Distributed home labs at the time of the Covid

A. Cigada, S. Manzoni

Department of Mechanical Engineering
Department of Mechanical Engineering
Politecnico di Milano ITALY

ABSTRACT

The well known difficulties with the recent pandemic have forced people to find new communication means, especially concerning educational methods. University courses have been dramatically changed in their structure, just in a few weeks. While traditional lectures have been more easily switched to “on line” methods and tools, classes mainly based on experimental lab activities have suffered more from the new forced approaches: a new and stronger effort had to be produced to guarantee the proper knowledge transfer. Many ways have been tried to export experimental labs into students’ houses, preserving and stimulating their curiosity. However there was a risk to foster a more passive role; students watching a movie or listening to a far away teacher couldn’t have direct interaction with the instrumentation locked in not accessible labs, nor had the important chance to develop “hands on” sessions.

The paper deals with the ideas and attempts to preserve the value of the experimental activities during the COVID period, in which experimentation has also meant experimenting a new way of teaching; early attempts will be described up to a final proposal, which has been successfully tested with students of both the bachelor and the master of science.

Keywords: Smartphone, Educational Laboratories

INTRODUCTION

During the recent pandemic it seemed that a real chance to perform experimental classes was completely lost. Students could not have access to the University classrooms, most of them had returned to their native countries: even if on-line teaching seemed to make the world smaller, some distances proved to be incredibly wider, as the personal contact and the possibility to interact with real instrumentation seemed unrecoverable.

A proper problem introduction requires a short history related to the environment in which the project to get over the mentioned difficulties was born: this history relates to the situation of University studies, mainly in Mechanical Engineering, in Italy.

Italy has a specific situation as, in University courses, Measurements are considered a discipline on its own. The advance of metrology issues and the complexity linked to a proper management of measurement systems and networks, together with the needed data management strategies, have led to consider a specific skill: the measurement specialist. This is the reason why, especially in Mechanical Engineering, a long tradition exists in creating and managing experimental labs, to properly train students, since the bachelor courses.

This is the reason why, from the 90s on, in many Italian universities an effort has been spent not just in setting up experimental laboratories, but also to make them an effective educational tool, overcoming a series of barriers which leads to consider experimentation less important than modeling. Literature on this topic tends to focus on single experiments or tests, rather than working on a general method: one of the few examples in this direction is given by the works of the Portuguese group of Maria Teresa Restivo [1] [2].

EXPERIMENTAL LABORATORIES AS A TOOL FOR PRACTIONER ENGINEERING

The first attempts to set up educational labs consisted in big rooms having desks equipped with the basic instrumentation: power supply, multimeter, frequency generator, data acquisition boards and some sensors (Figure *1*). Is was immediately recognized that the main effort was not just in setting up the lab, but in maintaining it. Maintenance was not just related to the relevant use of these facilities, creating wear and damage, but also to instrumentation ageing and the need to substitute it. Safety issues had to be properly transferred to students working in the labs, instructors had to be trained: in the end all these aspects often made the choice of having experimental labs very expensive, sometimes not sustainable.

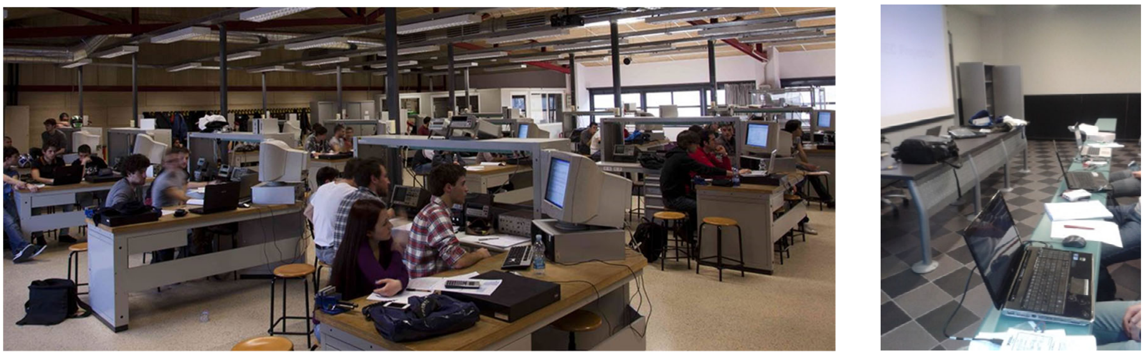

Figure 1: The first educational laboratories in Politecnico di Milano (left); the "Flying Lab": every classroom can become a lab

