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MASTER THESIS

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Abstract

Printing plate is carrier of an image which will be print out and multiply in the reproduction process. It consists of surfaces which will, by using a printing ink, transfer the digitally made image onto the printing substrate. Quality of the image and final imprint depend on a number of parameters which have to be monitored and adjusted during the printing plate making and reproduction processes.

Quality control of printing plate can be conducted by observing the printing areas, made of photosensitive layer; or by observing the non-printing areas, made of aluminium-oxide. Quality of the image on the printing plate surface is usually controlled by using different devices for measuring the quality level of plates. These devices work on the principle of determining several parameters for monitoring the quality of printing plates, where, the most significant is, the surface coverage of the printing elements.

Beside those devices, market today offers a range of alternative methods which allow the determination and characterization of tones by using a software support for image analysis. Those methods are using the microscopic images of the surface and can define the surface coverage of printing elements and other necessary information about the quality of the printing plate.

The aim of this work is the defining of printing plate quality level through introduction of different image analysis applications. The results of this research may indicate that it is also possible to use alternative applications for monitoring the quality of the printing plates. Furthermore, this paper would provide a general overview of quality control possibilities for printing plates and could be useful to the systems where such controls are regularly conducted.

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1. Introduction

1.1. Offset Printing

Offset printing is today the most common used printing technique. The principle of offset printing is based on the physico-chemical differences between printing and non-printing areas (Figure 1). Printing plate is made of aluminium foil and ensures the transfer of the printing ink onto the printing substrate. On the printing plate for the offset printing, printing and non-printing areas are in the same plane. Between printing and non-printing areas there is a difference in height of 2-3 micrometers but it is negligible compared to the other printing techniques [1-2]. Printing areas are made of non-polar organic material (photosensitive layer) and have hydrophobic properties [3]. On the other side, non-printing areas are hydrophilic and made of polar material (aluminium oxide) [4]. Apart from hydrophobic properties, printing areas have oleophilic characteristics, which mean that oil-based printing ink will be adhered on them during the reproduction process. Furthermore, non-printing areas which are hydrophilic, when accepting the fountain solution, become completely oleophobic.
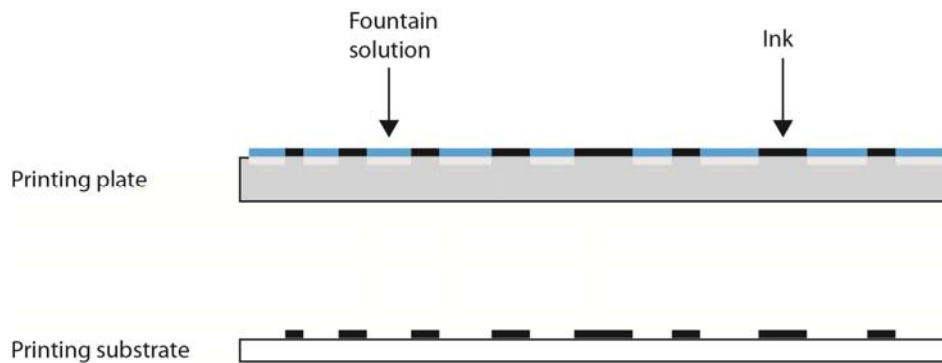

Figure 1. Offset printing plate after applying fountain solution and ink

The printing process starts with the application of the fountain solution of a strictly defined quantity. The fountain solution adheres only on the hydrophilic non-printing areas. After the fountain solution, follows the application of the

printing ink which covers places on the printing plate covered with photosensitive layer called printing areas. After the printing ink is applied, begins the ink transfer to the printing substrate. The printing unit for the offset printing consists of three main cylinders: plate cylinder, offset (blanket, rubber) cylinder and impression cylinder (Figure 2) [5]. Dampening and inking system are in contact with the printing plate which is placed on the plate cylinder. The fountain solution and printing ink are transferred directly to the printing plate. Since this is an indirect printing technique, the ink transfers from the printing plate to the offset cylinder, covered with the rubber, and after that to the printing substrate. To make this transfer possible, the pressure which is achieved between offset and impression cylinder is required. Printing substrate, mostly sheets or rolls of paper, pass between this two cylinders. Offset printing was first used in the United States, where the first offset press was built in 1905.
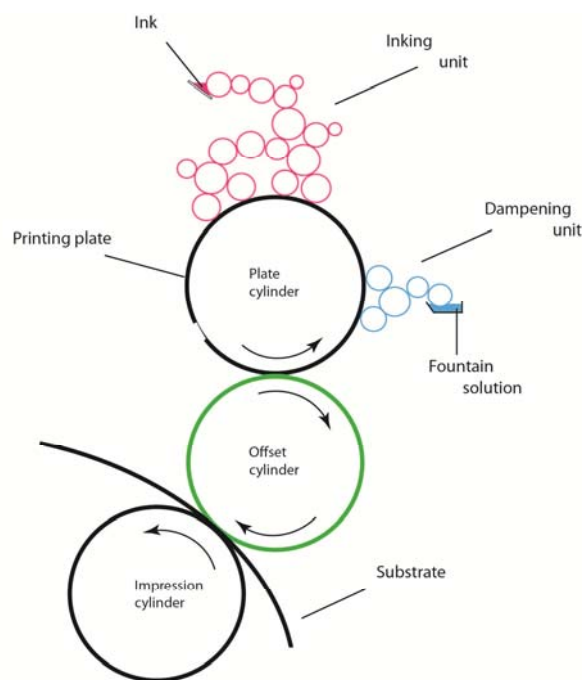

Figure 2. Key elements in an offset process

1.1.1. Printing plates for the offset printing

Printing plates for the offset printing can be made of one material, i.e. monometal or few materials, i.e. polymetal plates. Monometal printing plates are made of aluminium foil and a thin photosensitive layer is applied on to aluminium surface (Figure 3). They are processed by selective light exposure and chemical developing of the soluble parts of photosensitive layer. As said before, commonly used metal in monometal printing plates is aluminium, while zinc and steel are rarely used. To get the aluminium foil firstly all the mass of aluminum must pass through the system of rolls to produce a thin metal sheet. On the surface of the thin metal sheet, a coating of aluminium oxide (Al_2O_3) which has good hydrophilic characteristics is created spontaneously. Roughening the surface can be performed by a sand-blasting, while today the most commonly used process is electrochemical roughening. After the roughening process, the aluminium surface has a defined micro-roughness, thus additionally affecting the adhesion of the photosensitive layer and the adsorption of the fountain solution in the printing process [6-7]. With anodization, which is the next step in production of the printing plates, a thin porous layer (2-4 micrometers) of aluminium-oxide is created. The role of the layer is to increase hydrophilic properties of the non-printing areas. Beside this, the coating also protects aluminium from corrosion and gives a greater durability to the printing plate, because the aluminium-oxide has better mechanical properties than aluminium.

a)
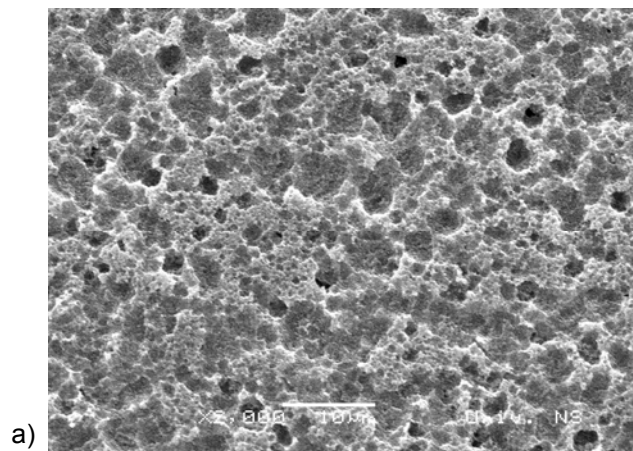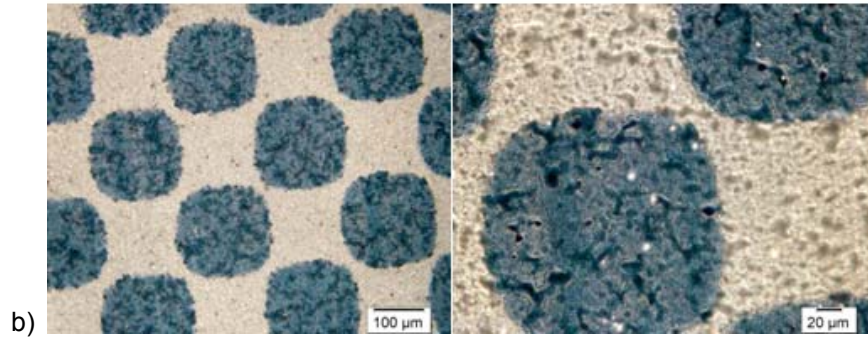
Figure 3. Offset printing plate surfaces
a) SEM image of the aluminium oxide surface, magnification 2000×,
b) Images of printing (photosensitive) and non-printing (aluminium oxide) surfaces

Polymetal printing plates consist of at least two metals (bimetal) where one metal has a function of printing areas, and the other of non-printing areas. For forming the printing areas usually copper, zinc and brass are used, which show good hydrophobic characteristics. Nickel, steel, aluminium and chromium are metals with good hydrophilic characteristics and therefore are used for forming the non-printing areas [8]. Polymetal printing plates are rarely used, because their production is more complex than that of the monometal plates, although they have better abrasion resistance and higher quality of reproduction.

1.1.2. Offset printing plate workflow

On the prepared aluminium foil, a thin photosensitive layer which is later removed from defined surfaces during, the production process, is applied. There are two types of printing plate production workflow: conventional and digital procedure.

1.1.2.1.   Conventional procedure

Conventional procedure of printing plate production is based on process of exposing and making of films which are being copied on the printing plate.
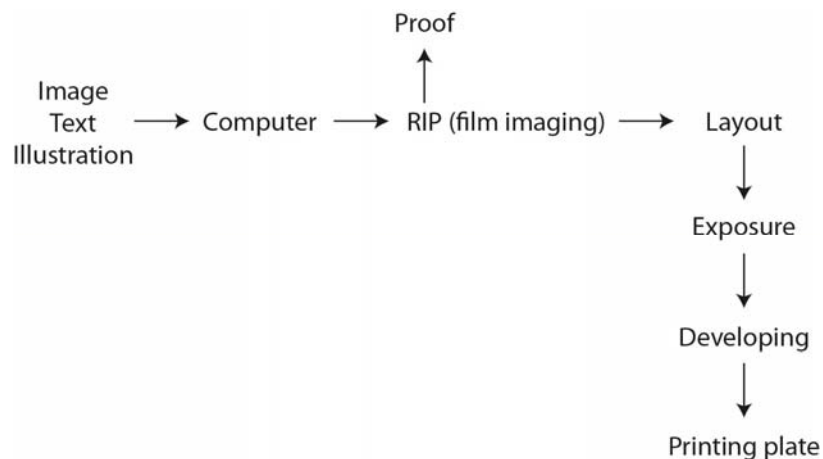
Figure 4. Workflow of the conventional offset plate making process

Input data (image, text, illustration) are sent to the computer where they are processed. Processed data are sent to RIP (Raster Image Processor) which transforms the original to the screen image of input data (Figure 4). After processing in Raster Image Processor, films are made by printing them on foil. By exposing the films, which are mounted on the plate, photosensitive layer changes its solubility. The developing process follows, where soluble part is removed, thus creating the non-printing areas.

Conventional procedure of printing plate production could be positive or negative process, depending on the type of photosensitive layer.

If the process is negative, on the thin aluminium sheet a negative photosensitive layer is applied, with a negative copy film on top (Figure 5). Negative photosensitive layer is soluble in the defined developing solution, and after exposure it becomes insoluble. In the developing process, soluble or unexposed layer is removed and in the end a printing plate with clearly defined non-printing and printing areas is obtained.
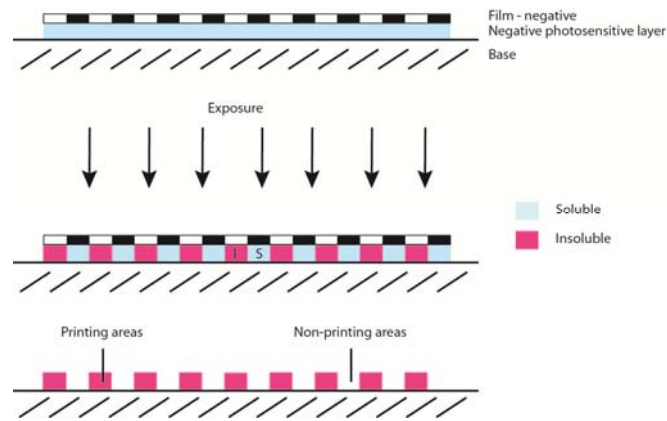
Figure 5. Negative printing plate making process

The other type of printing plate making procedure is the positive process (Figure 6). Positive photosensitive layer is insoluble before, and becomes soluble in the defined developing solution after exposure. Exposure is also performed through the positive film, and followed by the developing process. The printing plate with visible printing and non-printing (Al_2O_3) areas is obtained after developing [1-2]. Regardless which method is used, the result on the printing plate should be the same.
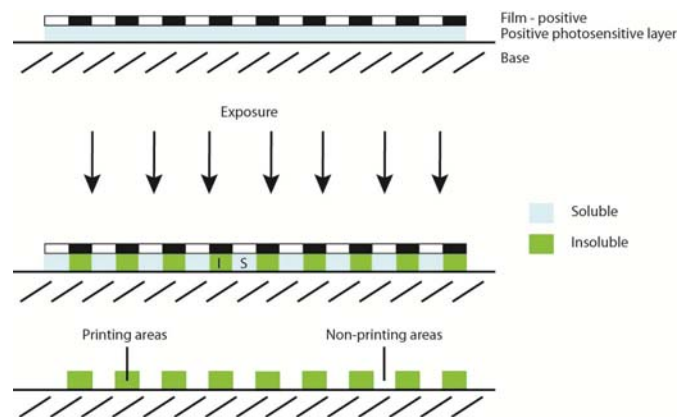
Figure 6. Positive printing plate making process

1.1.2.2. Digital procedure

With technology development, the process of printing plates making procedure has improved in the way that the environmentally least acceptable part, film production and development, is not needed anymore (Figure 7) [10]. Digital procedure or CtP (Computer to Plate) presents a process where the digital information is directly formed on the printing plate. They can be, depending on which type of photosensitive layer is used, divided in three groups: thermal procedures, silver salt diffusion procedures and procedures with photopolymerization [11].
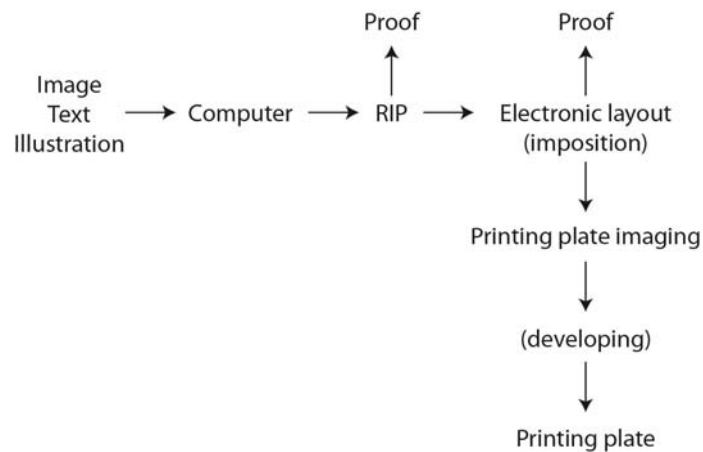
Figure 7. Workflow of the digital offset plate making process

Today market offers different types of CTP technologies for production of the offset printing plates. There are several platesetter units which differs in the type of laser used in the plate exposure process [9]. By laser exposing of the printing plate the solubility of photosensitive layer is changed. The laser with visible light makes chemical changes on the photosensitive layer which is then removed from non-printing areas. On the other hand, physical changes are made with thermal laser where the printing areas are hardened and photosensitive layer from non-printing areas is removed [9]. Besides differences in the used lasers, platesetters may differ in their construction: internal drum, external drum and flat-bed platesetters [10].

