Low-cost open-source high-frequency portable pulse counter for Raspberry Pi and its application to Xray transmission rate measurement

A.T. Zengin

Computer Engineering, Istanbul S. Zaim University,
Halkali, K.Cekmece, Istanbul, Turkey

E-mail: tarik.zengin@izu.edu.tr

ABSTRACT: Affordable electronics for instrumentation play a vital role in academia since research budgets are tight nowadays. In this paper a low-cost open-source high-frequency portable Raspberry Pi-based pulse counter is presented. Although it is designed as a 2 channel counter, it can be easily modified to a 4 channel counter. It provides a relay control interface for experimental-setup integration and counts pulses up to 10 MHz frequency. Presented system is proved to be accurate by an Xray transmission rate measurement experiment.

KEYWORDS: Control and monitor systems online; Data acquisition circuits; Digital electronic circuits; Front-end electronics for detector readout
1 Introduction

Low-cost electronics are vital for researchers due to limited research budgets. Limited sources of open-source hardware electronics has barred research since some researchers cannot either afford or easily acquire the required laboratory electronic equipment. Recently there have been some efforts to provide affordable electronics that perform various kinds of measurements. S. Ritt et al. introduced an open-source software interface for their GHz rate waveform digitizer [1]. A.E. Beltran developed open-source hardware, low-cost acquisition board with ADCs and various filters [2]. E. Zahedi proposed open-source hardware and software dual-channel biosignal recorder [3]. K. Jin and Y. Song developed an open-source hardware, beaglebone-black-based sensor monitoring hardware [4]. G. Real et al. combined the industrial controllers and data acquisition features in one open-source hardware and software board [5]. As seen in the examples above, more and more open-source hardware and software designs were being introduced for the researchers. This paper presents an affordable, portable, and open-source-hardware (OSHW) and open-source-software (OSSW) frequency/pulse counter for high frequency signals. The hardware was designed as a Raspberry-Pi hat that can be directly connected to the I/O ports. The software was implemented in Python on a Qt based graphical user interface running on Raspberry Pi.

2 Design methods

In order to make the system affordable, it was designed as an extension board for Raspberry Pi (RPi). Owing to its being a widely known and commonly used embedded system, the Rpi-based designs can be easily obtained and installed by scientists. Presented system consists of 2 components; the hardware and software parts.
2.1 Hardware design

Hardware system includes 2 independent 32-bit hardware counters (SN74LV8154) [6] each has 1 clock input, 1 clear input, 4 control inputs and 8 data outputs as shown in figure 1. Therefore most of the RPi I/O pins were used by the counters in this project. 32-bit output data were multiplexed to the output pins in bytes by using 4 control inputs GAL, GAU, GBL, GBU, ordered from least significant byte to most significant byte, respectively. Both of the counters were connected to common control inputs. Therefore the selected byte of the data was always the same for both counters. Although the presented system was designed as a 2-channel 32-bit counter, it can easily be modified to function as a 4-channel 16-bit counter by disconnecting RCOA–CLKBEN and CLKB–CLKA connections. In such case, the 3rd and 4th clock signals should be applied to CLKB pins. The pinout diagram of RPi showing where the counter pins are connected is given in figure 2.

To acquire 32-bit data from the counter, each 8-bit section of it should be taken sequentially by iterating 4 control inputs as it’s explained above. Then a simple logic/arithmetic operation was applied to reconstruct the 32-bit data. Data structure is shown in figure 3.
Each counter had an opamp comparator as their clock input as shown in figure 4. Comparators had a voltage divider at the inverting inputs to adjust the reference comparison voltage. In this specific application, voltage divider resistors are chosen as $R_{11} = R_{21} = 470 \, \Omega$ and $P_1 = P_2 = 47 \, k\Omega$. Values can be adjusted according to the application.

Printed Circuit Board (PCB) was designed by using Eagle EDA software. Signal inputs and relay outputs were placed on the sides of the board for easy accessibility. Voltage divider potentiometers were chosen as top-adjust worm-gear trimpots for easy operation. Test pins for reference voltages, comparator outputs and source voltages were placed around the board for easy troubleshooting. The design is shown in figure 5. Schematics and board design files were published\(^1\) freely under the GPL license. It can freely be changed, improved and republished.

2.2 Software design

Graphical user interface (GUI) was programmed by using Python and Qt library. Data acquired from the board were shown in the middle part of the screen with timestamps for each interval set by the operator.

Hardware counters count automatically on reception of a trigger signal fired by the opamp comparators. Interval of count retrieval can be set in milliseconds from the GUI. On every interval set by the GUI, data were multiplexed and combined by the software.

The GUI provides an on-off interface for relays to control any hardware in the experimental setup. In this specific example, an Xray source was controlled via \textit{XRAY ON} and \textit{XRAY OFF} buttons. It was also possible to set an on-time in seconds for the relay that was on for the chosen time and turned off automatically at the end of this period. \textit{Save Log} feature saves the count logs with timestamps as a .txt file. The source code was published\(^2\) freely on Github under the GPL license. Touchscreen- and mouse-operation-compatible GUI is shown in figure 6.