Other issues were related to the need to provide quick instructions for the students, to help them learning how to use the instrumentation. This aspect required times not always available in courses, which need to run fast, usually around three months. The proposed experiments spanned across the whole world of measurements, every test having an introduction, some guided tests and in the end some hints to develop some work on own, in which the instructor had the main role of a living manual; particular care was devoted to the dynamic performances in measurements, being this the most tricky part in mechanical measurements: most examples, coming from the area of sound and vibrations, were modeled on the remarkable activity of Anders Brandt [3][4][5][6][7]. In the end, due to the usually high number of students attending courses, it is hardly possible to allow each individual to practice "hands on sessions": students usually work in small groups. The dynamics of social relations inside groups has to be carefully studied, as some students tend to hide themselves, not being very active, while others do most of the job, although in the end the single student activity has to be evaluated. In case we really wanted each single student to practice in person on the instrumentation, time and resources were not enough.

This is the reason why research about the best way to perform experimental activities in university classes never stopped. A first and almost immediate solution was trying to lower the high pressure on experimental labs, by transferring some activities into common classrooms. This was possible thanks to a joint initiative with National Instruments and PCB. The first company offered help in the use of a product, my-DAQ [8], which can be adapted to multiple uses, like a multimeter, a function generator, a spectrum analyzer, a data acquisition system and many others, relying on virtual instrumentation developed on a computer with Labview [20]. PCB [21] offered some instrumentation out of production, still perfectly working, which could be used to work on simple experiments: they were microphones and accelerometers, giving many chances to develop small classroom projects, assuming that a table can pretend to be a bridge, fan coils are narrow band noise generator, a set of microphones can be used to get the speed of sound and so on. In some specific cases students could borrow the sensors for their tests, to be carried on own: in one case an archery champion asked to measure the bow vibrations while shooting an arrow, also getting interesting results to improve his performances. In addition students had the chance to obtain a free of charge student edition of Labview; this solution was chosen because the Express VI family allows one to use the basic tools of data acquisition and spectral analysis even without being an expert in programming and in a very short time. The idea of having a laboratory easily transferrable everywhere was really challenging and effective in getting the goals of making lab activity easier and accessible to everyone: for this reason, this project was given a name: "Flying Lab" meaning the possibility of easily reach every place. But many problems were still not solved and a new revolution was starting

THE NEW REVOLUTION OFFERED BY MICROELECTRONICS

Although the “Flying lab” was an important step forward, still it did not solve some main issues, among the others the availability of sensors for all students, to get directly in touch with measurement problems. Moreover Academia should train students to use what they will more easily use in their everyday life: the huge spread of the new low cost MEMS sensors created a revolution not just in industry, as a reflection also on the new educational labs. At the same time, as sensors can be used by everybody, a huge effort was spent to increase awareness about metrology and its rules, to get good measurements: the new sensor performances had to be fully known to allow for the right choice in every application.

New problems were behind the corner, as the reduced cost of each sensor modifies the general strategy in measurements; the new sensors have lower performances but allow denser networks; information redundancy becomes a main requirement, adding new issues related to networks of sensors, a topic seldom faced in measurement courses.

The new systems come out equipped with microcontrollers: although their use is not complex, all the same the very short time allowed inside courses, especially in mechanical engineering, does not allow to learn even the basic and simple rules needed to start with their use.

The first attempt was therefore to use analog output sensors, coupled to the already available boards, providing the power supply from the USB computer ports, to further push on the development of the “Flying Lab”, therefore making it richer and more autonomous.