1.2.   Computer vision

Nowadays, the big effort is investing in the development of the computer systems which will be closer to human understanding and thinking. In that way the artificial intelligence is developed and systems acquire the necessary skills such as: ability to communicate in natural language, the ability to learn and apply knowledge, reasoning, understanding of the surroundings, etc.

Particularly interesting and very complex component of computer science is the computer vision. Its role is of modeling and replicating human vision using computer software and hardware in way to extract useful information from images and subsequently analyse them (Figure 8) [12]. In other words computer vision is meant to complement the biological vision and for this reason definition of the computer vision would be a study of analysis of images and videos in order to achieve results similar to those obtained by people. It is the great challenge to develop a computer system that is able to understand what a human being "see" because it is estimated that human eyes collect about 80% of information from the environment. The technical definition of computer vision would be that it is the science of having computers acquire process and analyse digital images [13].
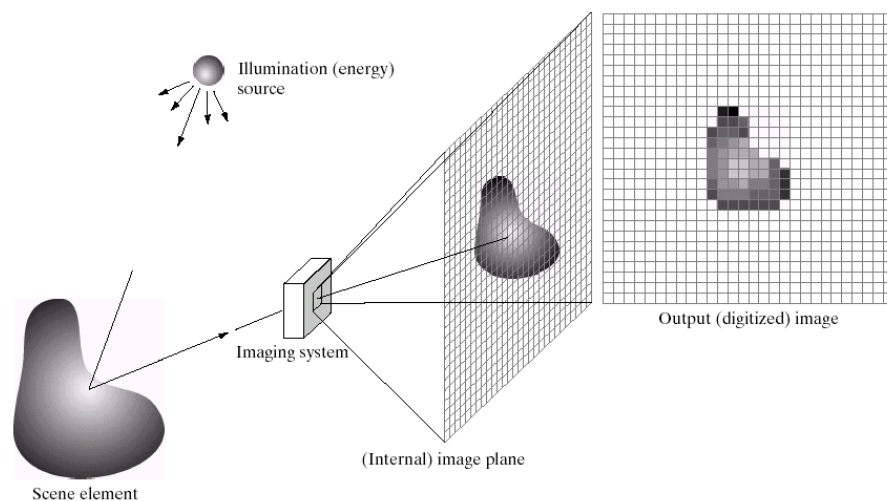
Figure 8. Acquiring and further analysing an image regarding computer vision (Image taken from Gonzalez & Woods, Digital Image Processing (2002))

Growing image and videos distribution coupled with widespread usage of cameras, either through desktop computers or mobile devices, contribute to the fact that today computer vision as an engineering discipline is becoming an increasingly used tool [13]. The last 40 years, from its first attempt in 1960s, computer vision is in constant development, doing small steps, but some already created systems show that for this part of computer science is a bright future. For example, the development of mechanisms for monitoring visual objects has enabled the emergence of augmented reality and mechanisms for monitoring human body have prompted the emergence of a concept called natural user interface [14].

As a field that includes methods for acquiring, processing, analysing and understanding images and high-dimensional data, in order to get numerical or symbolic information, is built upon the learning from diverse scientific areas, such as that of mathematics, physics, biology, engineering and computer science. For achieving computer vision goals, descriptions, interpretations or measurements, many techniques are used, such as image processing and pattern recognition.

The computer vision is used in robotics, medicine, security, transportation, industrial automation; image/video databases and human computer interface (Figure 9) [16].
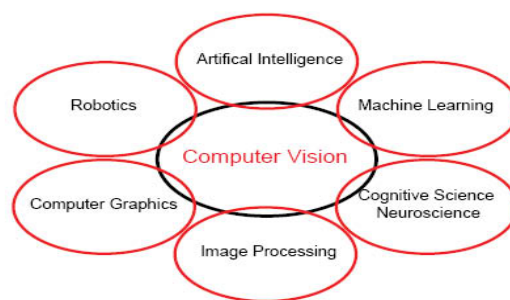
Figure 9. Connection with other fields

There are known three levels of computer vision: low, mid and high level. Low-level vision is based on low-level image processing. Its aim is image matching, optical flow computation and motion analysis. Image matching is used for finding similarities between two or more images. The motion analysis and optical flow are related with observing of motion, where optical flow only measures the optical changes in images. Low-level vision involves tasks in which the quality of the image is improved for the benefit of human observers, including useful measurements such as colour, spatial frequency, binocular disparity, motion processing. Two highly related aspects, inferring the geometry and inferring the motion, represent mid-level of computer vision. The main question on which mid-level gives an answer is: "How the object moves?" Also, mid-level vision involves the processes of feature extraction and pattern detection tasks. Furthermore, high-level vision deals with object recognition and there are two possible ways: model-based recognition and learning-based recognition [15]. High-level vision involves interpretation of scene through specific tasks such as relational reasoning, knowledge building and object recognition and as well other tasks to get information required for human understanding of objects. For design these computer systems in many applications, a hierarchized approach, is used as shown in Figure 10.
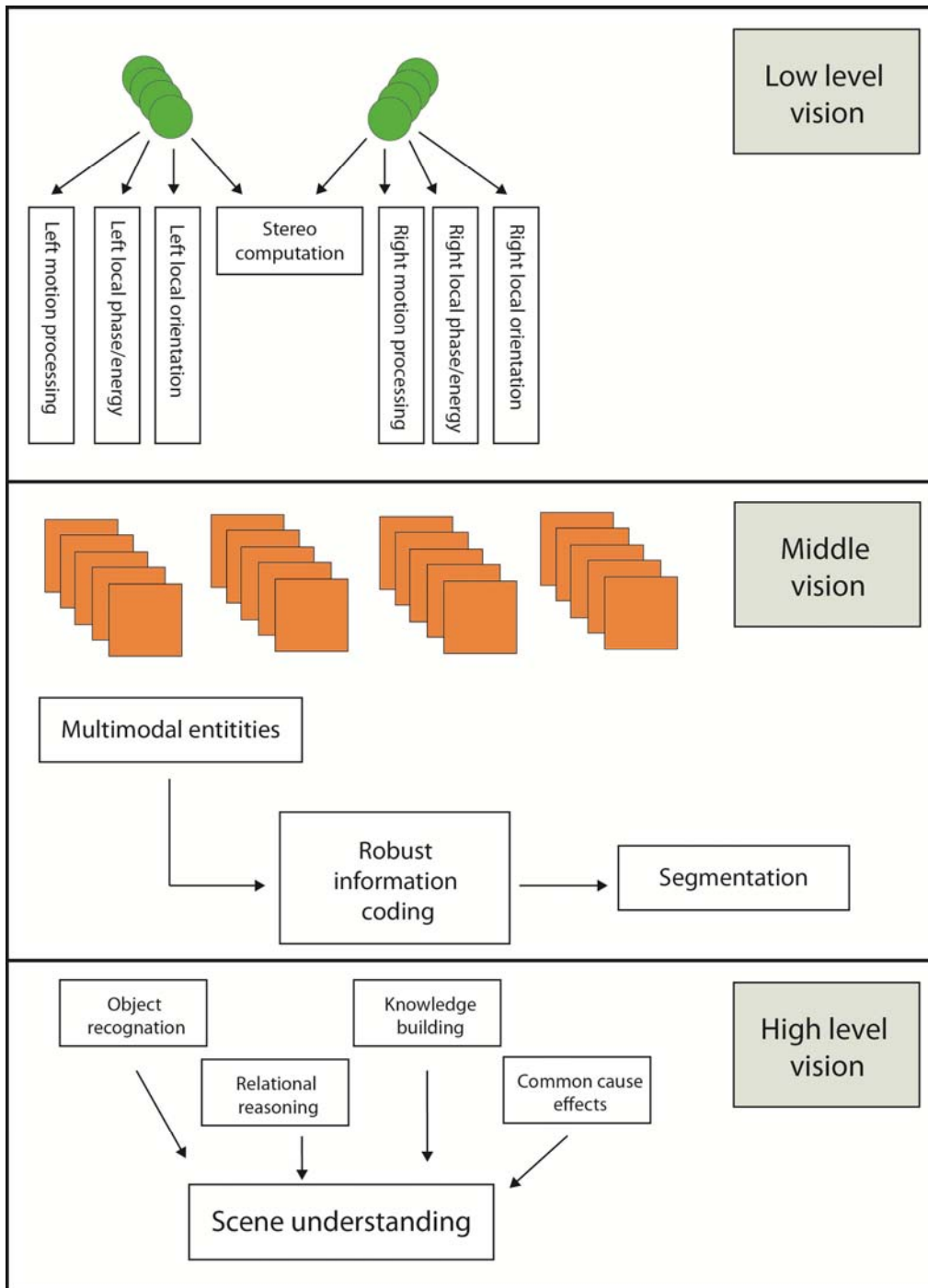
Figure 10. Taxonomy of the computer vision

As it finds implementation in a variety of fields (Figure 9) its importance is growing. In all these applications, computer vision found its role and is used as:

- automatic face recognition, and interpretation of expression
- visual guidance of autonomous vehicles
- automated medical image analysis, interpretation, and diagnosis
- robotic manufacturing: manipulation, grading, and assembly of parts
- OCR: recognition of printed or handwritten characters and words
- agricultural robots: visual grading and harvesting of produce
- smart offices: tracking of persons and objects; understanding gestures
- biometric-based visual identification of persons
- visually endowed robotic helpers
- security monitoring and alerting; detection of anomaly
- intelligent interpretive prostheses for the blind
- tracking of moving objects; collision avoidance; stereoscopic depth
- object-based (model-based) compression of video streams
- general scene understanding [17].

2. State of Art

2.1. Defining the quality level of the printing plate

Quality control is a procedure or set of procedures intended to ensure that manufactured products meet the quality criteria and requirements of the client. Mostly, it involves thorough examination and testing the product quality in every step in the reproduction chain, such as control of the printing plates.

To avoid unwanted consequences in the printing process, it is necessary to control the quality of the printing plates. Today the quality control is of major importance in the printing industry. The printing plate is often the last and sometimes only chance for a visible inspection before starting the printing process.

Quality control of a printing plate can be conducted by observing the printing areas, made of photosensitive layer; or by observing the non-printing areas, made of aluminium-oxide [18]. Many factors affect the quality level such as: type of photosensitive layer, sensitivity and thickness of the photosensitive layer, imagesetter, laser power in platesetter, developing process, etc. [19].

Image quality on the printing plate surface is usually controlled by using different devices for measuring the quality level of the plates. These devices work on the principle of determining several parameters for monitoring the quality of printing plates, where the most significant is the surface coverage of the printing elements.

2.1.1. Defining the quality level of printing areas

The quality of printing areas can be described with certain parameters which can be measured and defined. They are resolution, surface coverage of the printing elements, distance between the printing elements and their diameter, screening angle and raster type [19-20] (Figure 11).
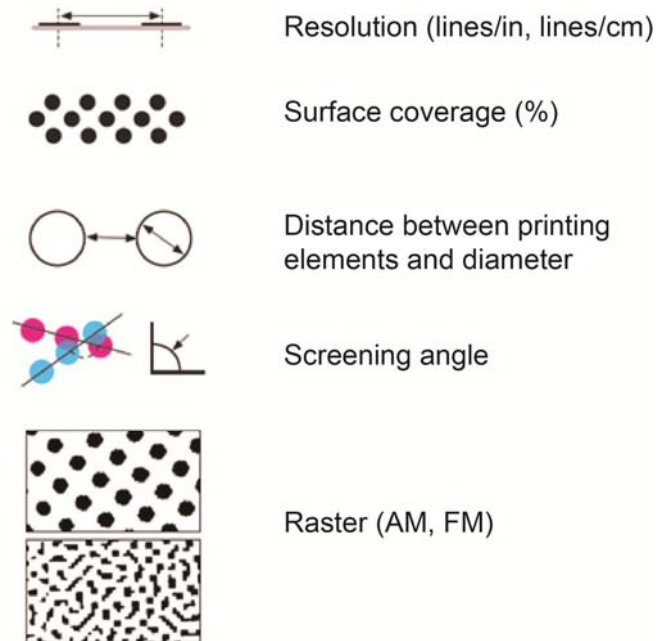
Figure 11. Quality defining parameters on offset printing plate (Image taken from Mahović Poljaček, S., Tiskovne forme 2, Lecture presentation)

The most significant parameter which shows the printing plate quality level is the surface coverage of the printing elements [21]. The surface coverage represents the ideal situation when the field on the printing plate, which is 10% covered with printing elements on the printing plate, is equal to the printed field on the substrate. As this situation is impossible in practice due to different technological limitations, for every printing machine, for every type of substrate and printing plate it is necessary to make a calibration curve. It is a curve of the whole tone range set in a digital file to optimize the reproduction process and to achieve the best possible match on the printing substrate.

