

# BANKNOTE CHARACTERIZATION USING THE FTIR SPECTROSCOPY

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**Abstract:** Counterfeit methods are more sophisticated than ever before, so it is necessary to implement as many different methods as possible to get reliable information on the origin of the banknotes. The FTIR spectroscopy provides exactly this, a different approach to the identification of different banknote components, from the paper itself to the characterization of the inks, holograms and watermarks. This paper examines the similarities and differences in the composition of the paper used for making banknotes in six different currencies, and at the same time deals with the characterization of the unique features of a particular currency. Moreover, the consistency within the particular currency is examined by comparing multiple banknotes of the same denomination.

**Keywords:** banknote; FTIR spectroscopy; counterfeit.

## 1 INTRODUCTION

Counterfeiting money is one of the oldest criminal activities; it dates back all the way to the 5<sup>th</sup> century AD, and it got more and more sophisticated during the centuries.

Every year approximately 600 000 euro notes are removed from the circulation [1]. As for Croatia, a total of 353 counterfeit kuna banknotes were withdrawn from circulation in the first six months of 2016, which is an increase of 64.2 % relative to the number of counterfeit kuna banknotes registered in the same period in 2015 [2]. In the same period, 72 counterfeit US dollar banknotes were registered, as well as 206 counterfeit euro banknotes.

The authentication of the detected counterfeit banknotes has shown that counterfeiters often imitate some security features, such as the security thread, watermark, hologram and optical variable ink element.

In order to prevent banknote counterfeiting, every new edition increases the number of security elements of the banknotes, from adding security threads that react to UV light, 3-D security ribbons woven into paper, watermarks and colour shifting inks, in addition to the microprinting and raised printing elements. Of course, paper itself contains additional security fibres. Naturally, the number of counterfeit elements depends on the denomination of the banknote.

Nearly all modern banknotes incorporate multiple anti-counterfeiting devices. Some notes, especially the high-denomination ones, may have as many as fifty such elements, some obvious, some secret. This ranges from multiple alphabetical fonts and differing sizes and shapes for letters and digits in serial numbers to special inks that can only be seen under ultra-violet or infrared light. Heat transfers of optical variable devices (OVD) and/or holograms are also favoured on modern banknotes

Throughout history, cotton paper was used for hundreds of years as a basis for the major currencies, and it is still widely spread due to its customizing ability during the production process with security threads, embedded watermarks and machine-readable elements, while at the same time it offers unlimited opportunities for attractive

banknote design due to its high print quality. Eventhough most of the generally used banknotes around the world are made of paper, different plastic materials are emerging and proving themselves useful.

## 2 MATERIALS AND METHODS

Since it is much easier to forge a banknote with a similar visual characteristic as the original banknote than to produce a banknote with the identical chemical composition as the original, the FTIR spectroscopy is a great solution for genuine validation.

The FTIR spectra of samples were recorded in the ATR mode, as the method is suitable for determining the composition of organic binder materials, and in some respect the identification of pigments. Regarding the inorganic pigments, many of them have characteristic absorption bands in the mid-IR region, but at the same time there are many that either do not absorb in that region at all, or have absorptions that have their peaks at the low wave number end and are not characteristic enough [3]. The penetration depth ( $d_p$ ) of the IR radiation into the sample depends on the wavelength ( $\lambda$ ) of the IR radiation, the angle of the incidence of the radiation ( $\theta$ ), the refractive index of the ATR crystal ( $n_c$ ) and the refractive index of the sample ( $n_s$ ), Eq. (1):

$$d_p = \frac{\lambda}{2\pi} \cdot n_c \cdot \left[ \sin^2 \theta - \left( \frac{n_s}{n_c} \right)^2 \right]^{\frac{1}{2}} \quad (1)$$

The FTIR spectra were recorded by the FTIR IRAffinity-21 spectrometer with the Specac Silver Gate Evolution as a single reflection ATR sampling accessory with the angle of incidence at 45° and a ZnSe flat crystal plate (index of refraction 2.4). A total of 15 cumulative scans were taken for each sample with the resolution of 4 cm<sup>-1</sup> in the spectral range of 600÷3700 cm<sup>-1</sup>.

