THE USE OF DIFFERENT DEVICES FOR PRINT DIGITIZATION IN PRINT QUALITY ANALYSIS OF PRINT MOTTLE

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Abstract: *The goal of this paper was to find the best solution for digitization of print samples for Print Quality Analysis. A crucial step in this method for print quality control is a sampling of the area to be analyzed. The print could be acquired with various input devices, such as camera, microscope or scanner. In this study, we used the camera, two mobile devices, and two scanners. Samples used in the experiment were printed on digital printing machines, based on electrophotography. We also used various papers to obtain the largest possible number of different samples. Results showed that there is a huge difference depending on the device being used to digitize.*

Keywords: *print sampling, print quality, scanner-based systems, camera-based systems*

INTRODUCTION

There are developed various methods for print quality control, starting from densitometry until spectrophotometry. Recently, one new method has been also introduced for evaluating the print quality of lines, text, print uniformity, registration, etc. It is still underdeveloped but is certainly used for print quality control. The new method is called Image Quality Analysis by some authors [1] and it is based on an analysis of the acquired images (i.e., printed samples). We adjusted the name and called it the Print Quality Analysis (PQA) because it closely describes the quality control of the printed samples. Schematic representation of the method is presented in Figure 1. From the original to the numerical values, we need to go through few steps. The method can be incorporated in one device (such as *QEA Personal IAS or vipFLEX*), or the steps could be performed independently.

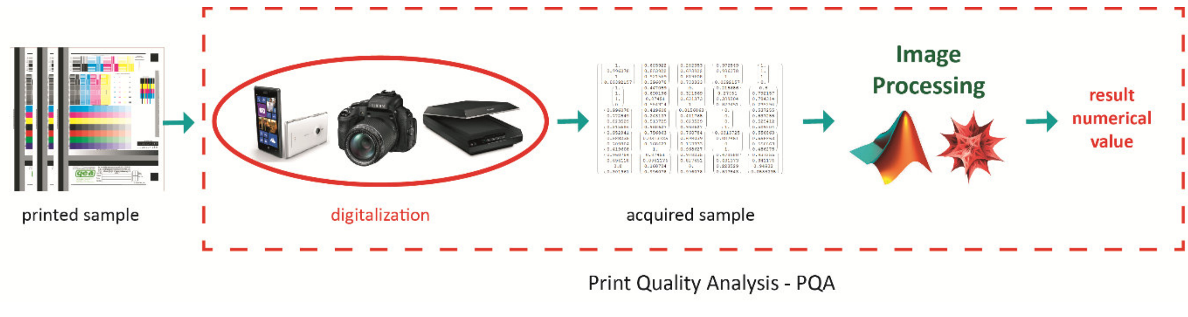

Figure 1: Schematic representation of Print Quality Analysis

The first international standard that defines procedures and methodology for quantifying basic print quality attributes is ISO 13660:2001 [2,3]. The standard is device independent; we can analyse digital, flexo, offset or any other prints [4]. According to the standard, the image to be analysed needs to be digitized using any input device as long as it is capable of sampling the image at a minimum resolution of 600 ppi [2]. Responding to the needs of the new standard, instrumentation manufacturers developed a class of devices called image analysers [1]. In such device, the print is acquired with camera and analysed (processed) to quantify attributes such as dot gain, line, and text quality, or print uniformity such as graininess and mottle. Beside image analyser, that way of control could be accomplished by using several devices, which together form a system for quality control, called Image Analysis System [1]. We also adjust this name as Print Analysis System (PAS). PAS includes a light source and some kind of the photodetector in a defined geometric arrangement. In this case, photodetector could be CCD or CMOS sensor. Hence, PAS could be developed in two main styles: the camera-based or flatbed scanner-based system [1]. Each system has its advantages and disadvantages.

The advantages of the scanner-based system are low cost, and it can easily acquire the entire page area, which can facilitate many print quality analyses [1]. The scanner also has built-in illumination and we have the ability to define an area of interest during scanning, which reduces the time of later image processing. On the other hand, this system is time-consuming at high resolutions and it is a contact method, which leads to the unnaturalness of the scanned sample.

