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A Single Board Computer Pupillometer to Evaluate Quantitative Pupillary Reflexes in Response to Auditory Stimuli

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Highlights

- Innovative approach to studies in human physiology particularly the human pupillary response to auditory stimuli, realtime quantitative data acquisition
- Application of sensors and Raspberry pi technology for health sciences
- Novel and low cost design of pupillometer

Abstract

Physiological psychology, as a subarea of experimental psychology, is a field that incorporates two sciences - Physiology and Psychology - to investigate human behavior with the functions and structure of the nervous system or other mechanisms of the human physiology. The aim of the physiological psychology is to examine human perceptual processing. The main objective of the research was to design A Single Board Computer Pupillometer to Evaluate Quantitative Pupillary Reflexes in Response to Auditory Stimuli to be used in experimentation and researches in human physiology and psychology. The project is a functional laboratory tool for the analysis of pupillary sizes in response to auditory stimuli in the form of five (5) genres of music, particularly, Classical, Pop, Hip-hop, Rock and Jazz. The Pupillometer module is equipped with a camera that records the real-time video of the pupil dilaton, and an ultrasonic sensor that measures the distance of the camera from the eye. A data logger was incorporated in the system so that the results of each experiment can be retrieved and a graph is presented at the user interface. Testing of the system was done iteratively throughout the construction. The ICC Inter-rater estimate for reliability ratings obtained was 0.8735 based on the 95 percent confidence interval which denotes good consistency and repeatability of the readings obtained from the system. Accuracy tests resulted to a standard error of mean difference approximated to 7.121 percent. This project highlights technologies that hold the capacity to inexpensively enhance the experimentation methods in understanding theories in human physiology and psychology.

Key Words: pupil dilation, microcomputer, Raspberry pi, psychological experimentation

1. Introduction

Physiological psychology, as a subarea of experimental psychology, is a field that incorporates two sciences - Physiology and Psychology - to investigate human behavior with the functions and structure of the nervous system or other mechanisms of the human physiology. Experts in this field use apparatus and techniques of Physiology to determine bodily processes while Psychology is used to relate these mechanisms to human consciousness. For instance, increased heart rate and sweating is often reported by individuals who are stressed and anxious (Hodges, 2015). Physiological research techniques monitor and record physiological responses like brainwave changes, electrodermal responses and pupil dilations using specialized equipment. These physiological responses serve as the subject of an arousal study (Lueken & Gallo, 2008). Arousal research investigates the relationship between the level of physiological response(s) and the level of individual performance.

Music is known to evoke an emotional response that can be associated with physiological arousal (Sloboda and Juslin, 2001). It also has an effect on a person’s cognitive development such as sharpening one’s memory, improving capability to learn, and others (Joshua and Fauzan, 2015). According to Coutinho and Cangelosi (2011), the most distinct results pertain to basic variables such as loudness, tempo, timbre, and pitch. Genres of music influence emotions and is demonstrated by observing the skin conductance, heart rate, pupil dilation and facial electromyography (Kent, 2006). Furthermore, researchers from the University of Vienna and University of Innsbruck, Austria were able to prove that emotional reaction to music reflect in the change in pupil size**.** According to Eldar, Cohen and Niv (2013) and Bradley (2008), measuring pupil size is used to obtain a result of physiological arousal during an emotional challenge.

The study of Physiological Psychology in universities abroad examines human perceptual processing by concentrating on Psychophysics particularly the visual and auditory systems, and the senses of touch, taste and smell. Several equipment used are the Magnetic Resonance Imaging (MRI) and Electroencephalogram (EEG) (University of Canberra, Australia website, n.d.).

In the Philippines, Physiological Psychology is studied as a course under the Bachelor of Science in Psychology undergraduate program as per mandated by the Commission on Higher Education (CHED)'s Memorandum Order No. 34 (Commission on Higher Education website, n.d). According to several psychology schools, there are very few experiments done yet to demonstrate the psychophysiological reactions to stimulus because there is no apparatus available in their laboratory to help them measure such. There are commercially available devices such as the NuerOptics PLR – 3000, Colvard and Procyon pupillometers but are expensive costing about 1000 to 4000 USD (DotMed website, n.d.). According to Mirtaheri (2010), existing pupillometers in the market are either too large to be handheld, or too expensive to be availed by health care services with lower budgets.

