# WIP: A Photoplethysmography Graphical User Interface for Teaching Signal Processing Concepts

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***Abstract*—In this Innovative Practice Work in Progress, we present a Graphical User Interface (GUI)-based tool that uses the photoplethysmograph (PPG) to demonstrate fundamental signal processing concepts such as periodicity, noise, jitter, and peak selection, offering students an interactive learning experience.**

**Extraction of the heart rate from the PPG has several steps, some appropriate for sophomore-level students in the signals and systems course, and others better suited for senior-level students in the digital signal processing course. For example, sophomore-level students can be exposed to concepts such as periodicity and statistical averages, which they see in signals and systems and introductory statistics courses. More complex topics such as peak selection and digital filtering are better suited to senior-level students.**

**This GUI was deployed in a sophomore-level signals and systems course in the spring semester of 2024 to help students understand concepts related to statistics and periodicity. The GUI will be similarly deployed in a senior-level digital signal processing course in the fall semester of 2024. Assessment results show that the GUI helped students improve learning across multiple concept areas, and survey questions showed that students found the GUI to be helpful.**

***Keywords—Electrical engineering, GUI, Signal processing, undergraduate, software***

## I. INTRODUCTION

Students in introductory signal processing courses, for the first time, see multiple concepts from earlier mathematics classes used together. These concepts are used to demonstrate theories in areas such as periodicity and statistics. Most exercises rely on mathematical analysis and do not provide students with (a) intuition as to what they are working on; and (b) exposure to real-life issues affecting periodic signals such as jitter and noise. Our work seeks to address this gap by providing students with a hands-on approach to understanding these abstract concepts.

Several studies have shown that students have better attitudes to learning when concepts are linked to hands-on activities and real-life applications [1-5]. Specific to signal processing, several efforts to improve student learning through online and hybrid solutions have been introduced [6-11].

In this paper, we describe our efforts to design a tool to assist students and instructors in signal processing courses. This tool, via the application of photoplethysmography (PPG), can help students better understand concepts such as periodicity, statistics, digital filtering, noise, and video handling. Activities and exercises have been designed to draw the attention of the students to these topics so they can see the concepts in action. The tool is an interactive graphical user interface (GUI) that allows students to modify various parameters and settings and see the impacts in real time. We hypothesize that using the PPG GUI will allow students in these classes to better understand abstract signal processing topics by interacting with the hands-on demonstrations.

The effectiveness of our tool has been assessed by deploying it in a sophomore-level signals and systems course in the Spring semester of 2024. Pre- and post-quizzes and a survey were given to the students. Improvements were seen across all concepts covered and students indicated that they found the GUI helpful. The GUI will also be used in a senior-level digital signal processing course in the fall semester of 2024. Preliminary assessment results from this course will be presented at the conference.

The rest of the paper will be organized as follows. In Section II, we introduce the concept of photoplethysmography and show how the heart rate and oxygen saturation can be extracted from the PPG video. The GUI is described in Section III. The use of the GUI in signal processing courses is described in Section IV and assessment results are shown in Section V. Finally, concluding remarks are presented in Section VI.

## II. THE PHOTOPLETHYSMOGRAPH

### *A. The PPG*

Photoplethysmography (PPG) is a non-invasive method of measuring the changes in blood volume at the microvascular bed of tissue, such as the fingertip. The vascular bed is illuminated, and during the systolic and diastolic phases of the heart, the intensity of light reflected changes, as different amounts of blood absorb different amounts of light. This change in illumination is recorded and yields the PPG [12]. Since the levels of intensity in the PPG are driven by the heartbeat, and are (mostly) periodic, it can be used to extract the heart rate [12]. Additionally, by using multiple frequencies, other vital signs and health metrics such as oxygen saturation and arterial stiffness can be calculated [13-14]. Recent work has also shown that PPG can be used for user identification [15-17].

