# FT-IR Spectroscopy as a discrimination Method for establishing Authenticity of Euro Banknotes

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## Abstract

The number of counterfeit banknotes in the world is increasing every year. Since it is much easier to forge banknote with a similar visual characteristic as the original than to produce a banknote with the identical chemical composition as the original, FT-IR spectroscopy is great solution for the genuine validation. The paper will look at the similarities and differences between counterfeit and original banknotes with respect to the materials used. The emphasis will be on euro banknotes; therefore, the characteristic areas of the recorded spectra will be adjusted to the security elements of the given currency. The paper confirmed that FTIR spectroscopy is a suitable method for non-destructive measurements and allows for easy identification of counterfeits.

**Keywords:** banknote, counterfeit, FT-IR spectroscopy

## 1. Introduction

Detection of forgeries is of utmost importance in the various domains of human life. Namely, technology development has made it easy to copy original products from medicines and medical products, food products, electronic products, toys, luxurious products to banknotes. Counterfeits (especially banknotes) often mimic individual protective features, such as a protective thread, watermark, hologram, optically variable colours, micro lettering and fluorescence, which make them harder to identify. In the second half of 2017, a total of 814 counterfeit banknotes were registered in Croatia, 20% of which is occupied by Kuna banknotes (163 counterfeit pieces) which is an increase of 98.8% compared to the number of counterfeit Kuna banknotes registered in the same period of the previous year. The most commonly falsified denomination of the domestic currency was a banknote of 200 Kuna's which accounts for 57.7% of banknotes, followed by 100 and 500 Kuna banknotes, together accounting for 31.3% of the total number of counterfeit Kuna banknotes (1). As far as counterfeit euro banknotes are concerned, 50 euros counterfeits were dominant with 58% of the total number of counterfeit euro banknotes registered.

Several methods have been used to examine the banknote authenticity, the most common one being based on sensory inspection (look, feel, tilt) of security features, followed by optical and microscopic evaluation (2,3). Dealing with high quality forgeries requires non-destructive chemical analyses. Micro-Raman spectroscopy and X-ray florescence spectrometry proved to be effective for analysing genuine and counterfeit Euro, Croatian Kuna, Brazilian Real banknotes and Hungarian postage stamps (4–6). Our previous research (7) based on the research from (8,9) has pointed to the possibility of using FT-IR spectroscopy in the characterization of original banknotes of different currencies by identifying the most prominent functional groups of different parts of the banknote. Table 1 shows the overview of currencies and denominations used.

**Table 1. Currencies used in the previous research**

| Curreny | denomination | number of banknotes | Denomination | number of banknotes |
|---|---|---|---|---|
| Croatian kuna | 50 | 10 | 20 | 5 |
| US dollar | 100 | 1 | 1 | 5 |
| Russian ruble | 500 | 2 | 50 | 1 |
| Indonesian rupiah | 5000 | 1 | 1000 | 1 |
| Euro | 50 | 5 | 10 | 5 |
| Romanian leu | 10 | 1 | 1 | 1 |

The results pointed to clear currency differences, which allow the use of FT-IR spectroscopy as a reliable non-destructive method in identifying counterfeit banknotes. Furthermore, it allows grouping of counterfeits with the respect to certain characteristics of the materials used.

## 2. Materials and methods

Due to the limited number of available original and counterfeit banknotes of the same denomination, measurements are made on only one original and one counterfeit 200 euro banknote.

The FT-IR spectra of original and counterfeit 200 euro banknote samples were recorded in the ATR mode, since the method is suitable for determining the composition of organic binder materials, and in some respect the identification of pigments. Some inorganic pigments have characteristic absorption bands in the mid-IR region, but simultaneously 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 (10). 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)

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

The FT-IR spectra were recorded by the FT-IR 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 $cm^{-1}$ in the spectral range of 600-3700 $cm^{-1}$.