The camera-based system offers higher resolution and very accurate position measurement [1]. This type of system can be installed directly on the printing machine and provide inline control during printing. It also allows us to upgrade the system by adding other devices such as densitometers and colourimeters. The other strength of this system is the light source, which is away from the sample, so we get a more natural digital sample, as opposed to scanning. The light source is not embedded; therefore, this system is more expensive than the scanner-based one. In addition, the camera-based system typically captures only a small section of the printed page at a time, so we need some vacuum table for placing the sample. Using PQA, we can evaluate print quality according to a large number of attributes. One of the most frequently used attribute is print (non)uniformity [3,5–7]. In the reviewed literature [7–12], there are several different definitions of print (non)uniformity. General physical definition would be that the print nonuniformity is an unwanted variation of optical density (reflected light) from the print. Different types of print nonuniformity are presented in Figure 2. Two main groups are random and systematic nonuniformity.

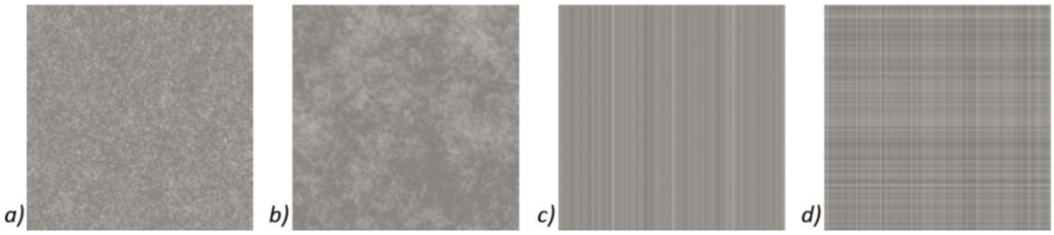

Figure 2: Different types of print nonuniformity: a) small-scale (graininess), b) large-scale (print mottle) random nonuniformity, c) stripes and d) wire mark texture – as systematic nonuniformity [8]

In this paper, we only analyzed one type od print nonuniformity – print mottle. Print mottle could be quantified using different methods: NU index [13], GLCM method [14,15], standard ISO 13660, method by [8], etc. Common to all methods is that they are based on the PQA method. All methods use digitized sample for obtaining the numerical value of a print quality attribute which is evaluated. The only difference between them is in the processing of digitized sample, some of them use gray level of pixels, some Fast Fourier Transform, etc.

In this paper, we used the method proposed by ISO standard 13660:2001. According to the standard, print mottle is ’’aperiodic fluctuations of density at a spatial frequency less than 0,4 cycles per millimeter in all directions’’ [2,p.11]. The patch for analyzing print mottle is divided into 100 equal tiles (as shown in Figure 3). Optical density is measured across each tile i several times and m_i is the average of density measurement. The measure of print mottle across the entire patch is the standard deviation of all m_i [11]:

$$ISO\_M = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(m_i - (\frac{1}{n}\sum_{i=1}^{n} m_i))^2} \quad (1)$$

where m_i is the average density measurement of tile i, n is the total number of tiles.

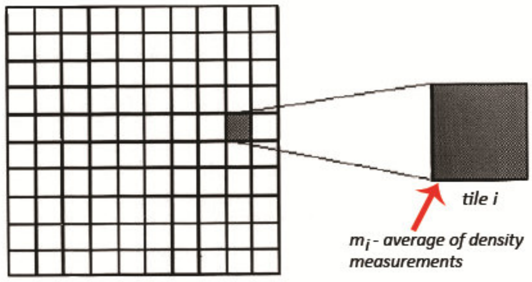

Figure 3: ROI divided into 100 equal parts (tiles), inside which is calculated optical density

The standard ISO 13660:2001 defines the procedures and methodology of various print quality attributes measurement, but has its drawbacks. One major drawback of this standard is the lack of reference values. There are no defined acceptance criteria; the user defines it. Once print quality measurements have been made, it is up to those involved to determine if the print quality is acceptable. In this study, we analyzed the effect of using different devices for digitizing prints on the final value of print quality, measuring only one parameter – print mottle. As it is shown in Figure 1, we can use the camera, scanner or any other device that has sufficiently high-quality image sensor, such as mobile device.

MATERIALS AND METHODS

This experiment included analysis of different devices for digitizing print samples. To obtain the largest possible number of different samples, we used various papers, coated and uncoated and two different digital printing machines. Test image used for the experiment contained patch (130 x 130 mm) with C: 65, M: 50, Y: 50 and K: 50%. FOGRA proposes that proportions of CMYK for evaluation of print mottle [16]. The test image was printed using two electrophotographic printing machines: Xerox 1000 based on dry toner and HP Indigo Press 1000 based on liquid toner.

