Security of Infocommunication Systems and Internet of Things

2023 Vol 1, No 1

https://doi.org/10.31861/sisiot2023.1.01010

Received 05 June 2023; revised 20 June 2023; accepted 27 June 2023; published 30 June 2023

Reading of Sensor Signals with Automatic Selection of Sampling Frequency

Serhiy Balovsyak*, Vitaly Lacusta and Khrystyna Odaiska

Computer Systems and Networks Department, Yuriy Fedkovych Chernivtsi National University, Chernivtsi, Ukraine

*Corresponding author (E-mail: s.balovsyak@chnu.edu.ua)

ABSTRACT The correct selection of sampling frequency when reading signals from sensors ensures high quality of digitized data and saves memory when storing such data. The complexity of automatic selection of the sampling frequency is explained by the fact that this frequency depends on the frequencies of the useful signal, which are not always known. Therefore, in the work the computer system for reading signals from temperature, humidity, and lighting sensors with automatic selection of the sampling frequency based on the Fourier spectrum analysis of the signals was developed. Signals from digital sensors (DHT22) are transmitted directly to the Raspberry Pi3 microcomputer. Signals from analog sensors (LM335M, light sensor) are fed to the Arduino Uno device. An algorithm for the analysis of Fourier spectra of one-dimensional signals has been developed, which is designed to determine the optimal sampling frequency and decimation coefficient of signals read from sensors. Based on the initial signals, their Fourier spectra are calculated, and by analyzing the spectra, the maximum frequency of the useful signal and the optimal sampling frequency are determined. Specified sampling frequency according to the sampling theorem is calculated as a double value of the maximum frequency of the useful signal. Decimation (thinning) of the signal is performed with a coefficient determined by the ratio of the initial and specified sampling frequencies. To assess the quality of the signal after decimation, the decimated values were interpolated by splines. The root mean square error of interpolation was calculated. Experimental testing of the developed tools for reading and analyzing signals from temperature, humidity and lighting sensors was carried out. In all considered cases, the sampling frequency is determined correctly. The resulting sampling rates can be used for decimation of signals or for subsequent reading of signals from sensors.

KEYWORDS temperature, humidity and light sensors, frequency sampling, Fourier spectrum, Python.

I. INTRODUCTION

The task of developing a computer system for reading the signals of temperature, humidity and lighting sensors with automatic selection of the sampling frequency is important, since the correct selection of the sampling frequency ensures high quality of digitized data and saves memory when storing it [1-4]. The complexity of automatic selection of the sampling frequency is explained by the dependence of this frequency on the frequencies of the useful signal, which are not always known. Setting the same frequency when reading different signals is technically a simple solution, but it has two significant disadvantages: undersampling leads to signal distortions, and oversampling leads to excessive memory consumption when storing data. In modern computer systems, the shape and spectra of signals are analyzed to select the optimal sampling frequency [1-2]. For this purpose, artificial neural networks (ANN), in particular, convolutional neural networks (CNN) [3] are also used. However, the analysis of the shape and spectra of signals is not yet fully automated, and the use of ANN requires a complex learning process. At the same time, choosing the sampling frequency in manual mode is a time-consuming process. Therefore, an urgent task is to create a computer system for reading sensor signals with automatic selection of the sampling frequency based on the analysis of the Fourier spectra of the signals.

II. ANALYSIS OF SPECTRA OF FOURIER SIGNALS

The one-dimensional direct Discrete Fourier Transform [4, 5] of the digital signal $y(i)$, where $i = 0, 1, ..., Q-1$, is determined by the formula

$$F(n) = \frac{1}{Q}\sum_{i=0}^{Q-1} y(i)\exp\left(-j\cdot 2\pi\left(\frac{n\cdot i}{Q-1}\right)\right), \qquad (1)$$

where F is the Fourier image (Fourier coefficients); j is an imaginary unit ($j^2 = -1$); n is the reference number for the signal frequency, where $n = 0, 1, ..., Q-1$.

Based on the Fourier spectrum F, the initial function $y(i)$, where $i = 0, 1, ..., Q-1$, can be obtained using a one-dimensional inverse discrete Fourier transform

$$y(i) = \sum_{n=0}^{Q-1} F(n)\exp\left(j\cdot 2\pi\left(\frac{n\cdot i}{Q-1}\right)\right). \qquad (2)$$

Analysis of Fourier spectra allows to determine the value of the signal frequencies f and use them to calculate the sampling frequency fd. If the maximum frequency of the signal in the spectrum is fs_max, then according to the counting theorem, the sampling frequency should be chosen equal to $fd = 2fs\_max$. The Fourier amplitude spectrum is determined by the formula

$$F_a = |F| = \sqrt{\mathrm{Re}(F)^2 + \mathrm{Im}(F)^2}\ , \qquad (3)$$

where $\mathrm{Re}(F)$ is the real part of F, $\mathrm{Im}(F)$ – imaginary part.

