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Faculty of Transport and Mechanical Engineering
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The direction "Medical engineering and medical physics"

DIGITAL MEDICAL X-RAY DEVICE RADIATION STABILITY EVALUATION METHOD

Field: Mechanical engineering
Subfield: Measurement instrumentation and metrology

PhD Thesis summary

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PROMOTION WORK HAS BEEN SUBMITED FOR OBTAINING OF ENGINEERING SCIENCES DOCTOR DEGREE IN RIGA TECHNICAL UNIVERSITY

The doctoral thesis is written in Latvian language. It includes an introduction, four parts, conclusions, 12 attachments, 53 figures, with 97 pages. The bibliography consists of 114 titles. Promotion work for obtaining engineering sciences doctor scientific degree will be defended in Jun of 10th year 2014 in Riga Technical University faculty of Transport and Engineering Science, to address: Ezermalas street 6, room 405.

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CONFIRMATION

I confirm that I have worked out the doctoral thesis submitted for consideration to Riga Technical University to obtain of doctor engineering sciences degree. The doctoral thesis has not submitted to any other university for obtaining of scientific degree.

Lada Bumbure ……………………………. (Signature)

Date: ………………………

Content

THE OVERALL CHARACTERISTIC OF THE DOCTORAL THESIS

Significance of research

Nowadays common (conventional) radiography is being replaced by digital. The digital image has many significant advantages such as: increasing diagnostic objectivity, because it is possible to quickly organize a wide range of remote type council, image acquisition is fast and does not require chemicals for developing film technology, is available digital image filtering, windowing, and so on. Images can be digitally archived and recorded to the external storage medium - CDs, DVDs, etc., Digital images can be transferred to any professional (therapist, surgeon, etc.), using external or internal protected network, etc.

Despite all the great opportunities offered by digital radiography, digital X-ray device quality examination today is not different from the conventional X-ray device quality examination. The "visual" image evaluation method is in use [3,4,5,8]. This method is subjective, for the evaluation result depends on the evaluator's visual acuity, visual perception and interpretation skills. Standard quality control procedures are usually measured x-ray image quality parameters such as resolution, contrast, uniformity (noise). In order to increase the objectivity of X-ray quality examination substantial financial contributions are required, such as measuring devices (KVP meters, dosimeters), special phantoms and testobjects, software, and specially trained in medical physics personnel. Digital technology allows for daily operational check of x-ray equipment. Unfortunately, ***today there are no express-estimation methods to evaluate digital medical X-ray performance quality and timely notice a change in it.***

The daily necessities in clinical practice require x-ray device radiation parameter stability test, i.e. deviation from the nominal parameters. As the generation of x-ray photons conforms to Poisson statistics, the deviation within radiation parameters can be estimated by examining the radiation detector signal difference from Poisson statistical distribution corresponding to the nominal x-ray machine parameters.

The thesis is devoted to development of new express-estimation methods for digital medical x-ray device quality assessment.

Goal and tasks of the research

The goal:

Create a digital medical X-ray device radiation stability assessment method for digital radiography.

The tasks:

1. Substantiate and develop the research method.
2. Determine the x-ray image brightness distribution conforming to Poisson statistics
3. Explore the influence of x-ray beam generation parameters (x-ray tube focus, energy etc.) on the statistics of x-ray image brightness distribution.
4. Evaluate measurements uncertainty
5. Create an algorithm of the method for clinical use
6. Take approbation of the developed method in clinics

Defendable theses

1) The experimental results show that the X-rays irradiated detector digital image pixel brightness distribution corresponds to the Poisson law (95% confidence level)
2) Created a new digital medical X-ray device radiation stability evaluation method, based on the brightness distribution in detector image pixel that uses a Poisson distribution.
3) Proven a possibility for use Kolmogorov - Smirnov criterion as a digital x-ray device radiation quality indicators in the range of x-ray generation: 66kV-96kV; 80mA-188mA..