The set of available MEMS sensors is quite rich, as pressure, temperature, acceleration, sound, rotation, rotation speed and many others can be measured, the main drawback consisting in the rather brittle connection between the sensors, often hosted on naked boards, and the data acquisition unit. The two most commonly adopted solutions have been Arduino [9] and STM32 [10] by STMicroelectronics, both having wide suites of already developed basic programs to perform the easiest tasks [11]. Students have also been invited to develop projects on own, and this served to develop awareness about the most common problems in experimental activities. A continuous interaction with developers has pointed out how the main problem for non electronic engineers, using such devices, is the lack of a user friendly interface. That’s why a huge effort was spent in helping to get over the barrier constituted by the needed software and hardware skills; this was recognized as a problem not only for education, but also for industrial applications and this is the reason why some products came out recently, with specific aids aimed at allowing everybody to use them.

A line of products developed by STMicroelectronics for IoT has helped a lot also in education: the SensorTile.box [12] first, then the brand new STWIN [13] have been considered quite interesting. In the case of STWIN a single board, created with the aim to prototype new measurement systems, without designing ad-hoc boards, hosts many different sensors, a microcontroller, a wireless connection, a USB port, a Bluetooth antenna and a slot for a micro-SD board; power to the system is provided by a small lithium battery and some AI tools are already available on board. The burdensome task of microcontroller programming can be jumped over, as a simple smartphone app allows one to select the sensors to be used, the data rate, the storage output destination. Once the acquisition is over, data can be read back, thanks to a library developed in the most common programming languages for further evaluation.

Though very powerful, some issues are still related to costs, not yet allowing to provide a board to each student, especially for crowded courses, unless a specific budget is provided. All the same this approach is still considered really powerful, as new MEMS sensors are available almost every day, making the available database richer and richer. This was the teaching standard we were working on, in our group, until February 2020.

THE SMARTPHONE: A COMPLETE MEASUREMENT LAB

Parallel to the described progress, the same MEMS sensors gained a lot of attention, being essential tools in every smartphone: smartphones are complete and rich labs, equipped with a number of sensors measuring a lot of different quantities.

During February 2020 all educational activities had a sudden stop due to the pandemic. At a first glance the impact over laboratory activities was feared to be a disaster, as both students and instructors were working at home. Many solutions have been tried to overcome these difficulties [14] [15]

A first attempt to heal this trouble consisted in trying to move at least some lab activities at home. Paired to this, there was a long lasting experience in managing the students' psychological approach to experimental activities: since the start of the experimental projects in the early 90s, a clear need was recognized to force each individual to directly interact with hardware and instrumentation: some students, less familiar with practical issues, tend to refuse this activity; written reports were also considered an unavoidable completion to the lab activity, forcing students to pay attention to their work as real professionals, gaining awareness and critical sense. Three labs have been carefully selected, with short movies recorded at the trainers' houses, not as a substitution, rather as an aid to the on line explanation provided by the instructors. Measurements have not been collected in tables or files: the students have been invited to work on clips or photos sent to them, to get data on own starting from the readings: to check their attention also wrong measurements were inserted too. In the end the topics have been chosen in such a way that everybody could eventually and easily replicate the same measurements at home. The three chosen topics have been (Figure *2*):

- Uncertainty: dimensional measurements with a caliper and a micrometer (available in many houses)
- Calibration: a cantilever loaded with different weights and a camera as the displacement sensor (a webcam is on every notebook)
- Step response of first order systems, with a thermometer inserted in a hot water pot

Anyway even if the effort to produce material for these experiments has been huge, a physical separation remained between the hardware and the students, creating a gap impossible to be filled.

Figure 2: Images from the home labs: uncertainty (left), calibration of a load cell (middle), step response of a thermometer (right)

At this point a clear idea came out: almost every student has a smartphone and a smartphone is already a complete lab in our hands [16] [17] [18] [19]: it is equipped with many sensors and it already has some data acquisition capability, calculation and storage: these are the same MEMS sensors already introduced in the previous paragraph. Up to here there was not so much novelty: many apps already allowed one to directly connect to the smartphone sensors, though most of them were a sort of game, demonstrators rather than real data acquisition systems: just to mention an example most of them do not have any control on the sampling frequency, continuously varying, according to the load given by the other apps running on the smartphone; then no care is devoted to those metrological issues, changing a simple sensor into a measurement device.

Under this point of view Phyphox, an app developed by a group of physicists from RWTH Aachen [16] [17] [19] was something completely different: the smartphone was converted into a real small laboratory, offering a suite of tools to directly connect to the available sensors, with specific attention to metrological issues. A series of already developed tests is also included in the app, then a calibration tool is provided; data files can be easily transferred after the tests through the e-mail and there is also the possibility to transfer the system control to a computer, creating a local network.