### *B. Extracting the PPG*

A simple minimalist technique for acquiring PPG utilizes a phone camera and its flashlight feature [12]. A subject can place a finger across the camera, with the flashlight illuminating the

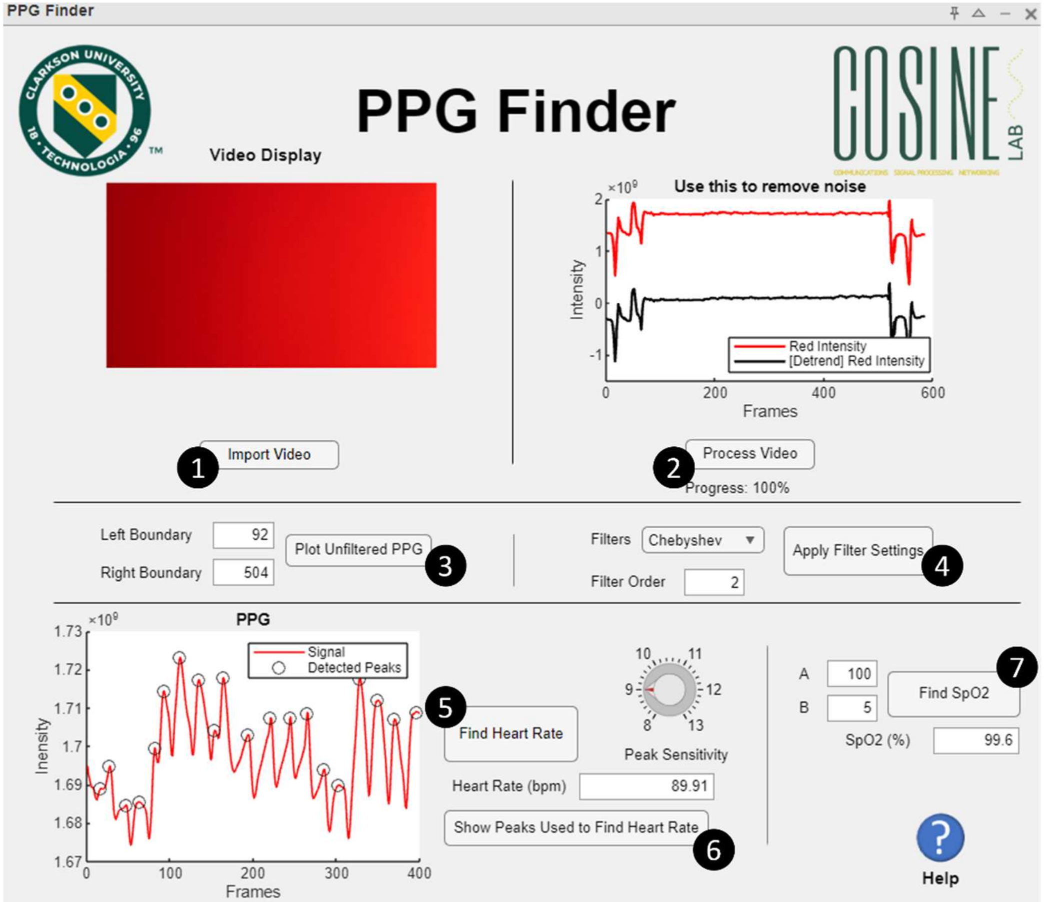


**Figure 1. The interactive graphical user interface (GUI) tool that performs vital sign extraction from photoplethysmographs (PPGs). From a PPG signal, heart rate and oxygen saturation values can be estimated. Users can change multiple parameters and see the effects in real time. The numbered parts of the GUI are described as follows: 1. Button used to import video files. 2. Button used to begin extracting the intensity of the red channel across video frames. Result is a plot of the raw, and noisy PPG. 3. Button used to plot the PPG after specifying the left and right boundary frames to remove from the noisy PPG. 4. After selecting the filter of choice and specifying the filter order, this button applies those settings. 5. Finds the heart rate upon click using filtered PPG. Use the knob to specify the minimum distance between two peaks. 6. Use this button to show all the peaks used to find the heart rate. An example is shown in the "PPG" graph. 7. Use this to find the SpO2 value after setting the A and B coefficients**

fingertip. Recording the illuminated fingertip creates a video from which the PPG can be extracted. The length of the video is ideally set to fifteen seconds, with shorter videos leading to errors and longer videos potentially improving performance at the cost of larger storage and processing needs.

