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SPECTRA OF THE MONTH

ANALYZING FLUORESCENT MARKERS IN U.S. BANKNOTES WITH THE AVASPEC-NEXOS

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INTRO

BACKGROUND OF APPLICATION

With instances of fraudulent currency ever increasing, it is necessary to be able to identify the markings of authentic notes. US banknotes of denominations $5 and greater incorporate fluorescent markings that emit different colors in various locations on the bill when placed under a UV light source. Identifying these fluorescent strips to be accurately colored and placed is a key part of counterfeit detection. Each bill has a unique color; either blue, orange, green, yellow or light red/pink for the $5, $10, $20, $50, and $100 bills respectively. While some colors are more distinct than others and can be identified with the natural eye, certain colors are difficult to see or similar in hue. Specifically, the fluorescence on the $100 bill is commonly hard to distinguish with the natural eye, and the shade of the yellow on the $50 and the orange on the $10 are often mistaken. Given these complexities, the use of a spectrometer to precisely determine the fluorescent color of the bill can be useful and result in more accurate identification.

In this fluorescence experiment, our objective was to quantify the fluorescence peak locations in each denomination of US banknotes (Figure 1) and compare the measured peaks to the reported colors. This involved exciting the fluorescent strip on the banknote with a UV light source and recording the emission with a fiber optic cable. The spectra associated with each of the different bills had identical peaks correlating to the UV excitation light but differed in the associated fluorescent peaks, indicating the dye color of the security thread. By identifying the wavelength of the measured fluorescence peaks, we compared these values to the true colors in which the bands are dyed to verify the authenticity of the bills.

FIGURE #1 Banknote samples ($5, $10, $20, $50, and $100) displayed under regular and UV light.

DESCRIPTION OF SPECTROSCOPY SETUP

The setup for this experiment (Figure 2) was based around our AvaSpec-NXS2048CL compact spectrometer, commonly known as the Nexos. This compact instrument is our next-generation photonics backbone spectrometer, designed to empower a wide range of applications in various industries. This device is built using our new semi-automated manufacturing technique that ensures higher levels of consistency and reproducibility unit-to-unit. The Nexos offers USB2.0 communication as well as RS232 and SPI communication protocols, a CMOS linear array detector, ultra-low stray light as low as 0.1%, and a signal/noise ratio of 375:1. Furthermore, this spectrometer can be customized with a wide range of gratings (13 total available) and the replaceable slit option is now standard for non-OEM units, which provides even more flexibility for a variety of application needs. The unit used in this experiment was selected to include the full visible spectrum along with a portion of the UV region in order to fully see the excitation from the light source. For this, the selected unit had a wavelength range of 370-915 nm wavelength range, with the range from 370-420 nm excluded from measurements to remove the excitation peak from the data set, and the range 720-915 nm excluded to focus on the region of interest. A 50-micron slit was installed for a balance of high throughput, a common limitation of fluorescence measurements, and resolution.

FIGURE #2 Experimental setup for fluorescence measurements: A spectrometer connected via fiber optic to a collimating lens and filter holder was aimed at the bill's fluorescent stripe. The bill was placed over a UV flashlight to enhance fluorescence.

The light source used for this experiment was a 395 nm UV flashlight purchased online. This was selected because it is a readily available, commonly used UV light wavelength for fraud detection. Other accessories used for this experiment included a 600-micron core fiber, a 400 nm long-pass filter to isolate emission peaks from the excitation peak, an in-line filter holder, a collimating lens, and a stand with clamps to hold the fiber in position.