III. HARDWARE AND SOFTWARE IMPLEMENTATION OF A COMPUTER SYSTEM FOR READING AND ANALYSIS OF SENSOR SIGNALS

In the developed computer system (Fig. 1), signals from digital temperature and humidity sensors (DHT22) are transmitted directly to the Raspberry Pi3 microcomputer [6-8]. The signals from the LM335M analog temperature sensor and the photoresistor [9] are first fed to the Arduino Uno device [10], where they are converted into digital form using an ADC and then sent to the computer (or Raspberry Pi). On the basis of the signals, their spectra are calculated, and by analyzing the spectra, the optimal sampling frequency fd is determined. The connection between the Raspberry Pi and the computer is made through a network connection, the connection of the Arduino Uno device with the computer is made through the USB port.

The software for the Arduino Uno device, which reads temperature and light signals, is written in the Processing language. The software in the Raspberry Pi3 that reads the temperature and humidity signals is written in Python.

The analysis of the signal spectra is performed by the "p_spectr_23" program developed in the Python language. Analysis of signal spectra is performed according to the following algorithm (Fig. 2). First, the initial signal $y(x)$ is read from the sensor (Fig. 3), the Q values of which are written into the arrays vx and vy. Voltage U, temperature T or humidity H are used as the y parameter of the signal. Time t is used as the x parameter of the signal. The Fourier spectrum F of the signal is calculated using the fftpack module of the scipy library with the function fft (Fast Fourier Transforms). Next, the Fourier spectrum is centered with the command Fc=np.fft.fftshift(F), after which the zero frequency f corresponds to the center of the spectrum Fc. The module of the Fourier coefficients is calculated by the command Fa=abs(Fc) (Fig. 4).

A number of parameters are calculated for the obtained Fourier spectrum. The sampling frequency of the initial signal $fd0$ is calculated through the sampling time Δx according to the formula $fd0 = 1/\Delta x$.

The maximum frequency of the spectrum f_max according to the Nyquist sampling theorem is calculated as half of the sampling frequency: $f\_max = fd/2$.

The maximum value of the modulus of the Fourier coefficients for noise FaN_max is calculated as the maximum value of the modulus of the spectrum Fa for 1/4 of the highest frequency part of the spectrum.

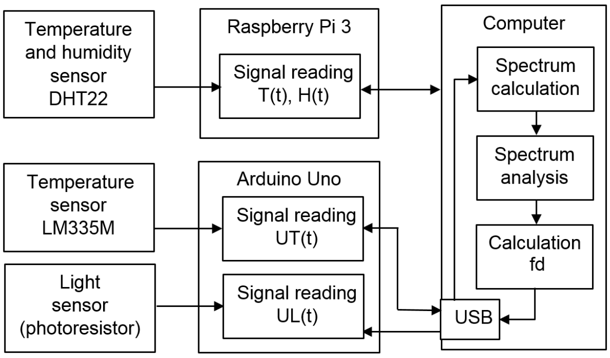


FIG. 1. Structure of a computer system.

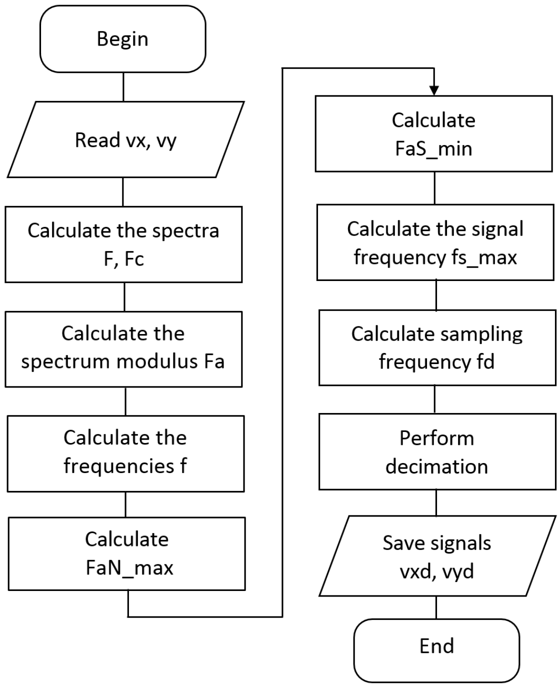


FIG. 2. Flowchart the signal spectrum analysis algorithm.