## 3. Results and discussion

The results of the measurements are given in Figures 1-4. Four different areas on the front side of the banknote were recorded (EU flag, hologram, paper, 19th century architecture), as well as three different areas on the back (white star, europe, yellow print).

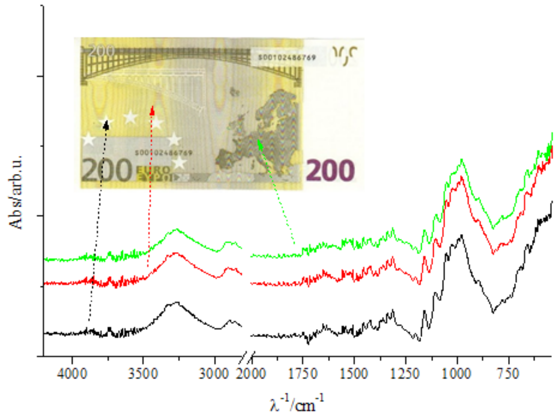


**Figure 1. FT-IR spectra of a genuine 200 euro banknote (front side)**

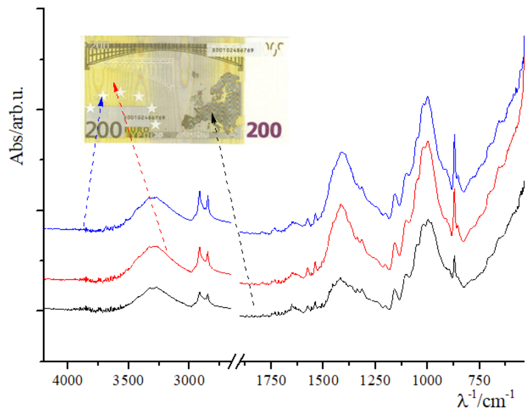


**Figure 2. FT-IR spectra of a counterfeit 200 euro banknote (front side)**

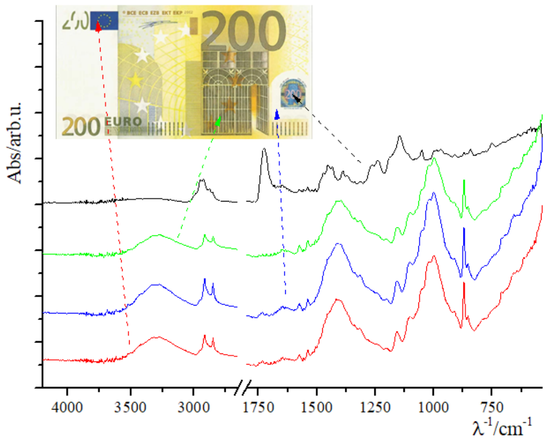


**Figure 3. FT-IR spectra of a genuine 200 euro banknote (back side)**

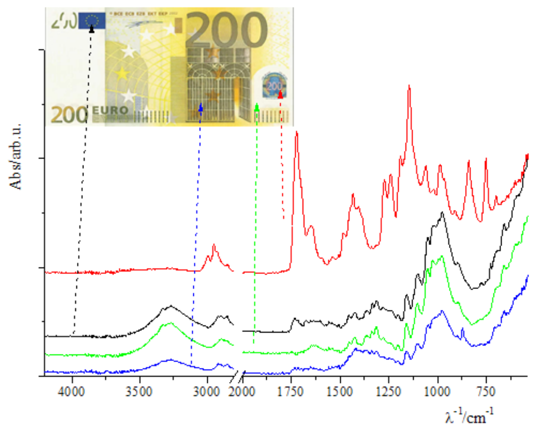


**Figure 4. FT-IR spectra of a counterfeit 200 euro banknote (back side)**

At first glance there are clear differences in the spectra of original and counterfeit banknotes, especially in the fingerprint region (1500 cm$^{-1}$-600cm$^{-1}$). Spectra of counterfeit banknote shows almost identical peak positions regardless of the part of the banknote being examined, while the peaks of genuine banknote point to different processes in the original production indicating several printing processes and different materials being applied.