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DESCRIPTION OF METHODOLOGY

The banknote samples used for this experiment were picked up from a local bank. One of each bill was selected to demonstrate the unique dye used for each bill. A $1 bill was also measured but was not included in the results since they contain no fluorescent dye, leading to a trivial measurement. No preparation of the samples was done, as we planned to measure each bill how it would be measured using a UV flashlight. For the measurements, we attached the fiber optic cable to the spectrometer and an in-line filter holder. A 400 nm long-pass filter was placed in the filter holder to isolate the emission peaks from the excitation peak. The filter holder was then attached to a collimating lens, which was used as the collection point for the fluorescence measurements. We first tested each bill by illuminating and measuring on the same side of the sample. We found this to give only small fluorescent peaks. Next, we took measurements with each bill placed on top of the UV flashlight and measuring the opposite side of the bill. We found that while this gave a higher peak for the UV flashlight, it also gave high peaks for the fluorescent dye that were much more workable for our study. With that, this was the method we used and included in our analysis.

For data analysis, we used Scope-Minus-Dark mode in AvaSoft, our custom software package. This is a common mode for fluorescence measurements, as it subtracts the dark spectrum (what the spectrometer measures with no light source) from the raw counts (i.e., scope mode) over the whole spectrum. This helps minimize noise in the spectrum and better isolate and identify the fluorescence peaks. We used an integration time of approximately 1 s, which can be adjusted to increase or decrease the amount of light being measured at one time and affects the overall magnitude of the reported spectrum. We set averaging to 5, meaning 5 values were averaged together to provide more consistent spectra results.

TEST DATA AND RESULTS

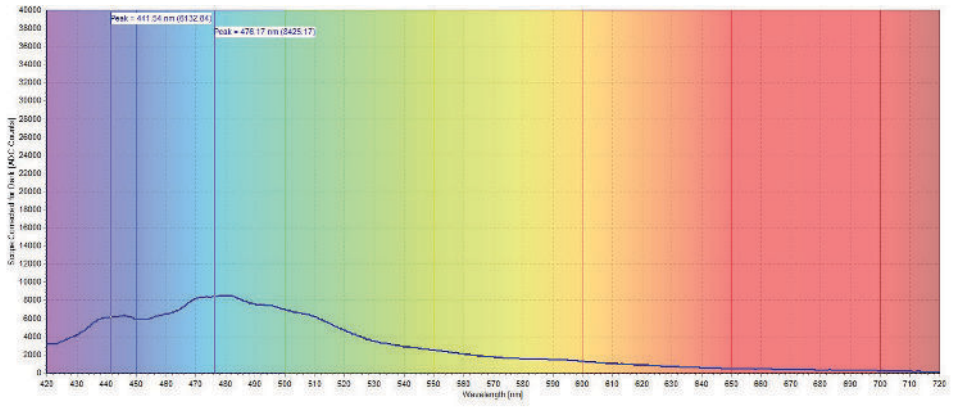

FIGURE #3: Fluorescence spectrum of $5 bill.

TEST DATA AND RESULTS

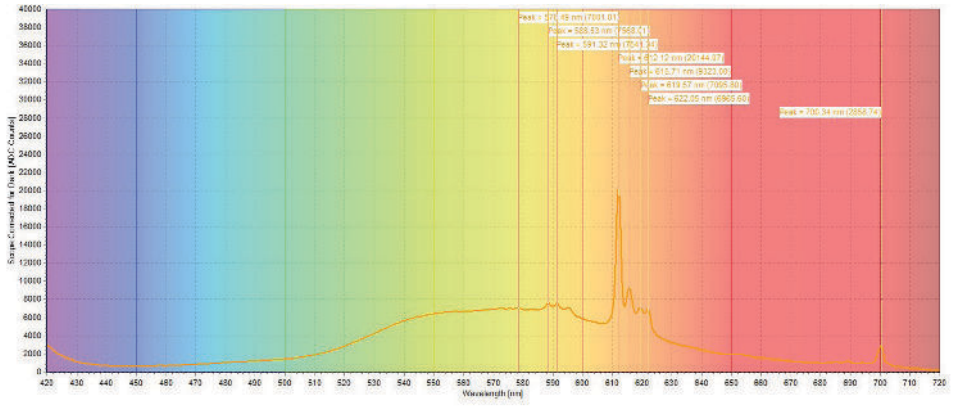

FIGURE #4: Fluorescence spectrum of $10 bill.