Main results of the research

1) Created a **new method of digital medical x-ray device radiation stability evaluation**, based on detectable image brightness statistical distribution conforming to Poisson statistics (defined as a statistical physics of x-ray photons generation).
   The method is intended for digital X-ray device quality daily monitoring.
2) It is shown that the Kolmogorov - Smirnov criterion characterizes conformity of the above mentioned statistics and can be used for digital X-ray device stability evaluation in a complex manner.
3) It was found that these Kolmogorov - Smirnov criterion is related to:
   - ✓ X-ray tube voltage (66 ÷ 96kV range)
   - ✓ X-ray tube current (80 ÷ 200 mA range)
   - ✓ X-ray tube fokuss (0.6mm; 1,2mm)

- ✓ Exposure dose (DAP (Dose Area Product) uncertainty range 0.2 ÷ 6.5 $\mu Gy \cdot m^2$ is (1.5÷1.8)%)

Scientific novelty

1) Created a **new method of digital medical x-ray device radiation stability evaluation**, based on detectable image brightness statistical distribution conforming to Poisson statistics (defined as a statistical physics of x-ray photons generation).
   The method is intended for digital X-ray device quality daily monitoring.
2) Finded the Kolmogorov - Smirnov criterion limit detection method, depending on the exposure dose

Main used methods

1) X-ray beam quality assessment visual method
2) Exposure dosimetry
3) X-ray image digitalization using Technologies of digital detectors
4) Kolmogorov - Smirnov method to check adequacy of statistical distribution

Practical application

Created method may be used in medical institutions in digital radiography for X-ray device physical parameters daily assessment of stability.

Methods will help:

- ✓ save resources in digital X-ray quality assurance (as for digital X-ray lens of performance testing using the traditional technology requires a number of measuring devices and specially trained personnel).
- ✓ increase the quality of medical radiography service (using the developed method medical staff have an early opportunity to detect non-compliance with X-ray quality and warn of the need of maintenance before the X-ray quality has remained inadequate, which can lead to inaccurate diagnosis and unnecessary increase in patient dose).

Publications

Springerlink and scopus database:

1. “X-Ray Radiation Statistics Towards Quality Assurance In Digital Radiography”; authors: L. Bumbure, J. Dekhtyar, A. Katashev, T. Kirsanova, V. Zemite; IFMBE Proceeding 2013, **Springer**, 4 pages
2. ”Focal spot size impact to digital x-ray image brightness statistics”; authors: L. Bumbure, Y. Dekhtyar, T. Kirsanova, J. Moshara, L. Shuvalova; Technologija, Kaunas, Lithuania, 2010; pages: 69 – 72 (**SCOPUS** datu bāzē)
3. „Statistics of digital x-ray image brightness histograms”; authors: L. Bumbure, J. Dekhtyar, T. Kirsanova; publisher: IFMBE Proceeding 2009, **Springer**, 4 p.
4. “Quality of the computed radiography image acquired with decreased dose”; authors: L. Bumbure, J. Dekhtyar, R. Falkans, U. Jaspers; publisher: IFMBE Proceeding 2008, **Springer**, Vol. 20, 4 pages.

Published in international peer-reviewed journals:

5. ”Brightness histogram vs. visual evaluation in digital radiography – the final stage”; authors: L. Bumbure, Y. Dekhtyar, T. Kirsanova, S. Bumbure; publisher: TECHNOLOGIJA, Kaunas, Lithuania, 2011; pages: 115 – 118
6. „Digital QA method’s calibration in digital radiography”; authors: L. Bumbure, Y. Dekhtyar, T. Kirsanova, A. Katashev, E. Pacukevich, L. Shuvalova; publisher: TECHNOLOGIJA, Kaunas, Lithuania, 2010; pages: 30 – 33

7. “A novel approach for evaluating the quality of a digital x-ray image” authors: L. Bumbure, Y. Dekhtyar, T. Kirsanova; publisher: TECHNOLOGIJA, Kaunas, Proceeding of International Conference 2009, p: 164 – 167
8. “Practical application of statistical approach on digital x-ray imaging quality verification”; authors: L.Bumbure, Y. Dekhtyar, Tatyana Kirsanova, Zhanna Yakovleva; publisher: Proceedings of International Conference 2009, publisher: TECHNOLOGIJA, Kaunas, pages: 11 – 14
9. “EVALUATION OF QUALITY OF DIGITAL X-RAY IMAGE”; authors: L.Bumbure, Y. Dekhtyar, A. Glazs, A. Katashev, K. Krechetova, A.Mortuzane; publisher: TECHNOLOGIJA, Kaunas, Proceeding of International Conference 2008, pages: 205 – 208.