\(^1\)https://github.com/atzengin/RPi-Frequency-Counter
\(^2\)https://github.com/atzengin/RPi-Frequency-Counter-Software
The final design combining the hardware and software is shown in figure 7. Back side of the casing having the signal input (only 1 channel was implemented for this specific application) and relay connector can be seen in the lower left frame. It can run on battery power source and does not require keyboard/mouse, hence, making it a portable system.

3 Accuracy test

In order to gauge the system’s accuracy, an AC signal sweeping from 100 Hz to 10 MHz was applied to the counter. Even though the proposed design supported millisecond level intervals, it was set to 1000 ms from the GUI since the frequency-counter-to-be-compared (UNI-T UT71D) supported...
this interval only. The count was displayed in real time during the sweep and the logs saved to a .txt data file. Sweep signal settings and count graph visualization of sweep data are given in figure 8 and figure 9, respectively. The graph shows that the system perfectly reflected the linearly incremented frequency over time. Therefore the system was sufficiently accurate.

4 Application of transmission rate measurement

In order to show the accuracy and to clarify the usage of proposed design, an experiment was conducted. Setup is given in figure 10. A 60keV Xray source and an SiPM (Silicon Photo Multiplier) detector were laid out in a straight line with 150 cm distance between them. Detector has a LYSO(Ce) — Lutetium Yttrium Orthosilicate ($\text{Lu}_{1.8}\text{Y}_{2}\text{SiO}_5$:Ce) scintillator for catching photons. Proposed counter received the output signal of detector and counted the pulses which
fired by detected photons [7, 8]. The pulse count gave the intensity of photons reached the detector. When there was no paraffin blocks in between the Xray source and detector, the count was recorded as $I_0$ (initial intensity of photons).

As measuring the transmission rate by using the proposed counter was the goal of the experiment, paraffin blocks — each is 14 mm thick — were placed in between the Xray source and detector. Intensity of photons is given as $I = I_0 e^{-\mu x}$ where $\mu$ is the linear attenuation coefficient ($\mu_{\text{paraffin}} = 0.18 \text{ cm}^{-1}$) and $x$ is the distance traveled in the material. Number of paraffin blocks placed in the setup changed intensity $I$ in connection with $x$.

Transmission rate for 60 keV photons through paraffin was calculated using the formula given above for different number of blocks were placed in front of the detector. Comparison of the calculated and measured transmission rate is given in figure 11. Xray source was controlled by the
proposed counter to shoot for a specific period of time that was set in the GUI. In this experiment, shooting time was selected as 5 s. Standard deviation of transmission during the Xray shoot and measurement error of the paraffin blocks’ thickness (±1 mm) were shown as the vertical and horizontal error bars, respectively, in the figure. It clearly showed the proposed counter was accurate.
5 Conclusion

In this paper, a low-cost frequency/pulse counter is presented. It was consisted of 2 32-bit independent channels with adjustable threshold levels. The design was published freely for both the hardware and software on Github. It can freely be downloaded and assembled by anyone who needs a low-cost pulse counting solution. The transmission rate test showed that system was accurate enough for the mid and high frequency pulses. Digitally adjustable threshold levels and increasing the channel number were left as the future works.

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References

[1] S. Ritt, R. Dinapoli and U. Hartmann, Application of the DRS chip for fast waveform digitizing, Nucl. Instrum. Meth. A 623 (2010) 486 [arXiv:1011.0226].

[2] A.E. Beltran, Low-cost acquisition and development board. An open source hardware proposal, in the proceedings of the Symposium of Signals, Images and Artificial Vision (STSIVA 2013), September 11–13, Bogotá, Colombia (2013), arXiv:1011.1669v3.

[3] E. Zahedi, Quick deployment of open-source hardware and software for a dual-channel biosignal recorder, in the proceedings of the 2013 IEEE International Conference on Smart Instrumentation, Measurement and Applications (ICSIMA 2013), November 25–27, Kuala Lumpur, Malaysia (2013).

[4] K.C. Jin and Y.H. Song, Open source monitoring hardware for sensor interface, in the proceedings of the International Conference on Electronics, Information, and Communications (ICEIC 2016), January 27–30, Danang, Vietnam (2016).

[5] G.E. Real, M. Florencia Jaure and A.O. Vitali, Data acquisition and industrial control system based on Arduino Due using open-source hardware and software, in the proceedings of the XIII Technologies Applied to Electronics Teaching Conference (TAAE), June 20–22, Tenerife, Spain (2018).

[6] Texas Instruments, SN74LV8154 dual 16-bit binary counters with 3-state output registers, http://www.ti.com/lit/ds/symlink/sn74lv8154.pdf (2015).

[7] E. Iren, T. Yetkin and M.N. Erduran, Gamma spectrum measurement by using SiPM and GEANT4 Simulation, in the proceedings of the 11th National Nuclear Science and Technologies Congress (in Turkish), October 12–14, Kusadasi, Aydin, Turkey (2016).

[8] T. Yetkin, E. Iren, F. Ozok and M.N. Erduran, Simulation results for novel gamma probe based on silicon photomultipliers, in the proceedings of the 3rd International Conference on Theoretical and Experimental Studies in Nuclear Applications and Technology (TESNAT 2017), May 10–12 May, Cukurova University, Turkey (2017).