FABLABOV SPEKTROMETAR SA PRIPADAJUĆOM OPREMOM

FABLAB SPECTROMETER WITH ASSOCIATED EQUIPMENT

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Stručni rad

REZIME
Ovaj rad opisuje dizajn 3D štampanog spektrometra za vidljivo i blisko infracrveno područje elektromagnetnog spektra svjetla. Uređaj ima rezoluciju od oko 2 nm i čini samo jedan dio cjeline koja se još sastoji od odgovarajućeg izvora svjetla, posude za uzorke odnosno kivete i pratećih optičkih kablova. Spektar svjetlosti se prikazuje na računaru u aplikaciji koja je posebno razvijena kako bi se demonstrirao rad ovog instrumenta. Implementacija ovog instrumenta je jeftina, pa bi se spektrometar mogao koristiti kao odlično sredstvo za pokazne eksperimente u školama, ali i za realizaciju jednostavnijih projekata u kojima je potrebno na brz i jednostavan način dobiti informaciju o spektru svjetlosti.

Ključne riječi:
laser, optika, spektrometar, 3D štampanje

Professional paper

ABSTRACT
This paper describes the design of a 3D printed spectrometer for the visible and near-infrared region of the electromagnetic spectrum of light. The device has a resolution of about 2 nm and forms only one part of the whole, which still consists of a suitable light source, sample container or cuvette, and accompanying optical cables. The spectrum of light is displayed on a computer in an application developed specifically to demonstrate the work of this instrument. The spectrometer is low-budget, and it is adequate as a teaching aid in schools or for simpler projects, aimed at obtaining information about the spectrum of light in a fast and simple way.

Keywords:
laser, optics, spectrometer, 3D printing

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1. UVOD

Spektrometar je optički instrument koji razlaže upadajuću svjetlost na komponente odnosno boje, i registruje jačinu svake boje posebno. Ovaj, u suštini vrlo jednostavan instrument, je jako koristan u nizu disciplina, naročito u hemiji, biologiji i fizici. Svaka tvar ili rastvor ima specifičan i unikatan spektar apsorpcije svjetla, tako da se npr. apsorpcionom spektrometrijom može utvrditi prisustvo određenog jedinjenja u uzorku. Spektrometrom je moguće pratiti i dinamiku neke hemijske ili biološke reakcije, praćenjem izmjene spektra, bilo apsorpcionog ili emisionog. Od posebnog aplikativnog značaja je spektrometrija u infracrvenom i dubokom infracrvenom području, ali svjetlost, u kontekstu spektrometrije, je praktično svako elektromagnetno zračenje, od ultraljubičastog do dubokog infracrvenog. Spektrometar može da mjeri i karakteristike svjetlosnih izvora ili da analizira refleksiju svjetla o različite površine, i time pomogne u procesu karakterizacije materijala ili čak objekata koji su eventualno van dometa laboratorija.

1. INTRODUCTION

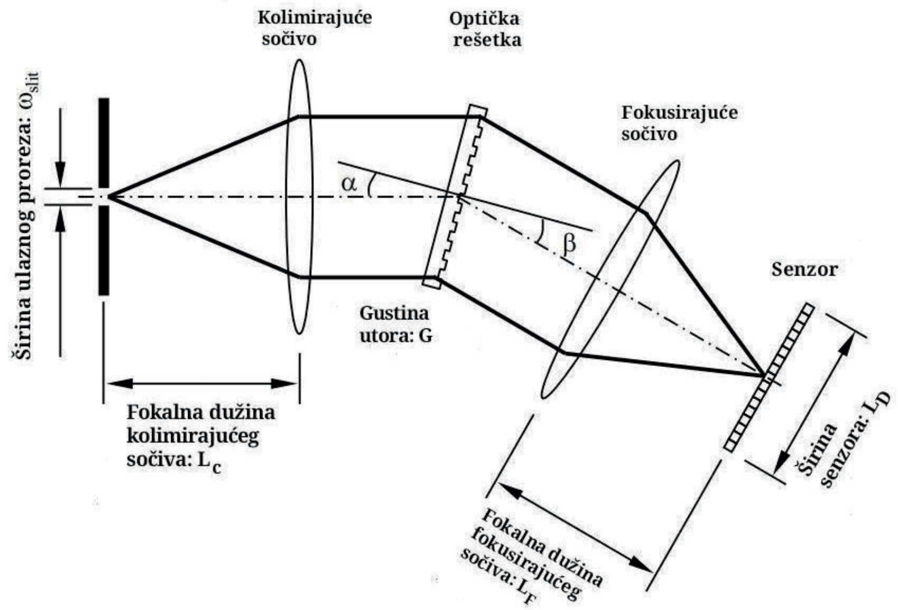
A spectrometer is an optical device that separates the source light into its components (colors) and registers the intensity of each color separately. This, essentially a very simple device, is useful in several science disciplines, especially in chemistry, biology, and physics. Each substance or solution has a specific, unique spectrum, by which absorption spectrometry is able to determine the presence of a particular compound in a given sample. In the same way it is possible to monitor the dynamics of a chemical or biological reaction by monitoring changes of the spectrum (absorption or emission). Particularly important is the application of spectrometry in the infra-red and deep infra-red range, but the light (in the context of spectrometry) is any electromagnetic radiation from ultraviolet to deep infra-red. In addition, with the spectrometer we can measure the characteristics of light sources or analyze the reflection of light on different surfaces, thus the spectrometer can help characterizing materials or even objects that are out of the laboratory's range.