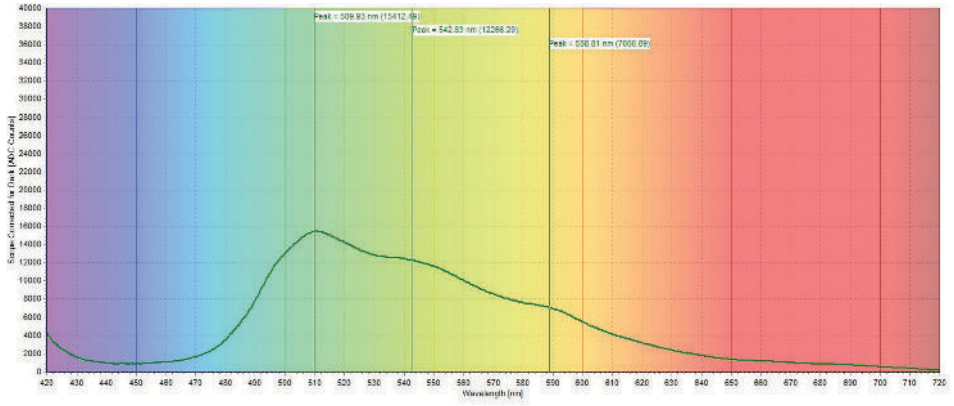

FIGURE #5: Fluorescence spectrum of $20 bill.

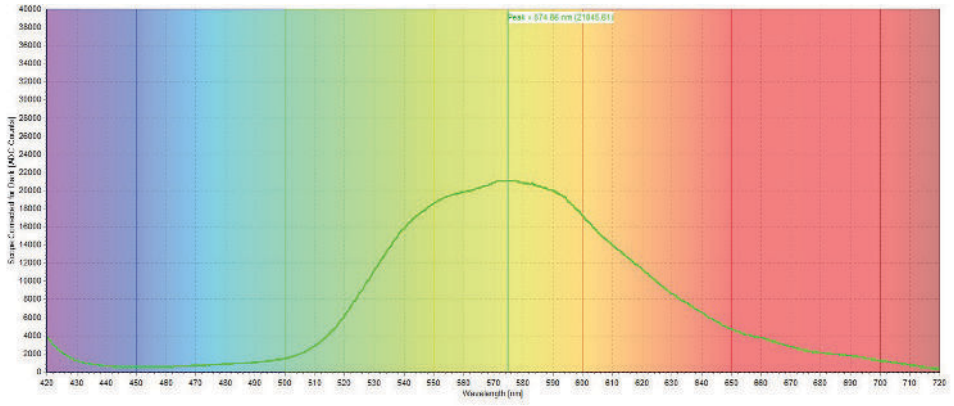

FIGURE #6: Fluorescence spectrum of $50 bill.

TEST DATA AND RESULTS

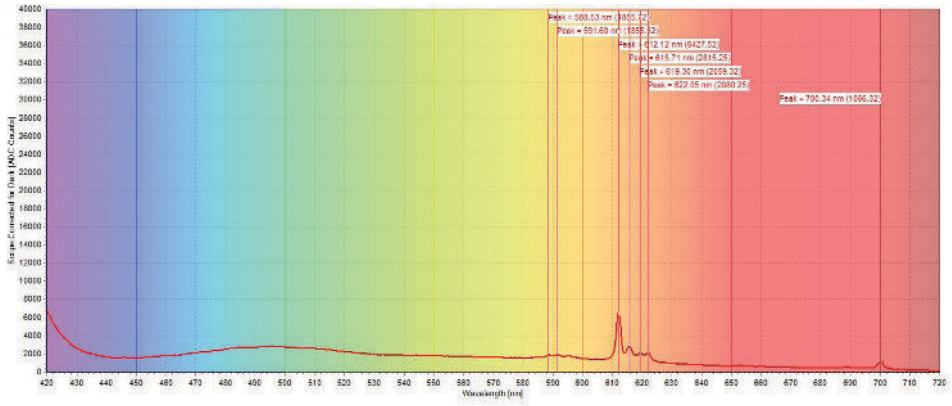

FIGURE #4: Fluorescence spectrum of $10 bill.