The aim of the researchers was to construct a system that is capable of measuring pupillary size changes to music as a stimulus. This project aimed to be a supplement to the Physiological Psychology and Experimental Psychology courses in the study of factors affecting emotions and behavior.

2. Methods

The design and implementation of the system followed the descriptive and applied research methodology. Specifically, the researchers followed the Rapid Application Development (RAD) methodology. RAD is based on the iterative tasks that start from initial planning, followed by requirements, analysis and design, implementation, testing and evaluation.

Testing and verification are important parts of the design process. Troubleshooting each encountered problem and program code modifications were done throughout the construction of the project. Verification is an evaluative activity to check that a device design meets its requirements. Simulations and measurements was done during this process. Furthermore, reliability, repeatability and accuracy tests were conducted to ensure the proper functionality of the system. Statistical analysis was done for these tests. The intraclass correlation coefficient (ICC) is widely used in biomedical research to assess the reproducibility of measurements between raters, labs, technicians, or devices.

3. Results and discussion

3.1. Overview of the System

The Single Board Computer (SBC) Pupillometer to Evaluate Quantitative Pupillary Reflexes in Response to Auditory Stimuli is an electronic system designed for Physiological and Experimental Psychology applications. Pupil size and reactivity to light have been used to diagnose neurological injuries (Pittasch, Lobmann, Behrens-Baumann, and Lehnert, 2002). Pupil size is controlled by circular and radial muscles. The circular muscle is innervated by parasympathetic fibers, and the radial muscle is innervated by sympathetic fibers. Thus, the former muscle controls the size of the pupil in light and other stimuli. This phenomenon is called the pupil light reflex (PLR). The pupillometer was developed to detect variations of pupil size in response to music as a stimulus. The common defect of a portable pupillometer is that it is unable to quickly and accurately analyze data. The purpose of this work was to design a portable device for quantitatively measuring pupillary sizes in real time. The cost of the pupillometer system was roughly around 7,000 Philippine pesos.

During the use of the pupillometer, the participants are asked to wear the pupillometer module. The earphones and computer then provide the auditory stimulus. The participant is instructed to listen to five (5) genres of music, particularly, Classical, Pop, Hip-hop, Rock and Jazz. As the experiment is conducted, a real time video with measurements of the participant's pupil is shown on the monitor. After the test is conducted, the values obtained are automatically tabulated in a file similar to a notepad that can be imported to Microsoft Office Excel. The file, the real time video, and a time vs. diameter graph is saved in a folder. From the data saved, the examiner could perform further analysis of the data on a per second duration. Figure 1 shows the block diagram of the pupillometer module.

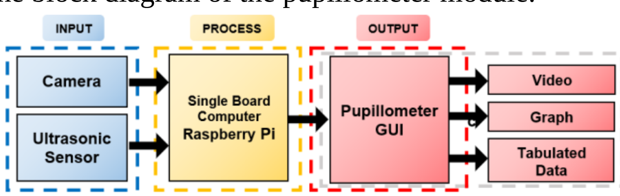

Figure 1. Block Diagram of the Pupillometer Module.

The Raspberry Pi camera module is a high quality 8-megapixel Sony IMX219 image sensor custom designed add-on board for Raspberry Pi, featuring a fixed focus lens. It is capable of 3280 x 2464 pixel static images, and also supports 1080p30, 720p60 and 640x480p60/90 video. It captures the pupillary responses and send it to the single board computer for analysis. The HC-SR04 ultrasonic sensor is responsible for determining the distance of the eye from the camera. This will be the basis for focusing the camera to be able to determine the sizes of pupils in pixels. The Single Board Computer system is programmed to perform the operations of measuring pupillary response wherein the pupil meter GUI is integrated. This component is essential because it is responsible for executing the program that should be incorporated for the whole project to work. The real time video of the participant's pupillary response is shown in the monitor. This is used to make observations with the variations of pupil size while the participant is listening to a particular genre of music. While these proceeds, a tabulated data of the measurement of the pupil size is presented in the monitor. Moreover, a graph corresponding to the changes in pupil size is illustrated after the test has been done. The final results for the experiment are displayed on the monitor.

