PEGASE4: A Generic Board for Embedded SHM Applications

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ABSTRACT

This article aims to present the newest version of PEGASE: a generic wireless board dedicated to SHM applications. The first part of the article consists in describing the technological advances of PEGASE (generic processing using an embedded buildroot Linux, inertial IMU unit, GNSS receivers, multiple IOs...). Then scientific aspects of PEGASE are specified : the original use of the GNSS/PPS signal as a core information inside Linux to make it synchronized up to some µs, the energy strategies that could be adopted in view of implementing the most efficient battery/solar cell usage,... Thus, real SHM use-cases are given as illustrations : PEGASE usage for a wireless acoustic emission monitoring system.

INTRODUCTION

Since around fifteen years Gustave Eiffel University (previously known as LCPC Laboratory until 2011, thus IFSTTAR until 2020) pays attention to capitalize its research activities in instrumentation dedicated to SHM into a capitalized and generic platform named PEGASE [1].

Based on PEGASE concept, many use-cases have been addressed in various fields such as : acoustic monitoring for wire-break in bridge cables [2], wireless operational modal analysis of structures [3], lightning detection and localization in power lines [4], etc

In this perspective, PEGASE aims to be as well a research platform for researchers as well a turnkey product able to be quickly integrated by engineers into a design to propose a new SHM solution. Thus, each version of PEGASE platform has been licensed to third-party partners in view of its dissemination [ref]. Due to the well known *metabolism* of electronic sector, it was time for Gustave Eiffel University to deliver a new version of PEGASE [5].

The main characteristic of PEGASE resides in its genericity obtained, from the hardware point of view, through a set of mother/daughter plugable boards, and, from the software point of view, via the usage of an embedded Linux operational system (buildroot, kernel version 5.10.10). The usage of Linux, added to a collection of customized drivers allows to monitor each physical IO (including interruption, timestamping…) without being a hardware expert but simply knowing standard C or Python programming. This article highlights two of PEGASE's strengths: its timestamping ability: in other words an embedded deterministic solution to be synchronized to the UT thanks to a GNSS solution [6].

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The qualification (up to some micro seconds) is demonstrated below its ability to take care of power consumption. Without being a low-power system, PEGASE offers energy consumption strategies described below.

PEGASE 4: DESIGN DESCRIPTION

Figure 1. *Mother board PEGASE4*

PEGASE is the french acronym for: Generic Platform for Embedded Wireless Applications". The PEGASE4 mother board (13x6,5 cm) is a generic board that integrates the main functions required for an embedded system.

The core of the PEGASE board resides in the OSD32MP157C module from OCTAVO. The OSD32MP157 integrates the versatile STMicroelectronics STM32MP157 processor, featuring two Arm® Cortex®-A7 cores and one Arm® Cortex®-M4 processor. The other main components are:

- A EMMC: SDINBDG4-64G-I1 SanDisk
- A high-precision GPS receiver time-oriented: Ublox NEOM8T
- A Wi-Fi and Bluetooth module: LBEE5XV1YM-574 from Murata
- An IMU 3D accelerometer, gyroscope, and magnetometer : ISM330DHCXTR from STMicroelectronics
- An NFC component: ST25DV04K from STMicroelectronics

Daughter boards have been developed within Gustave Eiffel University, such as a 16-channel low-frequency sampling daughter board [0-25 khZ], an 8-channel high-frequency daughter board [250 kHz – 1 Mhz], and other more specific boards depending on SHM applications.

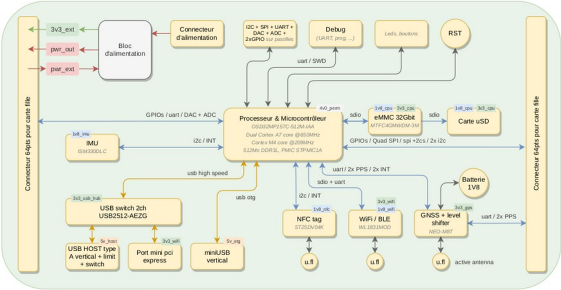

Figure 2. Board Architecture

PEGASE SYNCHRONIZATION QUALIFICATION

Introduction

Often forgotten when mentioning Wireless instrumentation, synchronization could become fundamental when applied to Wireless Sensor Networks. Examples of typical synchronization needs between sensors would be [7]:

- vibration monitoring: up to 1 ms
- acoustic monitoring: up to 10 µS
- optical or electrical waves : up to some nS

As stated in the introduction, synchronization is a strength of PEGASE's main applications. Thus, qualifying its capabilities in this regard is of utmost importance, in order to manage expectations and ensuring its ability to fit specific use cases.