Papers used in the experiment were characterized by optical properties (brightness, opacity, and tint) and geometrical characteristic of a surface (surface roughness R_a). For evaluation of the paper optical properties, we used software BabelColour CT&A (Whiteness Tool) and Eye-One (i1) spectrophotometer. The measurement setup was 45º/0º, standard illuminant D50 and standard observer 2º. Brightness is measured according to TAPPI T452/ASTM D985 and opacity is measured according to CGATS.5 / ISO 2471 [17]. During these measurements, we used appropriate white (required to measure brightness and opacity) and black backing (required to measure opacity). Surface roughness was measured with portable surface roughness tester TR200. The cut-off was set up according to the range of measured value. Other settings were: filter Gauss, measuring range +/- 20 µm, resolution 0.01 µm and head movement speed V_t = 0.5 mm/s. In Table 1 are presented papers used in the experiment. Papers are commercially available [18].

Table 1: Paper properties –brightness, opacity, tint and surface roughness

Samples	Paper name	Grammage [g/m^2]	Brightness	Opacity [%]	Tint	Surface roughness - Ra [µm]	Cut-off for Ra
1	**Gardapat/Kiara**	150	87,4	97,6	- 1,5	1,466	(0,8mm)
2	**Neobond**	200	84,8	91,6	- 0,16	4,913	(2,5mm)
3	**Options White**	220	97,5	99,5	- 0,51	2,962	(2,5mm)

4	**Revive 100 White Silk**	140	89,1	96,8	- 0,91	0,540	(0,8mm)
5	**Phoenixmotion Xantur**	115	88,1	95,5	- 0,22	0,802	(0,8mm)
6	**Phoenixmotion Xenox**	170	94,4	98,1	0,87	0,976	(0,8mm)

According to the results can be concluded that sample 6 is the brightest and sample 3 has the largest opacity. Most of the samples are neutral, except sample 1. Tint for that sample is quite moved from neutral (value of -1.5 indicate a reddish tint). Surface roughness is opposite to brightness. Sample with the smallest brightness has the largest roughness and vice versa. The influence of paper properties on print mottle was analyzed and presented in the previous work of the authors [19], so it isn't commented here because it isn't the main purpose of the experiment.

After printing, samples were digitized with one digital camera, two mobile phones, and two scanners. Input devices are presented in Table 2. There are their names and the most important technical parameters and adjustments. Depending on the sampling resolution, we obtained different sizes (in pixels) of the digital patch for the print mottle analysis, as it is emphasized in Table 2.

Table 2. Technical parameters and adjustments for used input devices

Device / Specification	**Canon EOS 550D**	**Nokia Lumia 925**	**Samsung S4 mini GT-I9195**	**Canon CanoScan 5600F**	**Epson V370 Perfection**
Type	**Digital camera**	**Mobile phone**	**Mobile phone**	**Flatbed scanner**	**Flatbed scanner**
Sensor	CMOS	BSI	CMOS	CCD	CCD
Resolution	72 ppi	72 ppi	72 ppi	1200 spi	1200 spi
Colour space	RGB	RGB	RGB	RGB	RGB
Image Format	JPEG	JPEG	JPEG	JPEG	JPEG
Patch dimensions for print mottle quantification	**2300 x 2300 px**	**1550 x 1550 px**	**1500 x 1550 px**	**3000 x 3000 px**	**3000 x 3000 px**
Other	No flash, auto white balance, F 4.0, focal length 24mm, 1/125, L image size	No flash, auto white balance, F 2.0, focal length 26mm	No flash, auto white balance, F 2.6	Light source: white LED	Light source: LED

Camera or mobile-based systems include a properly configured light source, optics, and an image sensor. Camera and mobile devices were placed at 21 cm from the samples, as shown in *Figure 4*. The devices were placed at that distance because in this case the entire printed patch was acquired at once. The lamps were mounted on both sides from the camera/mobile to achieve uniform illumination. We used Phillips fluorescent bulbs with 6500 K temperature (that corresponds to illuminant D65). In order to avoid the appearance of vignettes on the digitized samples for the analysis, we used only the central portion of the sample, cropped to the dimensions shown in *Table 2*.