Every study course and every trainer can decide which is the best usage level: concerning engineering studies the choice has been again to leave students as free as possible: smartphones are only used to get data and export them for further work in the best preferred environment: the already developed experiments have just been used as a tool to inspire new ideas. In our case the smartphone just offered the sensors and a data acquisition board to be carefully managed, as the data acquisition system is not a professional one: but this is considered quite useful for educational purposes.

Concerning our activity in educational labs, after a short preliminary training and explanation of Phyphox basic functions, students have been invited to plan tests on their own, in their houses, after some discussion with the instructor. There was a clear awareness about the risk of such an option: a student left alone without any strong guidance could have had opposite reactions: an unconditional surrender or the opposite, as students, alone in their houses, worried or bored for the unreal general situation, could have had the time to think about their project and come out with good ideas, also thanks to the link to the instructor. It was believed that this approach could also serve to better fix the theoretical explanations, through their real use. Trying to push students along this second path has forced all the instructors to spend much time providing assistance and discussing the problems each student met, but this stage was already part of the final exam. Luckily most reactions have been towards a good planning of nice projects.

SOME PRELIMINARY ATTEMPTS WITH SMALL GROUPS ON RESEARCH PROJECTS

Some preliminary approaches were already tempted during the last year to verify the feasibility of the proposed approach, with smaller groups, attending their labs in presence.

During a short course held at the University of Miami, in the early 2020, on experimental methods for SHM, students had to develop a project on a bridge in their campus, caring about many different aspects, both theoretical and experimental; that’s why they were also asked to get at least a rough description of the bridge dynamic behavior, to validate numerical models. The easiest way was to use Phyphox,, leaving some smartphones laid on the sidewalk, to measure vibrations for some time (Figure *3*); luckily some heavy trucks crossed the bridge, which was equipped with speed bumps at both ends, a good help in providing a high excitation. Lack of synchronization, different smartphone sampling rates, different positions along the bridge… All these aspects have not considered problems, rather hints which helped in deepening many aspects on the quality of measurements, much better than a perfect multi channel data acquisition system, which in the end was used, as a verification of the ideas previously discussed. We also took the occasion to have a benchmark, by performing the same measurements with the SensorTile.box by STMicroelectronics, getting similar outputs and managing similar problems: the main differences are that this latter device is not part of the smartphone, though being controlled by this device and the presence of an on-board micro-SD card allows for longer measurements.

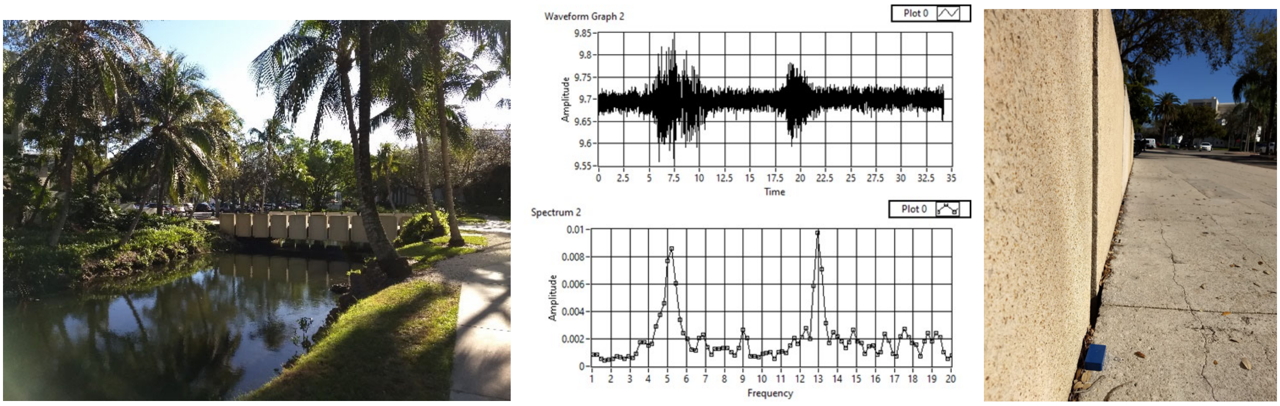

Figure 3: the tests on the bridge at the University of Miami: the bridge (left) a time record and its spectrum (middle), the SensorTile.box on the sidewalk during the tests

