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FILM AND PANEL TWO-DIMENSIONAL RELATIVE POSITION OPTIMIZATION

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Abstract

The article presents automatic films registration system for printed circuit board exposure units with a new proposed processing method, based on the Radon transformation. The conditions and criteria of alignment deviation evaluation for selected registration marks were defined. Proposition of a mechatronic unit built on a base images from to 2 or 4 movable cameras and 6-axis films positioning device is designed. Align film and panel for a solder mask targets images processing method, based on the Radon transformation, was used. Rules for 2- and 4-point films position optimization were created, as wells as marks and registration algorithms. Experimental results showing capability and limits of the registration system were presented.

1 Introduction

The manufacturing process of printed circuit boards (PCB) is complex. It consists of a sequence of complex operations. The PCB nevertheless it is single-sided, double sided or multilayer, is a base for electronic components assembly and it realizes electrical connections between them. Manufacturing cycle is conducted in a technological process consisting of following stages: exposure, development, etching, building assembly, lamination (for multilayer circuits), drilling, plating, solder mask applying and label printing. The whole process gets even more complicated when some connections in the multilayer printed circuit board are made using buried or blind holes. The majority of these stages require continuous control, which is in most cases conducted automatically in optical measuring devices. Geometry and electrical parameters of constructed circuit is measured to keep observed deviations within defined tolerance limits in order to reach the quality of the final product through applying required corrections to the technological process. Currently [1] the requirements for High Density Interconnect circuit boards are defined by an increased number of connections per area unit in comparison with traditional circuits. HDI technology reduces dimensions, weight and improves electrical qualities. Both minimal track width and minimal space width begins from 75 µm, minimal vias diameter from 150 µm, capture pads diameter from 400 µm and soldering pads density above 20/cm^2. Complexity of printed circuit boards can be defined using following equation [3]:

$$ComplexityIndex = \frac{(Area)\left(No.\frac{OfHoles}{UnitArea}\right)^2 (No.OfLayers)^3}{(MinTraceWidth)(MinAnnularRing)(MinHoleDiameter)}$$

Parameters presented above are exemplary. They describe environment and requirements for circuit boards and also define conditions for the alignment system, which is the subject of this paper. In an exposure machine operation of transferring image from film onto a requested place of resist layer which covers a copper laminated plate, can be conducted in 3 modes:

- outer layer,
- inner layer,
- solder mask.

Each of these modes differently defines the term of optimal position of the film in accordance to the board and/or the second film. Film to film relation is especially important for the double-sided exposure, which is mostly used for its productivity.

For the outer layers drilled holes in the board are used as a reference, and the transferred image must relate to their position. The goal is defined very simply: a hole in the board, and an element from the picture on the film belonging to that given hole should be positioned with the smallest possible deviation in relation to each other during exposure process. For quantity criteria we'll take position deviation defined like on Fig. 1, where as we see we can consider this as two deviations in the direction of OX and OY axes of Cartesian coordinate system, respectively dX and dY, or geometrical sum dPD called process deviation for positioning procedure and representing distance between the center of the hole and the center of the corresponding element on the film.

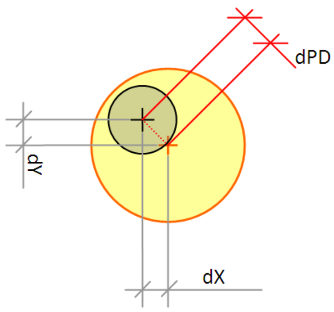


Fig.1 Position evaluation of the elements of the film (circle with bigger diameter) and the hole in the board (circle with smaller diameter) with shown deviations dX, dY, and process deviation dPD.

Since the minimal thickness of the ring surrounding the drilled holes in the board is one of the most important quality conditions, the position of the film has to be strictly related to the position of the drilled holes in the board during the exposure of outer layers. Taking into consideration the following plating process, reaching the limits of the acceptable deviation can lead to breakage of the surrounding ring and disqualification of a circuit board. It is important to note direct relations between total deviation and the size of the circuit components on the film. If the total deviation is smaller, then the sizes of all elements also can be smaller. In this place it would be right to mention that even though our considerations are placed on the area of registration and exposure process, the total geometrical deviations of the final product can also be harmed by: geometry of the films, etching, lamination, drilling and other more detailed steps. In fact, registration process is only one of the several factors that have a direct influence on the final quality of the product, namely the circuit board.

In most cases, for the inner layers we have to deal with a panel on both sides covered with copper and resist (dry or liquid). Also, inner layer mostly does not have any drilled holes and in this case registration has to be made only between the films. For this type of boards, it is required to have top and bottom film in relation to each other given by specification, what in the end makes elements of one film match elements of the other. In the case of films' only registration we can use the same criteria for evaluating deviations, and, like it was defined on the Fig. 1, we have to consider three values dX i dY and dPD.