In an ideal situation the curve will be line at an angle of 45° and it is called the optimal tone reproduction (Figure 12). In optimal tone reproduction the requirement that the optical density range of the originals (ΔD_o) is equal to the density range on the imprints (ΔD_r) is fulfilled [20].
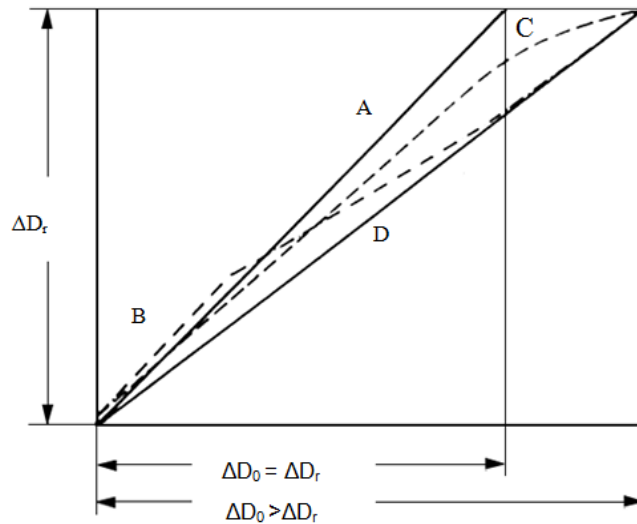
Figure 12. Optimal A and relative B, C, D tone reproduction (Image taken from Kumar, M., Standardizacija izrade I eksploatacija tiskovne forme za plošni tisak (1978))

Considering the fact that ideal situation cannot be achieved, calibration curves define the possible quality of final printing product and are defined to the image prior to platemaking. Nevertheless, measuring of the produced plate ensure the control of tones transformed from a digital file onto the printing plate before the printing process starts.

2.1.2. Defining the quality level of non-printing areas

In defining the quality level of non-printing areas it is very important to define the ability of these areas for accepting fountain solution. For this part two parameters are very important: contact angle and adsorption.

Contact angle (Θ) defines the level of surfaces wetting and is the angle which encloses the tangent drawn to the edge of the liquid drop, and the surface of the solid which is wetted by liquid (Figure 13).
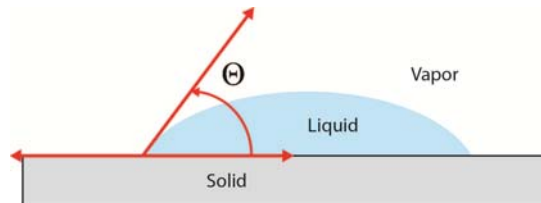
Figure 13. Contact angle

Wetting is a physic-chemical phenomenon which is a result of decrease of the surface tension forces and depends on the type of solid surface and the liquid. The surface tension of the liquid is generally less than the surface tension of solids, so liquids are mainly wetting solids. The measure of wetting solid surface is the cosine of the contact angle (cosΘ). In the case of complete wetting, the contact angle is 0 ° or cosΘ = 1. If the contact angle is 180 ° or cosΘ = -1, it represents non-wetting [4].

During the offset printing process, ink and fountain solution are applied to the printing plate (Figure 14). The fountain solution is applied first and is very important for it to show good wettability characteristics. Its role is to cover all non-printing areas, so that the ink adheres only on the printing areas. For better wettability characteristics, the additives are added to the fountain solution in order to decrease its surface tension and the contact angle. Accordingly, the smaller the contact angle is, the better the wetting.

Figure 14. Relation between photosensitive layer and aluminium oxide with fountain solution drop

Besides wetting, the quality level of non-printing areas can be determined by observing adsorption of the fountain solution on the non-printing areas. Adsorption is an accumulation of particles from a liquid or gas on the surface of a solid or liquid phase.

Adsorption is a reversible process, where the adsorbed particles are detached from the surface back to the surroundings. This phenomenon is called desorption.

Type of adsorption which is very important in production of printing plates is called chemisorption. Chemisorption is an irreversible process which involves a chemical reaction between the adsorb and the adsorbent which causes formation of monomolecular or multimolecular layer of a new chemical compound [22].

2.2. Tools and systems for test quality measuring

2.2.1. Materials and procedure

For this research, 23 printing plates samples have been made in the same processing conditions by copying control wedge with group of fields of 5%, 10%, 15%, … to 99% coverage value. Printing plate samples were exposed with metalhalide lamp for 60 impulses. After the exposure, samples were developed in commercial offset plate developer in a period of 15 seconds. Those processing conditions were defined by plate manufacturer for used workflow.

In order to define the printing plate's quality level, the surface coverage of the printing elements was observed. The surface coverage can be measured with devices, designed for controlling of the printing plates, which automatically show the coverage value or by image analysis software. In this research, both methods of determining the surface coverage of printing elements were used.

Measurements of coverage values were performed by Gretag Macbeth's IC Plate II plate reader and repeated five times for each sample. The coverage values were shown on the display of the portable device and also in the supported software. Besides this device, measurements were conducted by meant of VipFLEX, repeated five times for each sample. The results were shown in supported software.

Moreover, to get images for defining the surface coverage values with image analysis software, the samples were captured with VipFLEX device. After capturing images by means of VipFLEX, the obtained images were analyzed in softwares for image analysis, ImageJ and Matlab.

2.2.2. IC Plate II

Gretag Machbeth IC Plate II is a portable plate reader which provides quick and accurate quality control (Figure 15). Device has automatic calibration and the battery life is extended by LED illumination. The power-saving electronics and LED technology allow up to 30000 measurements per battery set. The measuring time is 3-4 seconds. Measuring unit is calibrated automatically. It is equipped with high-resolution camera and is able to capture images of the printing plate surface.

Figure 15. Gretag Macbeth's IC Plate II (Image taken from
http://www.idd.tudarmstadt.de/re_search/equipm/characterization_lab/index.en.jsp)

IC Plate II can measure a wide variety of plate types, metal and polyester plate, positive and negative, paper and foil. Also, it can measure and calculate surface coverage, diameter of printing element, screen resolution and screen angle. The algorithm built in device eliminates dust and scratches as it reads the printing plate. Also, screening algorithm allows measuring regular or stochastic type of raster. There are two measurement modes IC Plate II and Fogra Measuring Bar (FMB), which can be set in device settings. IC Plate II uses the specially developed plate measurement algorithm where the dots can be accurately detected. In Fogra Measuring Bar mode IC Plate II measures according to the FOGRA standard. In IC Plate II the image analysis algorithms are used. Type of sensor which is used is CMOS 648 x 488 with sensor resolution of 12,700 ppi [23].
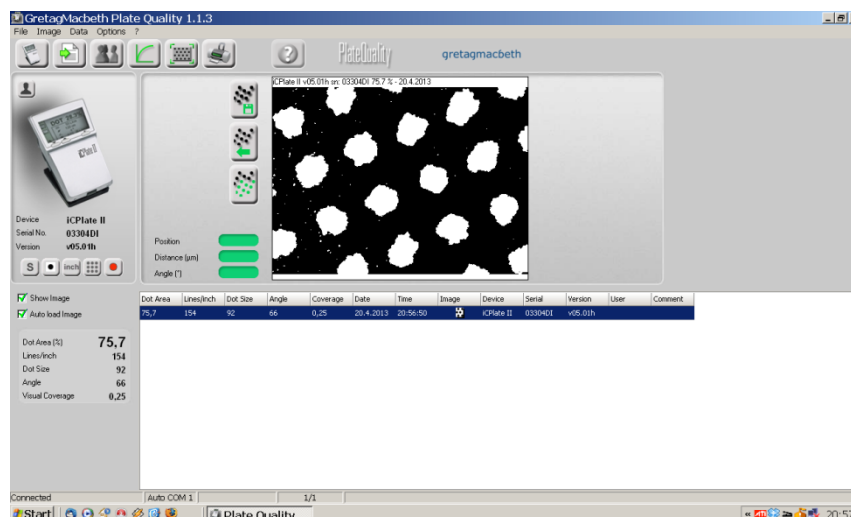
Figure 16. PlateQuality interface

Belonging software to the IC Plate II is the PlateQuality Software, but the device can also work independently, showing information on the display (Figure 16). The software stores, visualizes and document both individual measurements and plate characteristics curve measurements. PlateQuality Software has capture tool which allows getting the images and later that plate images can be compared for a detailed quality analysis [23].

2.2.3. VipFLEX

VipFLEX is mainly intended for flexography plates but it can be also used to measure paper, foils, film and aluminium plates (Figure 17). Measuring system includes the vipFLEX desktop plate reader and PlateQualityFlexo software. It is characterized by camera with high resolution and sophisticated image recognition. One battery set allows up to 50000 measurements. VipFLEX can measure dot area, dot size, edge factor and mottling. It has possibility that it can measure AM, FM and hybrid screening. Device is equipped with sensor RGB camera 640 x 480 with resolution sensor of 10000 ppi. Measuring time is very fast and it is less than 1 second. VipFLEX has two different measurement algorithms, chain dot and normal dot. Normal dot algorithm will produce the surface coverage value and contour factor while chain dot algorithm will only produce the surface coverage [24].

Figure 17. VipFLEX (Image taken from http://www.mgvcolor.com/vipflex/)

PlateQualityFlexo analyses and gives information about quality of the printing plate (Figure 18). Also, it gives all required information which can be printed in a variety of formats or stored in a database. It stores, visualizes, and documents both individual measurements and plate characteristic curve measurements.
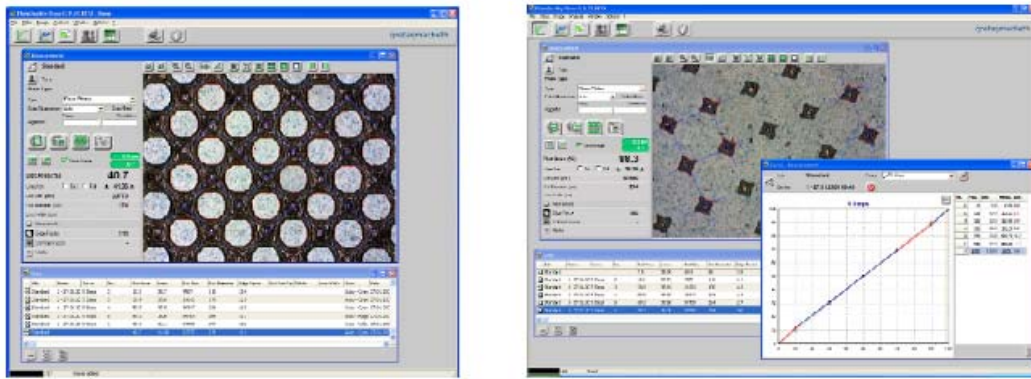
Figure 18. PlateQualityFlexo interface (Image taken from http://www.corona-grafica.com/PDFs/vipFLEX.pdf)

2.2.4.   Image analysis

In various scientific fields the image analysis technique is being used, such as in medicine, astronomy, security, robotics, graphic technology [10]. In image analysis the input parameter is usually the image and the output parameter is information, respectively the result of the measurement. Two main steps are receiving and digitalizing the image followed by processing and analysing of the image. Microscope, CCD camera and scanner are used for receiving and digitalizing the image. On the other hand, computer and appropriate software are used for processing and analysing to obtain results [25].

In graphic technology image analysis is used for examinations of imprints, substrates and printing plates. Analysing final imprint with an image analysis method is acceptable as a tool for control and examination of the reproduction processes [26]. Also, it is used to identify impurities in substrates. Analysing the microscopic images of the surface one can define the surface coverage of printing elements on the printing plate.

In this research, the image analysis is used for determining the surface coverage of printing elements on the printing plates. Firstly, the samples of the printing plate were captured with VIPFlex device. As software for image

analysis and processing, Wayne Rasband's ImageJ is used. Beside ImageJ Matlab software was also used in image analysis.

2.2.4.1.   ImageJ

ImageJ is software used for image processing and image analysis, created at the National Institutes of Health by Wayne Rasband. It is free public software based on Java [27]. In 1986 American programmer defined essential users' freedoms: user has the freedom to run the program for any purpose. Also, the user has the freedom to study how the program works and, change it or improve it, and release his improvements to the public. The user is able to redistribute copies, so anyone can use it.

ImageJ is possible to install on every computer which use Java 1.4 application. With ImageJ, it is possible to display, edit, analyze, process, save and print 8-bit, 16-bit and 32-bit images. This program accepts different formats of images including TIFF, PNG, JPEG, GIF, BMP and many more. Also, ImageJ has a range of 256 possible shown pixel values [28].

Because of its features and opportunities it offers, ImageJ has application in many scientific fields. Functions of the ImageJ can be modified by extras written in Java and applied in program. ImageJ is able to calculate the surface coverage and pixel value. It can measure distances, angles and create density histograms. Also it can perform standard image processing operations such as contrast manipulation, sharpening, smoothing, edge detection, median filtering, scaling, rotation and flips.

One of the options provided by the ImageJ is determination of the surface coverage. For getting the percentage of surface coverage with ImageJ, it is necessary to convert a multitone image into a duotone image in order to maximize the contrast between the printing and non-printing elements. For staining duotone images, a command Process – Binary – Make binary is used (Figure 19). After converting the images, the appearance of the noise is

possible; this may interfere with accurate determination of the surface coverage. To remove the noise, Process – Noise – Despeckle command is used.
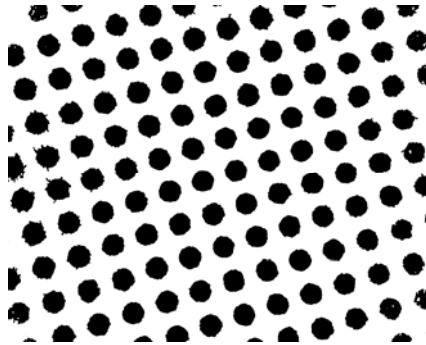
Figure 19. Capture of the sample used in image analysis

After converting image to binary mode the results were provided in two ways. First way was by using circular window and changing its size for 10%, and another was rectangular window. In both ways the coverage was measured for 10 times and then the main values were calculated. The results of analysis are given in results window and can be saved and printed (Figure 20). Selection of data shown in the result box can be adjusted with Analyse – Set Measurements command. Related to the percentage of surface coverage are Area and Area fraction commands, which must be activated.
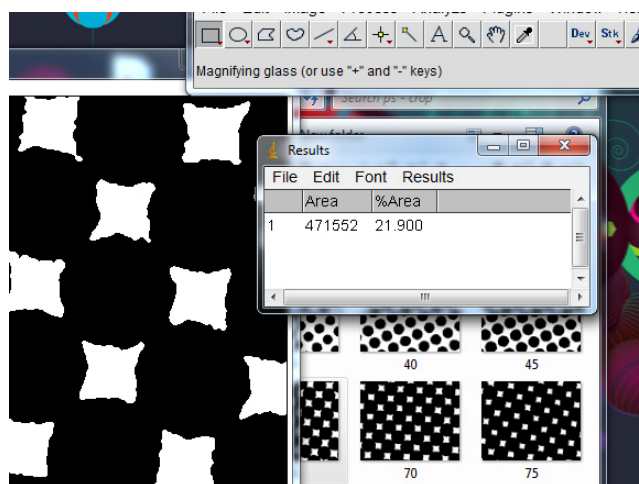
Figure 20. Interface of the ImageJ software

2.2.4.2.   Matlab tool used in this work.

The name of very well-known Matlab tool (widely used in academic and research institutions as well as industrial enterprises) comes from Matrix Laboratory, it is a numerical computing based environment and fourth-generation programming language, developed by MathWorks. This environment provides matrix manipulations, implementation of algorithms, plotting of functions and data, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran among other features.