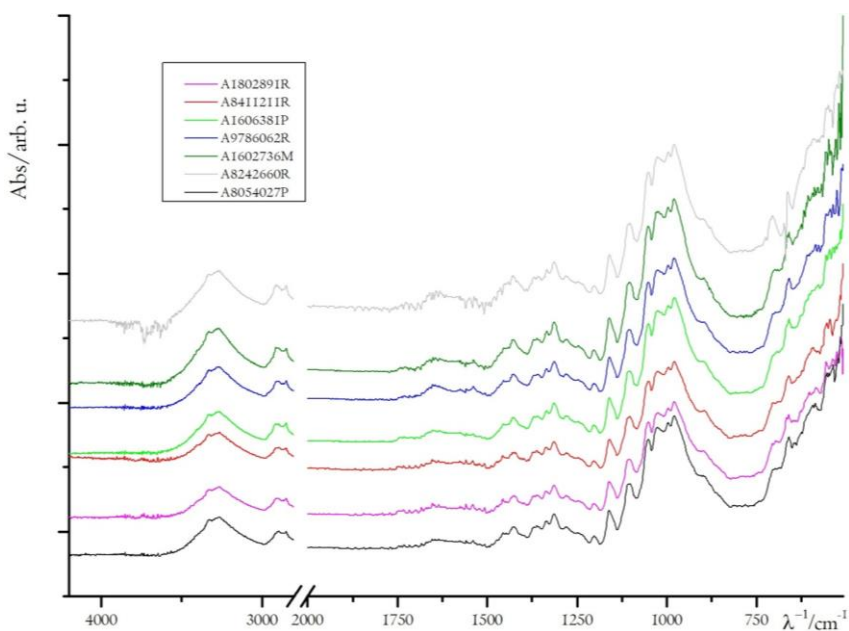
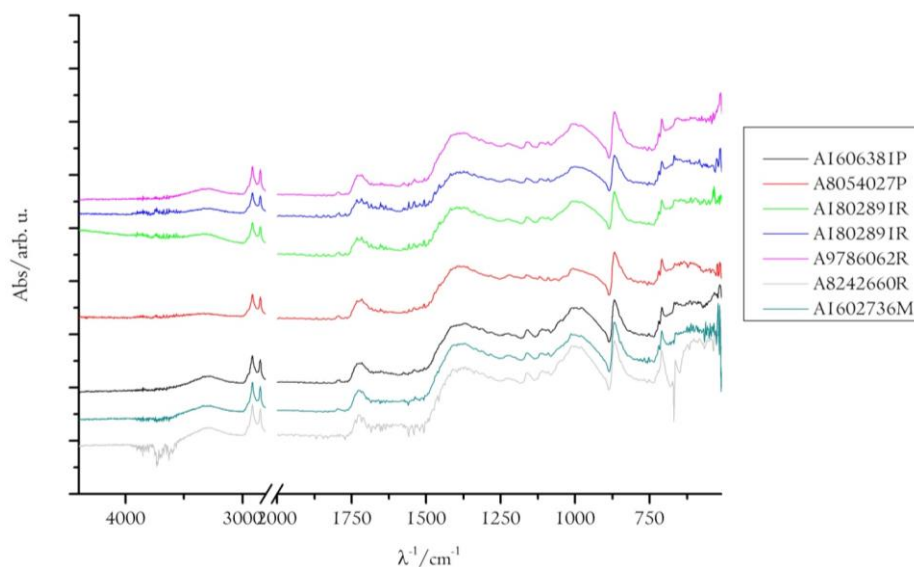
**Table 1** Currencies used in the study

Currency	Denomination	Number of banknotes	Denomination	Number of banknotes
Croatian kunas	50	7	20	5
US Dollars	100	1	1	1
Russian ruble	500	1	50	1
Indonesian rupiah	5000	1	1000	1
euro	50	1	10	1
Romanian leu	10	1	1	1

### 3 RESULTS

The results of the measurements are given in Figs. 1÷16. The spectra of the paper used for the printing of 50 kuna notes for all seven samples are shown in Fig. 1. The kuna banknotes are printed on a multicolour paper made of 100% cotton fibre [4]. Since the same spectra were obtained for the both of the examined denominations, 50 kunas and 20 kunas, only the spectra of 50 kuna notes will be given.

