB wireless card is plugged to the Raspberry Pi and is used to connect the system to an existing network.

### 2.4 Power Sources

Different power source combinations are possible depending on the use the system is given. The system can be powered by a pack of batteries, if no other type of power source can be found, or by connecting it to an external power source. Therefore, as discussed before, the AVAMS can be powered via AC electric power (such as in the Power Line case), by an external DC 12V source (solar panel, wind energy or POE, for instance). The internal power converter/regulator is available on the market, and gives 5V for powering computer and pre-amplifying the sensors.

The power consumption of the system is about 3W, most of it due to the computer board.

## 3. AVAMS SOFTWARE

The software was developed in a Linux environment using the open source Shell Script programming language (Blum, R., Bresnahan, C., 2011), and is located in a SD card that is connected to the hardware device. This software runs in both computer platforms: BeagleBone and Raspberry Pi. Signals (sound and/or vibration) samples are either stored in a data storage device (such as a USB flash drive or even hard drive) or, if a connection to a network is available, sent to a designated server for remote noise monitoring. This server needs to be configured as a SSH server (SSH, 2013) to be able to receive data. The main setup is executed just the first time to configure the server IP address.

The program can be setup in a number of different ways. All that is needed is some sort of connection to the hardware device. For instance, setup can be executed by connecting the Raspberry Pi using another computer through Secure Shell (SSH) protocol and editing the script embedded in the SD card. The established connection has been tested in Linux, Mac and Windows platforms. In the last case, the system uses the software Putty, a free SSH and telnet client for Windows (Putty, 2013). Once the connection is established, the program can be initiated remotely via SSH through a LAN or Internet connection. In fact, the AVAMS can be handled at any time, if such connections are available.

The system is built so that it is possible to record signal samples continually over time until the program is ended, or, if the goal is to acquire samples from specific instants of the day, set timetables for the beginning and ending of recordings. The sampling rate can be chosen as 32 kHz, 44.1 kHz and 48 kHz. By using information such as, date and time of recordings, sampling rate and duration, it is also possible to implement algorithms for automatic detection and classification of these samples.

Each signal recording can be saved in different smaller files, rather than in a big one with all the data. In doing so, the security of the recording operation is increased. The user, in the initial setup procedure, specifies the size of these files in "time" units (minutes). For instance, the user can specify two hours of recording to be saved in files of ten minutes. So, recording operation will generate 12 files.

Therefore, the main control and setup parameters are:

- Timetable: to control recording start and duration
- File size (in minutes of recording)
- Sampling frequency
- Data and time setup
- Turn on or off the continuous data transmission (if LAN or internet is available)

Furthermore sound samples are saved in the Waveform Audio File Format (.wav), with file names saved as the date plus time of the beginning of each recording. This timing data is taken from the computer clock, which can be updated and synchronized by Internet connection, if available. In the case that precise time handling is important, it can be managed by GPS. This can be the case where a sensor network is used, and time synchronization is a critical issue for event localization or signal cross-correlation among the nodes of the sensor network.

## 4. AVAMS FOR NOISE MONITORING AT POLI/USP CAMPUS

The AVAMS was tested, in LADIN (Laboratory of Dynamics and Instrumentation, EPUSP), in a configuration composed by BeagleBone and PowerLine for power and data transmission.

Additionally, a version with POE and Raspberry Pi (Figure 2) is installed in EPUSP campus, for continuous real-time ambient noise monitoring, as shows Figure 3. It is worth noting that the total cost of this last prototype is about USD 250, in Brazil.

For both configurations, measurements are sent to the LADIN server for further processing and analysis, and are used as laboratory database in different research projects.

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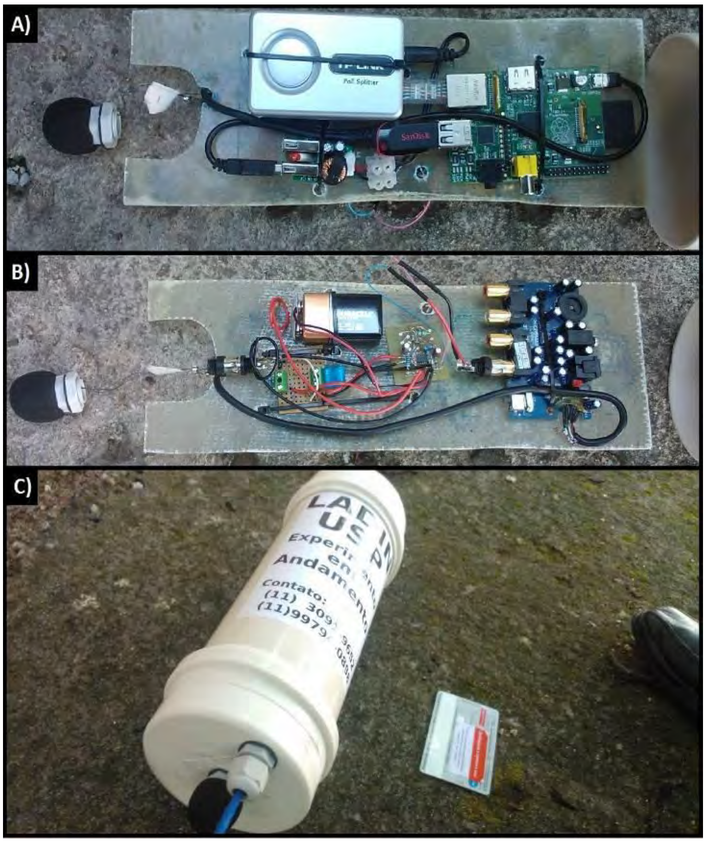