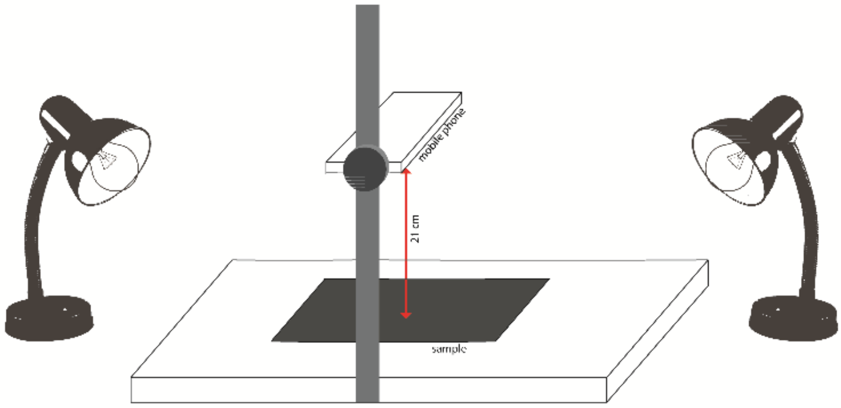

Figure 4: The camera/mobile-based system

In Introduction, we mentioned different methods for print mottle quantification and described procedure and methodology of ISO 13660 method, which was used in the experiment. For faster calculation, we made MATLAB add-in for quantifying print mottle based on the methodology described in the standard. The add-in contained following steps:

1. import of acquired patch (RGB image),
2. conversation into gray image using built-in Matlab function rgb2gray (*gray = 0.2989*R + 0.5870*G+0.1140*B*),
3. cropping the patch at 100 same tiles,
4. calculation of optical density into one tile (*optical density is calculated by the value of the gray level of each pixel) and*
5. calculation of print mottle according to standard ISO 13660.

RESULTS AND DISCUSSION

The results of print mottle when using different devices for print digitization are presented in *Table 3*. Based on the results it can be concluded that the utilization of the various devices for digitizing prints in the method of image analysis lead to different results. For the samples that were scanned with flatbed scanner 1 (CanoScan 5600F), we have obtained the highest values for print mottle. Much lower values were obtained when using the second scanner (Epson). All scanners have the same sensor (CCD), which means that other components of the capturing device (e.g. fluorescence lamps) could have also impact on the calculation of print mottle.

Table 3: Results of print mottle when using various input devices

Samples		Digital Camera	Mobile phone 1	Mobile phone 2	Flatbed Scanner 1	Flatbed Scanner 2
1	Gardapat - HP	20,8322	25,8076	30,6150	33,9248	24,3144
2	Neobond - HP	20,7623	25,8818	32,6713	36,0019	26,1865
3	Options White - HP	23,7341	25,4596	32,9147	37,2243	28,3820
4	Revive - HP	20,2122	24,9930	30,0338	32,6799	23,5789
5	Xantur - HP	22,1728	24,9190	30,2215	35,5388	25,6216
6	Xenox - HP	21,8880	25,4081	32,1302	35,2137	25,2374
7	Gardapat - Xerox	14,5762	23,5486	26,0533	26,7585	17,1841
8	Neobond - Xerox	16,2235	23,8174	29,3077	30,1154	20,3383
9	Options White - Xerox	16,9534	24,0788	28,0235	30,4541	20,5863
10	Revive - Xerox	16,0897	24,3488	28,1975	30,0127	19,4272
11	Xantur - Xerox	14,6349	23,2891	21,9535	27,0645	16,7282
12	Xenox - Xerox	16,0614	24,7201	27,0984	29,5280	19,2973

In Figure 5 is presented one sample (Xantur – HP) captured with different devices. The difference in captured image brightness is clearly visible. The sample is the brightest when it is digitized with the mobile phone 2 and flatbed scanner 1, which led to the highest values for the print mottle. The difference in the use of various cameras, digital or mobile device is also present, although the sample was illuminated with the same lamps. In this case, the different values of print mottle are influenced by the sensor devices.

