Prototyping New Systems for White Light Solar Flare Observation and Data Collection

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Abstract

White light solar flares are violent reconnection events of the Sun's magnetic field that can emit a wide range of the wavelengths of visible light. These flares can be powerful enough to create significant infrastructural disruptions due to their geomagnetic effects and thus are a focus of heliophysical research. This study details the composition and analysis of three days of solar data on June 9th, June 10th, and June 20th. We also describe the development of a new data collection system through automation of the observatory, along with the problems faced in both data collection and development. We found no white light solar flares on the days we took data, but white light solar flares occurred on June 17th and June 19th, illustrating the need for more consistent data collection systems to reduce the chance of missing a flare event. The development of more automated data collection systems means we can increase the efficiency of our observations and possibly observe more white light solar flares in future studies.

Introduction

A solar flare is a burst of electromagnetic radiation caused by the recombination of the Sun's magnetic field lines. A white light solar flare, also known as an X-class solar flare, is a special type of solar flare that’s powerful enough to be seen in the visible spectrum, indicating the emission of light energy along the entire electromagnetic spectrum. As a result, we can image these flares using white light telescopes that operate on visible frequencies for direct observation

(Fletcher et al., 2011). By analyzing pixel values to map out the location of certain flares on the Sun's surface, we can also track the time evolution of these flares and detect when they occur (Hao et al., 2017; Kerr & Fletcher, 2014).

White light solar flares can sometimes be powerful enough to damage objects in orbit such as communications satellites and disrupt major infrastructure such as radio communications, power grids, and global positioning systems. Smaller class solar flares are usually deflected by Earth's magnetic field, but white light solar flares can create radiation storms that can overpower Earth's geomagnetic fields and cause global blackouts (Kretzschmar, 2011; Penn et al., 2019). However, if given prior notice, we can prepare our communications infrastructure before a flare event happens. Thus, tracking the prevalence and causes of white light solar flares is an important part of maintaining Earth's global infrastructure.

This project used the solar telescope on the roof of the Neckers building at the Southern Illinois University of Carbondale (SIUC) to take images of the Sun multiple times over the course of two weeks, with three individual datasets for each of the three days we managed to collect data. We aim to use this data to draw conclusions about the Sun's status whilst pointing out flaws in the data collection process. Additionally, this project also concerns the development of a new solar observatory to be placed on the aforementioned roof and its planned automation system.

Methodology

This section will detail the current established system for data collection which was used to acquire all the data we used for this study. It will then go on to detail the process undertaken during this study to develop a newer data collection system, as well as future work planned for the new system.

Current System

For the observational setup used for this study's data, seen in Figure 7, we use the ZWO AM5 mount with an Askar FMA 180 Pro telescope and a Rainbow Symphony solar filter. The telescope is connected to a Windows laptop computer within a small box on the roof of the Neckers building, and this laptop can be used through another computer via a remote desktop set-up. The lid is manually opened at the start of the data collection period and the telescope is then slewed to the Sun using the ASCOM platform controller and the skymap software Cartes du Ciel on the remote desktop. From there, small adjustments are made to keep the telescope focused and pointed at the Sun using the SharpCap software. Cartes du Ciel automatically slews to the Sun throughout the day, requiring a meridian flip shortly after noon. At the end of the day, the telescope is manually controlled into a parked position and the lid is manually closed. During post-processing, a Python script is used along with the Planetary System Stacker (PSS) software to align the pictures taken over 15-second intervals within each minute. Pictures within the same interval are then stacked together to increase the resolution of the image (similar to how cameras take long-term exposure images, the telescope takes multiple frames to create a cleaner image of the Sun). The finished images are then uploaded to an online database. Other teams of astronomers from around North America also take their own observations and upload them to the online database using the same process.

When a day of data is collected without evidence of a solar flare, all groups that took data that day are allowed to delete their data. However, when a solar flare is detected, the data is saved and images of the solar flare are collected. The process for managing data when a solar flare is found is shown in Figures 1 and 2. A machine learning clustering algorithm is run on the finished images to find the edges of the Sun, and the picture is then cropped to only show the Sun. The algorithm is run again to find the edges of the Sun's solar flare, and more processing is used to find the center of the solar flare. The image is then cropped into a 100 pixel by 100 pixel format around that center, allowing for the mass generation of many flare-focused images. These images can be compared together to find out how the flare evolved over time: where it originated from, where it spread to, and how much energy it released.