Matlab is provided by some toolboxes regarding different disciplines and topics, focusing in Computer Vision Toolbox, it allows design and simulation of computer vision and video processing systems with a set of different algorithms and tools such as feature extraction, motion detection, object detection, object tracking, stereo vision, video processing, video analysis, etc.

In this presented work, we have not used the Image Processing toolbox, since we have constructed our Matlab scripts as close as possible to just raw C, for sake of portability to the hardware stage (ARM v7 processor) as it will be shown further.

3. Methodology

3.1.   Architecture of the system proposed and Stimuli used

In this section are described the methods and strategies performed for measuring the quality of printing plates.

3.1.1.   First strategy

Quality of the printing plates can be obtained in different ways and one of them is using computer vision algorithms. In computer vision algorithms the captured images of the printing plate surface were used. Computer vision algorithm which is used in first strategy is less complex and in only three steps gives the results of surface coverage counting black and white pixels.

```
        ┌─────────────────┐
        │    BINARIZE     │
        │ (Otsu's method) │
        └────────┬────────┘
                 │
                 ▼
        ┌─────────────────┐
        │    CROPPING     │
        │      IMAGE      │
        └────────┬────────┘
                 │
                 ▼
        ┌─────────────────┐
        │    COUNTING     │
        │     PIXELS      │
        └─────────────────┘
```

Figure 21. Flow chart from first method implemented
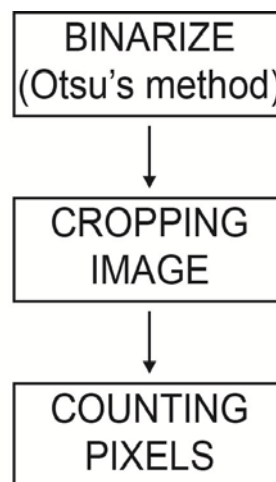
The first strategy (Figure 21) is based on image segmentation which plays an important role in image analysis and computer vision system. The image segmentation is separating objects, in this case printing elements, from the background. Among all segmentation techniques, the automatic thresholding methods are widely used because of their advantages of simple implement and

time saving. The basic idea of automatic thresholding is to automatically select an optimal or several optimal gray-level threshold values for separating objects of interest in an image from the background based on their gray-level distribution. For image segmentation the simple and effective Otsu method was used. Otsu method is one of thresholding methods which calculate the optimum threshold separating objects and background so that their combined spread is minimal.

Otsu method computes a global threshold (level) that can be used to convert a real time image to a binary image. Level is a normalized intensity value that lies in the range [0,1]. Otsu method chooses the threshold to minimize the intraclass variance of the threshold black and white pixels. It applies an automatic threshold in order to segment efficiently the image; it is based by a discriminant criterion to optimize the function of separation of obtained classes in gray levels. We describe very briefly the method used:

If supposing every pixels form an image represented by gray levels [1,2,..,L], number of the pixels at level L is denoted by n_i and the total number of pixels by N. The gray-level histogram is normalized regarding a probability distribution expression:

$$p_i = n_i / N, \ \sum_{i}^{L} p_i = 1 \tag{1}$$

Assuming a classification of pixels in two classes C0 and C1 (objects and background) by a threshold level k, where pixels with levels [1,…k] belongs to C0 and pixels with levels [k+1,..,L] belongs to C1. The probabilities of the class occurrence and class means levels are written by:

$$w_0 = \Pr(C_0) = \sum_{i=0}^{k} p_i \ ; w_1 = \Pr(C_1) = \sum_{i=k+1}^{L} p_i \tag{2}$$

$$\mu_0 = \sum_{i=1}^{k} i \Pr(i|C_0) = \sum_{i=1}^{k} i p_i / w_o \ ; \tag{3}$$

$$\mu_1 = \sum_{i=k+1}^{L} i \Pr(i|C_1) = \sum_{i=k+1}^{L} i p_i / w_1$$

In this step, we are ready to define the following relation for the choice of k, and the variance based on first order statistics (class means):

$$\mu_T = w_o \mu_0 + w_1 \mu_1; \; w_1 + w_o = 1 \tag{4}$$

$$\sigma_B^2(k) = \frac{[\mu_T w(k) - \mu(k)]^2}{w(k)[1-w(k)]} \tag{5}$$

The optimal threshold k^* that maximizes $\sigma_B{}^2$ is being selected by this sequential search using the cumulative quantities expressed in (1) and (2).

$$\sigma_B^2(k^*) = \max_{1 \le k \le L} \sigma_B^2(k); \; S^* = \{k; \; w_0\, w_1 = w(k)[1-w(k)] > 0\}; \tag{6}$$

The result of image segmentation is an image in binary mode, converted to black and white pixels which indicate what is printing element and what is background. The second step includes cropping binarize images applying circular and rectangular window. The circular and rectangular windows were applied for 10 times and each time the size of the window was changed keeping the proportions with the size of the image. In the last step, the algorithm was counting black and white pixels on the 10 circular and rectangular shape images and making the main value of the 10 results.

3.1.2.   Second strategy

The second strategy that was used is more complex than the first one. It consists of six different steps to obtain the printing plate quality results. The image was captured by means of VipFLEX device and because of the deficiency of this way of capturing; on the edges of the images the noise was appeared. To avoid unwanted noise the real time image was cropped in rectangular shape keeping proportion of width and height with the real image. The next step is binarizing the image which means to make image segmentation with Otsu method which is explained previously. Otsu method computes a global threshold (level) that can be used to convert a real time image to a binary image, after that, this Level is a normalized intensity value that lies in the range [0,1]. Otsu method chooses the threshold to minimize the intraclass variance of the threshold black and white pixels.

The third step is edge detection using Sobel operator which is used in image processing, particularly in edge detection algorithms. The Sobel operator is an algorithm which in a clear way discovers the boundaries between regions in an image. It works on the basis of the image gradient which is a change in intensity (or color) of an image. An edge in an image occurs when the gradient is greater and the Sobel operator makes use of this fact to find the edge in an image. The Sobel operator calculates the approximate image gradient of each pixel by convolving the image with a pair of 3x3 filters. The filters estimate the gradients in the horizontal and vertical directions.

In the next step the Hough transform is used which is a method for detecting curves by exploiting the duality between points on a curve and parameters of that curve. The process of identifying possible circular object is relatively simple. Hough transform technique first creates accumulator space which is made of a cell for each pixel. For each edge point in image, for each pixel is calculating the right radius. The calculating stops when the algorithm finds a center of the looking circle which is the intersection of all circles which have center in the edge of the object.

In the fifth step the algorithm is defining the threshold, the boundary which separates correct circles from the not correct. The threshold is defined by equation which is related with actual circle (candidate) and the circle which is following the actual:

$$Threshold = \frac{r^2}{(r+1)^2} \qquad (7)$$

If the threshold is lower than the coverage ratio, then the circle is not acceptable, the system removes that circle. This step is necessary to remove eventually noise on the binary images to obtain good quality results.

Since the last step, all circles which represent printing elements should be recognized by the algorithm. If any circle is not recognized, algorithm calculates the distance between the centers of two neighboring circles. Also, beside distance, algorithm also calculates the angle so that the system can replace if any circle is missing. We have a summary of the flow chart in the Figure 22.
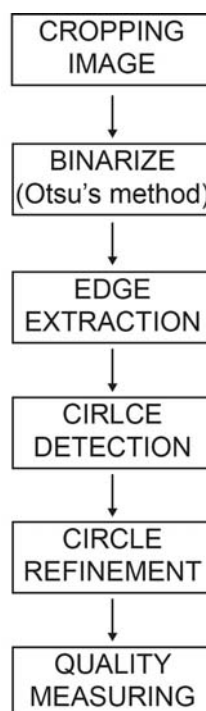
```
+-------------------+
|     CROPPING      |
|      IMAGE        |
+-------------------+
          |
          v
+-------------------+
|     BINARIZE      |
|  (Otsu's method)  |
+-------------------+
          |
          v
+-------------------+
|       EDGE        |
|    EXTRACTION     |
+-------------------+
          |
          v
+-------------------+
|     CIRLCE        |
|    DETECTION      |
+-------------------+
          |
          v
+-------------------+
|     CIRCLE        |
|    REFINEMENT     |
+-------------------+
          |
          v
+-------------------+
|     QUALITY       |
|    MEASURING      |
+-------------------+
```

Figure 22. Flow chart from second method implemented

Within the whole process, the Hough transform is the most important stage since it is responsible for obtaining the circle centers and their radius.

Hough transform is based on the assumption that circles have a particular R radius. If the equations of each circle are:

$$x = a + R\cos\theta \qquad (8)$$

$$y = b + R\sin\theta \qquad (9)$$

Every point in the (x,y) space will be equivalent to a circle in the (a,b) space (R isn't a parameter, we already know it). This is because on rearranging the equations, we get:

$$a = x_1 - R\cos\theta \qquad (10)$$

$$b = y_1 - R\sin\theta \qquad (11)$$

for a particular point (x_1, y_1), and θ sweeps from 0 to 360 degrees. The brighter spot, more the number of votes case at the point. And more votes imply a greater probability of a point being a center.

The following Figure 23 describes the Hough transform process graphically, each edge point is at the same distance from the center (R distance). If a circle of R radius is drawn for every point in the edge, is achieved a brightest point corresponding to the center searched. In the figure, three random points were chosen and its corresponding circle are drawn (the red, blue and green circles). And then, votes are cast at the pixels of these circles.

Figure 23. Scheme of Hough transform

In the terminology related to the Hough transform, the brightest spot corresponds with the highest energy pixel (most votes received). In our case of study of printing plates, it exits a growing trend of higher energy pixels until to the required R radius is found which means Hough method already converged.

4. Results

4.1. Comparison and critical evolution

Figure 24 represents the images of characteristic fields of the printing plate samples captured with different devices. The differences between images are visible. Wedge presents the digital data which was generated for this paper. IC Plate II and VipFLEX present images processed by IC Plate II and VipFlex devices. ImageJ and Matlab present bitmap-images obtained by tone and contrast adjustments. Therefore, one can conclude that each system uses different types of algorithms for image analysis. According to that, the deviations in the measurement results were expected.
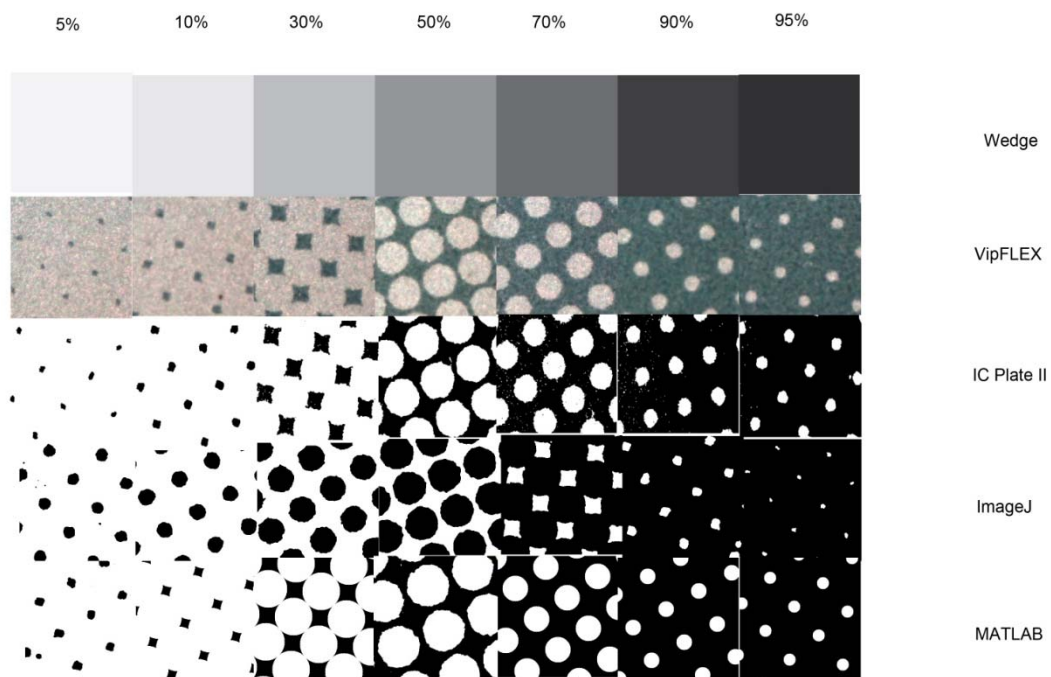

Figure 24. Images of selected printing plate's testing fields obtained by different systems

4.1.1.　First strategy

Results of the coverage value measurements were obtained by using six different measuring methods. For each sample the mean value was calculated and the results can be seen in Table 1.

Table 1. Nominal and calculated coverage values

Nominal values	VipFLEX	IC Plate II	ImageJ (rectangle)	ImageJ (circle)	Matlab (rectangle)	Matlab (circle)
0	0	0	6,052	4,637	5,183756083	5,23845873
5	1,32	1,1	5,893	5,184	5,303175069	5,81268804
10	3,48	3,54	5,986	6,108	5,968611725	6,66428341
15	7,32	6,68	8,053	8,141	8,149617467	8,54573225
20	10,96	9,84	14,404	13,543	15,809588	14,9088104
25	13,42	12,74	20,295	20,156	20,1902172	21,4752333
30	18,18	16,4	25,582	25,783	25,43315558	26,1085041
35	21,74	19,64	31,295	32,002	31,38582242	31,6429309
40	26,36	25,66	37,633	38,105	38,85946267	38,3818144
45	33,44	32,72	43,47	44,276	47,052289	44,8195896
50	38,24	38,88	48,775	49,513	48,06449592	48,3070892
55	44,38	45	55,251	56,107	55,63096608	55,4372752
60	52,28	51,62	59,297	59,187	63,275684	61,5942289
65	57,8	56,84	68,915	66,754	63,280043	66,3678112
70	64	63,08	70,912	73,146	69,96095433	70,9582246
75	69	69,32	78,515	78,434	80,57859975	78,8366476
80	75,8	75,16	81,939	82,579	82,68225142	82,1476209
85	81,06	80,48	83,699	86,047	83,42537442	83,8971929
90	87,26	86,52	87,014	88,292	89,440541	88,6698728
95	93,72	93,1	88,967	91,422	90,5437065	89,5879719
97	95,74	95,26	89,801	93,868	93,46326708	91,8110795
98	96,72	96,26	98,025	98,901	98,97629158	98,4084772
99	97,64	97,22	89,428	96,704	95,36123475	92,8174954

The mean values of surface coverage values were showed in graphic diagram which represent the reproduction of a whole tone scale (Figure 25). One can see that results calculated with Matlab and ImageJ differ from other methods for coverage calculation. The deviations can be explained through three areas.

