PENCIL DRAWN SENSOR FOR APPLICATION IN SMART BOXES FOR INDUSTRY 4.0

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Abstract: *In this article, we present an idea for enhancing functionality of ordinary cardboard boxes for Industry 4.0. The simple sheet of paper and pencil were used for making an environmentally friendly sensor. By using simple technology and adhesive tape a system for opening detection was made. Emphasis was put on using off-the-shelf items; thus, everyone can replicate such sensor.*

KEYWORDS: GRAPHITE SENSOR, LAB-ON-PAPER, PAPER TECHNOLOGY, CARBOARD BOX, INDUSTRY 4.0

1. Introduction

Nowadays, the logistics or grocery market demands much more automatization and security then before. Some exporting companies must defend themselves against counterfeits or even stealing while transporting their cargo. By implementing Industry 4.0 ideas, mentioned problems can be decreased to minimum, e.g. putting GPS localization module into courier vehicle. Even final client in grocery shop can be warned before buying i.e. expensive liquor[1]. Such bottle is enhanced with NFC chip and metal cord working as seal.

Researchers was always trying to find a better way for measuring physical values like gas concentration[2], content of the medical fluids [3] and many others [4]–[12]. The last trend is modifying such equipment for structures made on paper. Such objects are made for being one-time-use. Due to using only ecological structures like cellulose, they can be easily disposed in a fire [13].

Another problem to solve in logistic market is a restorable warranty or novelty seal. It is not a trouble for a thief to open a transported box, reseal it with tape and replace warranty stickers.

The purpose of the work is to manufacture paper seal with specified (known) resistance between its contact. If the resistance is different than expected, then it means that the item was opened or damaged earlier (Fig.1).

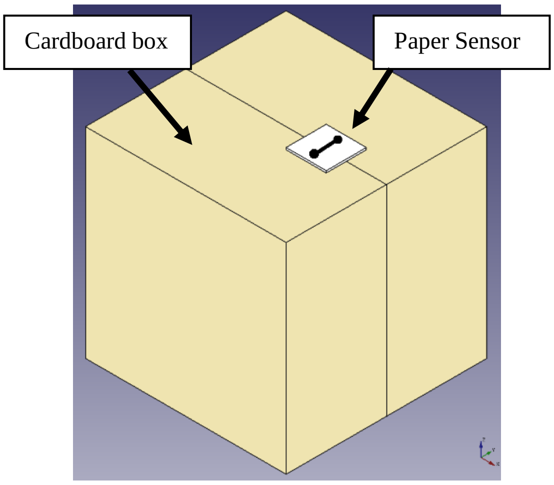

Fig. 1 *Visualization of the cardboard box with integrated pencil drawn sensor.*

Such sensor can be easily integrated with NFC/RFID system (resistance strip connected to ADC from NFC/RFID communication chip). Later mentioned system can be connected to the compute cloud for providing even more information for the manufacturer [14].

2. Manufacturing process

Authors have used a CO2 laser (type SL5030, SERON) and a Whatman filtration paper (for more fragile sensor). First move was cutting of paper into single structure (Fig.2). Project for CO2 laser was made in laserGRAV software, it is freeware program with CAD functions. Presented design in Fig.2 was made with perforation holes, for even more fragile structure. Such perforation is not mandatory step.

It was decided to set laser plotter values:

- output power: 12 W,
- scanning speed: 100 mm/s,
- work mode: cut.

Parameters depends on used paper substrate, for thicker paper output power should be larger.

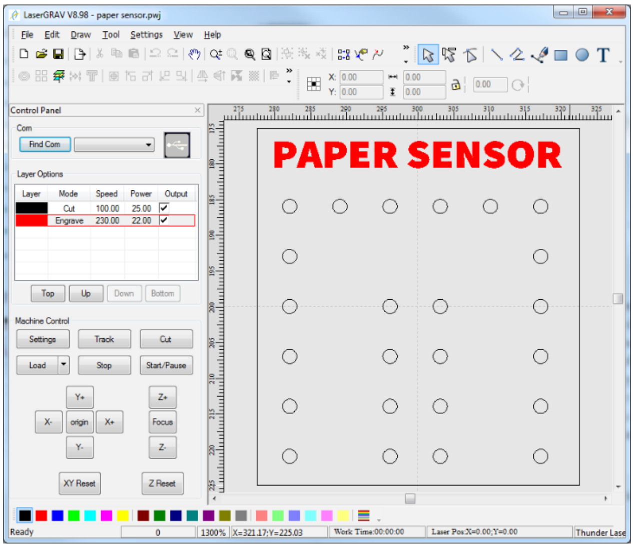

Fig. 2 *Screenshot taken from the laserGRAV with sensor's design.*

The next step was drawing conductive line with pencil. Ordinary 2B pencil was used for this research. To obtain line with lowest resistance, it has to be drawn multiple times with high pressure. The results of drawing with different pressure is presented in Fig.3. With line drawn on the paper surface (Fig.4), paper sensor is ready for further research and integration with boxes.