Exposing solder mask is one of the final operations for the already assembled multilayer circuit board, when outer layers are already exposed, registration for the films has to be made in relation to what was previously exposed, developed and etched on the panel. Solder mask has a task to leave open only soldering points for electronic assembly: placing and soldering. If all elements of the PCB construction are minimized then also place for the mask has to match existing pattern on the outer layer and follow precisely conditions defined in the specification.

It is evident, from the analysis presented above, that regardless of the mode of exposure the proper location of the film panel and / or second film is required. Evaluation of the registration process can be done by measuring the parameters of dX, dY, dPD (deviations). Activities taken to minimize deviation values always will refer to the whole panel and in fact never to a single selected point. It is possible to define the following criterion (1):

$$\exists dx, dy, d\alpha \forall (x, y) \in PCB, \min\left(dX(x, y), dY(x, y), dPD(x, y)\right) \quad (1)$$

Presented criterion (1) describing conditions to evaluate registration process shows film position referring to the whole board area. It takes into account all the points lying on the surface of the circuit. Nevertheless, we will analyze only critical locations from the standpoint of technology and board quality requirements. So, instead of an infinite set of points to analyze we will always use a discrete set with contents depending on design and technological conditions.

2 Proposed system

In order to design system, criterion (1) was taken as a starting point. At the stage of registration we have to deal with deviations depending on different sources:

- Changes of the film geometry depending on the imprecision of the laser plotter, changing line into curve and rectangle into polygon – all this is minimized by the proper calibration of the plotter,
- Changes of the film geometry depending on their thermal stability. Exposure process may lead to film temperature increase and cooling process to temperature decrease. As a consequence, we will observe expanding or shrinking of the film and potential dimensional instability. Typically, dimensional deviations are limited to a given, defined value,
- Random position deviations of drilled holes in the panel that depend on the precision restrictions of a numerically controlled drilling machine and tool (drill bits bending on the laminated surface of the panel).

For the sake of our analysis we assume that the films registration process has to minimize deviations, with no dependence on the source that they are coming from. Measured deviations will be compensated by applying corrections to the film position in a way to minimize their impact within the predefined tolerances.

The registration system should be a compromise between the number of measurement points on the board, the number of cameras used and the time needed to evaluate input data – images from all sources. Taking into account on one hand requirements and on the other the experience of production techniques for manual registration, two solutions were considered. The first uses two cameras and two marks on the board layout and films. In this case the marks are located centrally in the symmetry axis of two shorter sides of the panel. The second solution assumes the use of four cameras and appropriate marks located in the corners of the board.

Regardless of the number of marks and number of used cameras, film positioning is aimed at optimization. Optimization has a task of minimizing the position deviations, which depend on both instable film size and variable location of the panel holes used as registration marks.

We assumed that the system can operate in two different tolerance modes, respectively: dimensional deviations (film to board) and alignment deviation. The basic mode is the mode of DA (Dimensions / Alignment), in which dimensional tolerance (2) and the alignment tolerance (3) are defined separately. In this mode, the measuring system will calculate position of the registration marks on the basis of processed input images from the cameras, and using this data will calculate separately dimensional deviations for both the films and the alignment deviations film to board or film to film. All calculated values will be compared with given tolerance values. If the dimensional deviation is greater than the dimensional tolerance (DT), system will stop registration procedure and an error message describing the reason will be presented to the operator. In the case of crossing the tolerance limit for the alignment deviations (AT), the registration process will be repeated and new deviations will be compared once more with the given tolerance values.

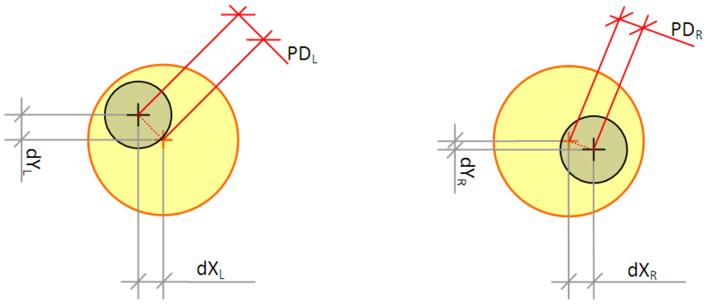


Fig. 2. Dimensional deviation and alignment deviation [dX, dY – alignment deviations (L – Left camera, R – right camera), PD – process deviation]

Beside basic tolerances mode we have also a second one, which is in fact simplified, using just one value of tolerance called PDT (4) (process deviation tolerance). In this mode the value of PDT has a task to define a border for all values of PD (Fig. 2) calculated for the every camera separately. We compare measured distances (PDL, PDR) between the center of the hole in the board and center of the mark on the film (both or single one, depending on the mode), and also distance between mark on both films, with a predefined value of PDT. In the PD mode we do not check separately the tolerances for dimensions and alignment, unlike the DA mode. Formally, the principle of tolerance rules with the use of DA, AT, PDT can be described in the following way (meaning of parameters shown on Fig. 2):

- DA – dimensional tolerance

$$|dXL - dXr| \le DT \tag{2}$$

- AT – alignment tolerance

$$\max\left(\left|\frac{dXL + dXR}{2}\right|, |dYL|, |dYR|\right) \le AT \tag{3}$$

- PDT – process deviation tolerance

$$\max(PDL, PDR) \tag{4}$$

where max - function to get maximum value from the comma delimited list of values.