The first one deviation is visible up to 15% of coverage (highlights) where Matlab and ImageJ results are higher than others. Second deviation is visible from 20 to 90% of coverage where Matlab and ImageJ results are higher than others too. And finally, third deviation can be seen in shadows (over 90%). There are two points of values equality calculated from all methods: at about 15% and 90% of coverage.
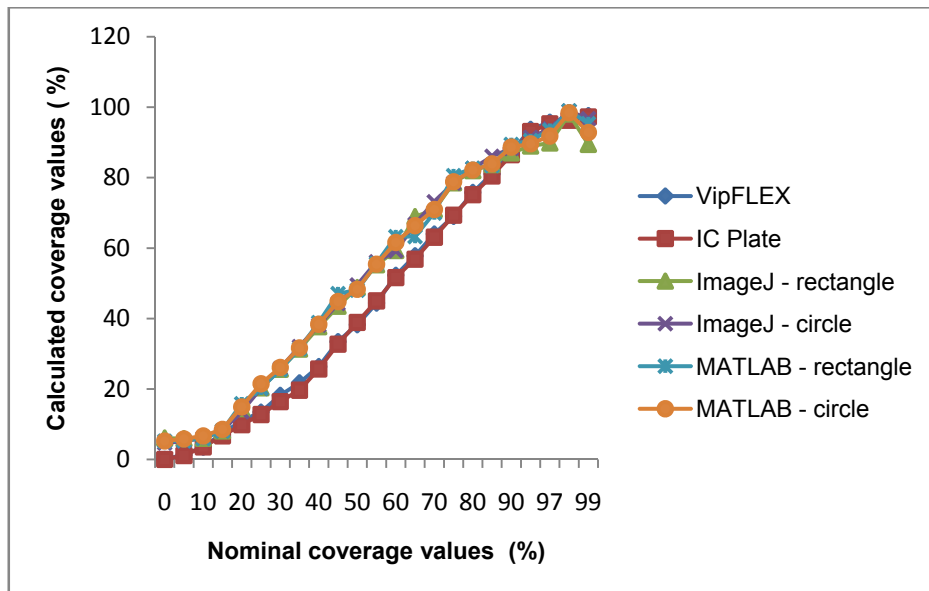

Figure 25. Comparison of nominal and measured coverage values obtained with different methods from 0% to 99% coverage values

For detailed preview, results were showed in two graphic diagrams, divided from 0% to 50% and 50% to 99% coverage values. Figure 26 shows the results of surface coverage values of first half of tone scale obtained with six methods. One can see that there are deviations between methods, especially between results measured with devices and results calculated with the image analysis

software. Results obtained with devices VipFLEX and IC Plate II have the same results from 0% to 15% of coverage. There are deviations in results between 15% and 40% of coverage which means that these areas cannot be measured correctly. After 40% of coverage the results measured with devices are the same. In the first half of tone scale are deviation between the image analysis software and devices with one exception when the results are the same at 15% of coverage. The possible reason for those deviations is in the usage of real images of printing plate samples. The images captured with VipFLEX had round noises on the edges because of the way they were captured.
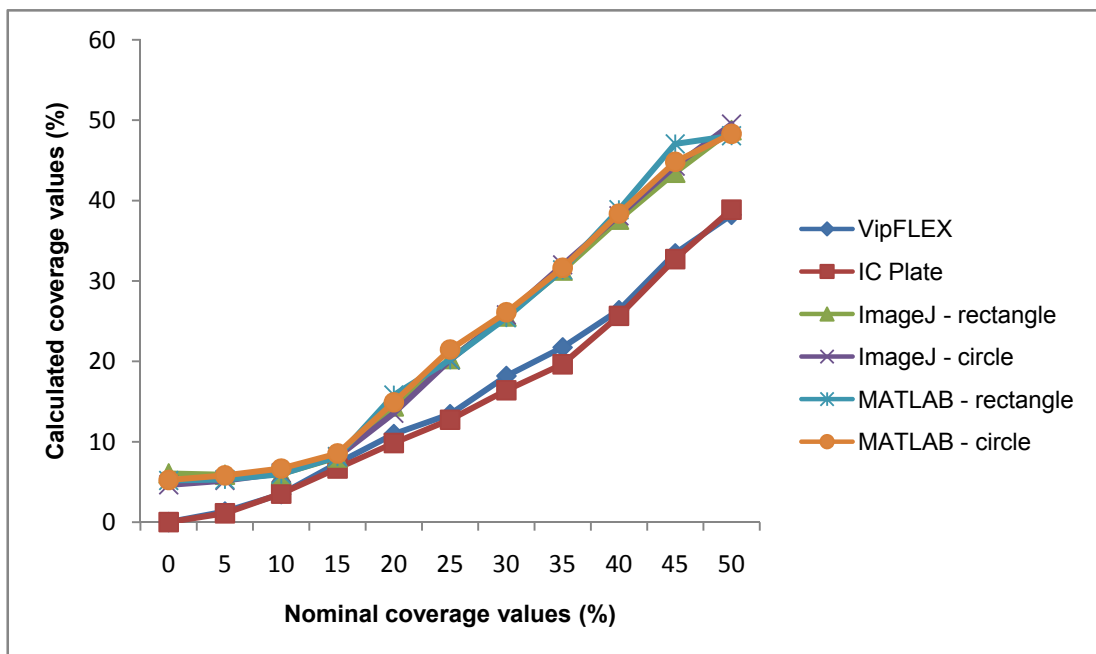

Figure 26. Comparison of nominal and measured coverage values obtained with different methods from 0% to 50% coverage values

In Figure 27 one can see the relation between measured and nominal coverage values for higher tone scale values (coverage values from 50% to 100%). Measuring performed by using devices showed the same results, as the one measured in highlights, but there are some deviations in the area from 95% to 98% which means that that area cannot be measured correctly. The deviations

between image analysis software and measuring devices can be seen up to 90% and after that results are quite similar.
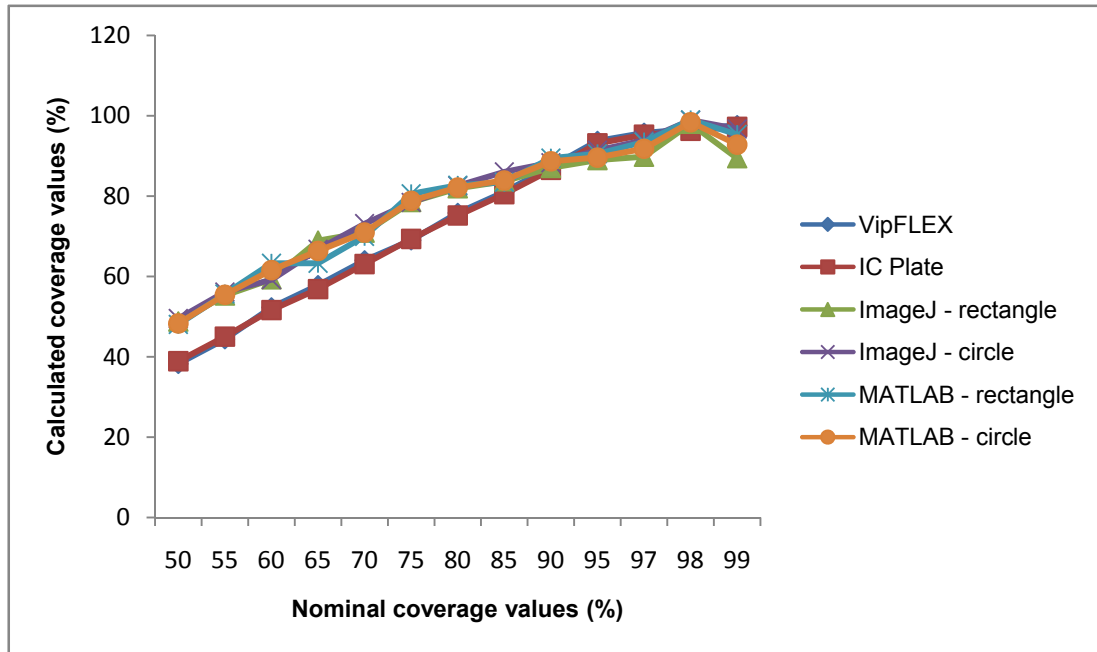

Figure 27. Comparison of nominal and measured coverage values obtained with different methods from 50% to 99% coverage values

As showed in graphic diagrams, there are deviations between nominal and measured coverage values obtained with different methods. The results which are the most similar to the nominal values are results obtained with measuring devices, IC Plate II and VipFLEX. Coverage values obtained with image analysis software, ImageJ and Matlab; show, to a certain extent, the deviations because the quality of their results depends on the quality of samples images which were used for calculation.

Table 2 presents the calculation of the correlation coefficient based on the Pearson model. According to the results one can see that the correlation is very high (approximately 1) for all observed methods for calculating the surface coverage. This means that application of any of these methods can obtain

reliable results. However, in graphic diagrams one can see deviation in measured coverage values, especially between 15% and 90% (Figure 25).

Table 2. Pearson correlation coefficient

Correlation	Correlation coefficient
VipFlex: IC Plate	0,9998
IC Plate: ImageJ(rectangle)	0,9885
IC Plate: ImageJ(circle)	0,9919
IC Plate: Matlab (rectangle)	0,9909
IC Plate: Matlab (circle)	0,9906
VipFlex: ImageJ(rectangle)	0,9885
VipFlex: ImageJ(circle)	0,9920
VipFlex: MatLAB(rectangle)	0,9908
VipFlex: MatLAB(circle)	0,9907
ImageJ(circle): ImageJ(rectangle)	0,9989
Matlab (circle): Matlab (rectangle)	0,9994
ImageJ(circle): Matlab (circle)	0,9994
ImageJ(rectangle): Matlab (rectangle)	0,9979

For further analysis of results the standard deviations was calculated. Since VipFLEX and IC Plate II are devices designed for measuring of printing plates quality the standard deviation between their results were calculated firstly. The results are shown in Figure 28 where Δd presents difference between coverage values measured by IC Plate II and VipFLEX:

$$\Delta d = coverage\ value\ (IC\ Plate\ II) - coverage\ value\ (VipFLEX). \qquad (12)$$

One can see that correlation is good, so for the further calculating it is not important which method will be chosen. Since the IC Plate II device is

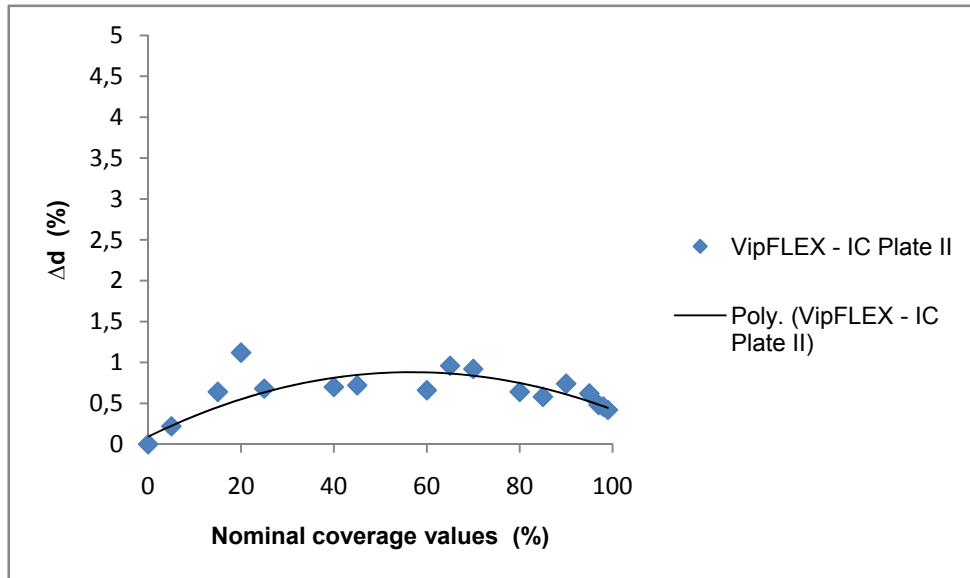specialized for offset printing measurements, it will be used in further calculations.

Figure 28. Comparison of coverage values calculated by VipFLEX and IC Plate II

As we can see in Figure 28, and was seen in diagrams in Figures from 25 to 27 the correlation coefficient is high (0,9998). According to those results one can conclude that there are no differences in calculation of surface coverage obtained by those devices. They can be used separately in analysis of offset printing plate quality and will give the optimal and same result of coverage. Since the IC Plate II device is specialized for offset printing measurements, that results were used in further calculations.