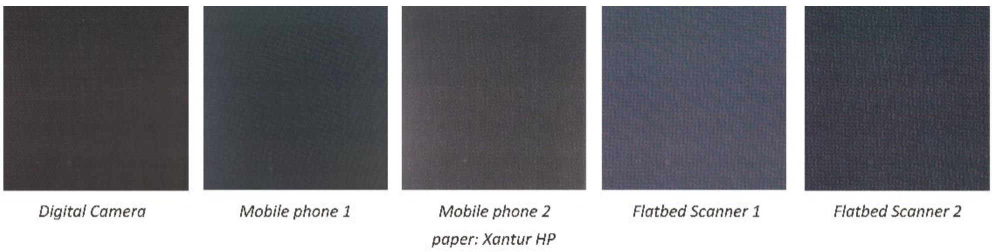

Figure 5: One sample (Xantur paper printed with HP printing machine) digitized with various devices

The relationship of the measured values of print mottle when using different input devices can be seen in Figures 6 and 7. In Figure 6 are presented values obtained for samples printed with HP printing machine. In Figure 7 are results obtained for samples printed with Xerox printing machine.

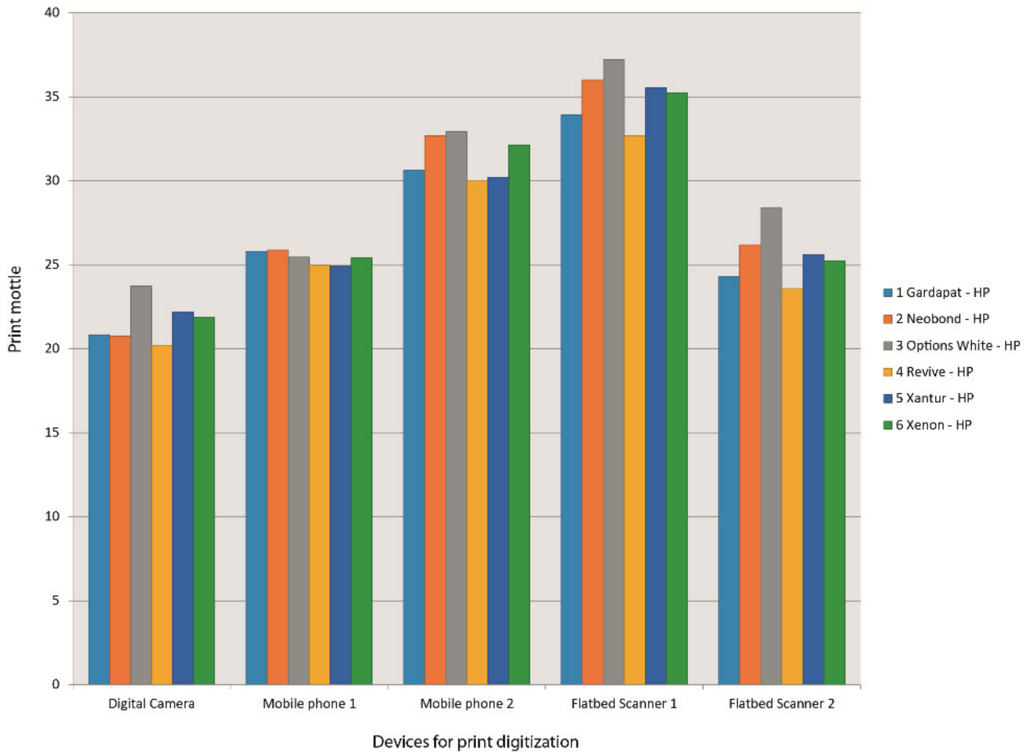

Figure 6: Print mottle for samples printed with HP printing machine and digitized with different input devices

