On the Use of Low-Cost Devices for the Validation of Theoretical Lessons at an Undergraduate Level

Juan A. Becerra
Dpto. Teoría de la Señal y Comunicaciones
Universidad de Sevilla
Sevilla, Spain
jabecerra@us.es

María J. Madero-Ayora
Dpto. Teoría de la Señal y Comunicaciones
Universidad de Sevilla
Sevilla, Spain
mjmadero@us.es

***Abstract*—This Innovative Practice Work-In-Progress presents the application of low-cost technology for the creation of practical demonstrations in the validation of theoretical lessons concepts. The creation of new activities is based on the fact that equipment related to laboratory sessions is costly and therefore difficult to access for the students. With this methodology, we expect an increase in the motivation and satisfaction of the students as well as a tool for themselves to experiment individually. Hardware as the well-known Raspberry Pi working with devices such as a software-defined radio (SDR) dongle and a sensor board were used in the experiments. Preliminary results show the students acceptance, becoming a promising technique in undergraduate-level courses.**

***Index Terms*—Educational technology, microcontrollers, motivation, Raspberry Pi.**

I. Introduction and Motivation

The Degree in Telecommunication Technologies Engineering qualifies for the design, planning, and management of communication networks and equipment, electronic devices, transmission and radiocommunications. Within the courses involved in this Degree, those that fall into the Signal Processing and Communications areas deal with layers close to the physical level, which are the most related to the subjects of physics and mathematics. In this context, practical evaluation of theoretical contents requires specific equipment in the laboratory (for example, signal generators, oscilloscopes, modulators, antennas, ...), which, in general, is characterized by its high economic cost and its limited mobility due to its weight and volume. The enormous variety of abstract concepts, as well as the intrinsic difficulty of the contents, produce the idea among students that such theory has limited practical value, restricting its use to laboratory practices without having the possibility of experimenting individually.

In this framework, the present proposal is related to the creation of practical demonstrations to conceptually validate theoretical teaching. For this purpose, low-cost devices will be used, since these are very attractive for students due to their low price and their great potential for experiments. Examples of these devices are the Raspberry Pi single-board computer [1] or the Arduino microcontroller with a set of external devices such as sensor boards, microphones, cameras, software-defined radio (SDR) dongles and antennas. Fig. 1 shows the hardware used in one of the experiments, a top view of the Raspberry Pi with two SDRs attached. These demonstrations will be performed after theoretical lessons in a selection of courses in a coordinated manner with the syllabus, so that the concepts are attractive, synchronized with the theory and allow students to experiment by themselves independently. The first results of the present Work-In-Progress show the effect of these demonstrations on the students perspective, concluding that adding practical laboratory activities that are easy to carry out by themselves enhances their engagement and improves their motivation.

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Fig. 1. Top view of a Raspberry Pi with two Nooelec NESDR SDR attached in its USB ports [2].

The rest of this communication is organized as follows. First, the work is put in context with literature in Section II. Next, Section III covers the proposed approach and activities that were conducted. The evaluation method and results are presented in Section IV, followed by Section V that provides a summary and outlook for these activities.

II. Related Work

The term low cost has become ubiquitous in modern discourse and is used in reference to anything relatively inexpensive or easy to do. The concept has permeated most if not all spheres, with the media constantly applying it in wide-ranging discussions as sports and investment funds [3].

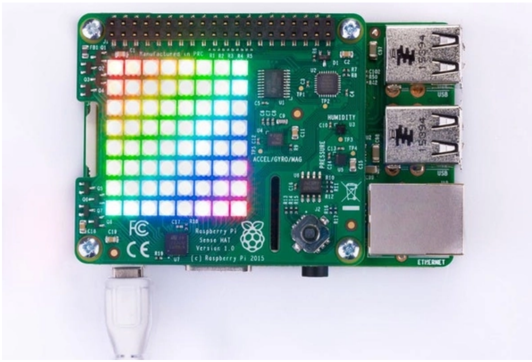

Fig. 2. Top view of a Raspberry Pi with the Sense HAT attached.