Figure 29 shows difference between coverage values measured by IC Plate II and calculated with ImageJ (circle and rectangle) and Matlab (circle and rectangle). One can see that certain differences are present. It was expected as the results of the coverage presented in Figure 25 showed similar differences. Since the ImageJ and Matlab are used for calculation of surface coverage based on image analysis their results were compared and shown in Figure 30.
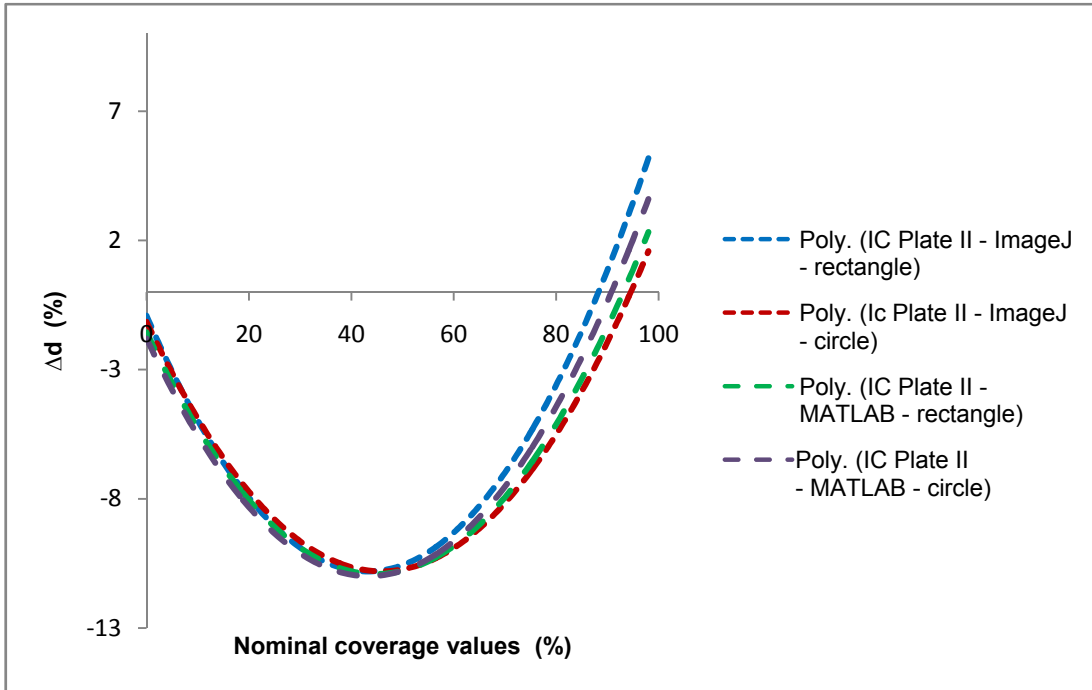
Figure 29. Comparison of coverage values calculated by IC Plate II, ImageJ (circle and rectangle) and Matlab (circle and rectangle)
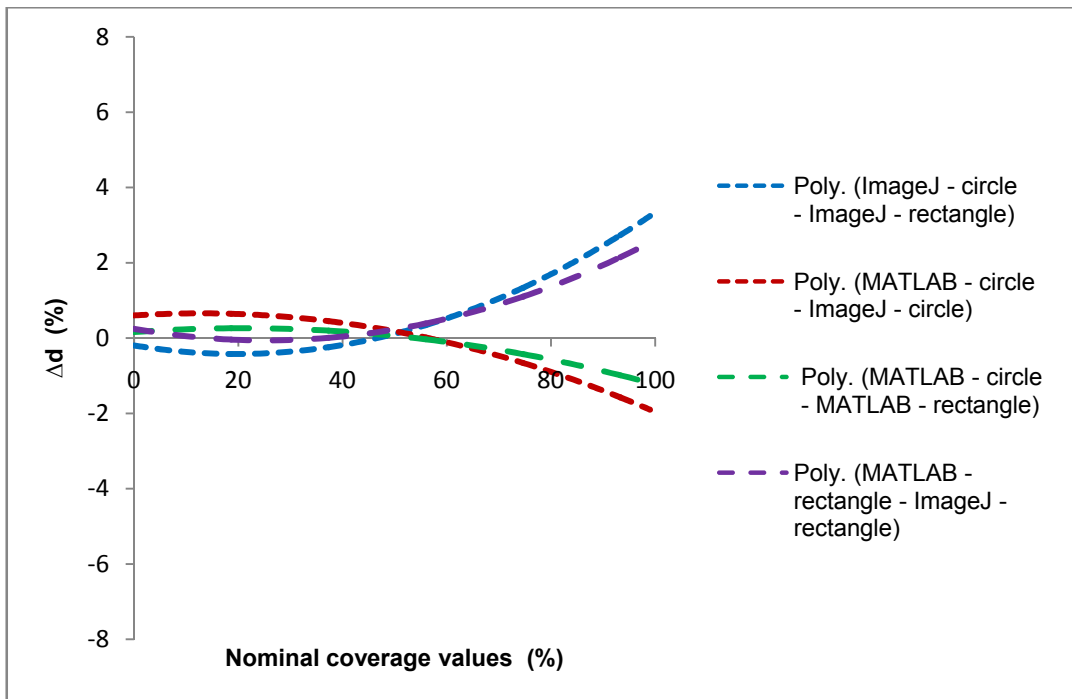

Figure 30. Comparison of coverage values calculated by ImageJ (circle and rectangle) and Matlab (circle and rectangle)

4.1.2.   Second strategy

The main objective of this strategy is to create an expert system which could determine the original circles plate and thus can come to assess the strain that has been in use. The following items summarize the steps involved in this strategy, which were described in detail in section 3.1.2.:

1. Initially, the image is cropped in order to eliminate possible aberrations due to lens in capture processing,
2. The input image cropped is now segmented by means of Otsu method,
3. Circle edges are extracted using Sobel operator,
4. Hough transform is performed that allows catching circles centers and their radius,
5. A refinement step is applied in order to disposal invalid circles,
6. An extrapolation mythology of resulting centers is done and final quality analysis of the resulting image is performed.

Table 3 presents the measures in terms of energy for different printing plates, where it is specified radius and its corresponding energy. The more energy index determined by one hand the more accurate radius and on the other hand the high probability of a center found.

Table 3. Presents radiuses and energies for potential candidates for each printing sample

Radius	Energy	Radius	Energy	Radius	Energy	Radius	Energy
10		**15**		**20**		**25**	
6	10	13	24	18	29	23	32
8	16	15	26	20	30	24	33
10	20	17	27	22	36	25	39
12	21	18	29	23	40	26	40
13	27	19	37	24	43	27	43
14	28	20	43	25	50	28	47
15	36	22	70	26	68	29	72
16	48			27	72	30	97
17	51						
30		**35**		**40**		**45**	
26	34	30	42	32	38	35	48
27	36	32	48	33	41	37	61
29	43	34	57	34	48	39	72
30	47	35	85	35	49	40	78
31	52	36	101	36	51	41	96
32	77			37	60	42	118
33	82			38	78		
34	90			39	131		
50		**55**		**60**		**65**	
38	48	40	50	43	52	45	50
39	57	42	53	44	58	46	54
42	72	43	59	45	65	47	65
43	104	44	79	47	89	48	74
44	112	45	94	48	101	49	102
		46	112	49	126	50	127
		47	124				
70		**75**		**80**		**85**	
46	40	48	49	50	44	52	35
47	44	51	51	53	45	55	39
48	48	52	66	54	70	56	43
49	53	53	75	56	73	57	59
50	60						
51	83						
52	97						

90		95	
53	32	58	30
54	33	59	32
56	38	60	33
57	40	63	41
58	43		
60	47		
61	49		

The Figure 31 shows correlation between radius and energy. It is evident that radius will grow when coverage values increase. Energy is higher for middle coverage values, when in the highlights and the shadows it is low. The reason of polygonal trendline comes from energy results, and the fact is that system detects the background as printing element instead of circles after 50% of coverage.
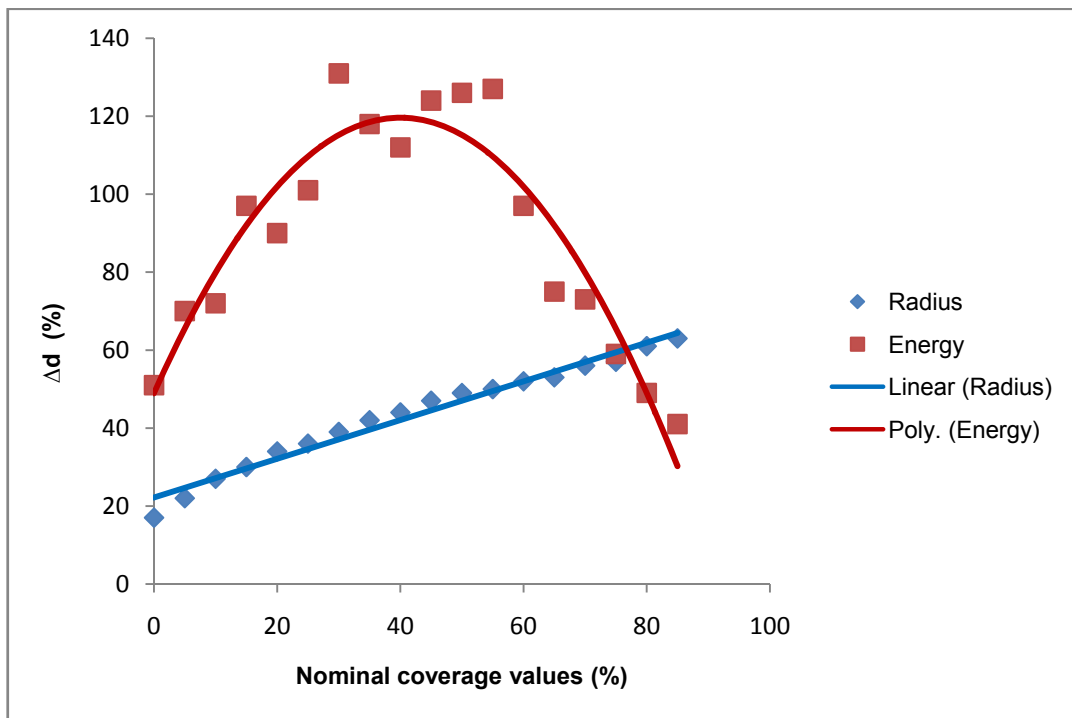
Figure 31. Radius and energy obtained for the different printing plates

After obtaining the candidate centers, it is proceeded to eliminate those we consider invalid respect to a quality metric. This metric corresponds to a threshold value equation described (7). Figure 32 shows on one hand the number of centers obtained with Hough transform (in blue bars) and those that remain after applying the aforementioned quality metric (in brown bars). Finally, we estimate the centers missing to complete the picture by generating a regular pattern extrapolating the distance between centers and their orientations. The total number of centers, either estimated or those remained from the previous phase are shown with the green bar.
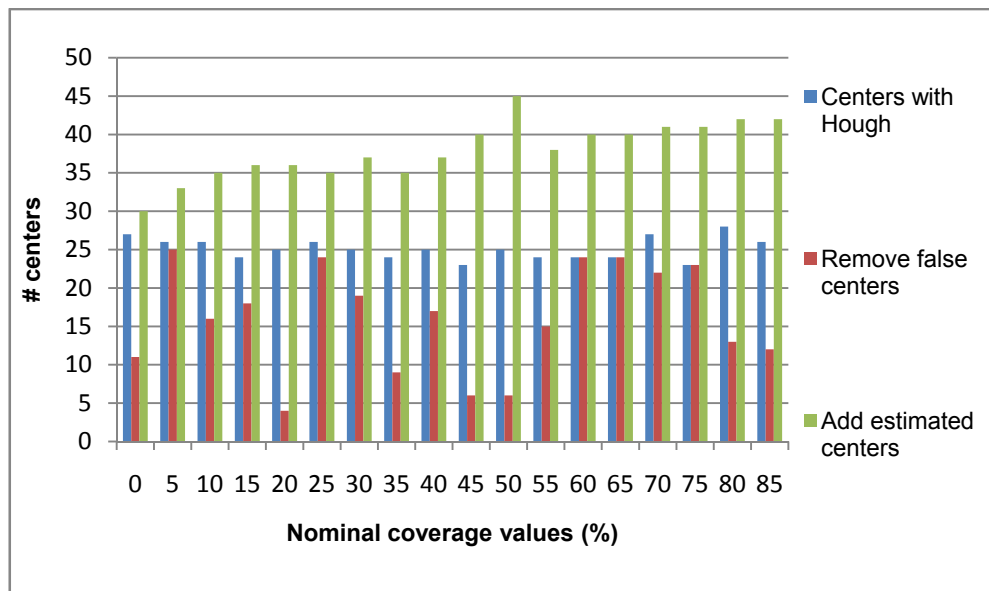
Figure 32. Number of center obtained with Hough (blue bar), after false center removal (red bar) and final estimation of new centers (green bar)
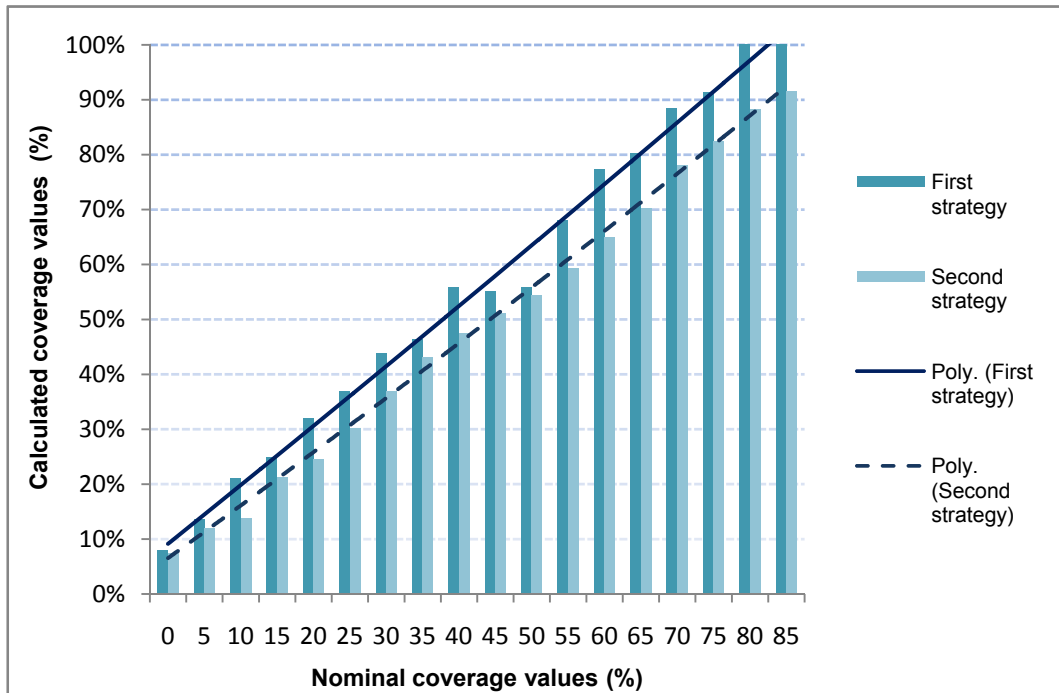
Figure 33. Results of total coverage obtained with first and second strategy

Finally, Figure 33 highlights the results of the total coverage for first and second strategy used.