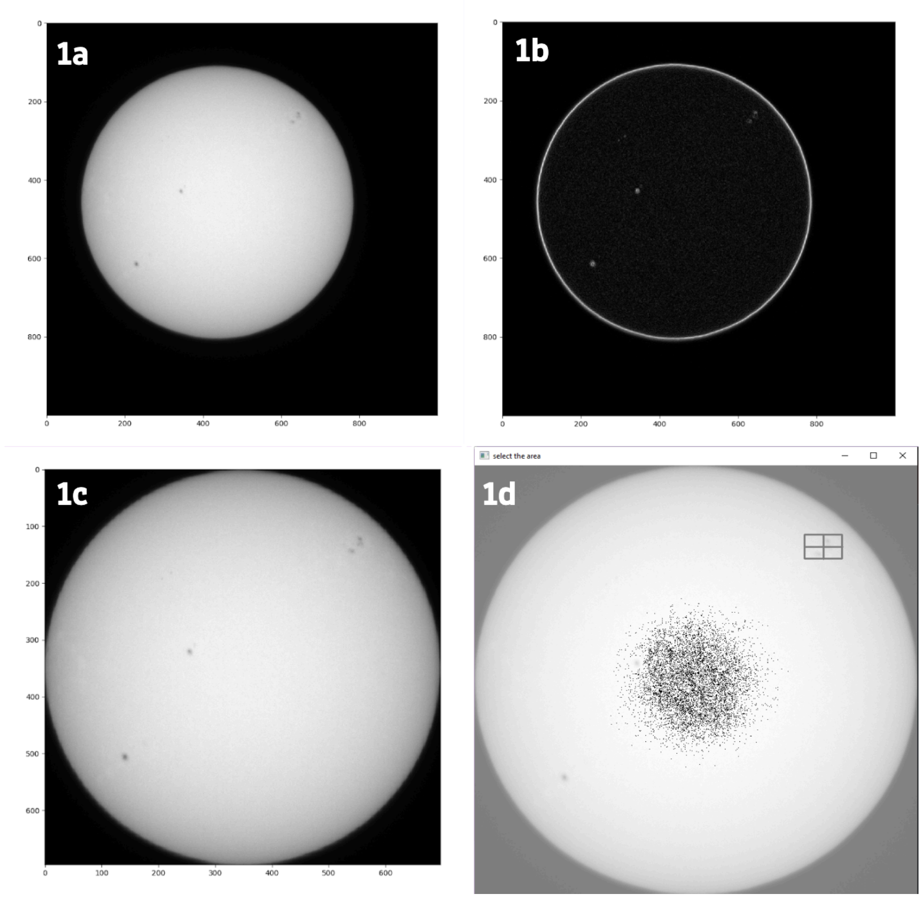

Figure 1: Pictures of each step of the data management process are shown to illustrate how our

code processes flare data from a raw image to a crisp frame of only the Sun.