3.2. Determining the pupil size measurements

The ultrasonic sensor was placed to be able to provide measurements of the distance of the eye from the camera. This is to allow the system to convert pixel readings to their respective millimeter readings in the program. The researchers used the measurement of distance taken from the ultrasonic sensor output using the set-up shown in Figure 2.

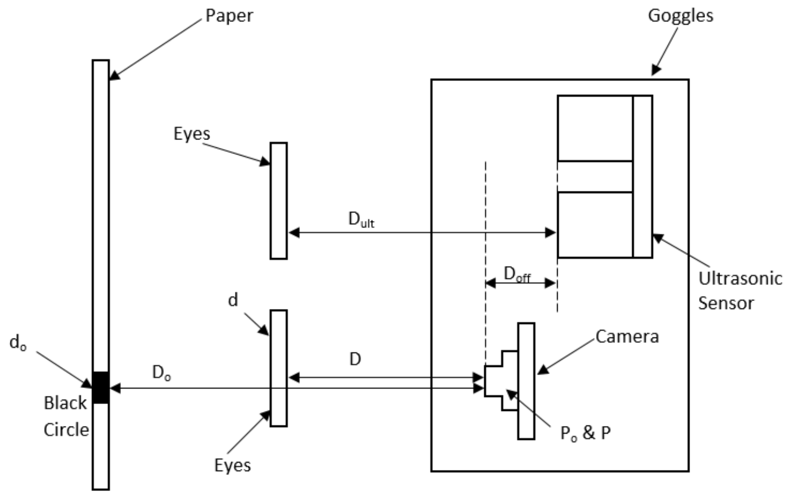

Figure 2. Set-up for determining the pupil measurement in millimeter readings

Using a printed circle with an initial diameter of 10mm placed on front of the camera, the perpendicular distance was measured using a ruler. Moreover, the perpendicular distance between the ultrasonic sensor and the paper placed in front of it is also measured. The measured values were used in ratio and proportion to be able to accurately convert pupil diameter in pixel readings to pupil diameter in millimeter measurements. The following formula was used to determine the final measurement of pupil diameter:

$$\boldsymbol{D} = (\boldsymbol{D_{ultrasound}}) - (\boldsymbol{D_{offset}}) \tag{1}$$

$$\frac{\boldsymbol{D_0}}{\boldsymbol{d_0}/\boldsymbol{P_0}} = \frac{\boldsymbol{D}}{\boldsymbol{d}/\boldsymbol{P}} \tag{2}$$

$$\boldsymbol{d} = \frac{\boldsymbol{D}\,(\boldsymbol{d_0})(\boldsymbol{P})}{(\boldsymbol{D_0})(\boldsymbol{P_0})} \tag{3}$$

where D is the measured distance of the camera from the pupil (in mm), D_0 is the initial distance of the camera from the printed black circle (29 mm), d_0 is the initial diameter of the printed black circle (10 mm), P_0 is the initial diameter of the printed black circle in pixels (218.5 px), P is the measured pupil diameter (in pixel), and d is the final measured pupil diameter (in mm).

The flowchart shown in Figure 3 describes the algorithm used in determining the pupil size measurements. The user starts by providing the folder path and selecting the sound file for calibration to proceed. Once the calibration is done, the camera records and computes ten (10) samples per second for the pupil measurements for a set duration. After the recording, the results of the readings are saved as a video file, a graph and a data file which can then be converted as a MSExcel file.

3.3. Programming tool for the Single Board Computer

The programming of the Raspberry pi single board computer consists of a numerically oriented programming dynamically compiled and linked with other languages such as Python, Fortran, Java, C++, and C. The Integrated Development Environment (IDE) used for organizing the system is to provide simplicity in the programming process.