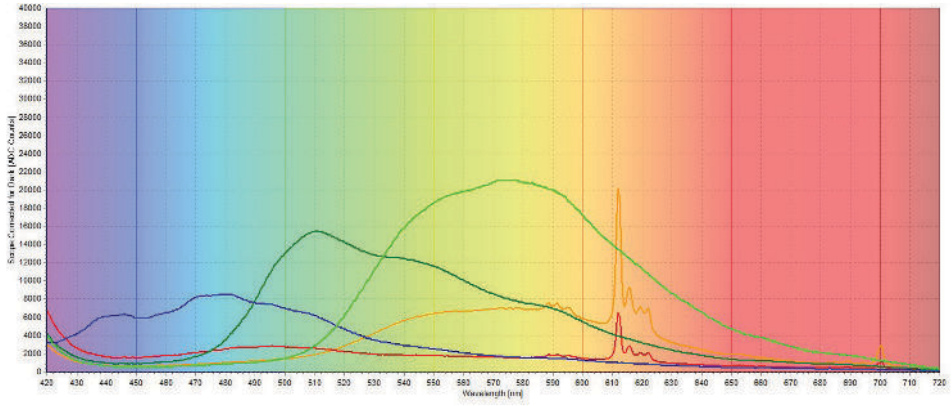

FIGURE #5: Fluorescence spectrum of $20 bill.

ANALYSIS

Each banknote sample exhibited fluorescence peaks that closely matched the reported dye colors.

- $5 bill: Reported blue fluorescence, with peaks at ~440 nm and 475 nm—both within the blue region (Figure 3).
- $10 bill: Reported orange fluorescence, shown as a broad peak from 520–600 nm (peak around 575 nm), and sharp peaks at 588, 591, 612, 615, 620, 622, and 700 nm—covering yellow, orange, and red regions (Figure 4).
- $20 bill: Reported green fluorescence, with a strong peak at ~510 nm and smaller peaks at 545 and 590 nm (Figure 5).
- $50 bill: Reported yellow fluorescence, with a broad peak from 510–660 nm and a maximum around 575 nm (Figure 6).
- $100 bill: Reported pink/light red fluorescence, with sharp peaks at 588, 591, 612, 615, 620, 622, and 700 nm (Figure 7).

A combined plot of all five spectra is shown in Figure 8 for comparison

Notably, the $10 bill shares several fluorescence peaks with both the $50 and $100 bills, supporting its classification as orange—between yellow and red on the spectrum. The $100 bill also showed the least intense fluorescence, consistent with reports that its stripe appears dimmer in authentic notes. This subtlety may serve as a fraud deterrent, as counterfeiters often use overly bright dyes.

While this analysis confirms that peak positions align with reported fluorescence colors, future studies could further quantify peak magnitude and width. Doing so could enhance counterfeit detection, especially if fraudulent notes attempt to mimic authentic fluorescence. Accurate spectral verification could offer a strong layer of protection against advanced counterfeiting efforts.

CONCLUSION

In conclusion, the present experiment highlights the use of our spectrometers to measure the wavelength of fluorescent stripes in US dollar bills. While these stripes can be seen visually, being able to measure and quantify their exact wavelength is critical during both the production process and for fraud detection. The measured peaks for each sample matched well with the reported colors for each dye, and the peaks seen in the orange fluorescent dye of the $10 bill showed a combination of the peaks seen in the $50 bill and $100 bill, which use yellow and light red fluorescent dyes, respectively. Further quantification could be implemented to correlate both fluorescent peak locations and magnitudes to authentic versus counterfeit bills to easily detect if a counterfeit bill has used a different type of fluorescent dye to mimic what is currently used. The AvaSpec-NXS2048CL is an ideal instrument for a broad range of applications and industries, including fluorescence. Please contact Avantes for more information on the configuration that is best suited for your data collection.

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