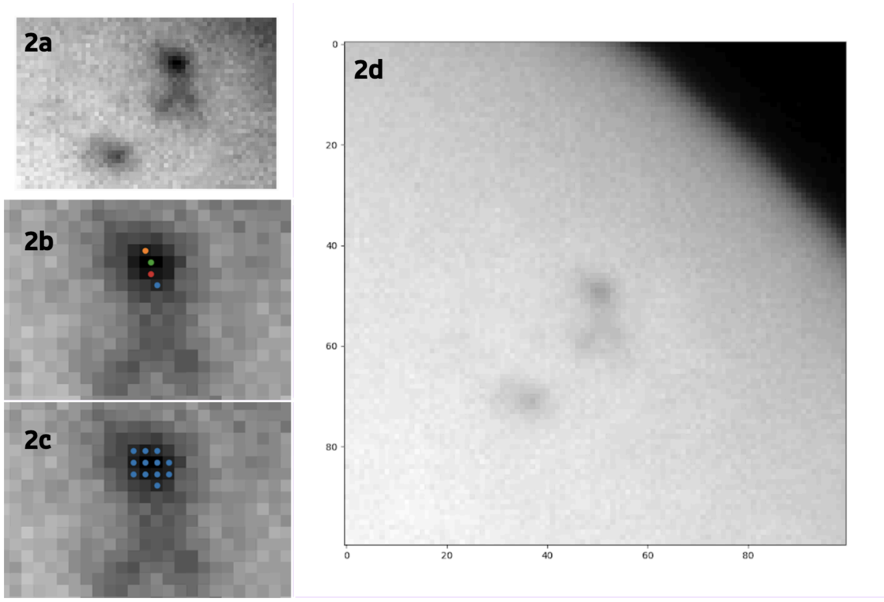

Figure 2: Pictures of each step of the clustering algorithm are shown to illustrate how our code processes flare data from a frame of the Sun to a zoomed-in image of the flare region.

Automation

While the remote desktop set-up and the upload program are helpful to the collation of data, taking data using the SIUC solar telescope still requires manual intervention to start and stop data collection. Additionally, weather events such as humidity, wind, and cloud coverage can all impact the focus of the telescope and the images that are taken of the Sun, meaning high quality images of the Sun can't be taken everyday. Rain and other storm conditions would mean we have to quickly close the lid to prevent water damage to the electronics inside the telescope box. A more automated system would allow for us to take data more conveniently and thus more consistently, as well as preventing the possibility of damage to the telescope or other electronics inside the observatory.

The development of an Arduino-based control system (using an Arduino Uno, referred to as an Arduino in this paper) to help better manage the telescope was explored in this study. A basic prototype of a system with two rain sensors for detecting water, three light emitting diodes (two for motor simulation and one for rain sensor output), and one switch was created. It is planned for this system to be scaled up to six rain sensors (four with analog output and two with digital output), two large DC motors, two relays, one external power source other than the Arduino's 5V power supply, and two pushbuttons. The components of the aforementioned prototype were all connected to the Arduino with jumper wires and a mini breadboard. However, we hope to use a soldered circuit board and dedicated microcontroller in the working model, along with other components for proper function within the new observatory's structure. The automation has four major parts:

1. The usage of both analog and digital signals from rain sensors to analyze if precipitation is present and how severe it is.
2. The control of two motors and two pushbuttons (represented by LEDs and a switch in the prototype) to open and close the lid of the observatory, depending on whether rain is present or not. The motors will run until the lid hits a pushbutton on the side of the box, indicating the lid is in a fully closed or fully open position.
3. A user interface for controlling said motors (opening and closing the telescope at the start and end of the day whilst refusing to open the lid if precipitation is detected). This interface is generated by a Python script run on a Windows laptop connected to the Arduino.
4. A connection between the telescope and the laptop that allows for the Python script to

send commands to the telescope so it can slew towards the sun (when the telescope is opening) or move back to its parked position (when the telescope is closing).

These were the four main goals for the prototype and the same functionality is planned for implementation into the future system.

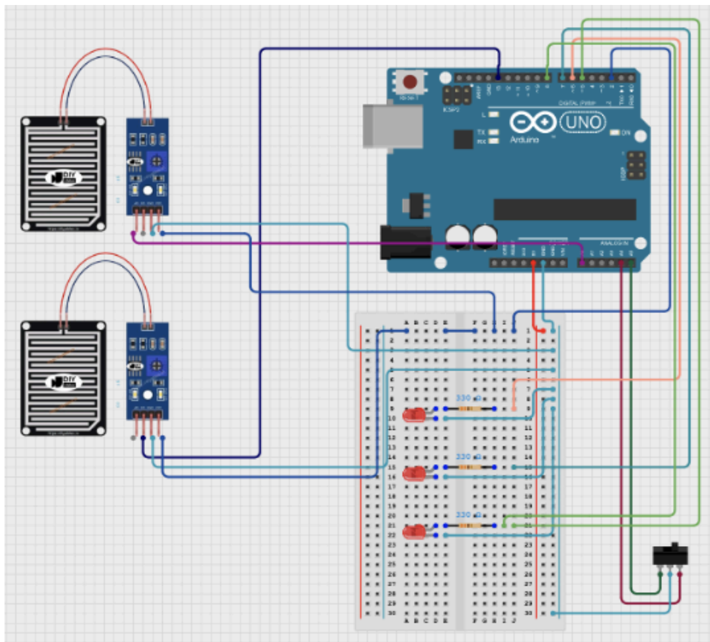

Figure 3: A schematic of the prototype's wiring is shown.