Abstracts:

10. „Clinical Approbation of a Novel Digital Quality Assurance Method in Digital Radiography”; authors: L. Bumbure, Y. Dekhtyar, T. Kirsanova, L. Shuvalova; publisher: Polish Journal of Medical Physics and Engineering, Warsaw, Poland, 2011; 17 (Suppl.1), s13.
11. “X-ray beam quality test inversed from a digital x-ray image”; authors: L. Bumbure, J. Dehtjars, T. Kirsanova and K. Stalidzane; publisher: Malmo University Hospital, 2009, Book of program and abstracts, page 88.
12. ”Medicīnas rentgenattēla kvalitātes pārbaudes digitalizēšanas metode”; autori: L. Bumbure, Y. Dekhtyar; PLZK tēžu krājums, RTU, Rīga 2011, 37.lpp.
13. “Homogeneity of the BaF(Br0.90,I0.10):Eu plate for radiography detector”; authors: L. Bumbure, J. Dehtjars, Kirsanova; publisher: Institute of Solid State Physics University of Latvia, 2009, Book of abstracts, page 142.

THE DOCTORAL THESIS CONTENT

The **first part** of dissertation

“X-RAY RADIATION AND THE DIGITAL RADIOGRAPHY”

is devoted to review of the literature on X-rays and digital radiography quality assurance.

There are reviewed quality parameters of x-ray image, quality assurance methods and techniques for digital radiography. It was concluded that at present there is no simple quality control methods can be used for routine X-ray examination. X-ray examination of the generation process and a digital detector (fosforplates, flat panel matrix) the physical principle was put forward the idea that it is possible to develop X-ray quality control method that uses radiation results in statistical physics and x-ray image digital capture technologies.

As a result of the first part of dissertation the goal and tasks of the work have been developed (please, see above).

The **second part** of dissertation

„RESEARCH METHOD”

is devoted to the method of research.

According to X-ray physics, X-ray photon generation process conforms to the Poisson distribution law [6,8,9,10]. Digital radiography detector captures the incident photon stream and converts it into electrical charge, and electrical charge amount generated is directly proportional to the incoming x-ray photons flow rate [1,2,6,7,9]. The detector's charge is then transformed to x-ray image brightness, which, respectively, is proportional to the size of the electric charge [9,11,12,13,14].

Since the X-ray photons have a Poisson distribution, then the electric charge in the digital detector elements, as well as x-ray image brightness over pixels divided by the Poisson law, provided, if, of course, x-ray beam is not affected destabilizing factors (for example: x-ray tube focuss discharge, unstable voltage of electric generator, etc.).

Therefore, when assessing x-ray image brightness distribution over pixels with Poisson statistics, it is possible to judge whether the X-rays, detected by a detector are influenced by destabilization factors. In this way it is possible to follow changes in the quality of x-ray device.

Each pixel in x-ray image has a specific brightness value. People see it graduated in gradation of gray color from full black to full white. Brightness level of each pixel is determined by x-ray photon dose J_0, which went into the detector. The detector in turn passed out the signal PS (Fig. 1).

$$PS = k_1 k_2 k_3 J_0, \tag{1}$$

where:

k_1 – X-ray conversion coefficient in the detector active layer

k_2 – conversion in TFT („thin film transistor ”) matrix layer

k_3 – an electrical signal to brightness conversion effectivity .

From literature data: $k_1 = 1000$; $k_2 = 0{,}1 \div 1$; $k_3 \approx 1$.

Monitor pixel brightness S_i appear, because of the detector pixel was excitated by J_{0i}. Brightness is related on J_0