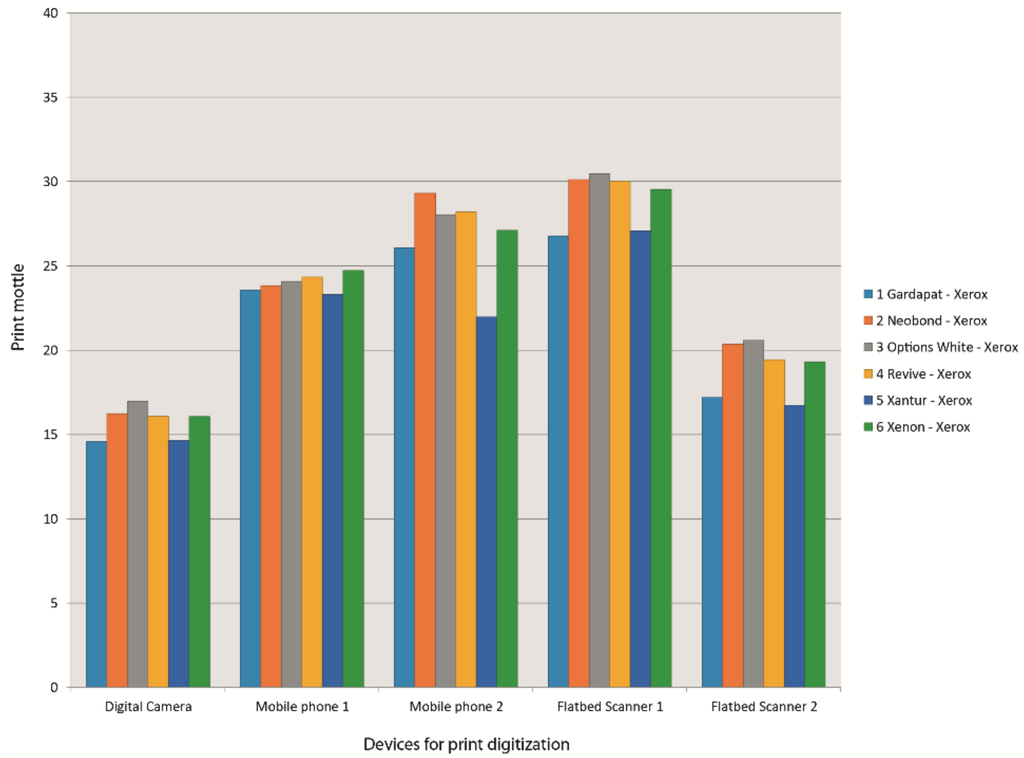

Figure 7: Print mottle for samples printed with Xerox printing machine and digitized with different input devices

As an additional conclusion of this research can be established that regardless of the used input device, we can see that the greater print mottle was obtained on samples printed with HP printing machine which uses liquid toners unlike the Xerox machine, which is based on dry toner. This was also the conclusion of the study [13].

According to the coefficient of variation (CV) presented in Table 4, we can conclude that any device could be used for digitization if we want to evaluate the quality of the print mottle between several prints. Variability is relatively low; it is between 17-23 % [17]. For example, if we want to check which sample will have the highest or smallest print mottle when using the same paper and different printing machines, we can choose any device for digitizing.

Table 4: Print mottle mean values for five different capturing devices, and the corresponding standard deviations and coefficient of variations

Samples		Average	St.dev.	CV [%]
1	Gardapat - HP	27,10	4,64	17
2	Neobond - HP	28,30	5,40	19
3	Options White - HP	29,54	4,94	17
4	Revive - HP	26,30	4,49	17
5	Xantur - HP	27,69	4,70	17
6	Xenox - HP	27,98	4,92	18
7	Gardapat - Xerox	21,62	4,88	23
8	Neobond - Xerox	23,96	5,28	22
9	Options White - Xerox	24,02	4,88	20
10	Revive - Xerox	23,62	5,23	22
11	Xantur - Xerox	20,73	4,50	22
12	Xenox - Xerox	23,34	4,97	21

But, if we would like to compare results of one sample with the reference values, then the device for digitizing has a tremendous impact. For example, print nonuniformity values for sample Gardapat - HP are 20.8322, 25.8076, 30.615, 33.9248 and 24.3144 when using different devices for digitization. The results are drastically different. Currently, the reference values are not defined, so that neither the results can't be compared to some standard.

CONCLUSIONS

A fundamental step in measuring print quality according to the PQA method is acquiring a digital image of the area (print) to be analyzed. We can use any input device such as camera, mobile phone or scanner, as long as they have minimal sampling resolution of 600 ppi. Comparing the results obtained for print mottle in this research, we can clearly see that there is a difference between results obtained when using different input device. Each device has its advantages and disadvantages, and since there are no reference values for print mottle, we can't now give the final conclusion which device is the best. Our goal of the further research is to define the optimal choice of an input device according to its structure, price and the need for the additional elements and also to define the reference values for print mottle when such device is used.

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