In the four point (marks) registration mode, the basic rule and optimization condition (5) is still valid. We proceed with an alignment of the film in a way that minimizes the value of $\max(PD)$, measured using images from all used cameras, described as CQ_1, CQ_2, CQ_3, CQ_4, where symbols $CQ, \dots, CQ_4$ are representing corresponding 4 quadrants of the XOY coordinate system. Every camera CQ_i belongs to the corresponding corner of the board with associated reference hole and film marks.

$$\max\left(PDQ_1, PDQ_2, PDQ_3, PDQ_4\right) \qquad (5)$$

where PDQ_i is a value of PD measured in the corner of the board belonging to the quadrant i.

Movements of the films can be described by parameters of a flat displacement, represented by offset and rotation value, corresponding respectively to movement along the OX axis, movement along the axis OY and rotation round the zero point of XOY system. Modified and generalized optimization criterion can be written as:

$$\exists(dx, dy, d\alpha), \min\left(\max\left(PDQ_1, PDQ_2, PDQ_3, PDQ_4\right)\right) \qquad (6)$$

As we can see we search for the value of $(dx, dy, d\alpha)$ that minimizes the maximum deviation PD (6) at all points where the position has to be verified. This criterion also fits into the system with two sets of targets as well. In such case in the optimal position appropriate deviations will have following values (7):

$$dXL = -dXR, dYL = 0, dYR = 0 \qquad (7)$$

Proposed arrangement to allow the positioning of films and plate is shown below in Fig. 3. illustrating the concept of the device for carrying out this idea.

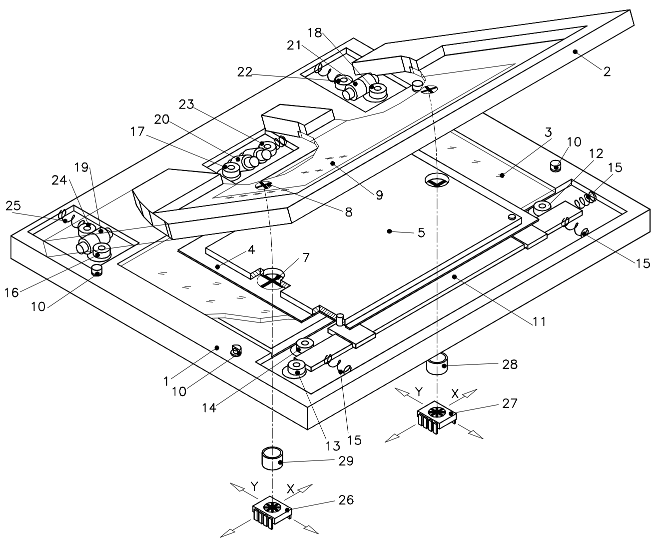


Fig. 3. Concept of the frame to position films and panel before exposure, equipped with cameras to check registration target location and critical deviations

It consists (Fig. 3) of two frames, the lower /1/ and upper /2/, containing glass /3/. Top film /5/ and bottom /4/ has marks placed in the technological margin on the axis of symmetry of the panel's short side for 2 target registration or in the panel corners for 4 targets registration. Eccentric rollers /18, 17, 16/ move top frame. Springs /25/ and rollers /19, 22, 20, 23, 24/ provide play less drive and roller bearings for vertical movement of the frame /2/. Panel /5/ is attached to the panel holder bar 11, also driven by eccentric rolls/12, 13, 14/ supported with a backlash springs /15/. Image with film targets and holes in the panel is projected thru an optical path /28, 29/ to image sensors /26, 27/ – CMOS cameras. Depending on the type and location of targets on the panel cameras with optical system moving in the directions x, y.