The video is split into red, blue, and green channels, and the intensity of each channel is calculated for every frame of the video. The periodicity of the intensity of the red frame can be used to calculate the heart rate [12], the red and blue channels together can be used to calculate the oxygen saturation [14], and the second difference of the red channel can be used to find the arterial stiffness [13].

### C. *Estimating vital signs from RGB videos*

Once the intensities of the red frames are calculated, we can use that signal to calculate the heart rate. Using the frame rate of the video (number of frames per second), the number of frames between successive peaks, and consequently, the time between two successive peaks can be calculated. Using this, the heart rate can be calculated as:

$$\text{HR (beats per minute)} = \frac{60}{mean\ time\ between\ peaks} \quad (1)$$

By using both the red and blue channels, the oxygen saturation ($SpO_2$) can be calculated as:

$$Sp0_2 = A - \left(B\,\frac{R_r}{B_r}\right), \quad (2)$$

where $A$ and $B$ are tuning parameters generally set to 100 and 5, respectively [14],

$$R_r = \frac{R_{ac}}{R_{dc}}, \quad (3)$$

and

$$B_r = \frac{B_{ac}}{B_{dc}}. \quad (4)$$

with the mean of the red and blue channel intensities ($R_{dc}$ and $B_{dc}$) and their standard deviations ($R_{ac}$ and $B_{ac}$).

From this, we note that these calculations require knowledge of statistics and video processing, and the heart rate calculations will have to account for noise and variability in the periodicity. These topics are covered in signals and systems courses, making this an ideal project for the class that covers concepts and links to real-life applications.

To help students understand these concepts, we designed and implemented a GUI-based tool that shows how these calculations are performed. The GUI is described in Section III. Further, in Section IV, we present how we use the GUI in two signal processing courses by linking it to class projects to help introduce the students to these concepts.

## III. Graphical User Interface (GUI) Design

A graphical user interface (GUI) was implemented where the GUI takes in a video and calculates and displays the heart rate and oxygen saturation values from that video. Users have the option to specify the bounds to eliminate extremely noisy sections and retain relatively "clean" signals. Once the bounds are marked, the GUI will replot the "clean" PPG signal.

Next, users have the option to apply a filter. Two options are presented: a low-pass Chebyshev filter, and a low-pass averaging filter, both with user-defined orders. These filters smooth out the signal and can suppress some noise. However, the filter can also distort the signal and lead to wrong results in the heart rate and oxygen saturation calculations. A peak-selection algorithm is then implemented to identify the peaks in the filtered signal. Users can select the sensitivity of the peak-selection algorithm, which is used to determine the number of peaks selected by the algorithm. Once the peaks are selected, the number of frames between successive peaks is calculated and the heart rate is determined. Additionally, the GUI calculates the oxygen saturation from the input video, with the $A$ and $B$ parameters in (2) provided as user inputs.

The GUI is shown in Figure 1. Multiple graphs can be generated to better visualize intermediate steps when calculating parameters derived from the video and the PPG.

## IV. Use of the Tool

The GUI, presented in Section III and shown in Figure 1, is used in class projects in two courses: a sophomore-level signals and systems course and a senior-level digital signal processing course. In what follows, we present how the GUI is used in each class.

### A. Sophomore-level Signals and Systems Course

Electrical Engineering students have a course in signals and systems in their sophomore or junior years. This course introduces students to basic concepts in systems, signal definitions, signal manipulation, interactions between signals and systems, and integral transforms such as the Fourier transform. As part of this course, students are given a project where they have to implement a PPG system, as described in Section II. Key concepts covered in this project include statistics, periodicity, noise, and video handling, which are also key concepts of the course.

In the spring semester of 2024, to assist the students with the project, the GUI described in Section III was given to the students. Students were allowed to use the complete functionality of the GUI. However, the code used to run the GUI was hidden from the students. The authors hypothesized that if students are given access to the GUI, not only will it help them understand the project details and deliverables, but it will also help them better understand the basic concepts of the PPG including statistics, periodicity, noise, and video handling.