All seven spectra of the 50 kuna notes, regardless of their date of issue or their current condition, show almost an identical paper composition, which implies a great reproducibility within the same denomination notes. Same can be said for the spectra of the hologram within the same samples (Fig. 2). In the Fig. 1, a clear evidence of the cellulose substrate is given with the peaks from 1160÷998  $\text{cm}^{-1}$  and at 898  $\text{cm}^{-1}$ .

**Figure 1** FTIR spectra of the paper used for the 50 kuna notes**Figure 2** FTIR spectra of holograms printed on the 50 kuna notes

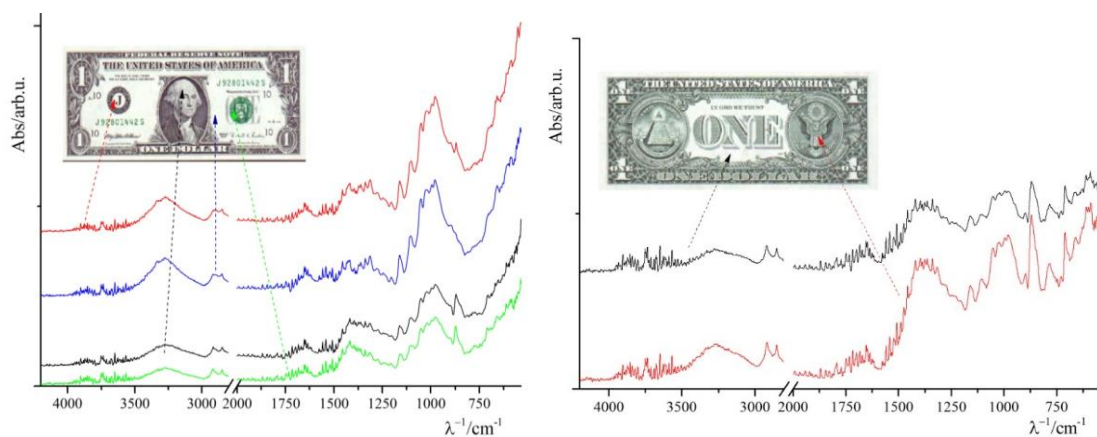


Figure 3 FTIR spectra of a one dollar note: front side (left) and back side (right)

The FTIR spectra of a one dollar note (Fig. 3) again shows the characteristic peaks of the cellulose substrate with the peaks from  $1160\div 998\text{ cm}^{-1}$  and at  $898\text{ cm}^{-1}$ , and additionally, the spectra of the treasury seal and the portrait of George Washington show an extra band at  $870\text{ cm}^{-1}$  which can be attributed to  $\text{CaCO}_3$  responsible for the relief appearance. The intensity of the cellulose peaks is influenced by the composition of the paper, which is 25% linen and 75% cotton. The spectra from the backside show the same peaks, with different intensities.

The backside of the 100 dollar note (Fig. 4) again confirms the equality, while the front side gives different spectra for the characteristic areas (Fig. 4), the 3D security ribbon includes strong absorption peaks at  $1700$ ,  $1280$ ,  $825$  and  $750\text{ cm}^{-1}$ , the treasury seal and the Benjamin Franklin portrait spectra show the additional peak characteristic of  $\text{CaCO}_3$  connected with the raised printing, while the federal reserve seal, watermark and the suptrat itself show the characteristic cellulose bands mentioned already.