*Figure 2. AVAMS prototype with Microphone, Raspberry Pi and POE. This version has two sides, the first one (A) has the Raspberry Pi, POE, USB Flash Drive and voltage regulator; the second side(B) has an AD Interface, preamplifier and amplifier (powered by a 9V battery). C) External case with a microphone.*

*Figure 3. AVAMS prototype with Raspberry Pi and POE installed in the Poli/USP campus*

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## 5. SOME EXAMPLES OF APPLICATIONS

The increased awareness of modern society for environmental issues has brought the problem of environmental noise to the fore. Airports, Freeways, Industrial plants, Civil construction sites, Ports and Harbours, which expansion is a demand of the same society, are examples of aggressive vibration and noise sources. Therefore, these industries are now required to monitor their environmental noise impact. In what follows, some few examples of possible applications of AVAMS are presented.

### 5.1 Civil construction and industrial plants

In civil construction projects and industrial plants, ambient noise and vibration monitoring is a concern in order to maintain their levels within boundaries established by law (Mello Junior, 2010). Thus, the proposed vibro-acoustic monitoring system can be used in civil construction and industrial plants by constantly recording noise and vibration levels and by acquiring real-time data for analysis and storage. In this context, the AVAMS can even be coupled with other informatics management systems, by automatically detecting if noise and vibration levels have exceeded a certain limit. Constant data streaming to a central server allows remote unmanned environmental noise and vibration measurements and processing with minimal human involvement

A precise handling of time variables is required in order to correctly classify the noise and vibration levels for future use in case of a possible complain. For that, using a GPS for data handling is optimal by given precise time and location information. Furthermore, usually in these kinds of industrial activities, power is not an issue, thus an internal pack of batteries may not be required. Additionally, to ensure good cost-benefit relation in this type of environment, the system should have an ingress protection of at least IP66 to ensure survivability and reliability.

Moreover, to achieve remote unmanned environmental noise and vibration measurements and processing with minimal human involvement, constant data streaming to a central server is used.

### 5.2 Control of maritime noise and traffic

A constant concern in protected/restricted maritime areas is the control and monitoring of maritime activity (traffic, harbor operations, oil&gas offshore installations) to ensure no illegal activity occurs and to maintain the acoustic noise, generated over and under water, bellow correct levels. Therefore, the proposed acoustic monitoring system can be used in the control of maritime traffic by constantly recording noise levels for real-time data analysis. In this context, the system can be built for either underwater or offshore deployment and thus, is built with an ingress protection of IP68.

By making use of the dual analogue input channels, different combinations for monitoring can be chosen. The system can have microphones on both channels for ambient monitoring. Likewise, it can also be built to use hydrophones on both channels for underwater monitoring. In addition to that, for optimal monitoring condition, the system can have a microphone in one input channel, and a hydrophone in the other.

In this context, due to the type of ambient the system is to be deployed, constant real-time data streaming to a central server for analysis must be used. Thus the use of a GPS for time handling is essential in this case.

### 5.3 Mining Activity

Drills, mills, shovels, crushers, and many other items used in mining activities are very noisy. This has impact not only on neighbors living close to the mines but also on mine employees health, the main problem being noise-induced hearing loss (McBride, 2004). Furthermore, concern in the mining industry is not only restricted to the acoustic noise, but also the seismic activity triggered by the use of explosives for the purpose of exploration.

In Brazil, the *National Department of Mineral Production (DNPM – Departamento Nacional de Produção Mineral*) imposes a set of mining regulatory norms (*NRM – Normas Reguladoras de Mineração*). The item 1.5.9.1 of DNPM ordinance N$^{o}$12/2002, mentions that DNPM may require periodic reports of control and monitoring noise and vibration levels. Also these logs need to be always available at the mine site for inspection (DNPM, 2013a and DNPM, 2013b).

In this context, the proposed system supports sensors as geophones and microphones, which adds a great value for use in noise monitoring in mining industry. With the measured data, it is possible to identify sources of acoustic or seismic noise and, if these levels get higher than the established norm, have actions taken to reduce noise levels. These actions can be made, for instance, by using natural obstacles or by creating artificial barriers.

### 5.4 Educational laboratory

Finally, since the AVAMS can be used with a variety of sensors and, additionally, can also be considered a low-cost system, very simple to be operated, it represents a nice choice to be employed in educational experimental laboratories.

Particularly, experiments regarding measurement problems with different sensor types can be easily implemented, and the equipment can give support for the signal-processing classes concerning analysis of the generated data.

## 6. CONCLUSION AND FUTURE DEVELOPEMENTS

This paper describes a low-cost, autonomous, flexible, multipurpose monitoring equipment (the AVAMS), completely developed and designed in accordance with an open source philosophy. The system may be used in applications related to several areas such as civil construction, control of maritime noise and traffic, mining activities, etc.

In the future, the development focus of the AVAMS will be pointed to two main software topics: embedded software improvement in order to incorporate some algorithms for automatic detection of events, and a Web-Based management system for data handling and real-time signals analysis. In this context, signal processing algorithms for event detection, identification and localization, as those already developed and available at LADIN will be adapted and added to the main computer software.

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