Alignment of the films is a very important operation in the exposure process, but not the only one which has to be done to get a ready exposed panel. Usually before alignment films has to be loaded into the frame. During exposure and alignment they are fixed to the glass with a dedicated vacuum, also, they must be pre-aligned in relation to the initial panel location when loaded. Switching the unit into the proper mode can be done by selecting the given job. Job is defining not only a mode for alignment but also the type, count and location for targets, all tolerances and tolerance mode, and other not alignment related parameters like: limits for the vacuums, time and the way how the panel must be exposed. Basic operations belonging to the exposure unit cycle are shown in Fig. 4.

```
//high level representation for the exposure machine activities
//Job is representing data definig task to do and all needed parameters
int ExposureUnitCycle(){

    InitializeUnit();
        //N will represent number of exposures to do
    int N = SelectJobToDo();

    LoadFilms();
    for (int i = 0; i < N; i++){
        LoadPanel();
        RunRegistrationForCurrentPanelAndFilms();

        if (Max(SetOfDeviations())<ProcessTolerance){
            ExposePanel();
        }
        UnloadPanel();
        if (UserBreak) return;
    }
    UnloadFilms();
}
```

Fig. 4. Exposure unit cycle showing basic operations performed during run

Exposure unit cycle Fig. 4 can be terminated as a result of positioning and exposing assumed number of panels or by the action of the operator depending on external conditions, or by equipment, taking into account the control parameters like, for example, thermal stability of films described above. Because the system automatically verifies the critical tolerances, the need to interrupt the process of alignment or exposure tasks can be transferred to the operator with a corresponding message describing exceptional conditions.

From the side of film positioning application, it is important *RunRegistrationForCurrentPanelAndFilms* function Fig. 4. Detailed activities belonging to this action are shown in Fig. 5. It is assumed that before registration the camera will move automatically to the position of marks according to the selected job. Since each camera is equipped with two axes driven by DC motors, a change in their location is done just by specifying the coordinates (xc, yc) for the new target position.

```
//high level representation for panel to films alignment
int RunRegistrationForCurrentPanelAndFilms(){
    int counter = 0;
    MeasureTargets();
    if (RepositionCamerasIfNeeded())
        MeasureTargets();
    do {
        SetFilmsToTheStartPosition();
        for (int i = 1; i < NumberOfSteps; i++){
            MeasureTargets();
            MoveFilmsToNewLocation(i,NumberOfSteps);
        }
        MeasureTargets();
        StartContactVacuum();
        MeasureTargets();
        done = (Max(SetOfDeviations())<ProcessTolerance);
    while (!done && (++counter < MaxRepetitionCounter));
    return 0;
}
```

Fig. 5. Alignment cycle to optimize films position

The target measurement process is described as *MeasureTargets* and is performed using the cameras. The calculated location of marks is used to evaluate the parameters, for each film separately. These values are the basis for determining the displacement for every of 6 axis used to

move films. The initial deviation is divided inside the function *MoveFilmsToNewLocation* using the variable "*i*" representing the next iteration and the parameter *NumberOfSteps* defining how many steps the system should take from a starting point the optimal position. Iterative approaching the optimal location is used to reduce the impact of hysteresis, backlash and stiffness of the mechanical system.
The cycle of positioning shown on Fig.5 may be repeated if after turning on the contact vacuum inside the function *StartContactVacuum* (), required during exposure, the resulting position of the films or panel will be disturbed and final verification will measure deviations being bigger then defined tolerances. Contact vacuum is created in a sealed space between both glasses and includes films and panel (Fig. 3). Contact vacuum has a potentially negative impact on positioning result. In the exposure process it has a very important function – it provides direct contact between the resist and film. Direct contact is necessary to eliminate the effect of undercutting or shade, being a side effect of non parallel rays from UV lamp when exposing.
To carry forward the process of alignment, system based on information from images obtained from cameras observing films and plate at a given location must be able to determine the values of relative displacements, using marks on the films and the hole in the plate. To do so, films and plate must be adequately represented in the image from the camera [7].

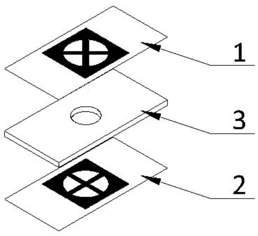


Fig. 6. A sample set of marks: 1 - for the upper film, 2 - for the bottom film, 3 - for the panel

A sample set of marks is shown in Fig.6. At the same location like the hole in the panel, the bottom film has a mark in the form of a "+"and the upper film mark in the form of an 'x'. Sample sizes are: a hole diameter of 3mm, the thickness of the line marks "+" and "x" is 0.254 mm. The form of marks usually is matching the mode of operation and the type of panels.

2.1 Image based marks position

To read detailed information from each single camera is essential for the proper function of the alignment device. Therefore, for this purpose a modified image processing technique based on Radon transform, allowing rapid and accurate determination of straight lines in the image, was used

The Radon transform (TR) is defined as [6]:

$$R_\theta(\rho) = \int_{-\infty}^{+\infty} f\left(x'\cos\theta - y'\sin\theta, x'\sin\theta + y'\cos\theta\right) dy' \tag{8}$$

where

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix} \tag{9}$$

The Radon operator maps the spatial domain $f(x, y)$ to the projection domain (ρ, θ), in which θ is the angle and ρ the smallest distance to the origin of the coordinate system. The discrete Radon transform is a useful tool in image processing for detecting of lines in digital images.