2. NAČIN RADA SPEKTROMETRA

Fablab Sarajevo je razvio spektrometar koji radi u vidljivom i blisko infracrvenom području svjetlosti i pogodan je za nastavne i demonstrativne svrhe, ali može poslužiti i u određenim razvojnim projektima. Šematska skica rada spektrometra, baziranog na transmisionoj rešetki, data je na slici 1.

2. MAIN PART

Fablab Sarajevo has developed a spectrometer that works in the visible and near-infrared areas of the light, and it is suitable for teaching and demonstration purposes, as well as for certain development projects. The basic principle the device is based on is shown in Figure 1.



Slika 1. Šematski prikaz spektrometra
***Figure 1** Basic principle of the spectrometer*

Kao što se može primijetiti na slici, upadno svjetlo dolazi iz standardnog multimodnog optičkog vlakna promjera jezgra 50µm, kroz jedan od zidova kućišta spektrometra, što djeluje kao prorez. Svjetlo se kolimira sočivom fokalne dužine 75 mm, a rešetka sa 1000 rebara po milimetru razlaže svjetlo na komponente. Konačno, drugo sočivo prethodno razloženu svjetlost fokusira na CCD senzor.

Detektor primljeno zračenje pretvara u električni naboj koji se očituje kao napon i pojačava, tako da mikrokontroler registruje niz napona kao spektar i šalje ga aplikaciji na računaru putem serijske komunikacije.

Ideja iza dizajna i izrade prvog spektrometra u FabLabu BiH, demo centar Sarajevo, bila je da se dizajnira cijenom pristupačan spektrometar, ali sa performansama komercijalnog proizvoda, te da se može proizvesti u bilo kojem lokalnom FabLabu, kao i drugim sličnim mjestima, koristeći lako dostupne materijale. FabLab posjeduje uslove za aditivnu proizvodnju, što je

As Figure 1 shows, the source light comes from a standard, multimode optical fiber with a core diameter of 50µm, through housing, acting as a slot. The light is collimated by a lens with a focal length of 75 mm, and the grid, with 1000 ribs per mm, decomposes the light. Finally, the second lens focuses the previously decomposed light on the CCD sensor.

The detector converts the received radiation into an electric charge, which is manifested as a voltage, that is being amplified, while the microcontroller registers a series of voltages as commercial unit, spectrum and sends it to the computer via serial communication.

The idea behind the design and development of the first spectrometer at FabLab BiH (Sarajevo Demo Center) was to develop an affordable spectrometer, but with the performance of a which can be produced in any other FabLab, or similar place, by using easily accessible materials.

omogućilo dizajn i izradu ovog niskobudžetnog proizvoda. Kućište spektrometra je napravljeno od materijala za 3D štampanje, povezano je preko mikrokontrolera *Teensy USB* serijskom komunikacijom sa računarom koji ima instaliran softver za spektralnu analizu u realnom vremenu. Jednostavno povezivanje uređaja sa računarom čini ga korisnim za učenje i analiziranje u učionicama i laboratorijima.
FabLabov spektrometar je dizajniran za analizu u vidljivom i bliskom infracrvenom području svjetlosti odnosno za talasne dužine od 400 nm do 800 nm sa ciljanom rezolucijom od oko 1 nm.