$$lg\, S_i = a\, lg\, J_{0i}, \tag{2}$$

where: *a* – koefficient

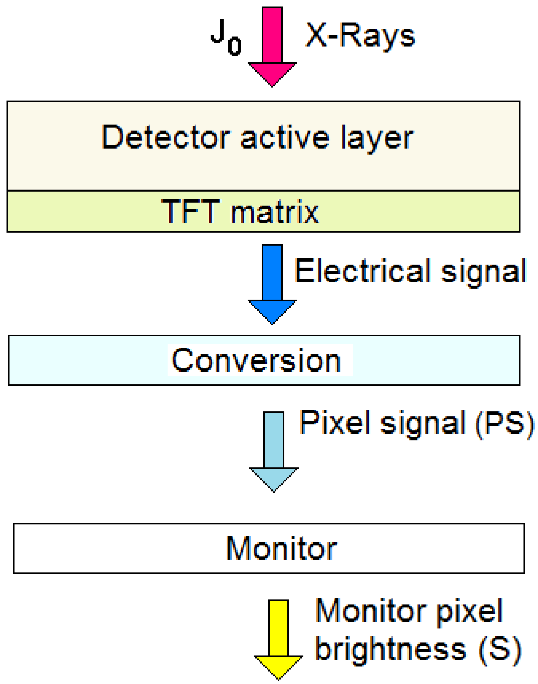

Fig.1 The scheme of signal registration

Brightness range was devided into 256 intervals. The range begins with „1” that is absolutely dark (black), but„256” is absolutely bright (white).

As the monitros ‘s picture is in negative, the most dark image part is related to the strongest signal J_{0i} (J_{0imax}), but the most bright – weakest, i.e. background signal (J_{0ifons}).

So:

$$a = \frac{lg\ (256-1)}{lg\left(J_{0imax} - J_{0ifons}\right)} \qquad (3)$$

If $J_{0ifons} << J_{0imax}$, then

$$a = lg\ 256 / lg\ J_{0imax} \text{ and} \quad (4)$$

$$lg\ S_i = \frac{lg\ 256}{lg\ J_{0imax}} \cdot J_{0i} \quad (5)$$

As the J_{0imax} is determined by the power of an x-ray tube and by characteristics of a detector that are constant for certain x-ray machine type

$$lg\ Si = const\ lg\ J_{0i}, \quad (6)$$

for pixel brightness is proportional to the electric signal levels accumulated per pixel, then

$$Si \sim J_{0i}, \quad (7)$$

Therefore, measuring *Si* is possible to evaluate J_{0i}. So the *Si* statistic in pixels certainly shows the J_{0i} statistic.

To verificate the distribution the Poisson statistics was in use:

$$P(S) = \frac{\mu(S)^S \cdot e^{-\mu(S)}}{S!} \quad (8)$$

Now using experimental *Si* data it would be able to construct a theoretical Poisson distribution function, then compare the theoretical distribution and the experimental histogram.

To compare histograms and the theoretical distribution, the Kolmogorov - Smirnov criterion was in use that is the best in the case of a known theoretical distribution function [50,98].

To calculate the Kolmogorov - Smirnov criteria need to find a difference between the theoretical S_t and experimental S_e Then choose the maximum absolute difference (B_{max}) and calculate the parameter D_{max}:

$$D_{max} = B_{max}/N, \quad (9)$$

where: N – pixel number

Next it is necessary to calculate criterion λ, which reflects the experimental histogram accordance with the theoretical distribution. Criterion λ is calculated using formulae:

$$\lambda = D_{max}\sqrt{N} \quad (10)$$

As smaller is calculated criterion λ , as better is the agreement between experimental distribution function and the theoretical distribution function.

The **third part**

„EXPERIMENT”

is devoted to the description of the experiment.

To obtain experimental measurements digital X-ray equipment "Digital Diagnost" was chosen. X-ray tube anode has tungsten / rhenium coating and 2 focal sizes: 0.6mm and 1.2mm. X-ray device equipped with a digital detector "Pixium 4600".

Experimental x-ray images were obtained by changing a variety of X-ray settings: focus size (1.2 mm high, the small 0.6 mm) voltage: 66kV, 81kV, 96kV, current: 80mA, 100mA, 125m, 160mA, 188mA.

By changing only one of the above parameters other parameters were maintained stabile. Exposure was carried out in series of 30 for each of changed parameters.

All experimental measurements were performed within one day. X-ray field collimation was 7 x 7 cm (Fig.2). After each exposure the DAP meter value was written in $\mu Gy \cdot m^2$, reflecting the exposure dose.