The application of the second strategy could be seen in Figure 34 where system calculated the distance and angle between the centers of two neighboring circle on the images of 15% and 75% of surface coverage. Because of the dust on printing plate sample during the capturing process, the noise is present on the images and the printing elements could not be seen on this part. According to this, system measured the distance and the angle between printing elements so it can interpolate new element on this place.
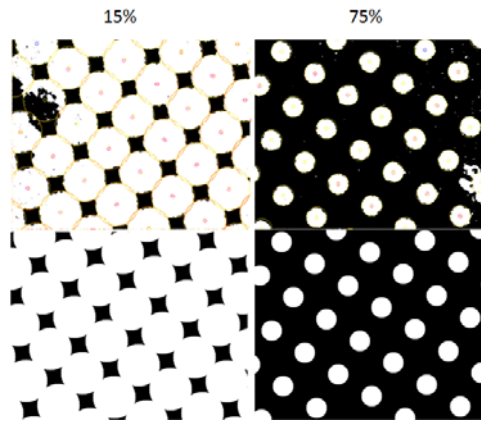
Figure 34. Noise part before and after system's calculating

Table 4. Pearson correlation model for second strategy

Correlation	Correlation coefficient
VipFLEX: Matlab (second strategy)	0,9844
IC Plate II: Matlab (second strategy)	0,983377
ImageJ (retangle): Matlab (second strategy)	0,994839
ImageJ (rcircle): Matlab (second strategy)	0,995164

Table 4 presents the calculation of the correlation coefficient based on the Pearson model. According to the results, the correlation is very high (approximately 1) for all observed methods for calculating the surface coverage. This fact means that application of any of these methods can obtain reliable results.
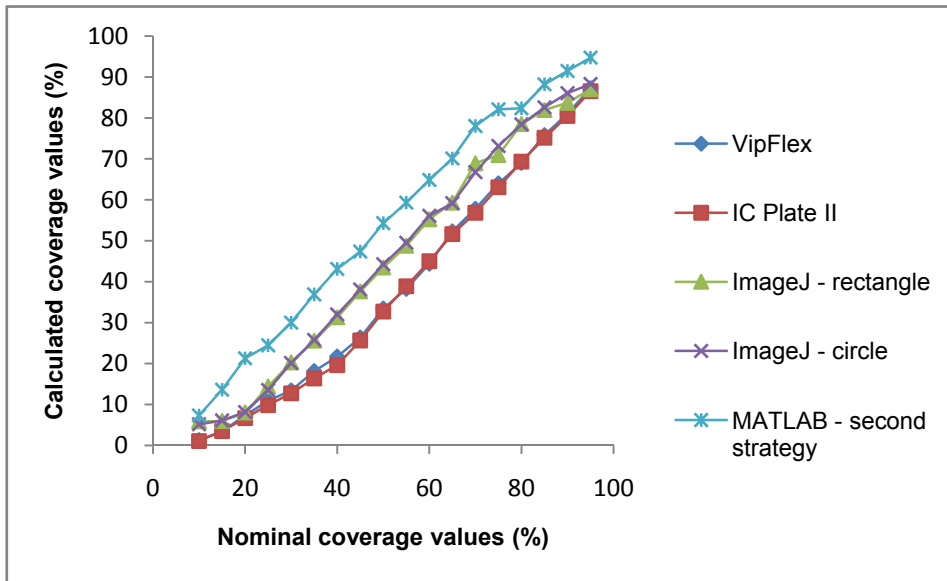
Figure 35. Comparison of nominal and measured coverage values obtained with different methods
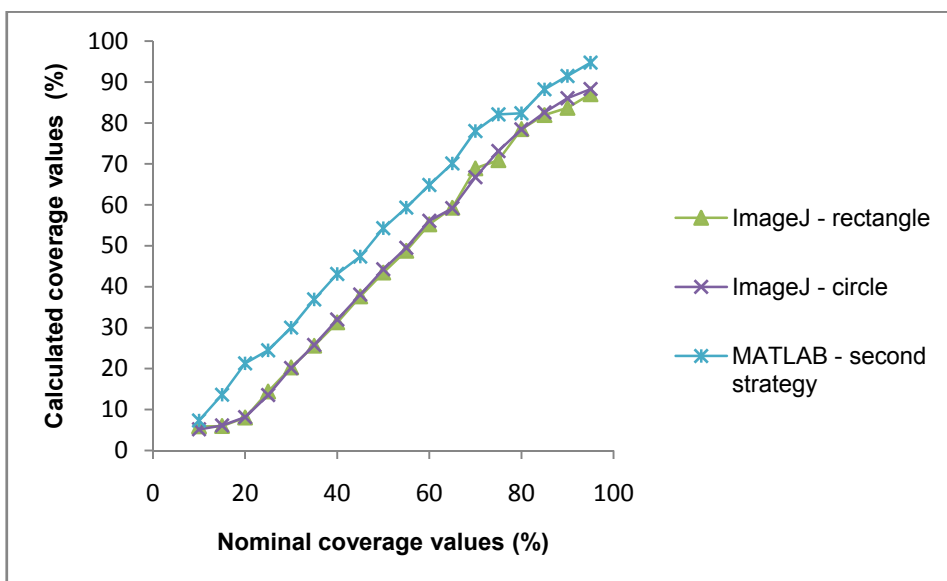

Figure 36. Comparison of nominal and measured coverage values obtained with ImageJ (circle and rectangle) and Matlab – second strategy

Figures 35 and 36 present comparison between different methods including 'Matlab-second strategy' which gets the surface coverage values. Due to the comparison graphic diagrams one can see the deviation between Matlab –

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second strategy and other used methods. Focusing just on image analysis software, as shown in Figures 37 and 38, the deviation is noticeable and Matlab – second strategy coverage values are approximately 15% higher than with ImageJ software. In Figures 37 and 38 *Δd* presents difference between coverage values measured by IC Plate II, VipFLEX, ImageJ (circle and rectangle) and Matlab (second strategy):

Δd = coverage value (VipFLEX) - coverage value (Matlab - second strategy),   *(13)*

Δd = coverage value (IC Plate II) - coverage value (Matlab - second strategy),   *(14)*

Δd = coverage value (ImageJ - circle) - coverage value (Matlab - second strategy),   *(15)*

Δd = coverage value (ImageJ - rectangle) - coverage value (Matlab - second strategy),   *(16)*

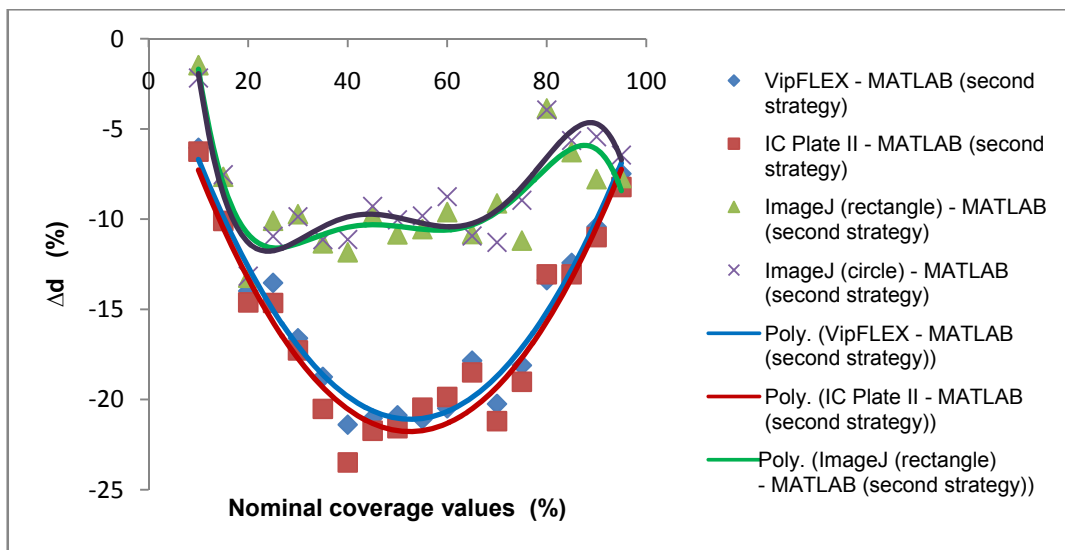*Δd = coverage value (VipFLEX) - coverage value (Matlab - second strategy).*   *(17)*

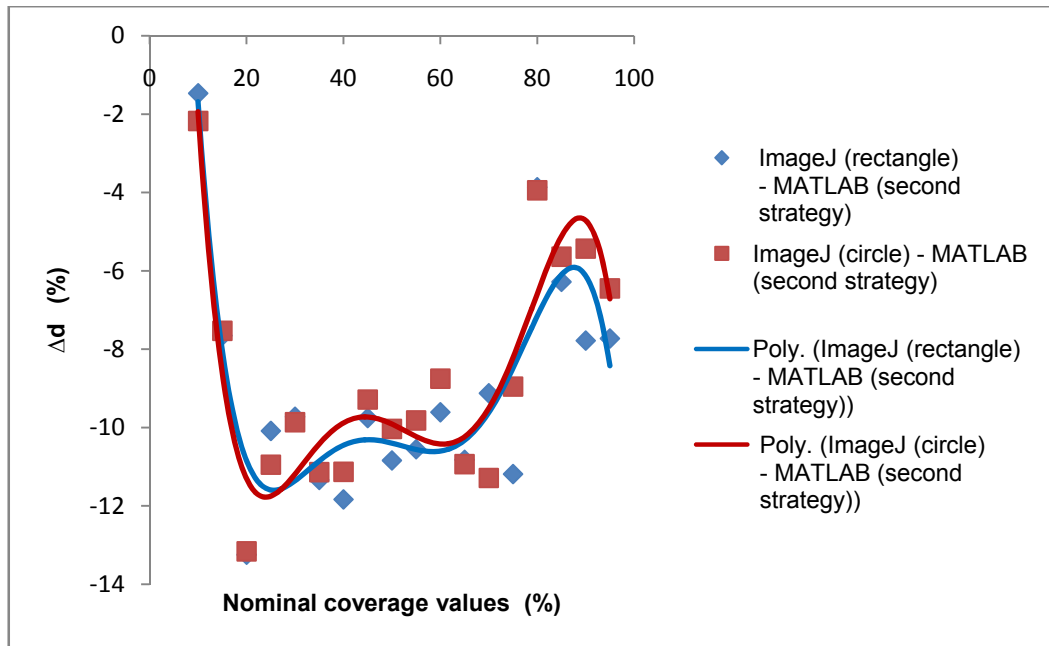**Figure 37.** Comparison of nominal and measured coverage values

Figure 38. Comparison of nominal and measured coverage values obtained with ImageJ (circle and rectangle) and MATLAB – second strategy

4.2. Implementation in a low-cost device

Once it has been shown in the previous section the advantages of our proposal system, a feasibility study for its implementation in a low-cost device was conducted.

The motivation behind this study is supported by the possibility of providing industrial printing systems of an embedded device that tests the state of quality printing plates in real time. This fact enables a possibility of avoiding a technical stop in order to evaluate the quality of printing plates, which allows the reproduction system to operate continuously. Under this premise, the methodologies of implementation described above in a low-cost device were studied.

The successful candidate is an ARMv7 processor that can be purchased for less than 30€. The ARM architecture is based on 32 bits RISC processors designed and licensed by British company ARM Holdings. The first design dates back in 1980s, however today is the chip used in the vast majority of

mobile devices representing 95% of smartphones, 35% of digital televisions and set-top boxes and 10% of mobile computers. The relevance of this processor is well demonstrated by net sales in 2010 with more than 6.1 billion shipments of ARM-based processors.

Figure 39. Scheme of the low-cost system

For this work we have used a system based on Carma platform [29] from SECO company [30] which integrates as CPU an NvidiaTegra with 3 Quad-Cores ARM A9. As GPUs it contains an NvidiaQuadro 1000M with 96 CUDA cores. In Figure 39 is represented a scheme of the low-cost prototyping board that contains the ARM's processor to be programmed.

The first study carried out corresponds to the processing times of the second strategy which is more time consuming. Figure 40 shows the times observed in the CARMA's system mentioned above. As shown, in all cases a quality test can be performed in less than one minute, which supposes a reasonable time if the system requires to be stopped in case of printing plates needs to be exchanged. As expected, the most demanding phase by far is the computation of radius and centers of the circles by means of Hough transform.
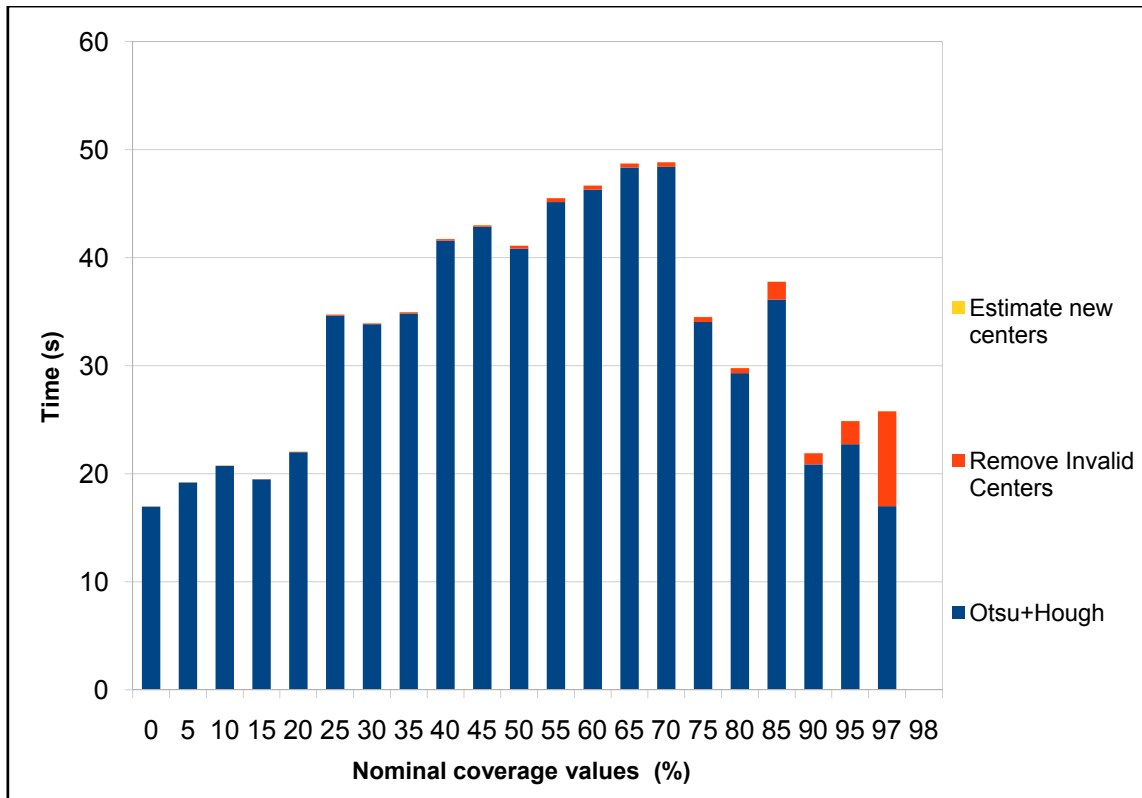
Figure 40. Execution time in an ARMv7 processor

Once demonstrated the feasibility of new proposal system, its scalability was studied. The system used consists on 4xARM processors, so parallelism task can be exploited with an important execution times reduction. A multithreaded application can be coded by means of OpenMP [31] standard programming.