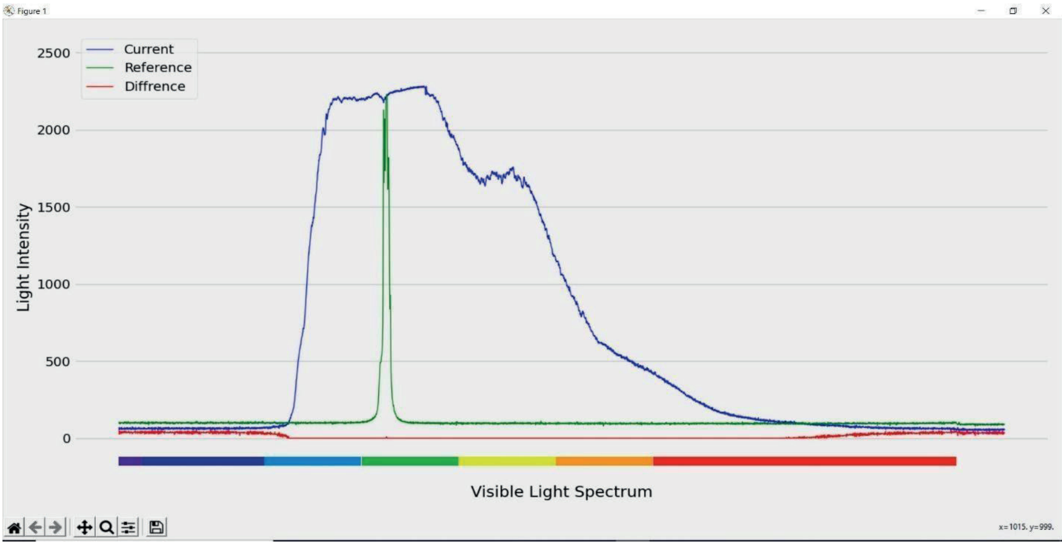
Optičke karakteristike proizvoda:

Minimalna talasna dužina: λ_1 = 400 nm
Maksimalna talasna dužina: λ_2 = 800 nm
Opseg talasne dužine: $\lambda_2 - \lambda_1$ = (800 nm - 400 nm) = 400 nm
Centralna talasna dužina: $\lambda_c=(\lambda_1+\lambda_2)/2$=600 nm
Gustina optičke rešetke: G=1000 g/m [1]

The spectrometer was made of material for 3D printing and connected via a Teensy USB microcontroller cable to a computer with a real-time spectrum analysis program, thus making it useful for education and practice in classrooms and laboratories.
The FabLab spectrometer was designed for analysis of the visible and near-infrared range of light, i.e., for 400 nm to 800 nm wavelengths with a targeted resolution of about 1 nm.

Optical characteristics of the product:

Minimum wavelength: λ_1 = 400 nm
Maximum wavelength: λ_2 = 800 nm
Wavelength range: $\lambda_2 - \lambda_1$ = (800 nm - 400 nm) = 400 nm
Central wavelength: $\lambda_c = (\lambda_1 + \lambda_2) / 2$ = 600 nm
Optical grating density: G = 1000 g / m [1]



Slika 2. Prikaz spektara lasera i bijelog svjetla Ce:YAG lampe u okruženju aplikacije
***Figure 2** Display of laser and white light spectrum Ce: YAG lamps in the application environment*

Upadni i difrakcioni uglovi α i β se računaju preko jednačina:

$$\alpha = sin^{-1}\left(\frac{\lambda_c G}{2cos\left(\frac{\Phi}{2}\right)}\right) - \frac{\Phi}{2} = 17{,}5° \quad ...(1)$$

$$\beta = \Phi - \alpha = 17{,}5° \quad ...(2)$$

Rezultirajuća rezolucija:

$$\Delta\lambda = \frac{w_{slit} \cos(\alpha)}{GL_c} = 0{,}64 \text{ nm} \quad ...(3)$$