GNSS-PPS synchronization solution

PEGASE uses a GNSS-PPS based synchronization solution, the underlying idea is that a GNSS device will regularly provide two signals:

- an RS232 signal used for data bytes transmission (location, timestamp…)
- a PPS (Pulse Per Second) binary signal in the form of a square wave, synced up to around 20 to 50ns around the UT (Universal Time).

On each PPS rising edge, the hardware resets its time-base in order to keep it synchronized with the signal.

The PPS is also associated with a timer that counts up to a second, with a degree of precision relative to our current needs, so that on each rising edge of the signal, the timer's value is captured and used in the time-base reset process. Accordingly, even if the physical quartz of the Wireless node runs too quickly or too slowly (with a typical drift of some PPM), this drift is canceled every second.

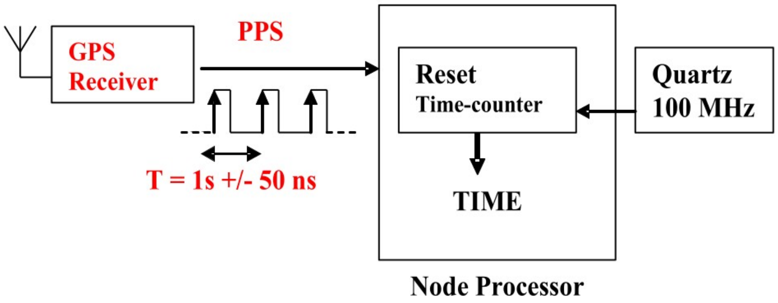

Figure 3. GNSS synchronization schematic example

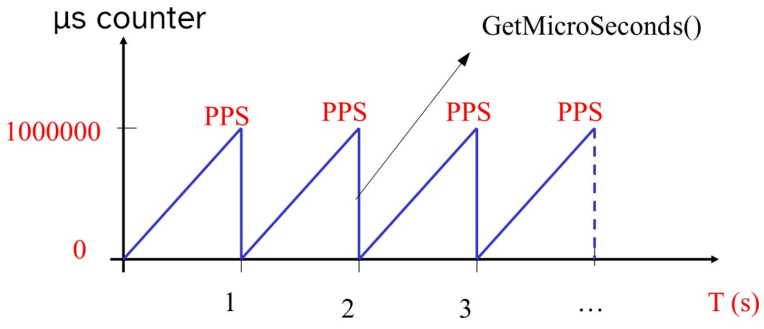

Figure 4. PPS timer counter illustration

Test-bench description

Considering the points described previously, the retained method to test out synchronization was as follow:

Two PEGASE 4 were used, both with a 1MHz internal timer associated with a modulo 1,000,000 counter, this way each counter value was equivalent to a µs and the counter would only count up to a second before resetting itself automatically.

Both of these were associated to a capture GPIO input, that would generates an interrupt which would send back the counter's value to a software set to record these values into a ".csv" file in order to analyze them later, before manually resetting the counter.

These GPIOs were then wired to common arbitrary function generator set to send a square impulse signal every 1,1s as an arbitrary value that would simulate a event occurring between two PPS.