A second interesting series of tests was about human structure interaction: this research poses many problems, as the effect of humans moving over a structure can be easily measured in terms of vibrations, strains, displacements… while the input is nearly impossible to be directly measured, consisting in the force produced by each single individual jumping, bobbing or just walking. Since some time ago the only possibility to measure the crowd motion was to use DIC approaches, relying on the use of cameras taking movies of the moving crowds. More recently a new approach has been tempted: groups of students having their smartphones equipped with Phyphox, have been asked to jump on a stadium grandstand or to walk on a very flexible and wobbling bridge, measuring each individual body acceleration (Figure *4*). Measurements provided by the accelerometers inside smartphones have allowed to compare different walking habits, to recognize the different step phases, the level of synchronization while walking or jumping, to check the motion frequency against the structural response. This case too has been an interesting test, which has probably helped in a better comprehension of measurement basics, by working on real problems, solving real needs.

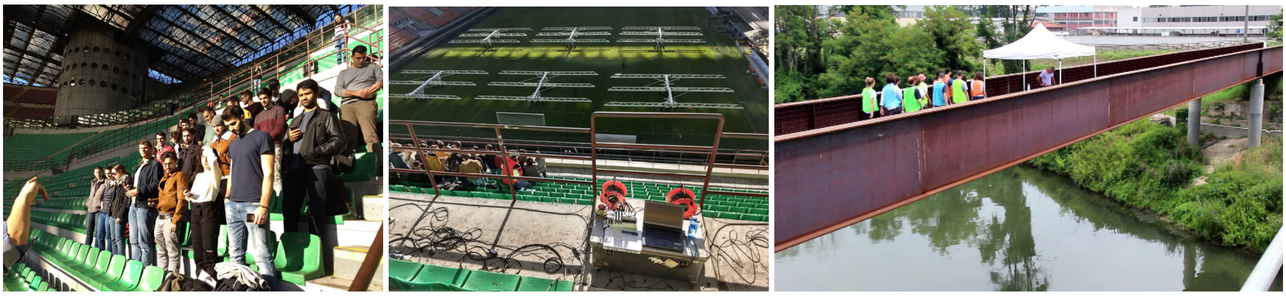

Figure 4: Tests relying on an extensive use of Phyphox: a group of students jumping on a stadium grandstand (left and middle); a group of students walking on a wobbling bridge (right)

SOME OF THE MOST INTERESTING PROJECTS

The above described testing provided good satisfaction. Due to this reason, when the pandemic forced to stop any classroom activities, the use of Phyphox was immediately considered as a possible solution for the experimental activities.

As already stated there was the will to leave students being the main players in their projects, having the smartphones as their data acquisition systems and then analyzing results with the best preferred software. Unfortunately, there was no time to write and deploy simple and robust basic data analysis software: that’s why only some hints have been given about the possibility to work with specific VIs written in Labview, or with Matlab GUIs, or again pointing at specific Python libraries.

Many projects have demonstrated a good students’sensitivity in acting as an engineer; we will report some of the most interesting ideas.