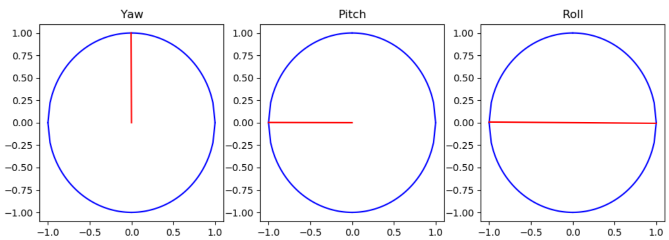

Fig. 3. Screenshot of the real-time orientation display that shows yaw, pitch and roll coordinates within a unit circle.

The use of low-cost techniques applied to education has an extensive literature base. Particularly, in the areas of science, technology, engineering, and mathematics (STEM), the application of this concept allows the substitution of laboratory equipment for affordable technology that offers equivalent features.

Previous work exists on the use of low-cost devices for education. In [4], a personal computer with a data acquisition card controlled by a graphical programming language was introduced for circuit analysis and electronics laboratories. A low-cost robot for the teaching of fuzzy logic applications in bioengineering was presented in [5]. Other examples are signal processing learning through student-owned hardware as a low-cost portable instrumentation and data acquisition platform [6] and the use of a low-cost communication systems bench [7]. With the evolution of electronics and open source tools such as Arduino, a virtual instrument for experimenting with digital integrated circuits was used in [8]. In the area of 3D technologies, low-cost technologies were applied to the development of educational augmented reality content [9].

In the field of low-cost hardware for general implementation, the Raspberry Pi is a single-board computer that offers multiple possibilities. The main characteristics that led us to choose this hardware in the proposed approach are:

- Architecture: it provides a Linux operating system that allows making experiments at a high level with Python programming language.
- The network connectivity is supported by WiFi, Bluetooth, and Ethernet, which enables an easy adaptation to several scenarios.
- External peripherals: because of its USB port and its general-purpose input/output (GPIO) pins, external devices can be connected. The external peripherals that can be connected range from any kind of USB device, such as keyboards or sound cards, to specific hardware-attached-on-top (HAT) electronic boards, that are available for a variety of uses.

Previous research has shown that students have benefitted from using the Raspberry Pi in computer science individual courses [10] in addition to employing it as a tool to integrate the learning of different subjects within a program [11].

III. Proposed Approach

The present Work-In-Progress is set in the context of an innovative practice project developed at the Universidad de Sevilla, Spain, by a group of lecturers of the Department of Signal Theory and Communications. In this project, the design of short practical demonstrations based on the use of low-cost devices is proposed in order to reinforce learning on a selection of courses. More specifically, the following objectives are pursued:

- Design of activities for the assistance of learning with an innovative nature, promoting the use of information and communication technologies as teaching support tools.
- Creation of new teaching materials.
- Development of activities that foster and improve the coordination between students and supervisors, as well as the quality and innovation of Final Degree Projects.

Following the project chronogram, it was planned to incorporate the practical demonstrations during the first semester in the course entitled "Radio Frequency Signals and Systems", pertaining to the third year of the Degree in Aerospace Engineering. The initial plan was to continue inserting the practical demonstrations in other courses during the second semester. However, the present situation caused by the novel Coronavirus Disease 2019 (CoViD-19) has forced us to move from face-to-face teaching to online teaching, thus postponing the rest of the planned activities. Therefore, the present Work-In-Progress will focus on the activities developed in the aforementioned course.

The syllabus of the course "Radio Frequency Signals and Systems" covers the following topics: continuous and discrete-time signals and systems, Fourier transform and frequency-domain representation, analog-to-digital conversion, random processes, analog and digital modulations, signal detection, radio transmitters and receivers, antennas and radio propagation, noise and sensitivity in radio frequency receivers. The students of the Degree in Aerospace Engineering are not familiar with the concept of a signal when they enroll in this course because their previous modules are basic courses on mathematics, physics and chemistry and others related to materials, structures, aerodynamics and propulsion. Commonly, the students consider the topics covered in the first half of the course as abstract and far from practice.