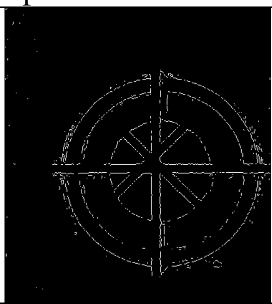
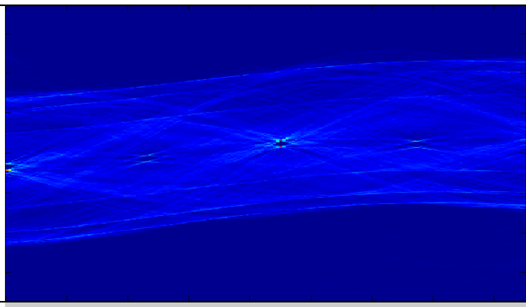
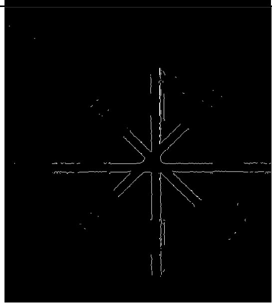
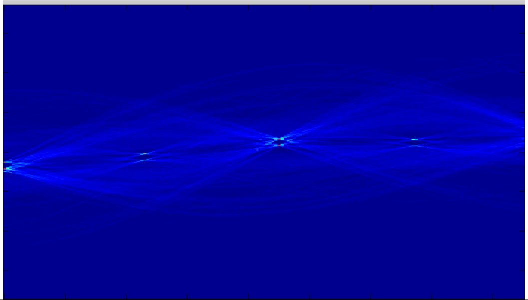
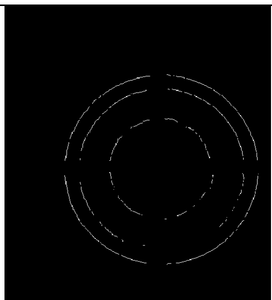
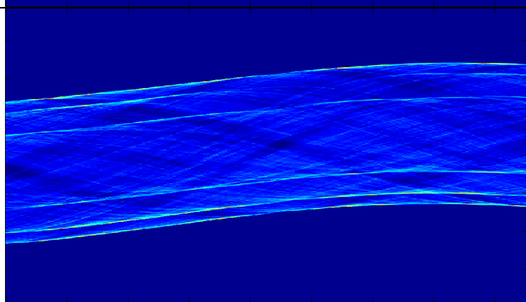
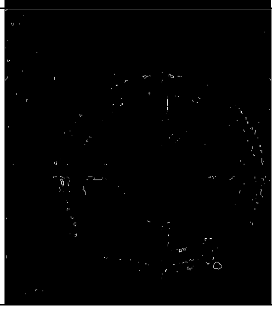
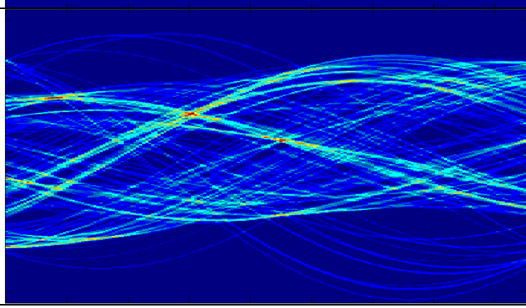
Major key properties of the Radon transform is that a line in an image is transformed into a peak in the parameter domain, where the position of the peak corresponds the line parameter [4,6,9].

Analyzed class of images is characterized by regular shapes such as lines and circles (several of them with a common axis of symmetry). All of them will include the possibility of noise captured directly from images sources, the electronic camera, which have potentially negative effects on parameters values in the field of RT. Studied class of images can be described as a sum of the individual components:

$$f(x,y) = f_l(x,y) + f_o(x,y) + f_e(x,y) \tag{10}$$

where $f_l(x,y)$ - a straight lines component of the image, $f_o(x,y)$ - circles component, and $f_e(x,y)$ - noise (Tab. 1).

Tab. 1. Edge image and its representation in the RT domain for individual components

	Spatial domain	Radon domain
$f(x,y)$		
$f_l(x,y)$		
$f_o(x,y)$		
$f_e(x,y)$		

The proposed algorithm consists of two independent stages:

- lines detection in the image,

- circle detection (position for circle axis of symmetry).

As it was mentioned earlier, straight lines detection in the image $f(x, y)$ is limited to the search finding local maxim (peaks) in the image transform. To limit the information contained in the RT coefficients original image is transformed with the use of Sobel filter. Radon transform is applied to the resulting image containing edges information. In the resulting array of RT coefficients, depending on the class of the analyzed image, search of 8 up to 10 local maxims is performed max-local $\max_{local}\left(R_\theta\left(x'\right)\right)_n$ for $n \in \{1,\ldots,10\}$. Using located angle θ and x' values position of individual straight lines can be calculated, depending on the position of individual marks needed to proceed with a alignment task the device.