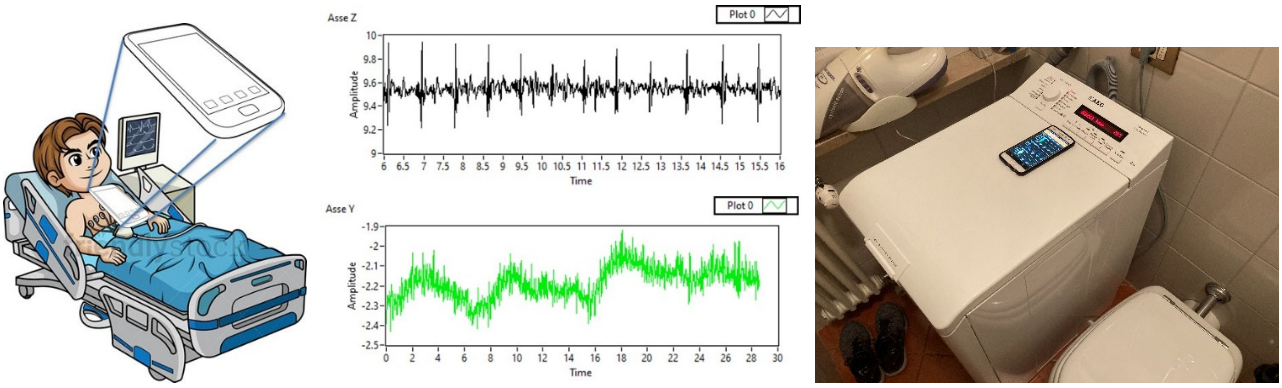

Figure 5: Smartphone used to detect heart beat and breathe (left and middle); washing machine rotating speed measurement (right)

A student, son of a cardiologist, just laid his smartphone on his chest and through acceleration measurements (including g - Figure *5*), he could detect both his heart-beat and his breath frequency: of course this was not an ECG, but a comparison with these data has offered the chance for a discussion about many aspects of filtering, as a tool capable of separating a low frequency range, typical of breathe, from a relatively higher frequency one, responding for the heart beat.

Another project was aimed at verifying that the rpm value during the spinning cycle of a washing machine was the same as declared in the instruction manual, again putting the smartphone on the top cover of the washing machine (Figure *5*): this test has offered another chance to work with spectral analysis under steady state conditions and with varying working conditions.

Some students, fond of music, have created tools to verify the sound quality of their playing instruments, by recording a single note with the associated harmonics; in one case a program to tune a guitar has been produced, by comparing the spectrum of the theoretical note of each string with that produced by the playing instrument and then comparing the spectra up to perfect superposition.

Other cases have been about vibrations produced by different machines, a coffee machine water pump, then a drilling machine (Figure *6*), cars or motorcycles under steady state conditions or under variable regime; in one case a students wanted to check his treadmill performances by the use of the clinometer and the accelerometer inside the smartphone.

Many students worked on the lift accelerations to recognize the number of travelled floors, to detect the door openings and closure, any eventual anomalous behavior.

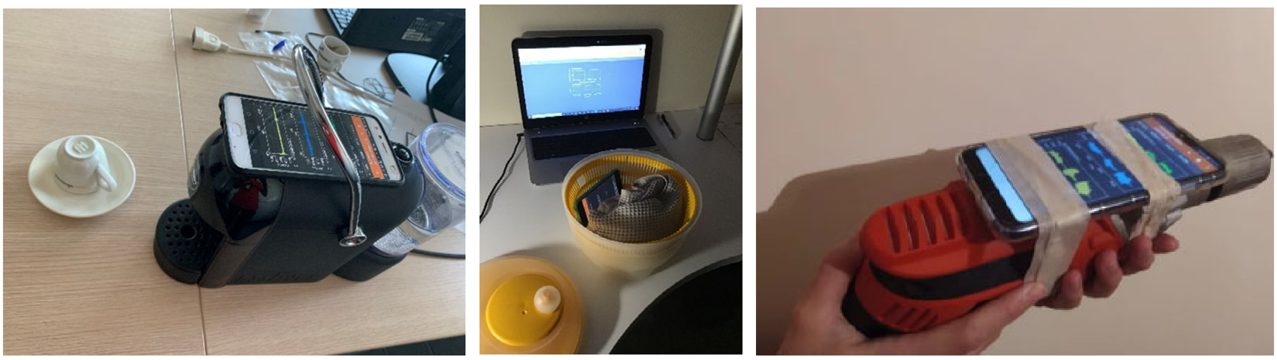

Figure 6: Some tests from the students' projects: vibrations produced by a coffee machine (left), kinematics of a salad spinner (middle), drilling machine (right)

A student having the restless leg syndrome has recorded his leg movements along several hours, to detect frequency, amplitude and number of cycles, trying to relate this to his health state. Another interesting experiment was carried out by some students in a group: during the pandemic they were forced to live at their parents' houses at the seaside or on the mountains: they recorded the atmospheric pressure for some time, trying to correlate results and find its change with the height above the sea level, or with the weather, also trying to define a reasonable uncertainty.