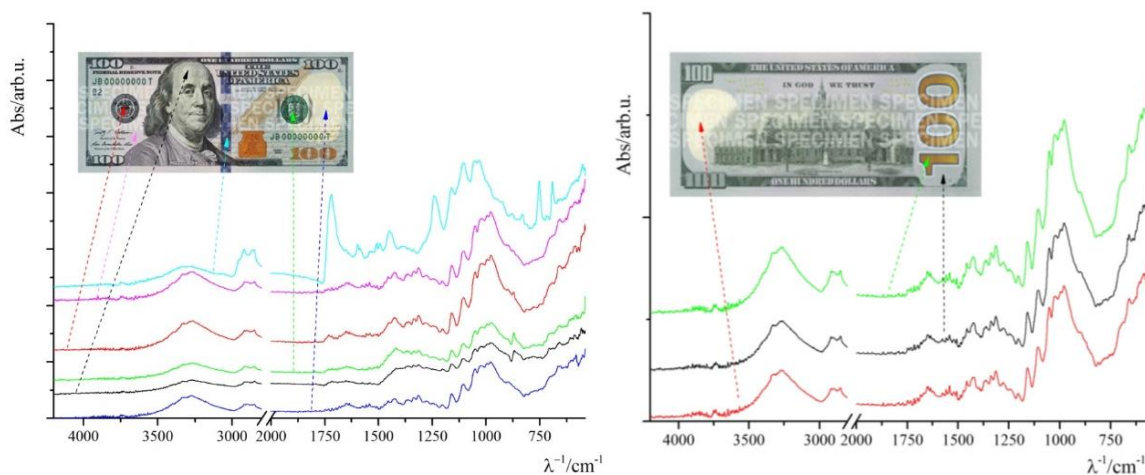


Figure 4 FTIR spectra of a 100 dollar note: front side (left) and back side (right)

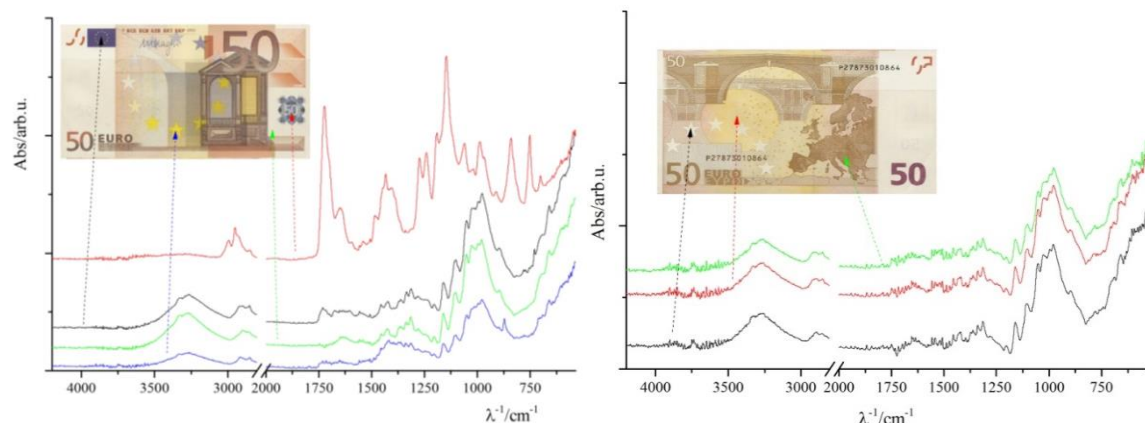


Figure 5 FTIR spectra of a 50 euro note: front side (left) and back side (right)

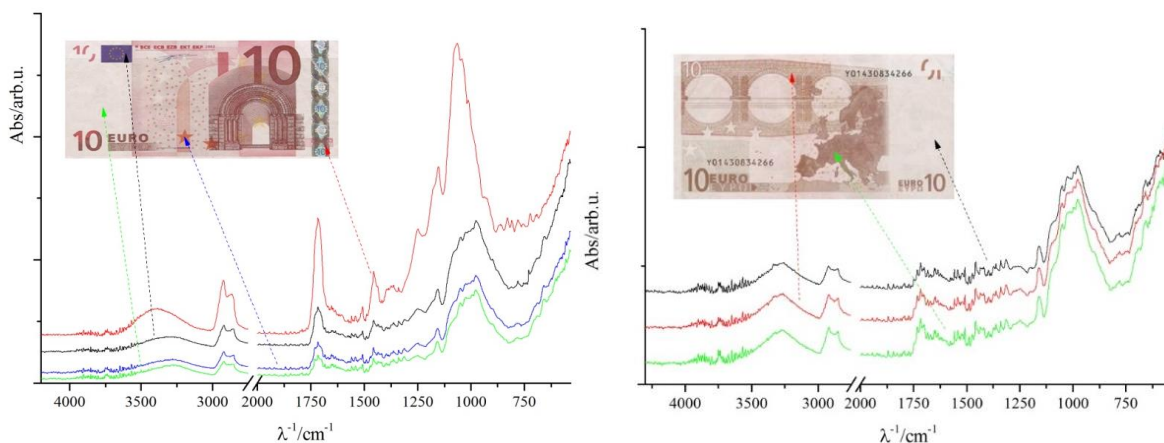


Figure 6 FTIR spectra of a 10 euro note: front side (left) and back side (right)