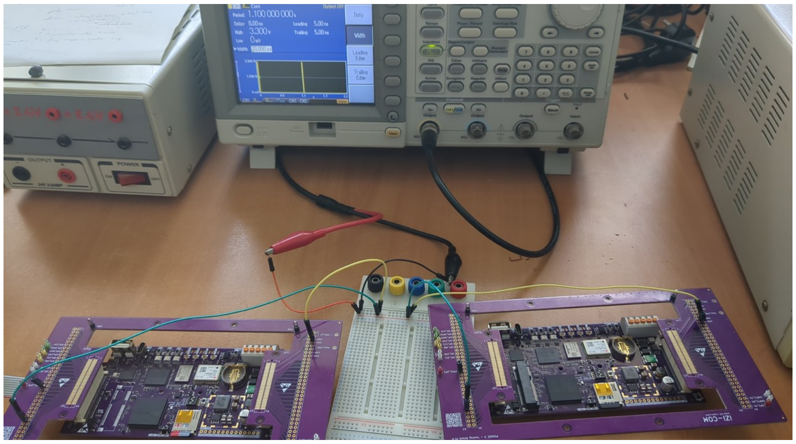

Figure 5. Synchronization test-bench

TABLE I. RESULTS OF ABSOLUTE TIME DIFFERENCES BETWEEN THE BOARDS

Mean devitation	Standard Deviation	Max Deviation
5.82 µs	4.75 µs	57.00 µs

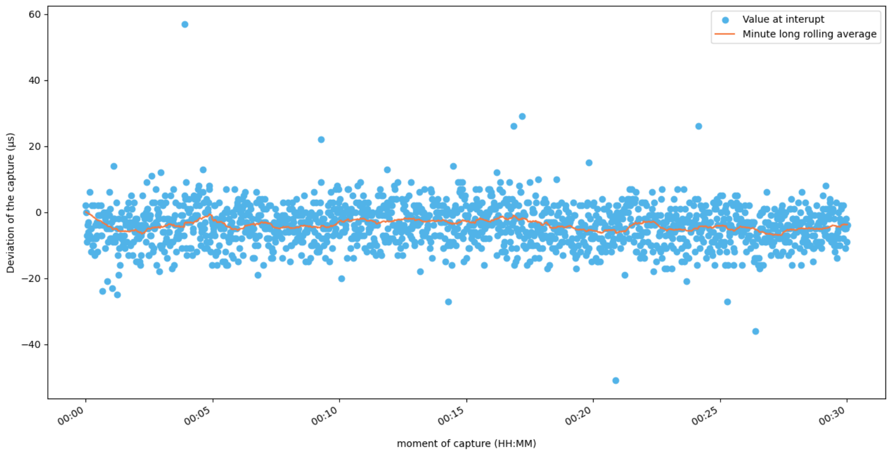

Figure 6. Graph of the relative differences in captured values

Results

Data collection lasted for about half an hour, leaving us with a total of 1639 data points per board, which were paired up before calculating their relative and absolute difference, giving us table I as well as figure 4, in which a positive value means that board 2 was late compared to board 1 and a negative value means that board 1 was late compared to board 2. The very positive result to retain in the average of 4,75 µs UT for a same event between two PEGASE4 platform that aren't aware of each other.

POWER CONSUMPTION QUALIFICATION

Introduction

Once again, as stated in the introduction, power consumption is a concern in most envisioned use-cases for PEGASE. Thus it is important to have at least a first impression of it in order to make sure that it will run as intended for long durations. Typically the implementation could use a battery coupled to solar cells. The following module or purpose are identified as potential "degrees of freedom" in order to tune PEGASE4 power-consumption:

- GNSS [7] : The general purpose nature of PEGASE means that GNSS data or a PPS may not be useful, or at least not constantly needed. In other words, PEGASE can ensure accurate time-stamping while turning ON/OFF its GPS module

- WIRELESS communications : On certain applications, constant communication will prove useless in favor of bursts of data being sent at specific time/on specific occasions for instance. WiFi module should then be turned ON or OFF as needed and not kept ON permanently.

- MIPS stress: It may happen that at some point a lot of data will need to be processed at once due to varying factor[3], such moments are more than likely to be critical, as such it is especially important to ensure that the board will stay operational as long as possible in these situations.

Test-bench description

In order to operate these measures, we used an INA219 module hooked to an Arduino nano 33 that would output the measures to a computer. The INA219 is wired between the power supply and the PEGASE and all of them share a common ground (Figure 7).

The PEGASE was then running in different configurations for a few minutes, and we gathered between 140 and 180 data points per configurations (mostly being around 150 data points).