Knowing already, the characteristics of RT parameters for $f_l(x, y)$ defined by calculated straight lines parameters occurring in the given image, it is possible to calculate the for $f_o(x, y) + f_e(x, y)$. Mentioned decomposition of the edge images, the best is to make in the spatial domain, because when transforming the discrete image both ways (including its inverse transformation), some simplifications can take place (rounding) what may lead to a number of imprecision.

The proposed method creates a synthetic image representing straight lines $f_l(x, y)$ - replacing (overwriting) information from the edge image. Resulting image is converted using the Radon transformation. The resulting RT coefficients represent concentric circles and noise only.

In order to eliminate component $f_e(x, y)$ we propose to use the classifier based on the parameters of the circle. In the RT domain given circle is basically defined by two curves, parallel to each other. Distance in Euclidean space between them for any θ is equal to diameter of the circle. While the curve of arithmetic average value in the spatial domain is a circle center. It should be added that any two values of the curve are enough $F(\theta)$ to designate a point in spatial domain.

Based on the above assumptions, for a classifier purpose, it has to be determined:

$$R_\theta\left(x'\right) = RT\left(f\left(x,y\right) - f_l\left(x,y\right)\right) = RT\left(f_o\left(x,y\right) + f_e\left(x,y\right)\right) \qquad (11)$$

The resulting image we transform using Sobel filter, and the result of this operation we interpret as a graph of several curves of $R_\theta\left(x'\right) \rightarrow F_k\left(\theta\right)$, where k is the index of a point in spatial domain.

Point to find (center of the circle) must meet the following criteria

- for each θ couple $F_k\left(\theta\right)$ and $F_{k+1}\left(\theta\right)$ distance in Euclidean space
- for any θ couple $F_o\left(\theta_n\right)$ and $F_o\left(\theta_{n+m}\right)$

$$\left(x_o, y_o\right) = \max\left\{iRT\left(F_o\left(\theta_n\right), F_o\left(\theta_{n+m}\right)\right)\right\} \qquad (12)$$

where $iRT\left(\cdot\right)$ is a inverse Radon transform.

Given point is a center of the circle to find for a diameter d (see Fig. 7).

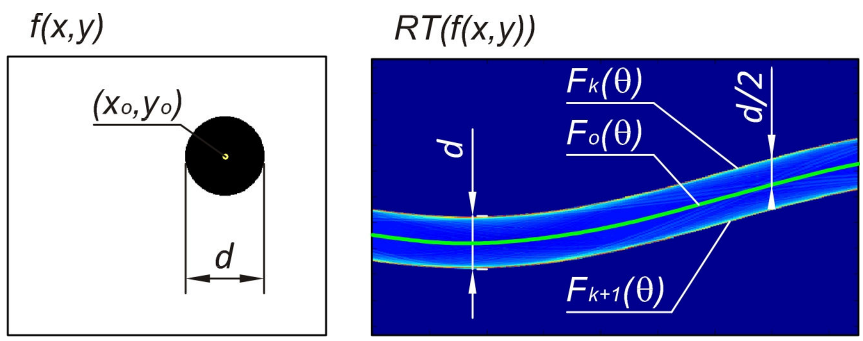
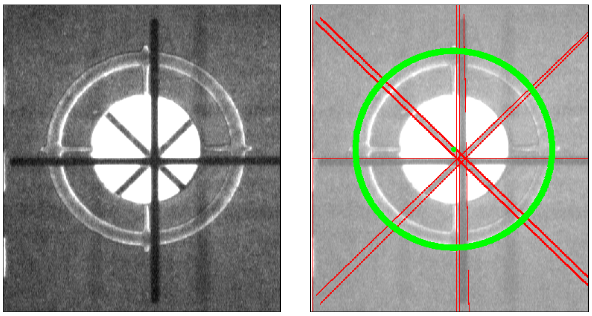


Fig. 7. Circle representation in the RT domain

3 Experimental results

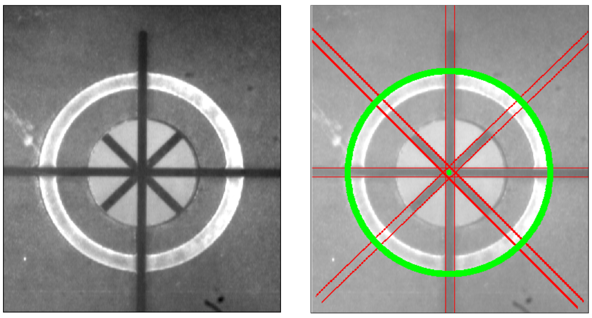
The registration method described above and its implementation, like shown on Fig. 3, was used in the frame of exposure unit, for positioning the film in the outer layer mode. Marks placed on the films and panel in regard to propose shown in Fig. 6. Following results are presented below:

- Results of alignment for the outer layers including the images obtained from cameras used to make final verification,
- Assessment of marks position deviations for the films and panel in relation to the calculated optimal value,
- Example of verification for the films and panel alignment based on images from the measuring machine OPTEK Video Optical Coordinate Measuring Machine.