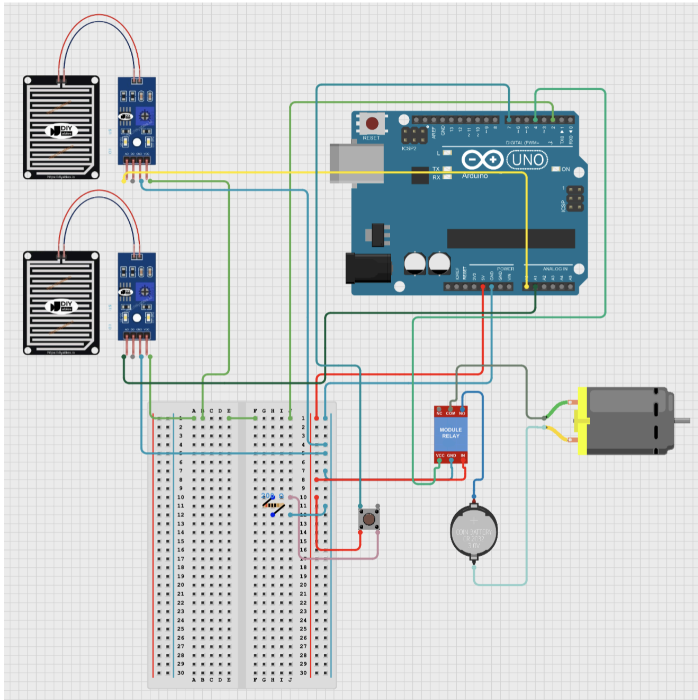

Figure 4: A schematic of the real implementation's proposed wiring (with the four additional rain sensors and second motor excluded for clarity).

Results and Discussion

This section will discuss the results of the study before detailing the problems we had with data collection and the development of the new observatory's automation system.

Data Collection

During the two weeks under study at SIUC, only three days were suitable for data collection: June 9th, June 10th, and June 20th. However, none of those three days had a solar flare, while on two of the unsuitable days (June 17th and June 19th) geostationary operational environmental (GOES) satellites detected X-class flares that could have been picked up by our telescope (Space Weather Prediction Center, n.d.). The reasons why our telescope can't take data everyday are detailed in the Methodology's Automation section. As a result, all of the images we took during our three days of data collection had no evidence of white light solar flares. Despite this, a sample of these images is shared in Figures 5 and 6 to showcase quiet Sun activity over normal days. The lack of interesting data only emphasizes the importance of automating our data collection further to optimize the amount of usable data we can get.