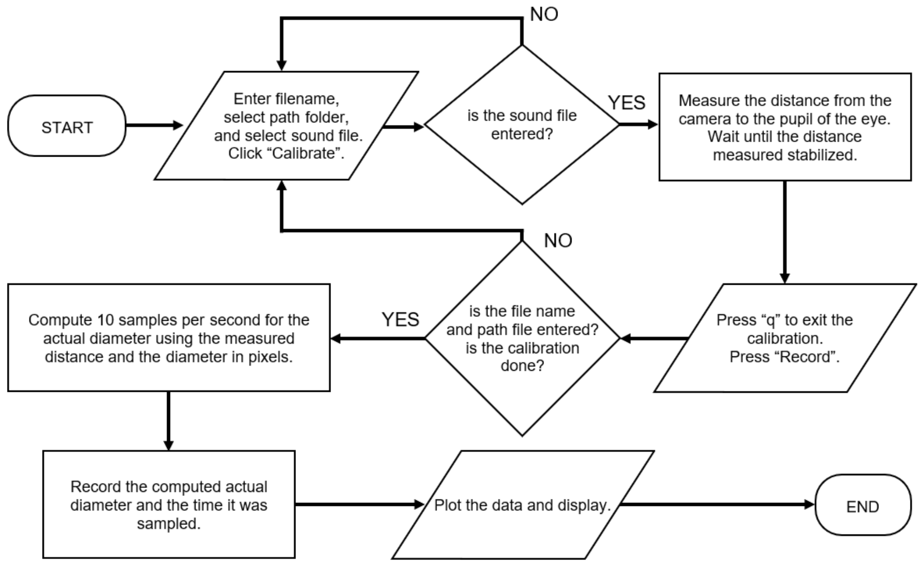

Figure 3. Program flowchart algorithm in determining pupil size measurements

3.4. Testing Results

3.4.1. Testing for Repeatability and Reliability of Results

The use of standardized tools is an essential component of evidence based practice. Reliability refers to the reproducibility of measurements (Portney & Watkins, 2000). Measurements are considered reliable if they are stable over time in stable subjects, show adequate levels of measurement variability, and are sensitive (precise) enough to detect certain specified measurements (Lexell & Downham, 2005). The intraclass correlation coefficient (ICC) is widely used in biomedical research to assess the reproducibility of measurements between raters, labs, technicians, or devices. A common approach to quantify the reliability of a measurement process is to calculate the intraclass correlation coefficient (ICC) along with a confidence interval. The Intraclass Correlation Coefficient (ICC) is a measure of the reliability of measurements or ratings. The reliability ICC Inter-rater estimate for reliability of averages of k ratings obtained for the pupillometer system was 0.8735 based on the 95% Confidence Interval was good according to the guidelines of interpreting ICC which means that the results obtained for 180 trials had good consistency and repeatability.

3.4.2. Testing for Accuracy of Results

Accuracy can be defined as the amount of uncertainty in a measurement with respect to an absolute standard. Accuracy refers to the closeness of a measured value to a standard or known value. In this procedure, the same video from the previous procedure was used. Initial readings for pupil sizes were taken based on the pupillometer module and a screenshot of the video was used to measure the initial readings. The results of the paired two-tail test (p=0.612627) using the MedCalc software as shown on Table 1 indicate that based on the computed values, there is no significant difference between the true means of the ruler and pupillometer readings. Thus, it can be concluded that the pupillometer readings are accurate, with standard error of mean difference approximated to 7.121 percent.

Table 1. Results of the accuracy testing using the MedCalc software

Paired samples t-test

Mean difference	-0.03702
Standard deviation of mean difference	0.2568
Standard error of mean difference	0.07121
95% CI	-0.1922 to 0.1181
Test statistic t	-0.520
Degrees of Freedom (DF)	12
Two-tailed probability	P = 0.6126

3.4.3. Testing for the functionality of the Pupillometer

This test was done to check if the system functions as intended. The pupillometer should be able to measure the pupillary changes to music induced-arousal. The module should display the output on the monitor and save as an h264 file. The measured pupil sizes should be graphed and saved as a portable network graphics (PNG) format. The tabulation of numerical values shall also be saved as a text format. All these output data should be contained in one folder. Figure 4 shows the final output as seen in the monitor and the pupillometers graphical user interface. Figure 5 shows the actual picture of the Pupillometer system and Figure 6 shows the complete schematic diagram of the system.