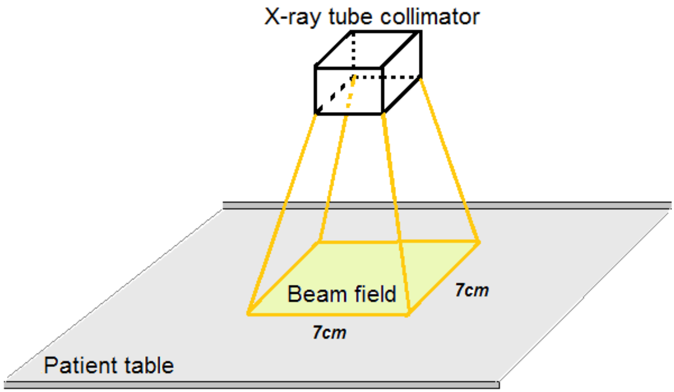

Fig.2 The collimation of an x-ray beam

The obtained images were recorded on disk in DICOM format, using the equipment in the station. Later images were converted to TIFF format and each image was cut out in squares of different sizes: 49 pixels (7 x 7), 625 pixels (25 x 25), 2500 pixels (50 x 50) and 10,000 pixels (100 x 100).

It was done using especially designed translucent template for monitor (Fig.3). Each square were saved in TIFF format, which did not affect N distribution. Then the brightness of each image area was converted to 8 bit digital form (the brightness range from 1 to 256).

During the study, it was generally handled 160 000 000 of data.

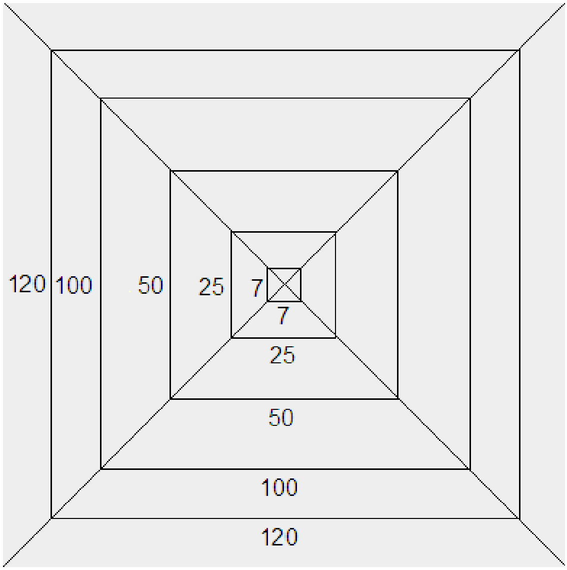

Fig.3 Translucent monitor template

The estimated λ was compared with the tabular value of λ_t at the confidence probability of 0.95. If the calculated $\lambda<\lambda_t$, then the hypothesis of the statistical distribution conformity with Poisson / Gaussian law was confirmed.

Theoretical curves of Poisson and Gaussian distributions were obtained using the experimental data values (the arithmetic mean and standard deviation).

Experimental data processing showed that the result depends on the size of the treated area, the x-ray tube focus, voltage and current.

Best match to Poisson distributions were achieved when the image area was equal to 100 x 100 pixels (4th and 5th Figures.).