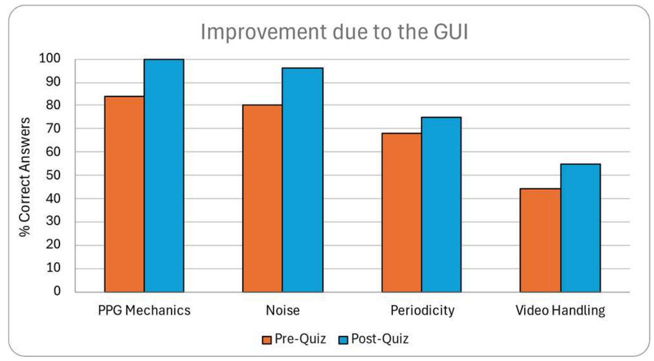


**Figure 2. Improvement in concept areas. Each graph shows the percentage of correct responses. The pre- and post-quizzes covered four concept areas. Improvement was seen in all areas.**

The effectiveness of our approach was assessed using pre- and post-quizzes and a survey. The results are as in Section V.

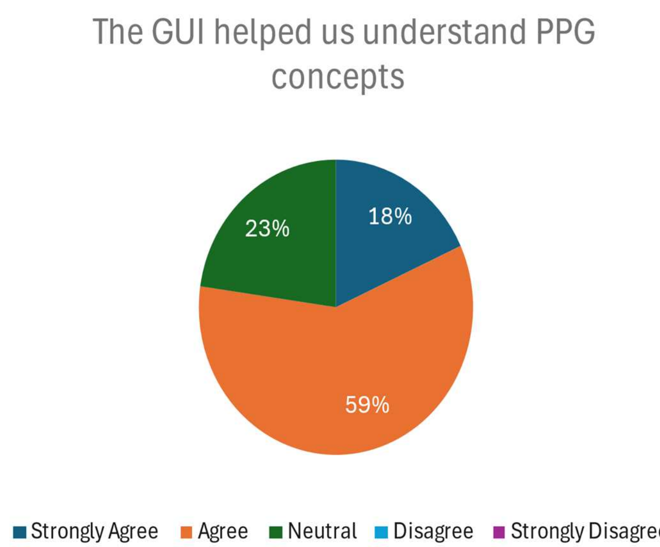


**Figure 3. Survey responses to the question "The GUI helped us understand PPG concepts." Over 77% of the students agreed (or strongly agreed) with this statement.**

### B. Senior-level Digital Signal Processing Course

In the senior-level digital signal processing course, students see advanced concepts such as filter design, the fast Fourier transform (FFT), and applications of optimization. As shown in Section II and Section III, these concepts can be applied to the

PPG for noise removal, removal of breathing artifacts, automatically estimating the periodicity using the FFT, and peak selection. For students in this class, while the project objectives may be similar, they are required to use the advanced concepts they learn in digital signal processing to achieve better results and automate the process to find the heart rate and oxygen saturation. Further, students are asked to find the breathing rate, which requires careful design of digital filters.

In the fall semester of 2024, the GUI will be made available to the students of the digital signal processing course. Students will be able to use all features of the GUI, but will not be able to access the code. The effectiveness of using the GUI in the digital signal processing class will be assessed and preliminary results will be presented at the conference.

## V. Assessment Results

The GUI, described in Section III, was deployed in the sophomore-level signals and systems course in the spring semester of 2024. The GUI was given to students to help them understand PPG concepts, signals and systems concepts, and to guide them on project deliverables.

To assess the effectiveness of the GUI, pre- and post-quizzes were administered to the students in the class. To make sure the project description did not interfere with the results and that only the GUI was assessed, the pre-quiz was deployed about a week after the project description was released to the students. The pre-quiz contained several questions that covered four basic concepts: PPG mechanics, noise, periodicity, and video handling. About a week before the projects were due, a post-quiz was administered to assess how well the GUI helped the students. The post-quiz contained the same questions as the pre-quiz and included three survey questions on the usability and usefulness of the interactive GUI tool.