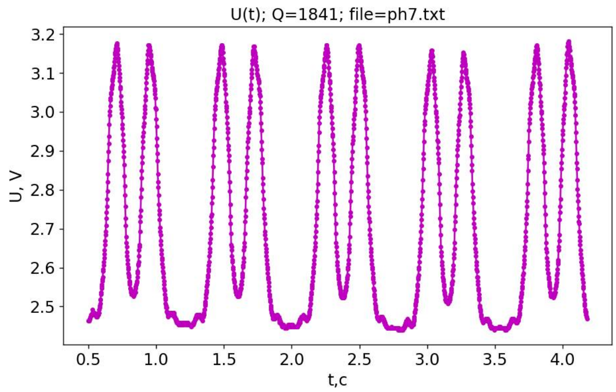


FIG. 3. The graph of the initial signal of the photoresistor.

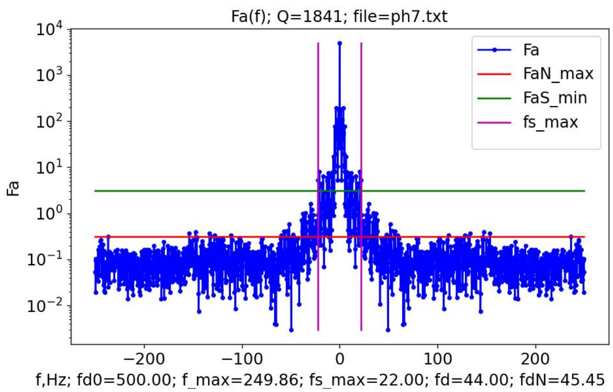


FIG. 4. Modulus of the spectrum Fa of the signal of the photoresistor.

The minimum value of the Fourier coefficients modulus for the signal is calculated by the formula

$$FaS\_min = FaN\_max \cdot kS, \qquad (4)$$

where kS is a coefficient that depends on the sensor:

$kS = 10$ for photoresistor;

$kS = 5$ for the DHT22 sensor (temperature signal);

$kS = 2$ for the LM335 thermal sensor.

The maximum frequency of the useful signal *fs_max* is calculated as the frequency value at which the modulus of the Fourier coefficients Fa exceeds the minimum value of the modulus of the Fourier coefficients *FaS_min*.

The specified sampling frequency *fd* according to the sampling theorem is calculated as the doubled value of the maximum frequency of the useful signal *fs_max*, i.e. $fd = 2 \cdot fs\_max$. Decimation (thinning) of the signal is performed with a coefficient

$$Nd = [fd0/fd]. \quad (5)$$

For example, if $Nd = 4$, then 1 of 4 readings remains. After decimation, the quantity of points for the signal values *Qd* is reduced by *Nd* times, i.e. $Qd=[Q/Nd]$, and the signal values after decimation are written into arrays *vxd* and *vxd*. Taking into account the decimation, the specified sampling frequency *fdN* is calculated

$$fdN = \mathrm{fd}0/Nd. \quad (6)$$

At this sampling frequency *fdN*, the waveform is preserved, but the signal does not contain redundant data (Fig. 5). To assess the quality of the signal after decimation, the estimated values of vyd were interpolated by splines using the «InterpolatedUnivariateSpline» function. The interpolated values of *yi* (Fig. 6) are close to the initial *y* and contain the same *Q* points, and the difference between them is described by the root mean square error (rmse).

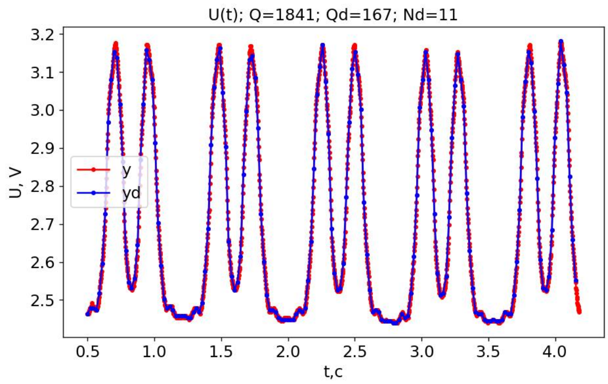


FIG. 5. Initial signal (y) and signal after decimation (yd).