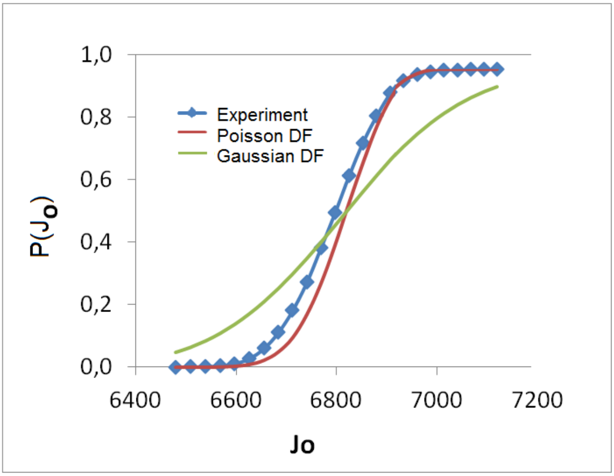

Fig.4 Distribution function using 81kV, small focus

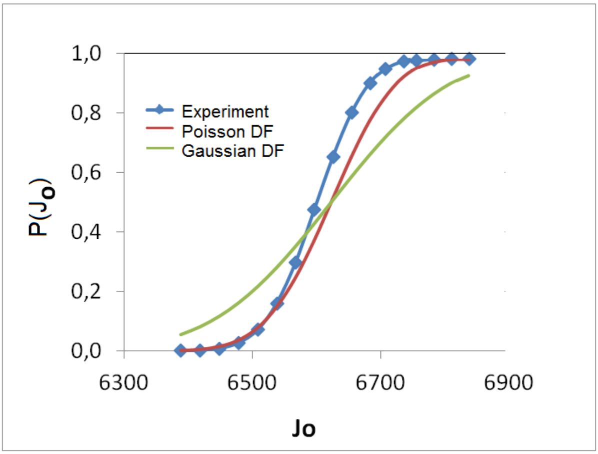

Fig.5 Distribution function using 81kV, large focus

It was found that increasing or decreasing the voltage from 81kV to 96kV and 66kV, respectively, compliance with the Poisson distribution is deteriorating (Fig. 6 and 7).

This is true using as small focus as well as the large focus. More likely this is due to X-ray spectrum changes by changing the voltage. At 66kV range still does not show the characteristic radiation of the pitch that appears to 81kV, 96kV turn to a significant increase in braking radiation component [8].

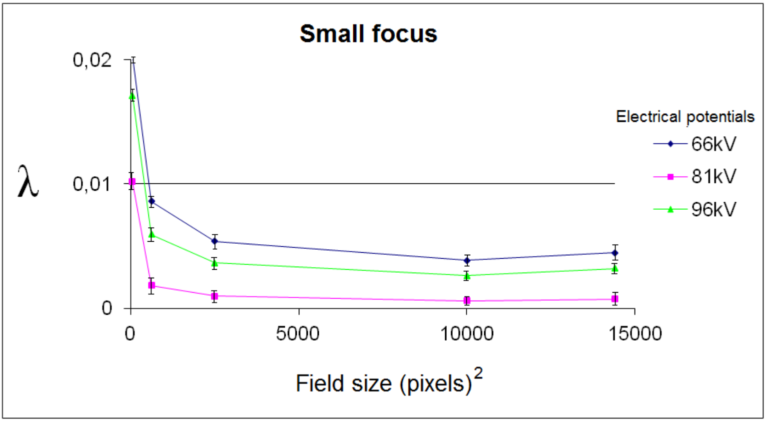

Fig.6 Criterion λ in dependence on area size using different electrical potentials (kV)

Processing of experimental data showed that the function depends on the size of the treated area, r-ray tube focus, voltage and current. It was found that if the size of the area is 7x7 pixels the criterion λ is largest (which, apparently, is due to the lack of statistical data sets), then it decreases, and, when the area size is 100x100 pixels, the criterion λ is the smalles. It grows again with the area size 120x120 pixels (Fig.6 and 7). It is possible that „heel effect" (Fig.8) cause this enlargement of the criterion λ.

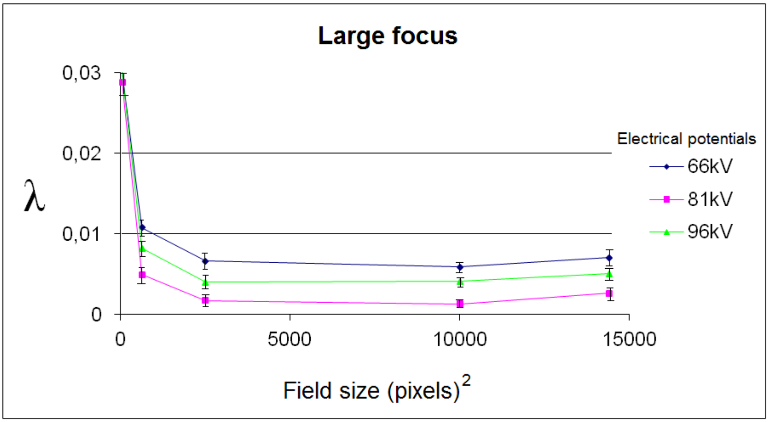

Fig.7 Criterion λ in dependence on area size using different electrical potentials (kV)

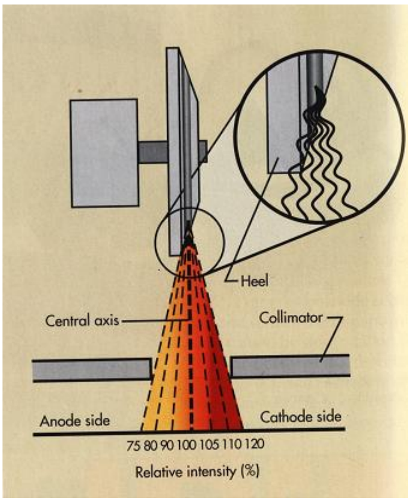

Fig.8. „Heel" effect impact on the relative intensity of an x-ray beam

Reducing x-ray tube focus, e.g. approaching a point source, improves compliance with the Poisson distribution (Fig.9).