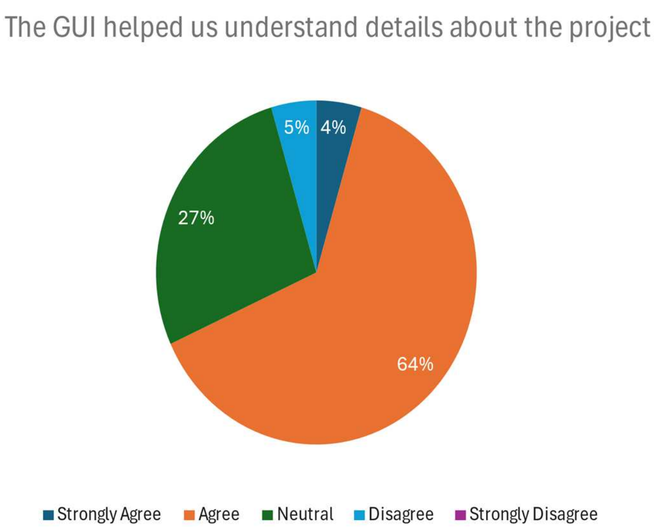


**Figure 4. Survey responses to the question "The GUI helped us understand details about the project." Over 68% of the students agreed (or strongly agreed) with this statement.**

The students who used the GUI showed improvement across all four concept areas as shown in Figure 2. Of the four areas, students were able to fully grasp concepts related to PPG mechanics and noise. However, while students showed some improvement, they continued to struggle with concepts related to periodicity and video handling. This indicates to us more emphasis needs to be placed on these concepts when covering materials (for periodicity) and through more hands-on activities (for both concepts).

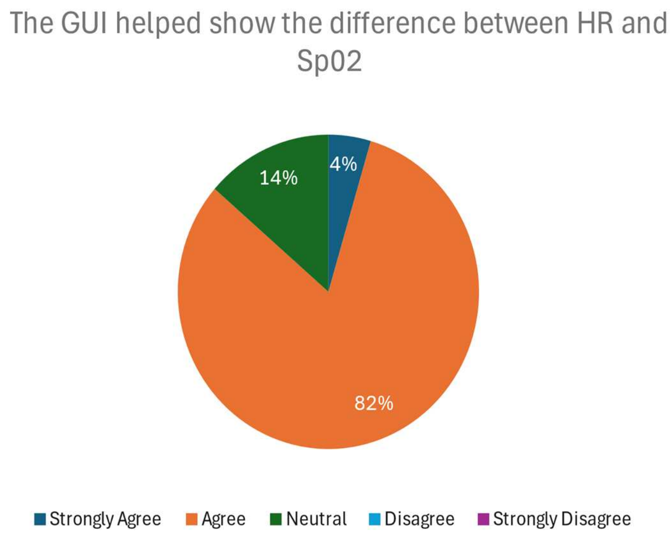


**Figure 5. Survey responses to the question "The GUI helped us understand the difference between heart rate (HR) and oxygen saturation ($Sp0_2$)." Over 86% of the students agreed (or strongly agreed) with this statement.**

Three survey questions were asked to evaluate whether the students found the GUI to be useful. The first question asked whether the GUI helped students better understand concepts related to the PPG (see Figure 3). The second question asked if the GUI helped the students better understand the project requirements and deliverables using the GUI outputs as models (see Figure 4). The final survey question asked if the students could better distinguish between how the PPG could help with the estimation of heart rate (HR) and oxygen saturation ($Sp0_2$) (see Figure 5). In all cases, students largely agreed with these statements, with agree and strongly agree receiving over 77%, 68%, and 86% of the responses, respectively, for each of the three survey questions.

## VI. Conclusions

In this paper, we described our work designing and implementing an interactive GUI tool to help students better understand concepts in signal processing. The tool was deployed in a sophomore-level signals and systems course. Students showed improvement across multiple areas and survey responses showed that they found the GUI to be a helpful tool.

The GUI will be used in a senior-level digital signal processing course in the fall and preliminary results will be presented at the conference.

## References


[1] H. Suherlan, *et al.*, "The Roles of Digital Application Innovates Student Academic in Higher Education," *Nazhruna: Jurnal Pendidikan Islam*, vol. 5, no. 2, pp. 672-689, 2022.