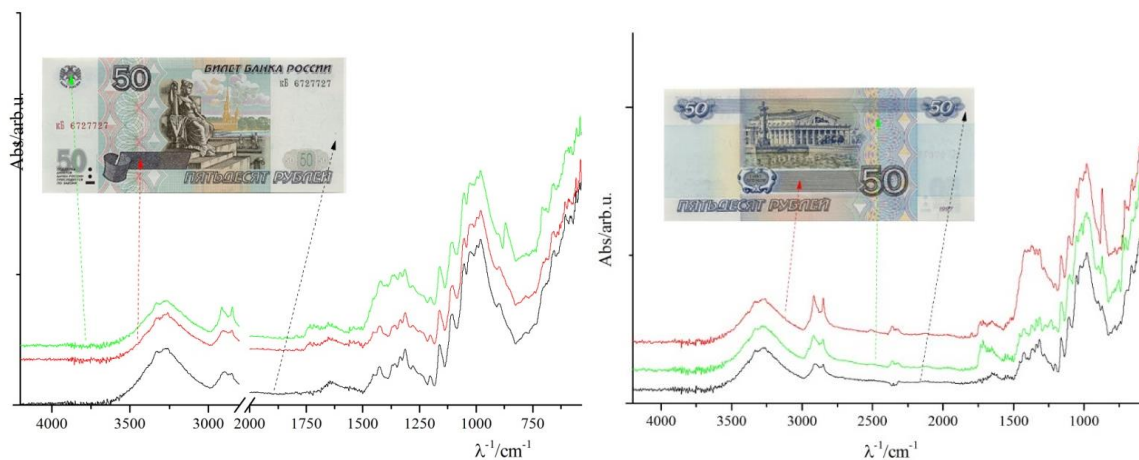


Figure 7 FTIR spectra of a 50 ruble note: front side (left) and back side (right)

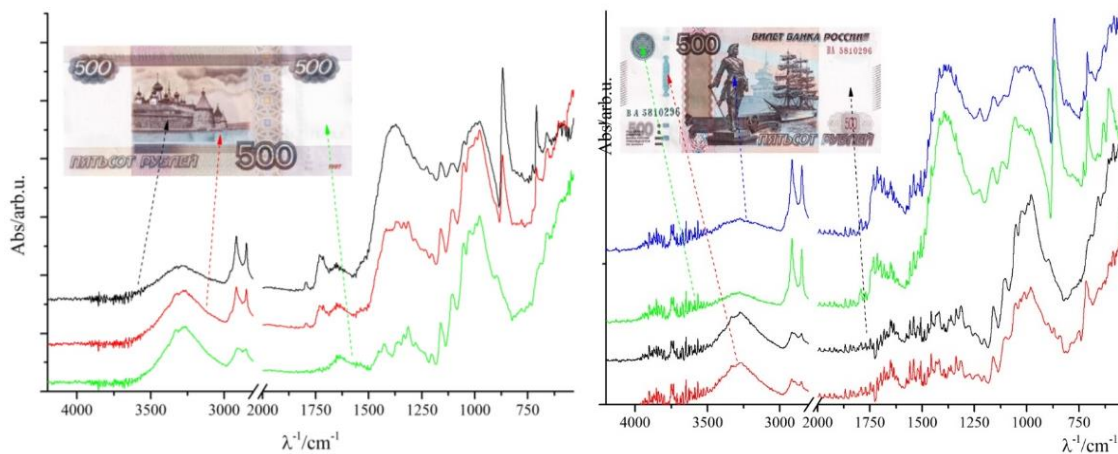


Figure 8 FTIR spectra of a 500 ruble note: front side (left) and back side (right)

Euro banknotes are made of 100% cotton fibre, so their spectra is similar to the Croatian kuna banknotes. The hologram spectra of a 50 euro note includes characteristic peaks at 1725, 1645, 1434, 1271, 1242, 1186, 1146, 1067, 991, 838, 757  $\text{cm}^{-1}$ , which are characteristic to the plastic film that covers the hologram. The hologram spectra of a 10 euro note (Fig. 6) includes a lower number of peaks than in the spectra obtained in the 50 euro note; the characteristic peaks are at 1725, 1434, 1271, 1242, 1186 and 1146  $\text{cm}^{-1}$ .