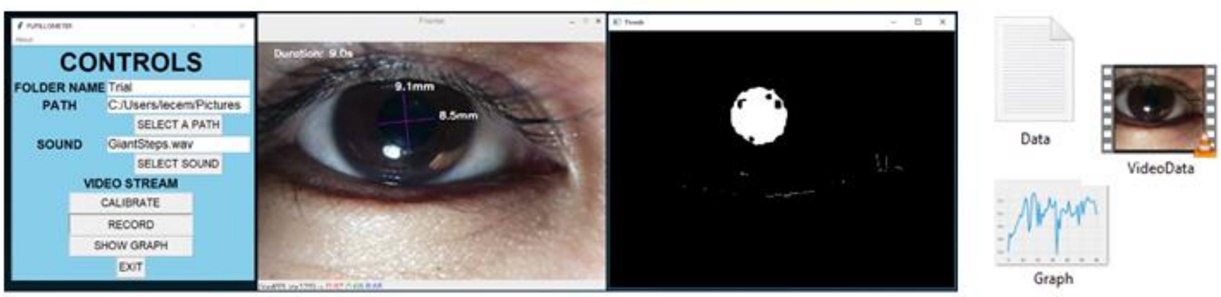

Figure 4. Output of the system as seen in the monitor and the graphical user interface.

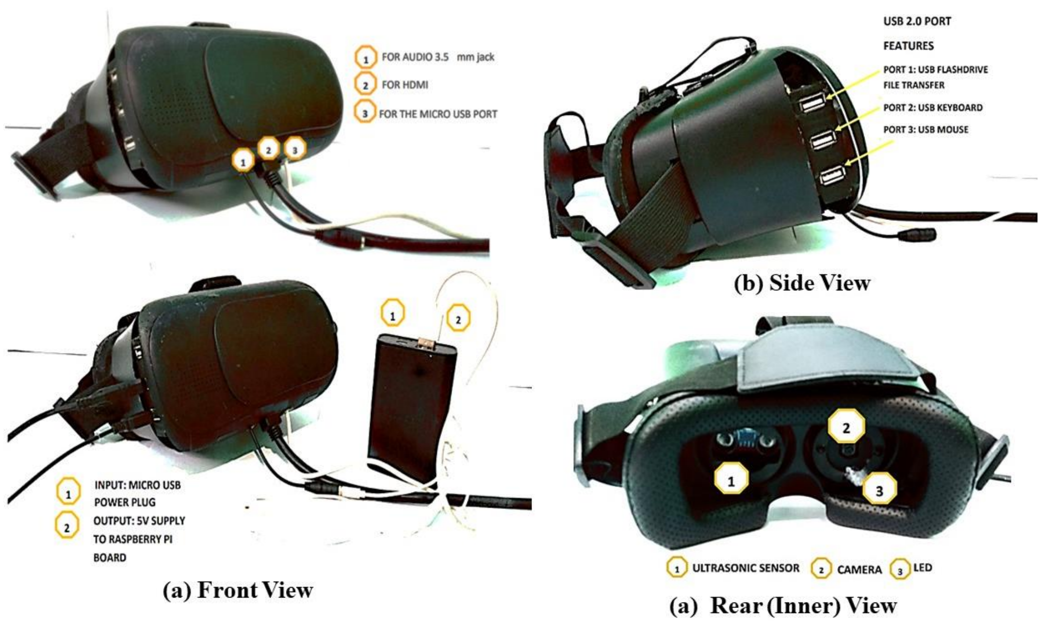

Figure 6. Actual picture of the Single Board Computer Pupillometer to Evaluate Quantitative Pupillary Reflexes in Response to Auditory Stimuli