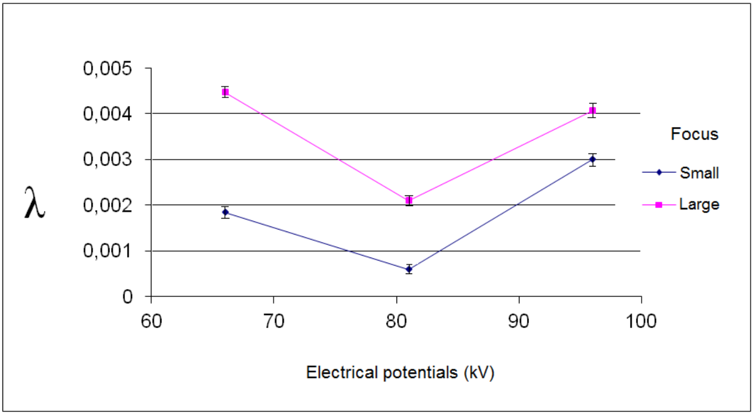

Fig.9 Criterion λ in dependence on different voltage (kV)

Increasing x-ray tube current was observed that the criterion λ declined (Fig.10.), which may be related to an increasing statistical data array.

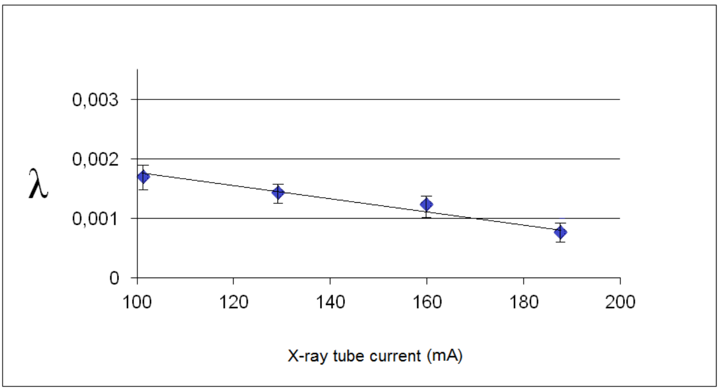

Fig.10 Criterion λ in dependence on x-ray tube current (mA)

In order to advance the method for clinical use (where the key value is DAP) a correlation between the criterion λ and DAP meter values was established. 30 x-ray images were obtained and processed in 30 min. For each image was calculated criterion λ and the correlation was established (Fig.11 and 12).

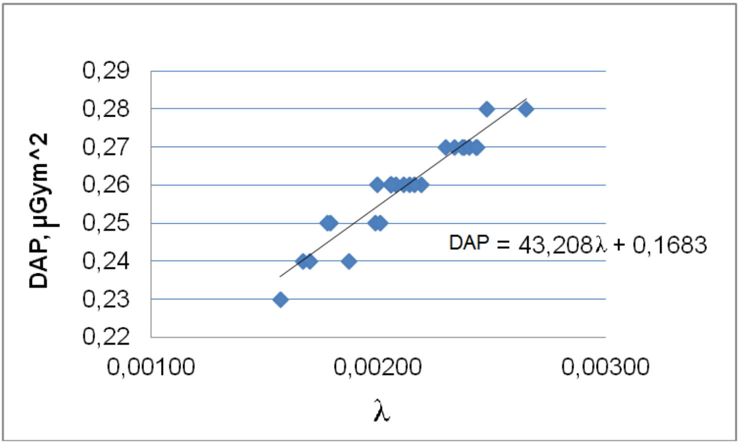

Fig.11 DAP meter value and criterion λ value correlation (DAP range: 0.2 - 0.3 μGy·m^2)

The correlation coefficient at the confidence probability of 0.95 was 0.94 (DAP range: 0.2 - 0.3 μGy·m^2) and 0.91 (DAP range: 5 - 6 μGy·m^2), respectively The correlation significant (correlation coefficient critical value is 0,31) [15].