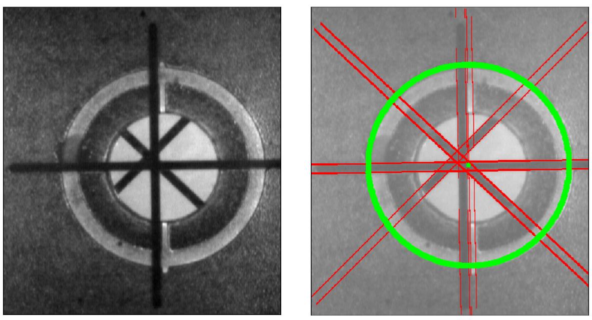
(a) (b)

Fig. 8. Image from the camera Q1; (a) Source image from the camera, (b) results of the image processing



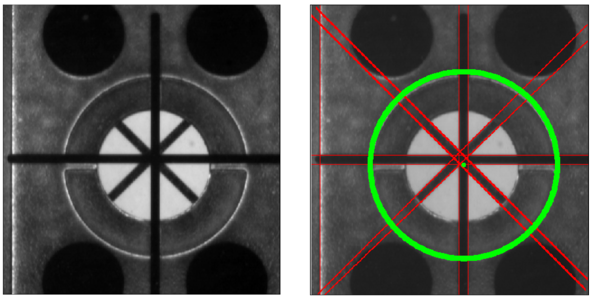
(a) (b)

Fig. 9. Image from the camera Q2; (a) Source image from the camera, (b) results of the image processing



(a) (b)

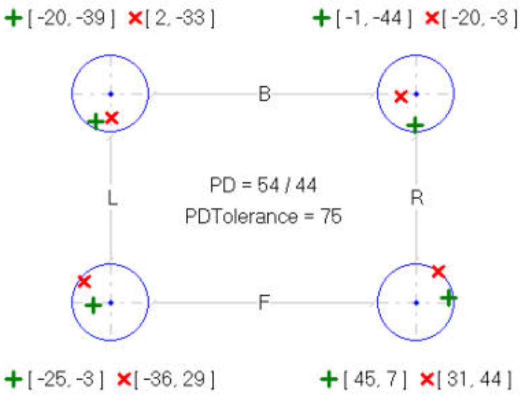
Fig. 10. Image from the camera Q3; (a) Source image from the camera, (b) results of the image processing



(a) (b)

Fig. 11. Image from the camera Q4; (a) Source image from the camera, (b) results of the image processing

For the given alignment and definition of targets, on the Fig. 8, 9, 10, 11, images from cameras placed in quadrants 1, 2, 3, 4, marked as Q_1, Q_2, Q_3, Q_4, are shown. Resulting position of films and panel marks reached during alignment process is presented. At this stage, the plate is ready for exposure. The image on the left is processed and the right one shows the result of image processing together with information describing the calculated coordinates of the marks. Deviation values in microns measured for all film marks in relation to the holes in the panel are shown in Fig. 12. All values obtained for the analyzed marks are presented in table Fig. 12, together with calculated values of dX, dY, dPD limited by predefined tolerances.



		H	T	B	HT	HB
Q1	x	-20	-40	-21	-20	-1
	y	527	524	483	-3	-44
	PD				20	44
Q2	x	-69	-67	-89	2	-20
	y	595	562	556	-33	-39
	PD				33	44
Q3	x	363	327	338	-36	-25
	y	145	174	142	29	-3
	PD				46	25
Q4	x	-131	-100	-86	31	45
	y	-67	-23	-60	44	7
	PD				54	46

Fig. 12. The result of films and panel alignment (a). Coordinates of marks and deviation values (b) measured at the verification stage before exposure for the outer layer job

Obtained values, like those shown on Fig. 12, are compared with calculated optimum. For each mark the PD value obtained in the alignment process is compared with calculated optimal PD and the maximum difference is limited by the value of tolerance. Optimal position for both films and marks from our experiment are shown on Fig. 13 and 14.