From Fig. 4 it is clear that the spectra from the backside of the original 200 euro banknote show an identical composition, regardless of the position from which the spectra was obtained. In comparison, spectra from the back of 200 euro counterfeit banknote shows different intensities of the peaks at 1500-1250 cm$^{-1}$ and 875 cm$^{-1}$, which can be assigned to calcium carbonate. If we compare only the spectra of both paper banknotes (Figure 5), we see unmistakable differences in the scope and intensity of the bands. The paper of Euro banknotes is 100% cellulose, in the form of cotton fibers which give the notes strength and characteristic feel and is characterised with the peaks from 1160-998 cm$^{-1}$ and at 898 cm$^{-1}$. The three areas circled in blue corresponded to $CaCO_3$, most commonly used filler in the papermaking industry which is not used in the production of banknote paper due it's negative influence on the tensile and compressive strength of the paper, but at the same time is still widely used in the papermaking industry as an affordable filler that improves optical properties of commonly used paper. The shape of the bands arising from ν(O-H) and ν(C-H) stretching modes around 3200 and 2900 cm$^{-1}$ also indicate the difference between the papers used.

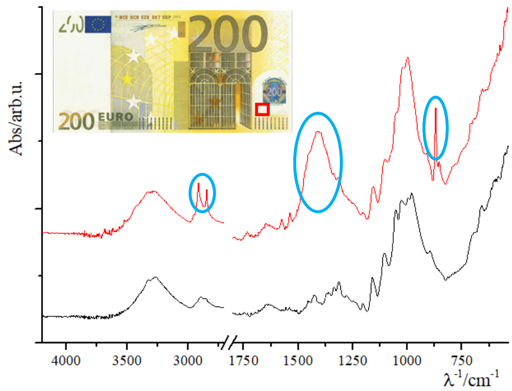


**Figure 5. FT-IR spectra of paper substrate of a counterfeit (red line), and genuine (black line) 200 euro banknote**

Other area with the highest differences in spectra is the hologram (Fig. 6).

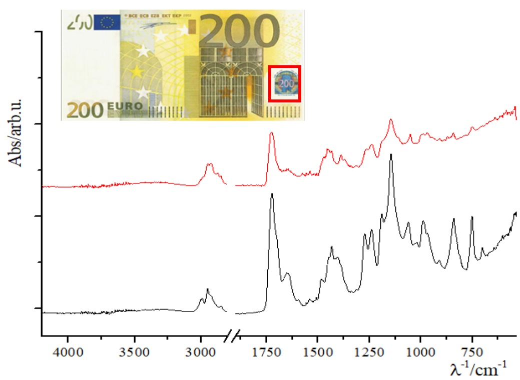


**Figure 6. FT-IR spectra of hologram of a counterfeit (red line), and genuine (black line) 200 euro banknote**

The hologram spectra of a 200 euro banknote includes characteristic peaks at 1725, 1645, 1434, 1271, 1242, 1186,1146, 1067, 991, 838, 757 $cm^{-1}$ which are characteristic to the plastic film that covers the hologram. Different shape of *C-H* stretch region around 2950 $cm^{-1}$ on it's own indicates differences in the type of the plastic film applied. Fingerprint region with enourmous differences in the shape and intensities of bands undoubtedly confirms materials used are different.

## 4. Conclusion

FT-IR spectroscopy allows fast and non-destructive identification of counterfeit banknotes by comparing similarities and differences in absorption spectrum and allowing them to be grouped according to the materials used in their production. The research showed that it is satisfactory to analyse just the two characteristic areas of 200 euro banknotes (paper substrate and hologram) to discriminate original and counterfeit banknotes. The production of portable miniature FT-IR Spectrometers goes in hand with the possible application of the method in everyday life. Namely, production of appropriate software that compared the database of the original banknotes with the possible counterfeits would allow the use for everyone, not just the members of the scientific community, which would position this method alongside other commercially available methods such as UV counterfeit detecting.

## 5. References

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