The difference might arise in the origin of the banknotes, since a 50 euro note was made in Germany, while the 10 euro note was made in Spain. From Fig. 5 it is clear that the spectra from the back side of the 50 euro banknote show an identical composition, regardless of the position from which the spectra was obtained. The same thing can also be said for the back side of a 10 euro note (Fig. 6).

The 50 and 500 ruble banknotes are printed on high quality cotton paper (50 ruble notes on light-blue paper, and 500 ruble notes on light purple paper) (Fig. 7 and Fig. 8).

The Romanian leu notes are unlike most other currencies which are cotton based; they are made of composed polymer. One leu note (Fig. 9) can be identified by its spectra with characteristic peaks at 1050, 1130, 1250,

1600÷1500 and 1700  $\text{cm}^{-1}$ . The spectra are the same from both sides with the exception of an eagle shaped window, and an extra peak at 890  $\text{cm}^{-1}$  in the spectra of the monastery at the backside.

The transparent window of a 10 leu note (Fig. 10) has the same spectra as the transparent window of one leu note.

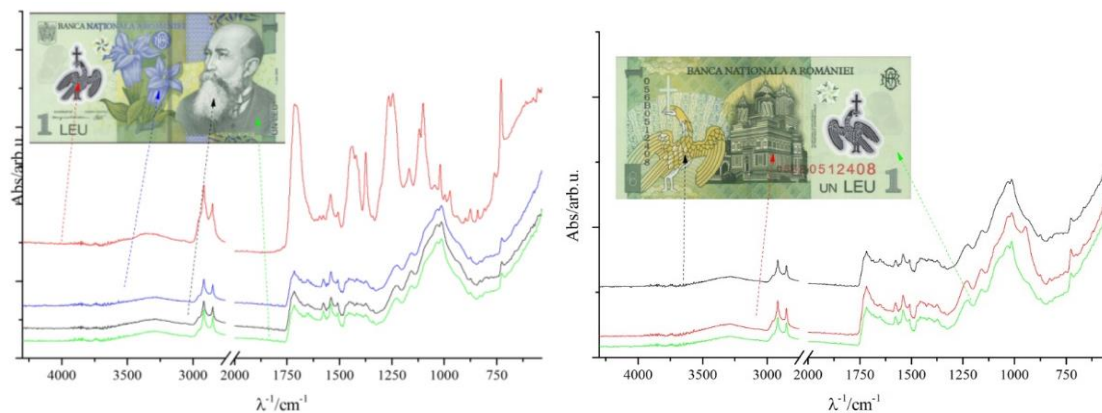


Figure 9 FTIR spectra of a one leu note: front side (left) and back side (right)

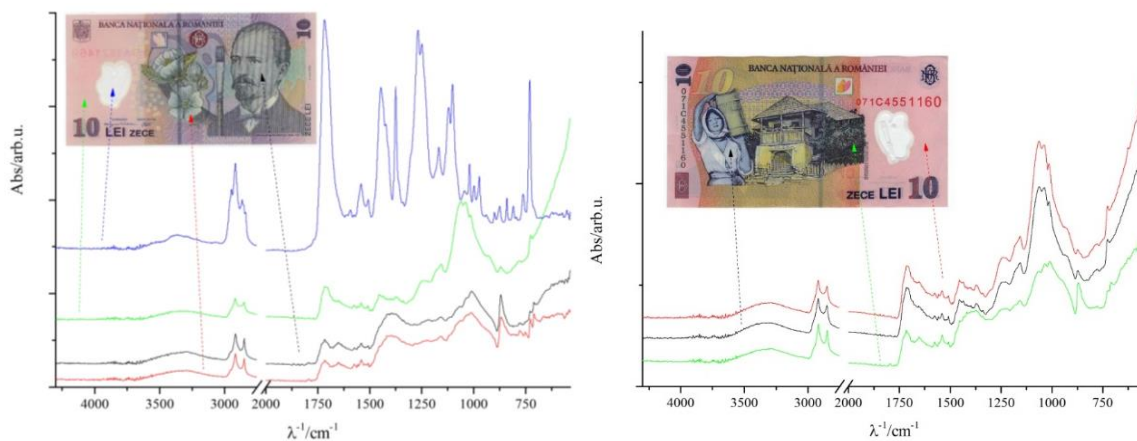


Figure 10 FTIR spectra of a 10 leu note: front side (left) and back side (right)