In the end, as the hardest lock-down was at least slightly released, some students have carried out tests on real structures getting again interesting data for discussion on the dynamics of structures (Figure *7*).

A number of students has recorded the acceleration to the floor or the noise related to living in close proximity of trains, heavy traffic or subway lines, trying to point out if any prevailing frequency component was present; one developed a simple anti-intrusion system based on the recognition of a change in the RMS acceleration value at the floor while someone walked in the room.

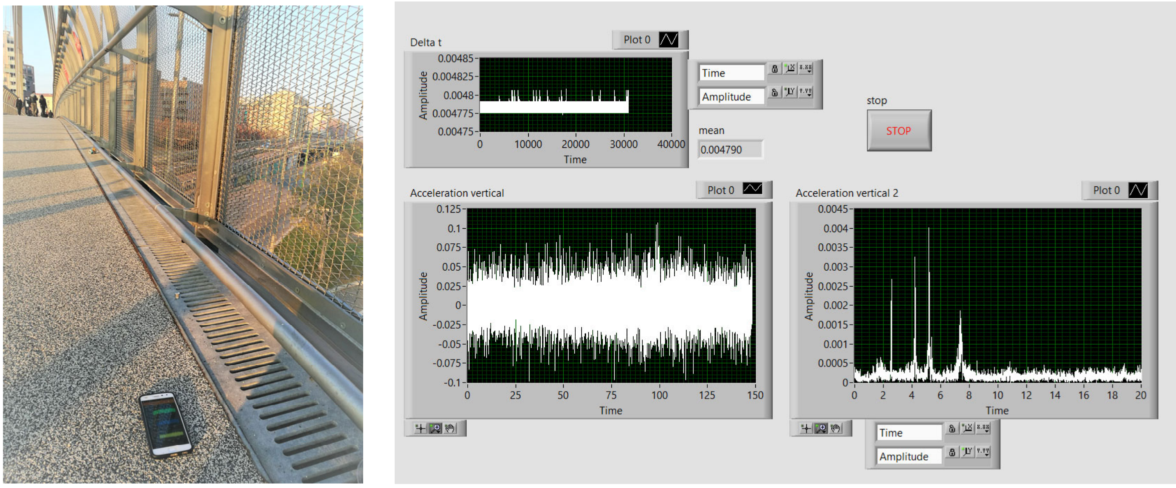

Figure 7: vibration measurements on a pedestrian bridge in Milano

In the end a student decided to put her smartphone in a salad spinner (Figure *6*) and by measuring the accelerations produced by the 3axis MEMS accelerometer has tried to reconstruct on own one of the experiences which are part of the standard packet in Phyphox.

FINAL REMARKS AND CONCLUSIONS

Helping students with their projects has for sure requested a remarkable effort by the instructors and by the students themselves, but the continuous discussions have helped in better fixing the course contents and have made the final exam easier and smoother, starting from the project presentation. Even if it is difficult to compare the final results with those of the preceding years, due to the strong differences in the exam organization, results over around 200 tests have been slightly better this year than in the past. Students demonstrated to be satisfied anyway and in a form they have been asked to fill after closing their exam, on one side they claimed real classroom lessons, as these were anyway preferred; on the other side they wrote they did not really think that they learned less due to the laboratory lack.

Being alone has probably convinced students that they had no backup solutions or that they could not hide in a working group. On the instructors' side even if the adopted solution has allowed to fix a problem which apparently had no solution, that is performing experimental classes at home, much has still to be done. A subtle balance has to be found, stimulating students to do as much as possible on own, at the same time maintaining a guidance on their activity and not making their tasks impossible. As an example one point deserving further attention is the software to manage data: this should be provided in an essential form, without the need to use programs occupying a wide space on disk, preventing from a passive approach, but at the same time also keeping the main attention on the problem to be solved and not on the programming task.

Even if the authors wish that any improvements in the presented approach will not be strictly necessary in the future, hoping in a fast return to the real experimental labs, it is strongly believed that some parts from the gained experience will remain: the use of a smartphone or of the new evaluation boards for the new MEMS sensors will remain, as these offer to every student the chance to work with real sensors at an almost null cost. The possibilities are really wide and will presumably grow in a near future, also because these tools can really help the implementation of the real internet of things.

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