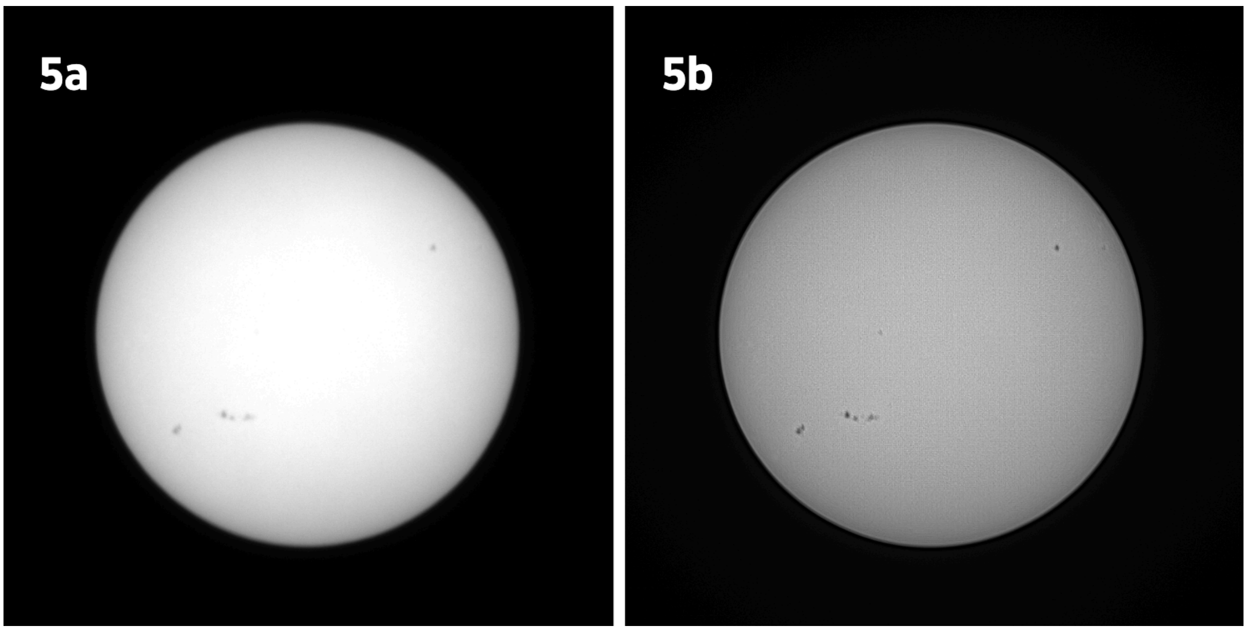

Figure 5: A picture of the sun (with no X-class flares occurring) under clear weather conditions. Figure 5a is a raw image while Figure 5b is a processed PSS image.

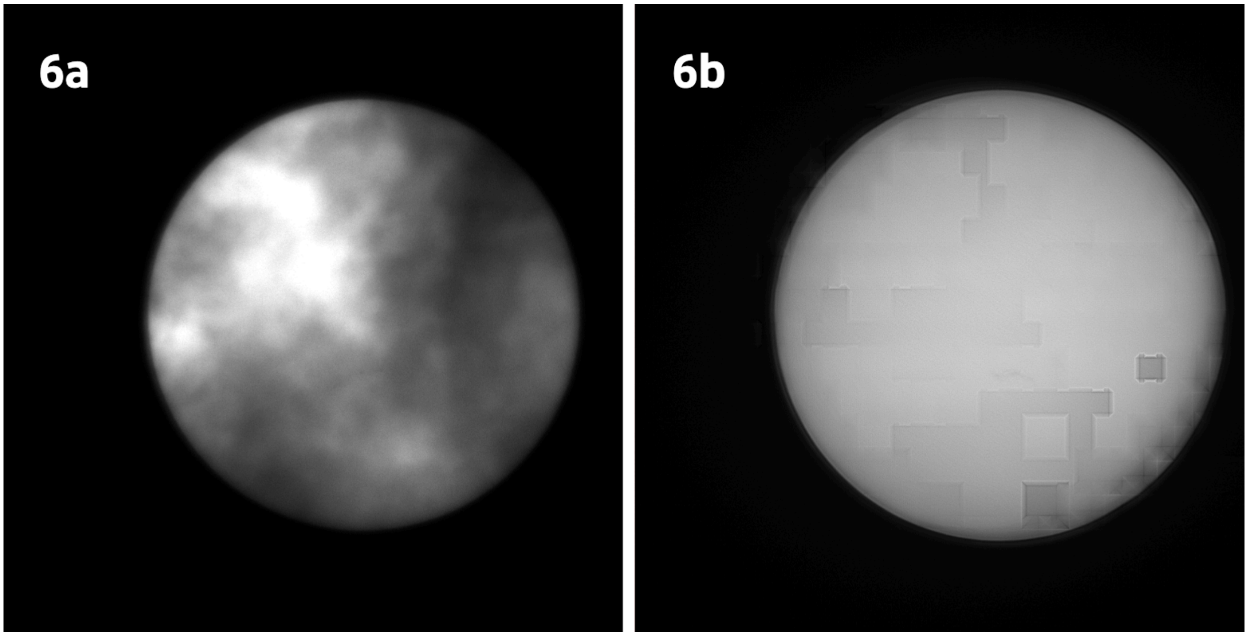

Figure 6: A picture of the sun (with no X-class flares occurring) under intense cloud cover, obscuring the observation. Figure 6a is a raw image while Figure 6b is a processed PSS image.