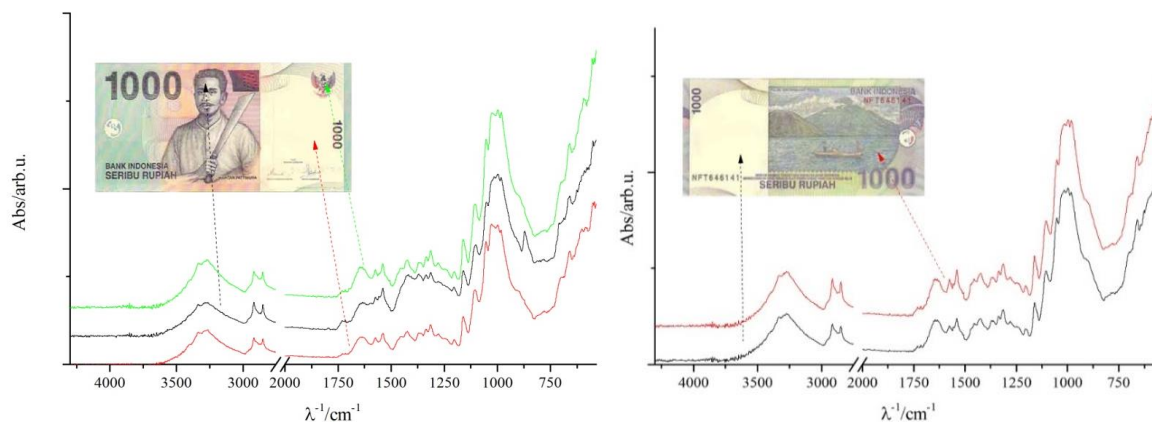


Figure 11 FTIR spectra of a 1000 rupiah note: front side (left) and back side (right)

Indonesian rupiahs are made of long fibers from any kind of wood, or a mix of different types of wood, with the abacá fiber used as a preferable material. The cellulose based material (Fig. 11) is confirmed with the peaks in the region from  $1160\div 998\text{ cm}^{-1}$ , again with the clear evidence of  $\text{CaCO}_3$  at  $877\text{ cm}^{-1}$  associated with the relief elements. The same reasoning and conclusion can be applied while analysing the 5000 rupiah note (Fig. 12).

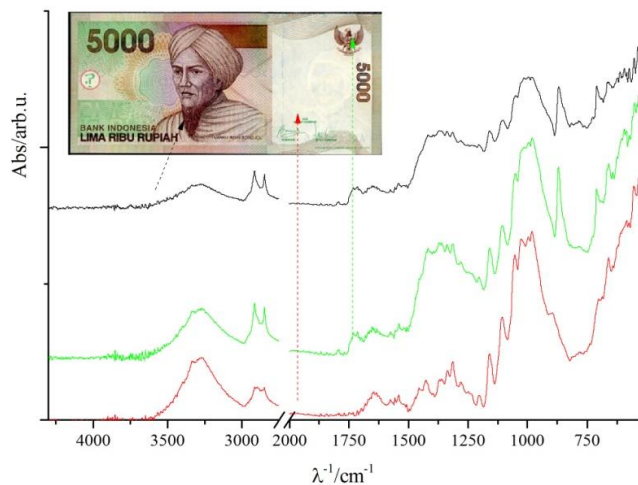


Figure 12 FTIR spectra of a 5000 rupiah note (front side)

#### 4 CONCLUSION

Our measurements confirmed that the production of banknotes, and especially inks, varies from country to country, which is clearly seen in the obtained FTIR spectra.

The spectra consistency was confirmed within the same denomination of the currency, regardless of the condition of the banknote itself.

Since the high quality forged notes can possess fluorescent inks, holograms and metal strips, the process of identifying counterfeit notes is becoming extremely challenging. Once the FTIR spectra of the genuine notes are obtained, it is quite easy, even for a non-scientist, to compare the main peaks of the forged and genuine banknotes. It also allows us to group fake notes according to the similarities of their spectra, which is beneficial in the process of investigating their origin.

With an increase in the measuring of different areas of banknotes, what is obtained is a larger data set which then results in a higher probability of discriminating between the original banknote and a counterfeit note.

**Note:** This research was presented at the International Conference MATRIB 2017 (29 June - 2 July 2017, Vela Luka, Croatia).

#### 5 REFERENCES

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