[2] D. S. Wulandari, B. A. Prayitno, and M. Marid, "Developing the Guided Inquiry-Based Module on the Circulatory System to Improve Student's Critical Thinking Skills," *Journal of Biological Education Indonesia (Jurnal Pendidikan Biologi Indonesia)*, vol. 8, no. 1, pp. 77-85, 2022.

[3] M. K. Banavar, *et al.*, "Teaching Signal Processing Applications using an Android Echolocation App," *Computers in Education Journal*, vol. 12, no. 1, 2021.

[4] S. T. Siddiqui, *et al.*, "Enhancing Efficiency and Empowering Institutions: Leveraging Wireless Sensor Devices, IoT Edge Computing, and Fog Computing in Educational Systems," in *2023 7th International Conference on Computation System and Information Technology for Sustainable Solutions (CSITSS), IEEE*, 2023, pp. 1-7.

[5] A. Y. Meneses, A. V. Poenitz, and J. E. G. Rogel, "Cognitive Performance and Use of Digital Tools as Predictors of Academic Success in University Students," in *International Conference in Information Technology and Education*, Singapore: Springer Nature Singapore, 2023, pp. 321-333.

[6] Y. Hong and J. Gao, "Exploration of Hierarchical Teaching in Digital Signal Processing Course," *International Journal of New Developments in Education*, vol. 6, no. 2, 2024.

[7] K. Kryger, C. Mitchum, and A. Higgins, "Localizing directed self-placement: UX stories and methods," *Journal of Writing Assessment*, vol. 17, no. 1, 2024.

[8] Z. Lei et al., "Controller effect in online laboratories—An overview," *IEEE Transactions on Learning Technologies*, 2023.

[9] C. Liguori et al., "Remote laboratories for measurement courses during the Covid-19 era," in *AIP Conference Proceedings*, vol. 2816, no. 1, Mar. 2024.

[10] N. P. Arun Kumar and A. P. Jagadeesh Chandra, "Development of Remote Instrumentation and Control for Laboratory Experiments Using Smart Phone Application," in *Cyber-physical Systems and Digital Twins: Proceedings of the 16th International Conference on Remote Engineering and Virtual Instrumentation 16*, Springer International Publishing, 2020.

[11] A. Dixit, *et al.*, "Development of signal processing online labs using HTML5 and mobile platforms," in *2017 IEEE Frontiers in Education Conference (FIE)*, IEEE, 2017, pp. 1-5.

[12] A. H. Ayesha, D. Qiao and F. Zulkernine, "Heart Rate Monitoring Using PPG With Smartphone Camera," *2021 IEEE International Conference on Bioinformatics and Biomedicine (BIBM)*, Houston, TX, USA, 2021, pp. 2985-2991, doi: 10.1109/BIBM52615.2021.9669735.

[13] P. Karimpour, J. M. May, and P. A. Kyriacou, “Photoplethysmography for the assessment of arterial stiffness,” *Sensors* (Basel, Switzerland), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10747425/ (accessed May 9, 2024).

[14] A. K. Kanva, C. J. Sharma and S. Deb, "Determination of SpO2 and heart-rate using smartphone camera," *Proceedings of The 2014 International Conference on Control, Instrumentation, Energy and Communication (CIEC)*, Calcutta, India, 2014, pp. 237-241, doi: 10.1109/CIEC.2014.6959086.

[15] L. Bastos, B. Cremonezi, T. Tavares, D. Rosario, E. Cerqueira, and A. Santos, “Smart Human Identification System Based on PPG and ECG Signals in Wearable Devices,” in *2021 International Wireless Communications and Mobile Computing (IWCMC)*, Harbin City, China: IEEE, Jun. 2021, pp. 347–352.

[16] Y. Ye, G. Xiong, Z. Wan, T. Pan, and Z. Huang, "PPG-based Biometric Identification: Discovering and Identifying a New User," *2021 43rd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC)*, Mexico, 2021, pp. 1145-1148.

[17] V. Jindal, J. Birjandtalab, M. B. Pouyan and M. Nourani, "An adaptive deep learning approach for PPG-based identification," *2016 38th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*, Orlando, FL, USA, 2016, pp. 6401-6404.