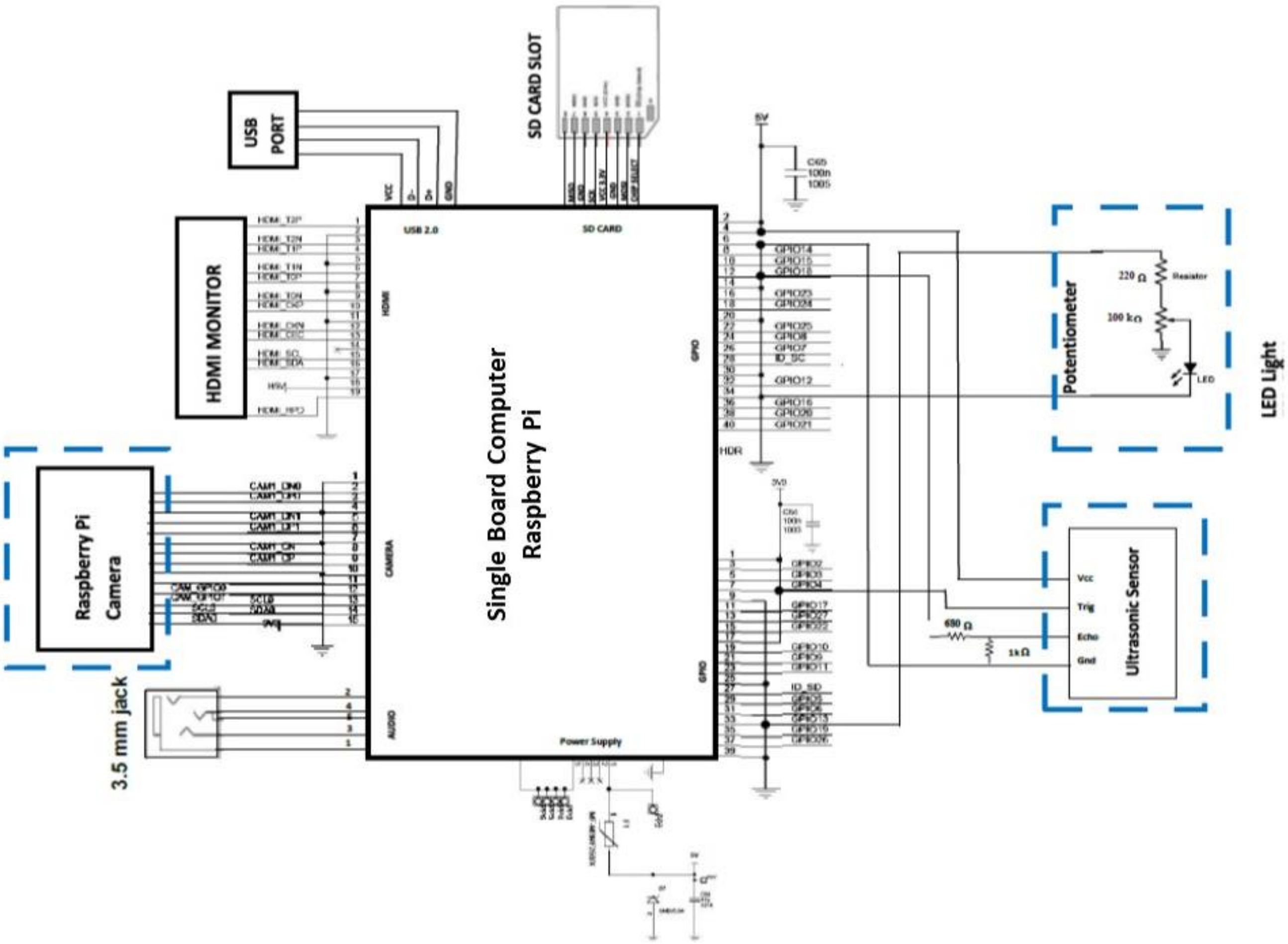

Figure 5. Complete Schematic Diagram of the Single Board Computer Pupillometer to Evaluate Quantitative Pupillary Reflexes in Response to Auditory Stimuli.

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4. Conclusions

The Single Board Computer Pupillometer functions to measure the pupillary responses with music as the stimulus. It consists of software and hardware components; the single board computer or Raspberry Pi served as the central processing device for the pupillometer. The input hardware was composed of the camera and the ultrasonic sensor. The output hardware was composed of the monitor to be able to display the results on the screen such as the real time video of the pupil, the graph (diameter vs. time), and the tabulated data of the variation in pupil size that is imported as an Excel file. Programming languages such as Python, Fortran, Java, C++, and C was used in the construction of the pupillometer. The testing process was initially iteratively conducted by the researchers for each component. Testing for repeatability, reliability, accuracy and functionality was done to ensure that the design achieves the desired operation. Finally, the pupillometer was evaluated for functionality by the Psychology department. This work illustrates an approach to assessment of stimulus-based performances that may be able to semi-automatically operate. This project highlights technologies that hold the capacity to inexpensively enhance the experimentation methods in understanding theories in psychology.

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