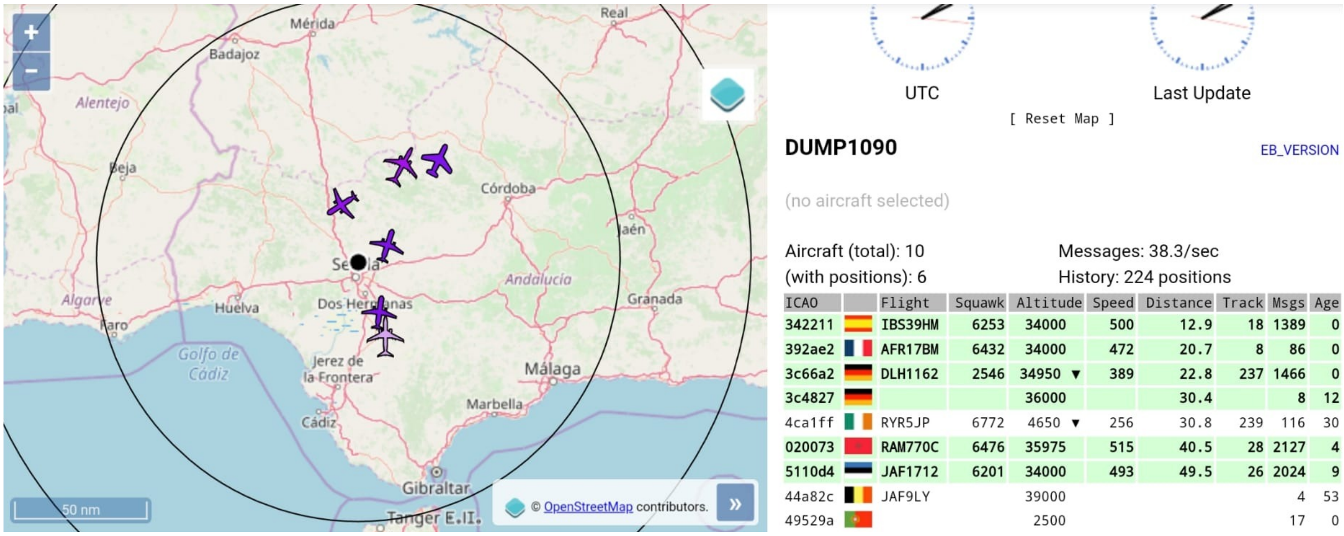

Fig. 4. Screenshot of the software Dump1090 for SDR devices. The screen shows the map of the South of Spain with the aircrafts near the city of Seville.

In order to help them conceptually validate some of the main topics of theoretical teaching, the following demonstrations were designed:

1) Development of a real-time orientation display based on the Inertial Measurement Unit (IMU) included in the Sense HAT [12] connected to the Raspberry Pi board (see Fig 2). The IMU sensors include three axes of gyroscope, an accelerometer and a magnetometer. The discrete-time data provided by the gyroscope was employed to exemplify the concept of a continuous-time signal —the movement of the board in the three spatial dimensions— being measured by the gyroscope and transferred through the microcontroller to the PC after being sampled or converted to discrete-time. A screenshot of the display is shown in Fig. 3.
2) Reception of an FM broadcast signal employing an SDR dongle with the appropriate external antenna connected to the Raspberry Pi board (see Fig. 1). This demonstration also included the visualization of the spectrum of the acquired signal, that was employed to get a better understanding of the representation of signals in the frequency domain. Furthermore, the concept of modulation was reviewed.
3) Construction of a receiver for the ADS-B (automatic dependent surveillance-broadcast) technology and visualization on a map of the tracking of aircrafts within reach (see Fig. 4). This example illustrated concepts related to the spectrum allocation for different services, radio propagation, magnitudes and units employed. In addition, it constituted a practical application in use in the field of aeronautical radio communications.

The demonstrations were performed by intern students of the department during part of a lesson. First, the lecturer introduced the motivation for each experiment while the intern students prepared the Raspberry Pi boards and connected the necessary external devices. Next, they conducted each demonstration while the lecturer reviewed the related theoretical concepts, and finally, time was left for answering the students' questions and for hands-on interaction of the students with the devices. After that, the students expressed their opinion not only about the demonstrations but also about the course and the context of their degree studies. The whole activity lasted about an hour and thirty minutes.

IV. Evaluation and Results

The evaluation of the activity was conducted by surveying. After the activity, a set of questions were addressed to the students. The survey was designed in order to measure the level of agreement on a Likert scale with respect to the following statements:

- *(Q1) The activity has interest for the course.*: This question was designed to measure the perceived correlation of the specific activity with the syllabus of the course.
- *(Q2) The activity has an interest for my own professional future.*: The intent of this question was to measure the professional applicability of the activity.
- *(Q3) I would include this content as a practical lesson within the course.*: The interest of doing the experiment by themselves at the laboratory was measured in this question.
- *(Q4) The activity has raised my interest in the course and its topic.*: This question rated the perceptual change in interest for the course and topic.