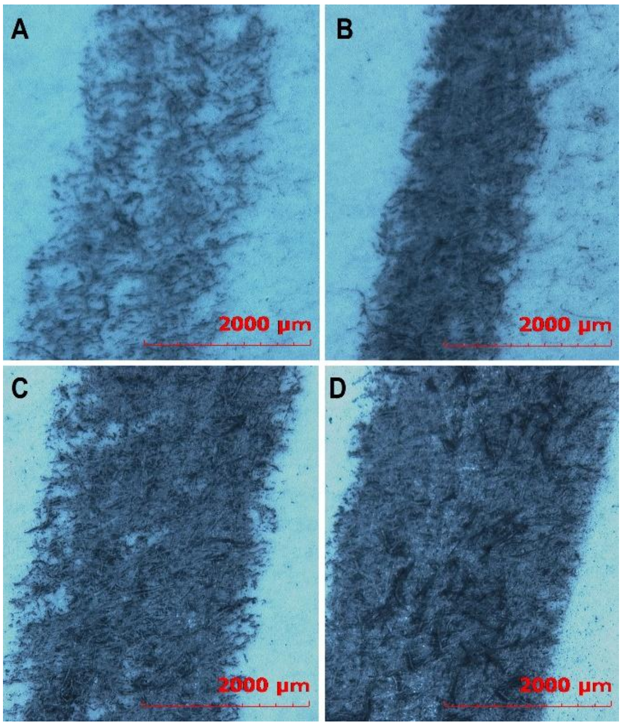

***Fig. 3** Photos of the drawn line with pencil. From lightly (A) through semi-heavily (B and C) to heavily drawn (D).*

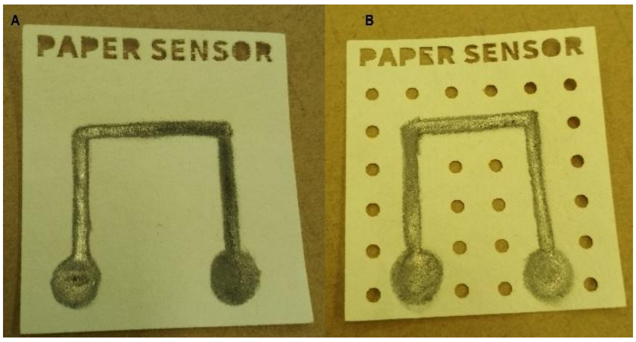

***Fig. 4** Photos of the paper sensor -without (A) and with perforation (B).*

3. Testing

The last part of the presented research is testing the paper sensor. Authors decided to check the precision of the CO2 laser. Mentioned in Chapter 2 settings was used once again. The strips with various width were cut with laser (Fig.5) and later were measured with Digital Microscope HIROX KH-7700. Results are presented in the Table 1.

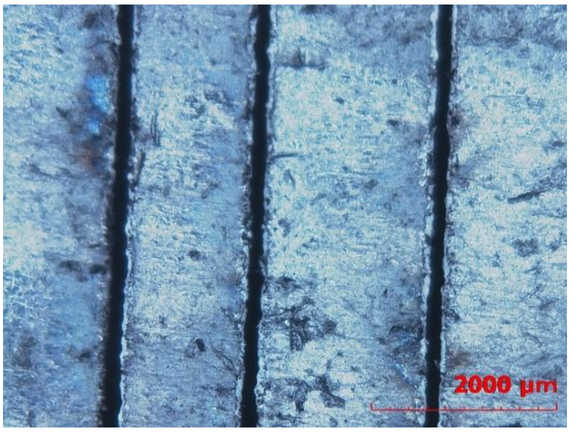

***Fig. 5** Photos of the laser cut strips for measuring experiment.*

***Table 1:** Measurement of the line width (cut with CO2 laser):*

	Designed width [µm]	Obtained width [µm]	Change [%]	Δ width [µm]
1	1500	1315	87,63	186
2	2000	1805	90,23	196
3	2500	2316	92,62	185
4	3000	2842	94,73	158
5	3500	3313	94,66	187

It was noticed that every shaped manufactured with laser was reduced by ca. 190 µm (or 85 µm from single edge). That proves every design needs to be corrected with this value. Such value comes from the finite size of the laser dot.

The next step was measuring pencil drawn strip resistance vs designed width. The very same design was used as previously. Before irradiating it with laser, the authors covered its surface with pencil drawing. The length of every mentioned strip is ca. 15mm, later resistance was measured by connecting probes at each end. Results are presented in the Table 2.

***Table 2:** Designed width of the line vs measured resistance (line length = 15mm):*

	Designed width [µm]	Measured resistance [kΩ]
1	1500	45,6
2	2000	31,5
3	2500	27,2
4	3000	19,3
5	3500	12,4

The last step of testing part was measuring resistance of the line from the paper sensor (presented in Fig. 4). The whole U-shaped drawing has the resistance equal to 120kΩ.

4. Integration with boxes

There are few ways of implementing paper sensor into cardboard boxes. First one is simply using tape while securing box (Fig.6). The tape must be previously prepared, with laser cut holes for measuring electrical parameters of the pencil drawn line. It can also be made in the sticker form (Fig.7).

Another approach is just simply using glue to attach the paper sensor to the surface. Mentioned in Chapter 2 paper sensor with perforation can be used. Perforation was made for making sensor even more fragile; thus, it would be torn with every attempt of removing it.

***Fig. 6** Photos of the implemented paper sensor with tape.*

Fig. 7 *Photos of the implemented paper sensor (perforated) with glue - closed and opened box.*

5. Conclusion

In this paper, a method of manufacturing a simple paper sensor was presented. Even with simple items, the whole sensor can be made. Such sensor provides important information about the packaging (i.e. if it is damaged or opened before the final client). Also, it can be easily connected to NFC chip and provides even more information for carrier or final client.

The main advantage of the presented sensor is the feature that it cannot be restored if the box was opened once. The the sensor resistance is only known for manufacturer. Thus, third party person would have a lot of difficulties to recreate such paper with the same resistance.

To avoid problem with widely known resistance of the pencil drawn strip, designer can change its resistance via its width (Table 2).

Also, this paper proves that using laser for such application is precise enough. CO2 laser did not burned paper covered with graphite.

This system is a great advantage over the standard seals, due to ecological materials like paper and graphite pencil.

6. References

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