The incident and diffraction angles α and β were calculated using the following equations:

$$\alpha = sin^{-1}\left(\frac{\lambda_c G}{2cos\left(\frac{\Phi}{2}\right)}\right) - \frac{\Phi}{2} = 17{,}5° \quad ...(1)$$

$$\beta = \Phi - \alpha = 17{,}5° \quad ...(2)$$

Resulting resolution:

$$\Delta\lambda = \frac{w_{slit} \cos(\alpha)}{GL_c} = 0{,}64 \text{ nm} \quad ...(3)$$

Realna rezolucija instrumenta je oko 2 nm, dok je izračunata rezolucija oko 0.64 nm. Spektri Ce:YAG lampe (širokopojasni) i zelenog lasera (uski spektar) prikazani su na slici 2. Program za obradu podataka je u stalnom razvoju, pa je u planu da uključi napredne analize, kao što su metode za eliminaciju buke, automatsko prepoznavanje maksimuma ili minimuma itd.
Na slikama 3.1., 3.2., kao i 4.1. i 4.2., prikazani su svi prateći detalji dizajna i komponenti spektrometra, gdje se kroz *render* prikaz vidi način sastavljanja svih postojećih elemenata. Izuzev sočiva i elektroničkih komponenti vezanih za senzor detekcije svjetla, svi ostali elementi napravljeni su metodom 3D štampanja. Konačan proizvod je prikazan na slikama 4.1 i 4.2.

The real resolution of the instrument is ca. 2 nm, while the calculated resolution is ca. 0.64 nm. The spectra of Ce: YAG laser (broadband) and green laser (narrow spectrum) are shown in Figure 2. The program for real-time data processing is constantly evolving, and it is planned to include advanced analysis methods like noise elimination and automatic detection of maximum/minimum values, etc.
In Figures 3.1, 3.2, 4.1 and 4.2 all the relevant details of the design and components of the spectrometer are shown, where the rendering shows the fit of all parts in the image. Except for the lenses and the electronic components, all spectrometer parts were 3D printed, which can be seen in Figures 4.1 and 4.2.

Slika 3.1. *Render* prikaz spektrometra
Figure 3.1 *Render view of spectrometer*

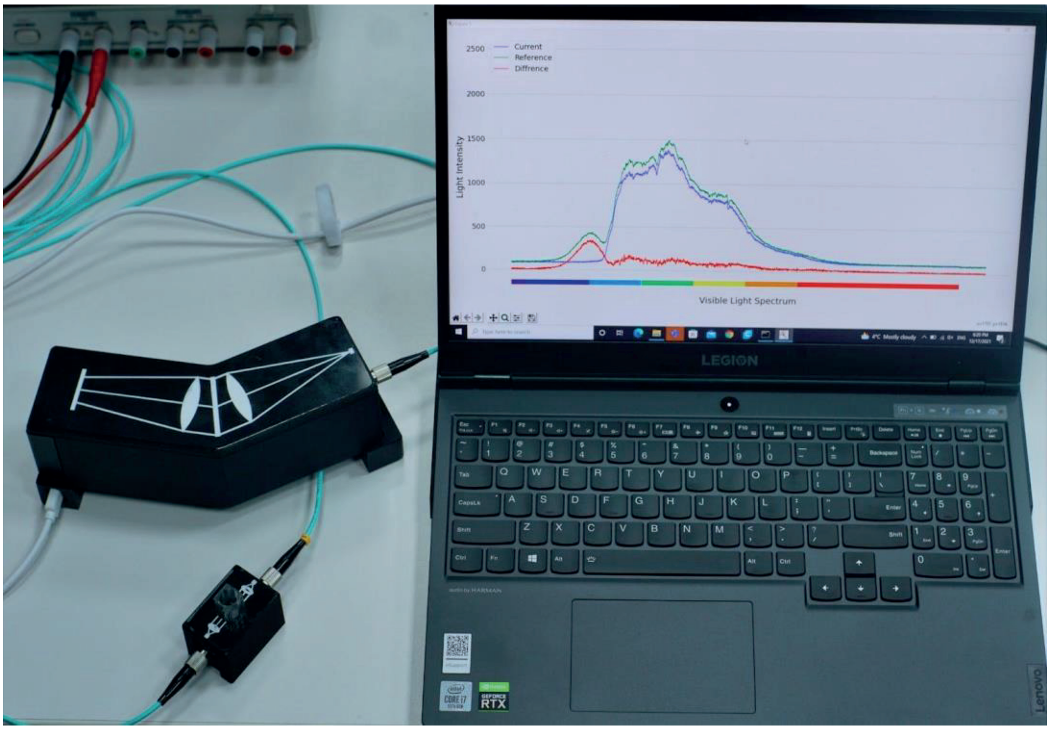
Slika 3.2. *Render* svih komponenti u sklopu
Figure 3.2 *Render of all components in the assembly*