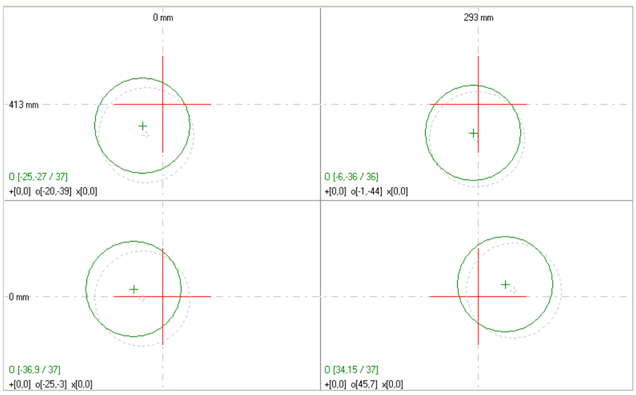


Fig. 13. Calculated optimal position of the bottom film used for verifying alignment of the outer layer

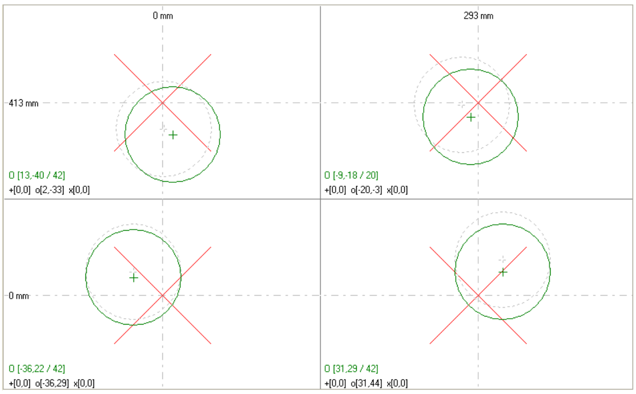
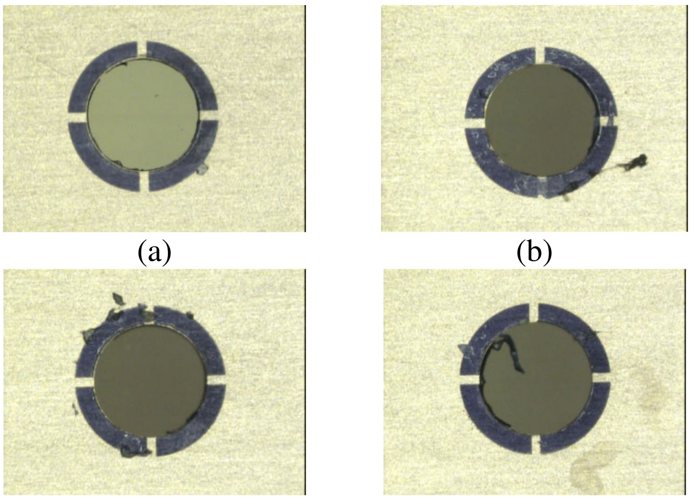


Fig. 14. Calculated optimal position of the top film used for verifying alignment of the outer layer

As shown in Fig. 13 and Fig. 14, the corresponding optimal values calculated for the *PD* are respectively 37 µm for the bottom film and 42µm for the top. Both values, when compared to the deviations obtained after alignment are respectively 44 µm and 54 µm, what gives 7 µm difference for the bottom film and 12 µm for the top. In this case, according to the algorithm from Fig. 6, depending on defined value of tolerance the board will be exposed for the tolerances *PD* greater than 12 µm, and for the smaller ones alignment will be repeated. To move the films to the optimal position, which will make the difference between the values, obtained in the alignment and calculated, to equal zero, both films position adjustments must be made with the parameters:

- Bottom film: $\left(dx = 11, dy = -15, d\alpha = 1.211e^{-5}\right)$,
- Top film: $\left(dx = 11, dy = -15, d\alpha = 1.211e^{-5}\right)$.

Verification of the alignment system operation can be done by an external optical measuring device (OPTEK Video Optical Coordinate Measuring Machine). Images obtained from such system used for the verification are shown on Fig. 15.



		HB
Q1	x	-3
	y	-42
	PD	42
Q2	x	-22
	y	-38
	PD	44
Q3	x	-22
	y	-1
	PD	22
Q4	x	47
	y	8
	PD	48

(c) (d) (e)

Fig.15. Images used for alignment external verification with exposed and developed targets (a),(b),(c),(d), for bottom film obtained from measuring machine (OPTEK) and table (e) of values for quadrants

The verification of the alignment process (Fig. 14) is only possible after exposure and panel development. Of course, such action is necessary only in order to confirm behavior of the alignment system, verify internal calibration and validate results. The maximum deviation of the measured values and the resulting positioning was less than 3 µm.

4 Conclusions

The presented system can be used as a tool for very precise films alignment in the exposure unit, with user-defined parameters. Cameras and obtained images allow to measure special targets' positions. Using position of targets measured on the base of image processing, current process deviations can be calculated and optimal film position as well. Alignment controller will use all those values to calculate displacement for the films, and using controller will move them into a location as close as possible to the optimal. Described process will minimize deviation for each of the films by appropriate corrections, evaluated and introduced independently for every film. Control for the alignment system is complex and requires taking into account many factors that may limit its accuracy, actually not mentioned in this paper. As a result, in addition to the basic alignment function, we get coordinates of film and panel marks that can be used to optimize, in a broader sense, process of manufacturing multilayer circuit boards.

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