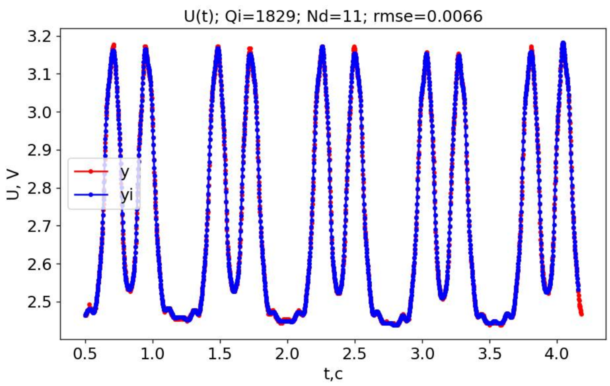


FIG. 6. Initial signal (y) and signal after interpolation (yi).

IV. EXPERIMENTAL CHECK OF THE DEVELOPED SYSTEM

By Arduino UNO device the signal from the LM335 temperature sensor was read (Fig. 7). The signal spectrum was calculated (Fig. 8). A fairly high value of the decimation coefficient (*Nd*=11) was obtained, but the signal shape was preserved.

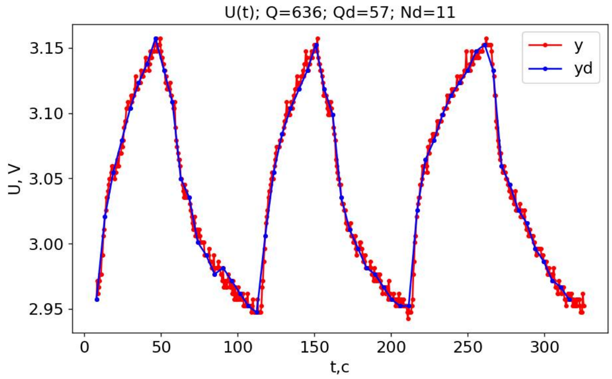


FIG. 7. The initial signal (y) from the LM335 temperature sensor and the signal after decimation (yd).

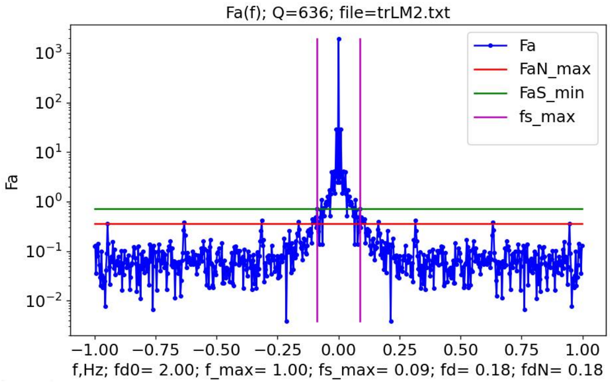


FIG. 8. The spectrum module Fa of the signal (Fig. 7).

The obtained sampling frequency *fdN* can be used for the subsequent reading of signals from sensors.

The temperature and humidity signals read from the DHT22 sensor are similarly processed. The sampling rates of the temperature, humidity and lighting signals are calculated correctly.

V. CONCLUSION

An algorithm for the analysis of Fourier spectra of one-dimensional signals has been developed, which is designed to determine the optimal sampling frequency and decimation coefficient of signals.

A computer system for read signals from the DHT22 temperature and humidity sensor, the LM335M temperature sensor, and the light sensor (photoresistor) was developed. Signals from digital sensors (DHT22) are transmitted directly to the Raspberry Pi3. Signals from analog sensors (LM335M, light sensor) are fed first to the Arduino Uno and then sent to the computer.

An experimental test of the developed tools for reading and analyzing signals from temperature, humidity and lighting sensors was carried out. The obtained sampling frequency can be used for subsequent reading of signals from sensors. In all considered cases, the optimal sampling frequencies were determined correctly.

AUTHOR CONTRIBUTIONS

S.B. – conceptualization, methodology, writing-review and editing, supervision; V.L. – software, resources, writing-original draft preparation; Kh.O. – validation, investigation, visualization.

COMPETING INTERESTS

The competing interests are absence.

REFERENCES

[1] G. Ferri, G. Barile, and A. Leoni. *Electronics for Sensors*. MDPI, 2021. doi: 10.3390/books978-3-0365-1241-9

[2] S. Fernandez, "Discretization Accuracy of Continuous Signal Peak Values in Limited Bandwidth Systems", *Computacion y Sistemas*. vol. 25, no. 1. pp. 173-183, 2021. doi: 10.13053/CyS-25-1-3889.

[3] J.A. Santoyo-Ramon, E. Casilari, and J.M. Cano-Garcia, "A study of the influence of the sensor sampling frequency on the performance of wearable fall detectors", *Measurement*, vol. 193. pp. 1-12, 2022. doi: 10.1016/j.measurement.2022.110945

[4] S. Palani, *Principles of Digital Signal Processing*. Springer Cham, 2022.