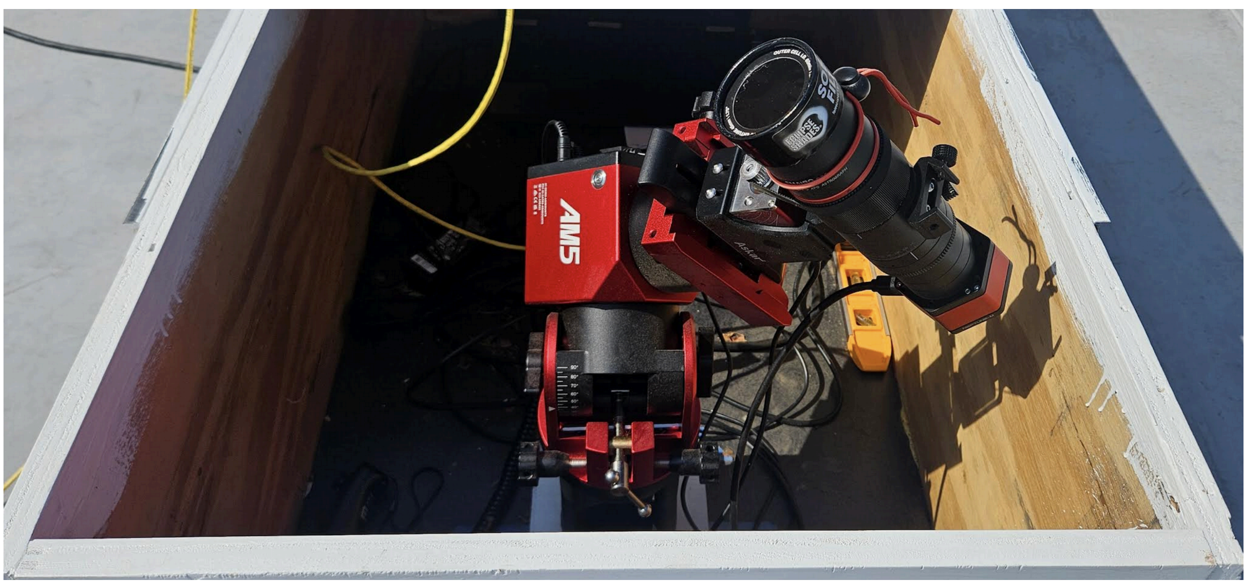

Figure 7: An image of the solar telescope used for this study's data on the roof of SIUC.

Problems Regarding Development

During the process of establishing the working prototype of the new observatory's automation setup, multiple problems were encountered. These issues are cataloged here due to their relevance to developing the system.

The Python module PySerial was originally used for communication between the Arduino and the Python script through the USB connection. The module leveraged printing to and from the serial monitor for communications, but due to port access restrictions, monitoring the serial while the serial was being used by the script would cause an error, making troubleshooting more difficult. Additionally, while the Arduino code could use the "Serial.available()" command to detect whether the serial monitor is being accessed by the script, the script had no command for detecting whether the Arduino was done processing data. As a result, code structures ended up being messy and required constant monitoring of the serial monitor to confirm that messages had been sent and received.

Due to repeated problems with PySerial, we decided to start using the Python module PyFirmata instead. While PyFirmata could also transmit String messages to the serial monitor, it also acted as a firmware for the Arduino. As a result, the Python script could make direct commands to access the input/output of Arduino board pins instead of having to transmit information between the Arduino and Python code.

The initial code scheme involved both the motor control and rain sensor control code being run at the same time on the Arduino. To prevent timing clashes, a main loop with a timer was implemented to time both the motors and the rain sensors at the same time. However, this code scheme was inefficient and increased the load on the Arduino. As a result, this was changed when we switched from PySerial to PyFirmata. Rain sensor code is hosted locally on the Arduino board to allow for continued rain sensor functionality in case the laptop connection to the board gets compromised. The motor code was separated and put into the Python script for simplistic and organizational purposes.

Summary and Future Work

This paper covered the basics of white light solar flares and why we benefit by collecting data on them and attempting to predict their occurrence. It then went on to cover the current system at SIUC for daily solar observations within the visible continuum, and explained the consistency and efficiency issues the system faces. Shortly after, a proposed automation system was covered and the actual data taken during the three days of observation was described. The paper described a prototype and the problems regarding its development to help give an idea of how the real automation system will work in the new observatory. Future work on this project will most likely focus on continued daily solar observations along with the continued development of the new automation system and second SIUC observatory. The automation prototype will serve as a guideline for further development, and the challenges encountered during initial development will hopefully provide insight for future issues.

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