Spektrometar kao nezavisan uređaj nije upotrebljiv bez adekvatne dodatne opreme. FabLab Sarajevo je razvio i konstantan izvor svjetlosti, kao i drzač kivete u kojem bi se nalazio analizirani uzorak. Kompletan sistem je i dalje jeftin za implementaciju, a uključuje i tutorijal za izvođenje i analizu osnovnih eksperimenata, kao i dodatnu opremu poput optičkih i elektroničkih kablova. Cijeli dizajn je *open-source*, a sam uređaj je u fazi daljeg unapređivanja.

Without adequate equipment, the spectrometer is not usable for a more serious experiment. In addition to the spectrometer development, FabLab Sarajevo has developed an intensive light source as well as a cuvette holder where the sample is being analyzed. The set of this equipment is still very cheap, and includes a tutorial for basic experiments with explanations, and has all the necessary cables (optical and electrical). The design is open-source and ready for upgrade.

Slika 4.1 *3D printani sklop spektrometra*
Figure 4.1 *3D printed spectrometer assembly*

Slika 4.2 *Unutrašnjost spektrometra*
Figure 4.2 *Inside of the spectrometer*



Slika 5. Spektrometar povezan sa kompjuterom, nosač kivete sa kolimatorima i fiberima
Figure 5 *Spectrometer connected to a computer, cuvette holder with collimators and fibers*

3. ZAKLJUČAK

U ovom radu razvijen je i testiran spektrometar za vidljivo područje sa pripadajućom opremom i zabilježeni su spektri raznih svjetlosnih izvora, kao i apsorpcioni spektri nekih uzoraka.

Ponovljivost rezultata je zadovoljavajuća, ali je potrebna rekalibracija prilikom svakog novog mjerenja. Teoretska rezolucija je oko 0,64 nm, ali je u praksi rezolucija oko 2 nm, što pripisujemo nepravilnostima u izvedbi i korištenju kućista i sočiva, tačnije tolerancijama u 3D štampanju i hromatskim i sferičnim aberacijama sočiva.

3. CONCLUSION

The developed spectrometer for the visible area, with the associated equipment, was being tested successfully, with the spectra of various light sources as well as the absorption spectra of samples being recorded. The reproducibility of the results is satisfactory, but recalibration is required with each measurement. The theoretical resolution is ca. 0.64 nm, with the real resolution being higher, ca. 2 nm, which we attribute to the imperfections in the performance, i.e., 3D printing tolerances, chromatic and spherical aberrations of the lens.

Ovo znači da se i multimodni fiberi sa dosta većom jezgrom, npr. 100 µm, mogu koristiti i povećati osjetljivost odnosno manje intenzivni izvori svjetlosti mogu da se koriste. CeYAG izvor, koji je ovdje korišten, ima relativno uzak spektar za spektroskopiju (od oko 100 nm), ali pokazao se kao dobar u mnogim aplikacijama gdje je potrebno vršiti demonstraciju sa vidljivom svjetlošću.

This implies that multimode fibers with a much larger core, e.g., 100 µm, can be used to increase sensitivity, meaning that less intense light sources can be used as well. The Ce:YAG source, which was used, has a relatively narrow spectrum for spectroscopy (ca. 100 nm), but has proven to be satisfactory in many applications where demonstration with visible light is required.

4. REFERENCE

[1] "Ibsen photonics. Spectrometer design guide" https://ibsen.com/resources/spectrometer-resources/spectrometer-design-guide/ ,

[2] Neumann, Wilfried. (2014). Fundamentals of Dispersive Optical Spectroscopy Systems. SPIE.

[3] Nikolai V. Tkachenko. (2006). Optical Spectroscopy Methods and Instrumentations.

[4] J. F. James, R. S. Sternberg. (1969). The design of optical spectrometers.

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