The available answers for each question were: strongly disagree, disagree, neutral, agree and strongly agree. Additionally, a free-answer opinion question and the following metrics were gathered:

- *Number of years since you started the degree.*: Numeric value indicating how long has the student been enrolled in the Degree.

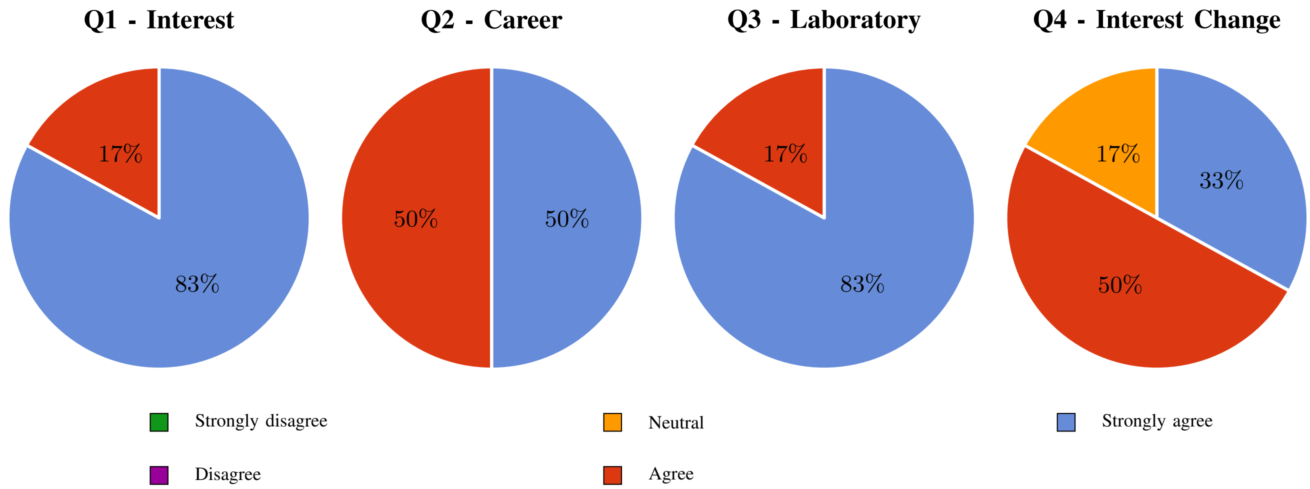

Fig. 5. Results of the acceptance survey in a Likert scale.

- *Is it the first time you are enrolled in the course?*: Yes/no value to indicate if it is the first time the student is undertaking the course or not.

The survey was conducted among six students, that represent the total number of enrolled students in the course. The number of students is justified by the type of course, which belongs to optative subjects. This data represents the first trial and the survey will be extended to other students in core courses.

Results are shown in Fig. 5. Questions 1 and 3 had a median of *Strongly agree*, which let us conclude that the experiments had significance with respect to the syllabus and that the implementation of practical or laboratory lessons for the topics would be of interest for the students. Question 2 resulted in an equal distribution between *Agree* and *Strongly agree*, which lead us to the conclusion that the experiment results are of practical applicability. Question 4 had inter-quartile range (IQR) of one with positive and neutral answers, therefore the tendency in interest change can be considered positive.

V. Summary and Outlook

This contribution shows the authors' preliminary experience with the use of low-cost devices for the practical demonstration of concepts related to a "Radio Frequency Signals and Systems" course. Three experiments were carried out: the use of a gyroscope to obtain the rotation degrees in the three axes, the live reception of a radio signal and the graphical representation of its spectrum, and the geographical positioning of airplanes thought the reception of the beacons they transmit during flight.

An initial validation of the proposal was carried out with surveys that gathered the students' perceived correlation of the activities with the course, their career and change of their interest on the subject. Results show that the activities were positively received and that the new contents are interesting for the students.

Future work will apply the same type of activities to other courses in the Degree in Telecommunication Technologies Engineering with an adaptation of the contents to the syllabus of the specific courses.

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