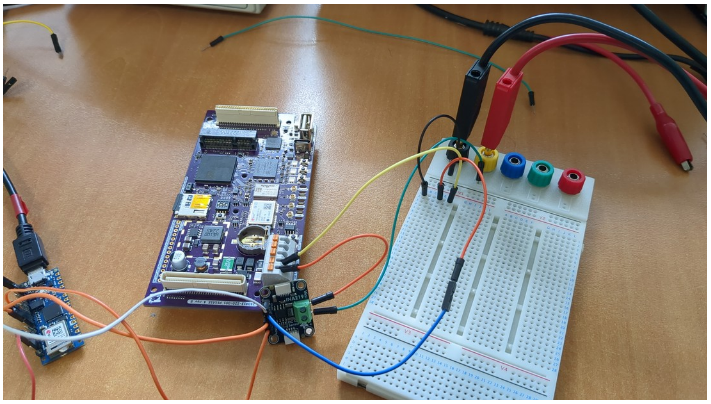

Figure 7. Power consumption test-bench

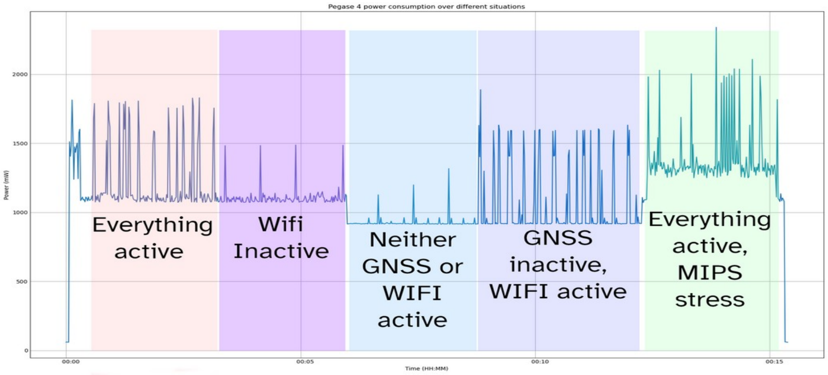

Figure 8. Data measured from the power-consumption test-bench

Table II. SUMMARY OF POWER CONSUMPTION DATA

configuration	Mean value (mW)	Standard deviation (mW)
GNSS and WIFI inactive	925.86	43.64
GNSS inactive and WIFI active	1050.38	251.19
GNSS active and WIFI inactive	1104.8	65.4
Both active	1221.70	240.4
Both active, MIPS stress	1389.06	216.8

Results

The various results were compiled into Figure 8, forming a simple graph of all the values during the test, and Table 2, compiling the means and standard deviations from the the results in those different configurations. As a general and positive conclusion those preliminary results demonstrate the ability of PEGASE to operate wirelessly with battery and reasonable solar cells dimensions.

USE-CASE GERONIMO : GUIDED WAVES SOLUTION BASED ON PEGASE

The PEGASE 4 board can be used in the field of guided waves to perform non-destructive diagnostics on various structures such as rails, concrete infrastructures, or composite materials. Equipped with its 8 fast channels daughter board integrating an FPGA, it enables both high-voltage wave emission and high-frequency signal reception.

The system is able to generate arbitrary waveforms on 8 channels at a frequency of 10 MHz, providing great flexibility in excitation depending on the material under inspection. Simultaneously, data acquisition is performed on 8 synchronized channels at a sampling rate of 2 MHz, ensuring high temporal resolution of some µS for the analysis of reflected or transmitted signals.

The board features both Ethernet and Wi-Fi interfaces, allowing remote configuration of acquisition parameters and data logging, thus facilitating deployment in remote or hard-to-access environments. Finally, multiple units can be synchronized using a GPS signal, enabling large-scale distributed measurements while maintaining precise temporal coherence between devices. Example at [8].

Figure 9 : GERONIMO

CONCLUSION AND PERSPECTIVES

This article has the simple goal of highlighting the new Gustave Eiffel instrumentation platform PEGASE 4 form now available on the shelf. After some general specifications, its ability in terms of wireless synchronization up to some 5 µS Universal Time whatever the distances are in the wireless network has been demonstrated . It has also been illustrated that some energy strategies are possible to target energy consumption in reasonable ranges (i.e. less than 1 W) to be implemented in a solution mixing battery and solar cells. An acoustic use-case of PEGASE4 is also given through the GERONIMO use-case now sold by a partner company.

The ongoing or future perspectives around PEGASE4 resides in 3 ways. First we are actually integrating the GNSS PPS synchronization mechanism as the core solution of the Linux gps.d daemon now a standard in Linux kernels. Regarding energy, we are going deeper in the possible energy strategies like by implementing the “post-facto” mechanism to keep the GPS module off most of the time. Finally, through some doctoral works, we will develop hardware and software embedded solutions to ensure auto-control and auto-correction of PEGASE4 measurements to provide certified data even during long-time SHM use-cases.

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