OpenMP uses a portable, scalable model that gives programmers a simple and flexible interface for developing parallel applications for platforms ranging from the standard desktop computer to supercomputer. OpenMP is an implementation of multithreading, a method of parallelizing where by a master thread (a series of instructions executed consecutively) forks a specified number of slave threads and a task is divided among them. The threads then run concurrently, with the runtime environment allocating threads to different processors.

The programming is based on directives or tags which eases the hard parallel coding task. The most common directive is *#pragma omp parallel for* which

distributes the loop iterations between different threads. It should be noted that to achieve successful scalability rates it is recommended to balance work-load among threads in a uniform way.

In our particular case, since the Hough transform is the most costly phase, we focus on parallelizing the main loop that projects different circles for each edge point. Although the way to exploit application parallelism is quite obvious, scalability results (Figure 40) show a successfully efficiency rates of 96% for two processors and 90% with 4 respectively. Figure 41 reinforces this effect, emphasizing the independence of the printing plate chosen.
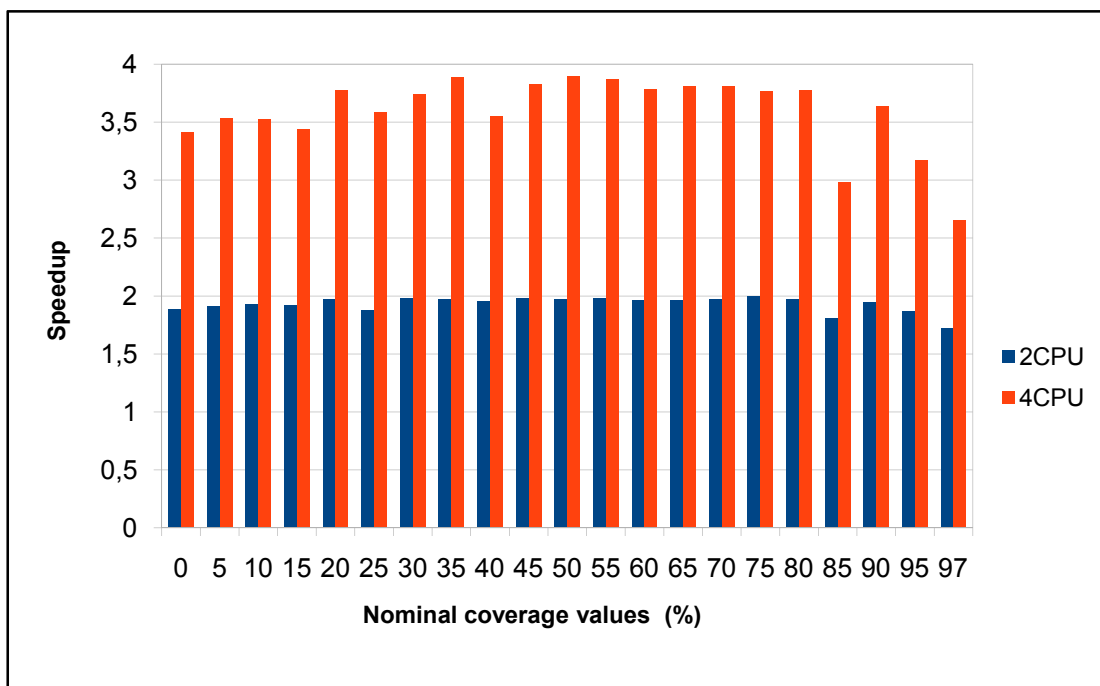

Figure 41. Speedup attained for 2 and 4 ARM's processors

4.3. Conclusions and Future work

There are few quality control methods on the printing plates, but the method with image analysis proved to be the best. This method uses microscopic images of the printing plate surface and software to analyze these images. The image analysis software shows percentage of the surface coverage with the printing elements.

This work describes the implementation of a low-cost system specially for measuring quality of printing plates. The real problem was evaluated under two strategies -just based on dynamic histogram segmentation- and -based on the previous steps plus Hough transform and refinement- in order to construct a robust machine vision system able to deal with noise and other drawbacks real environment. These algorithms have been implemented using the same processors than mobile devices as tablets, smartphones and so on.

Our results have shown that the algorithm is able to detect and visualize motion artefacts with a high rate. We are currently improving the system with the hierarchical multi-scale optical flow algorithm and we will evaluate the achieved motion correction based on Receiver Operating Characteristic (ROC) over different embedded GPUs in order to export that to mobile devices as well.

In this paper the surface coverage was measured with different methods, but the most valuable method by using the software code in Matlab and later translating it into C to be executed in a low-cost device. Captured images of the printing plate surface with circle printing elements were inserted in the software. For future experiment is possible to consider how to measure surface coverage when the elements are not circle shaped, for example oval, or when printing elements have special design shape.

In offset printing every color has a printing plate for itself with printing elements placed under different angle avoiding an appearance of moaré. Accordingly, for future work the software made in Matlab could check if the printing elements for different colors are under the corresponding angles.

Furthermore, developing this software and making it suitable for other printing techniques is also one of the possibilities for future work. Additionally, linking software with appropriate hardware could result in prototypes which could define quality of printing plates in the same way such as with expansive already existing devices.

5. Appendix

5.1. Example of real outputs from Source Code of the system

Figure 42 presents exit images after every step in second strategy. In the first column one can see images where the edge of the circle was detected. Also, it is possible to see centers of the circles colored in red after Hough transform. The yellow circle presents the first refinement, threshold which is used to determine which circle is good, and which one is not. Second column are images which are the product after interpolation where system detected the real size of the circle.

Circle overlapping are showed on the real image in third column and the last column presents final images of the printing plate samples where the circles were constructed using interpolation methods.

It is shown also a set of many examples with larger resolution in Figure 43 (a-d) for sake of clarity.
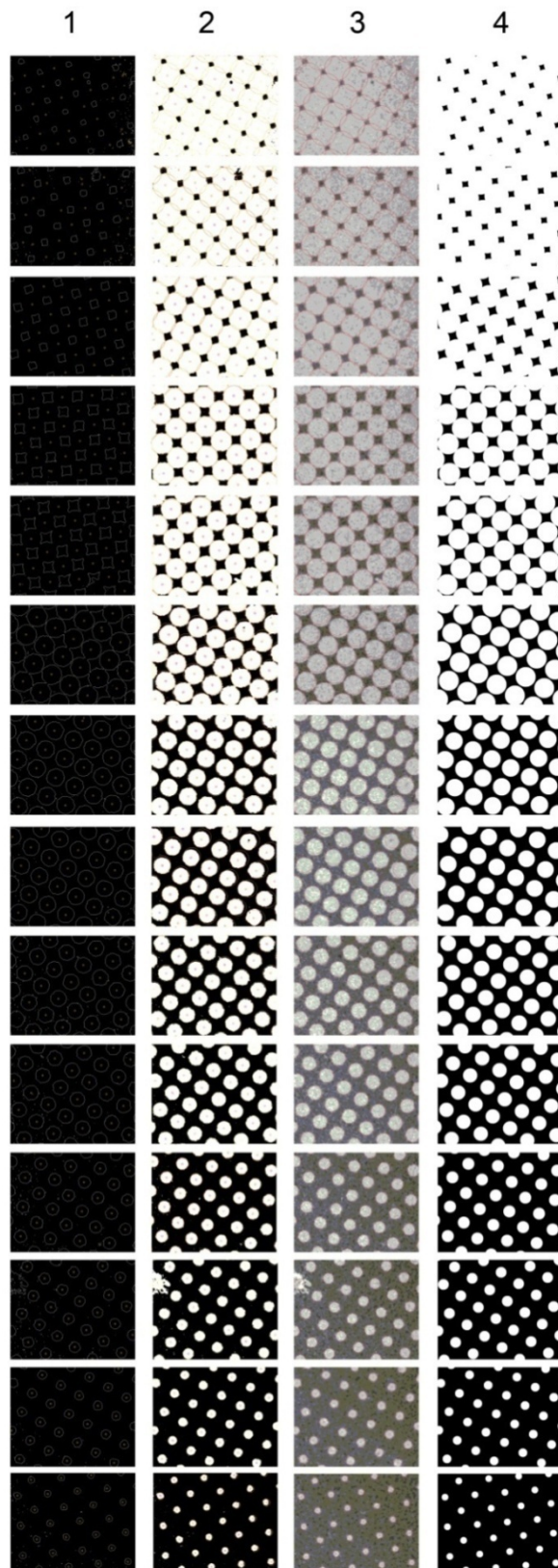
Figure 42. Images obtained after Matlab's calculation of second strategy
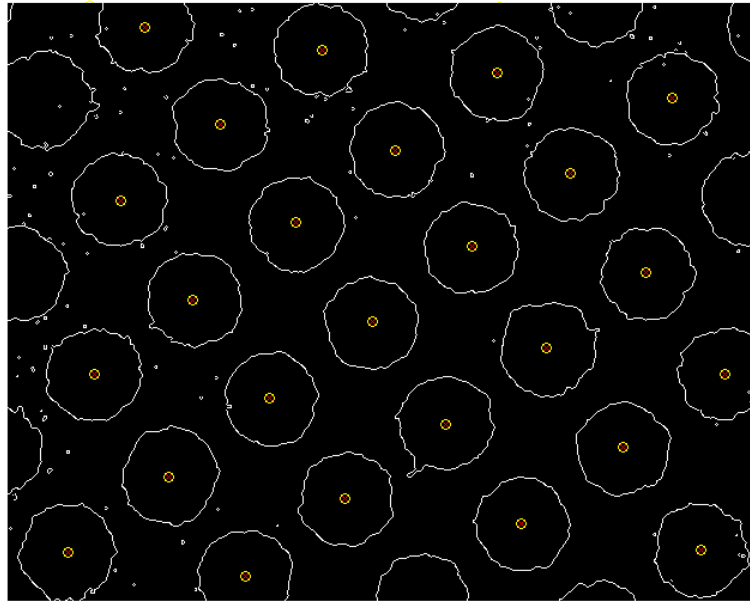(From 10% surface coverage to 95%)

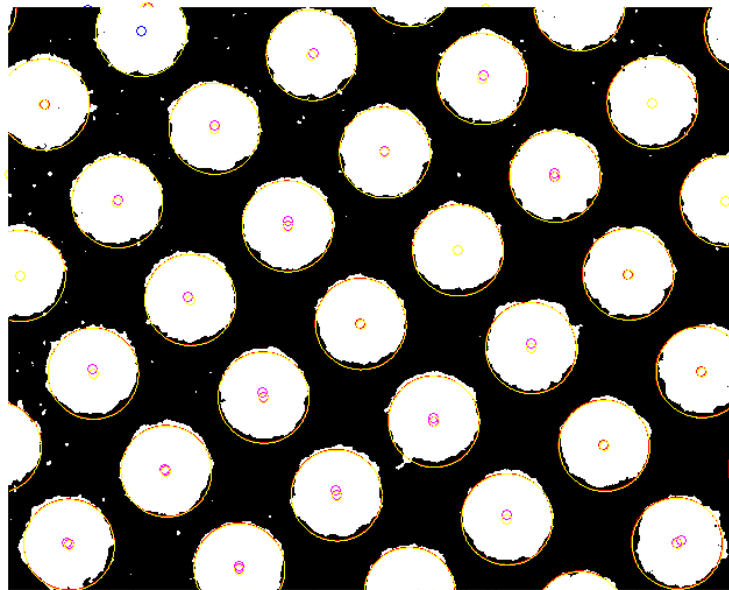**Figure 43 (a).** Examples of circles detected for the first stages of second strategy

Figure 43 (b). Examples of circles detected for the next stages of second strategy
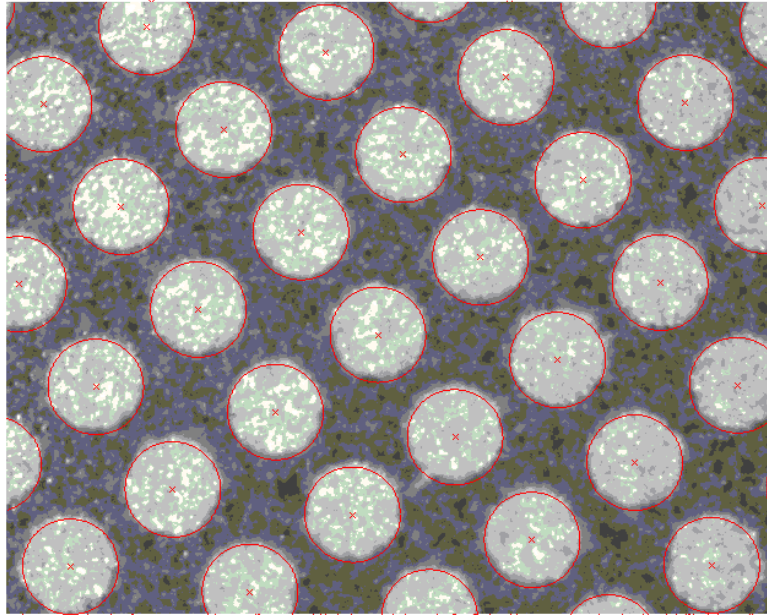
Figure 43 (c). Examples of circles overlapped with real image
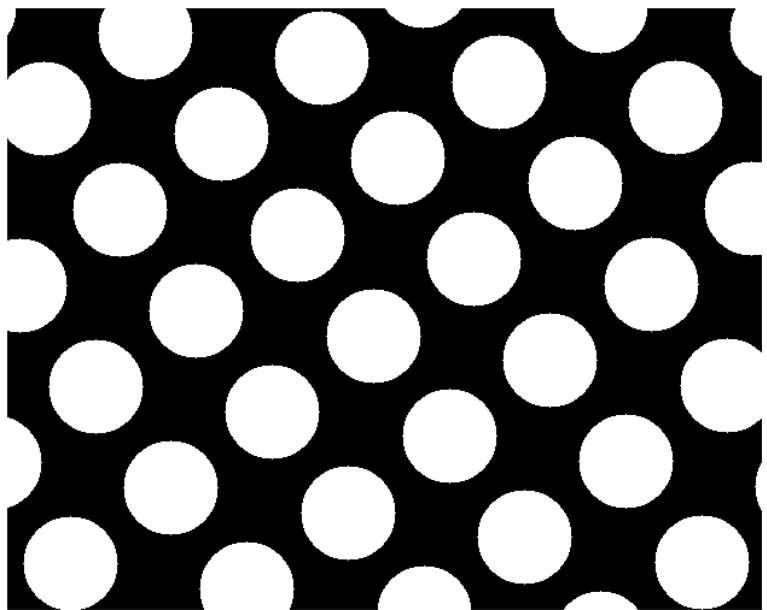

Figure 43 (d). Examples of circles recovered again the real image

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