[5] S.V. Balovsyak and Kh.S. Odaiska, "Automatic Determination of the Gaussian Noise Level on Digital Images by High-Pass Filtering for Regions of Interest", *Cybernetics and Systems Analysis*, vol. 54, no. 4, pp. 662-670, 2018.

[6] Digital-output relative humidity & temperature sensor/module DHT22. [Online]. Available: https://datasheetspdf.com/mobile/792211/Aosong/DHT22/1

[7] DHT22 Raspberry Pi Humidity Temperature Sensor Tutorial. [Online]. Available: https://www.youtube.com/watch?v=IHTnU1T8ETk.

[8] Raspberry Pi 3. [Online]. Available: https://www.raspberrypi.org/products

[9] Photosensitive resistance sensor, module16in1, sensor kit. [Online]. Available: www.weikedz.com.

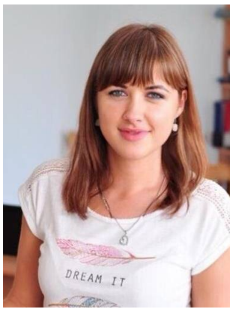
[10] Arduino. [Online]. Available: https://www.arduino.cc.

Serhiy Balovsyak

In 1995, graduated from Chernivtsi State University. In 2018, defended his doctoral dissertation in the specialty "Computer systems and components". Currently, works as an associate professor at the Department of Computer Systems and Networks of Chernivtsi National University. Research interests include digital signal processing, programming, artificial neural networks.

Vitaly Lacusta

In 2021, graduated from Yuriy Fedkovych Chernivtsi National University with a degree in "Computer Engineering" (bachelor's level). Currently studying at the Chernivtsi National University, majoring in "Computer Engineering" (master's level).



Khrystyna Odaiska

In 2013, graduated from Chernivtsi National University with a degree in Computer Engineering (master's level). In 2020, defended her PhD thesis in the specialty "Computer systems and components". Currently, works as an assistant professor at the Department of Computer Systems and Networks of Chernivtsi National University. Research interests include methods of digital image processing.

Зчитування сигналів сенсорів із автоматичним вибором частоти дискретизації

Сергій Баловсяк*, **Віталій Лакуста та Христина Одайська**

Кафедра комп'ютерних систем та мереж, Чернівецький національний університет імені Юрія Федьковича, Чернівці, Україна

*Автор-кореспондент (Електронна адреса: s.balovsyak@chnu.edu.ua)

АНОТАЦІЯ Правильний вибір частоти дискретизації при зчитуванні сигналів із сенсорів забезпечує високу якість оцифрованих даних та економію пам'яті при збереженні таких даних. Складність автоматичного вибору частоти дискретизації пояснюється тим, що така частота залежить від частот корисного сигналу, які не завжди відомі. Тому в роботі розроблено комп'ютерну систему для зчитування сигналів із сенсорів температури, вологості та освітлення із автоматичним вибором частоти дискретизації на основі аналізу спектрів Фур'є сигналів. Сигнали з цифрових сенсорів (DHT22) передаються безпосередньо в мікрокомп'ютер Raspberry Pi3. Сигнали з аналогових сенсорів (LM335M, сенсор освітлення) подаються на пристрій Arduino Uno. Розроблено алгоритм аналізу спектрів Фур'є одновимірних сигналів, який призначений для визначення оптимальної частоти дискретизації та коефіцієнту децимації сигналів, зчитаних з сенсорів. На основі початкових сигналів обчислюються їх спектри Фур'є, а шляхом аналізу спектрів визначається максимальна частота корисного сигналу та оптимальна частота дискретизації. Уточнена частота дискретизації за теоремою відліків обчислюється як подвоєне значення максимальної частоти корисного сигналу. Децимація (проріджування) сигналу виконується з коефіцієнтом, який визначається через відношення початкової та уточненої частот дискретизації. Для оцінки якості сигналу після децимації виконано інтерполяцію децимованих значень сплайнами. Обчислено середню квадратичну похибку інтерполяції. Проведено експериментальну перевірку розроблених засобів для зчитування та аналізу сигналів із сенсорів температури, вологості та освітлення. В усіх розглянутих випадках частота дискретизації визначається коректно. Отримані частоти дискретизації можуть використовуватися для децимації сигналів або для наступного зчитування сигналів з сенсорів.

КЛЮЧОВІ СЛОВА сенсори температури, вологість та освітлення, частота дискретизації, спектр Фур'є, Python.