Similarly, a correlation was established between the criterion λ and DAP meter measurement values of all X-ray machines, which were used method in clinical approbation.

Then the uncertainty ($\overline{\delta}_1$) was calculated using DAP = f (λ) regression:

$$DAP = 43{,}208\lambda + 0{,}1683 \qquad (11)$$

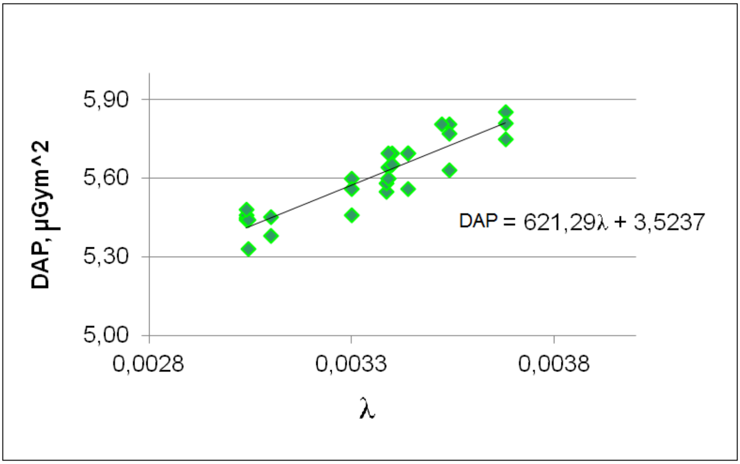

Fig.12 DAP meter value and criterion λ value correlation (DAP range: 5 - 6 $\mu Gy \cdot m^2$)

Similarly the uncertainty (δ_2) was calculated using DAP = f (λ) regression:

$$DAP = 621{,}29\lambda + 3{,}5237 \qquad (12)$$

Measured DAP_m values were compared with calculated DAP_c using differential module:

$$\Delta_i = | DAP_m – DAP_c | \qquad (13)$$

and evaluating deviations for each *i* measurement:

$$\delta_i = \Delta_i / DAP_{mi} \cdot 100\% , \qquad (14)$$

As a result, it was determined that $\delta_1 = (1.15 \pm 0.8)$ %, while $\delta_2 = (1.81 \pm 1.1)$ %

The calculated δ values do not exceed in LRMK rules permitted 20% dose measurement fluctuation [17].

To verify that the method can be used in any medical facility where the digital radiography is in use, a verification of the results was required using others x-ray devices.

The verification was carried out by checking the criterion λ, and DAP values using 7 x-ray devices in various medical institutions. In all medical institutions the method worked, a correlation DAP = f (λ) was observed using all the X-ray devices. Measurement uncertainty δ was not more than 6%.

The **fourth part**
„CLINICAL APPROBATION OF THE METHOD" describes the method approbation in medical clinics.

Each medical facility, which uses X-ray has a quality assurance program to determine all the measures which are directed to diagnostic radiology quality control and improvement.

One part of these measures is related to inspections carried out by X-ray equipment to check the performance and stability. These tests are used in procedures, methods, and additional equipment (test objects, phantoms, measuring devices). Most of the procedures related to x-ray image quality parameter estimation.

Using the new method developed through the thesis, the relationship between the DAP and the criterion λ values were found and the method was tested. Quality parameters analysis was carried out in various medical institutions in Latvia using 7 X-ray digital devices in radiography in 8 months, using the criterion of λ values changes depending on time. More than 1000 x-ray images were processed in the time of research.

During testing it was found that the criterion λ values increase over time, reflecting the deterioration of the x-ray device.

To find the critical λ value the results of correlation between the DAP and the criterion λ values founded during verification was used:

$$DAP = 395{,}44\lambda + 3{,}1567 \qquad (15)$$

Using formulae can find the criterion λ value.

$$\lambda = (DAP - 3{,}1567)/ 395{,}44 \qquad (16)$$

Now, knowing the initial average value of the DAP meter and tolerance, which in accordance with the Cabinet of Ministers Regulations No. 97 of Annex 8 shall not exceed ± 20% [17], it is possible to calculate the tolerance of DAP (ΔDAP) as well as maximal and minimal value of criterion λ (λ_{max} and λ_{min} respectively) for each x-ray device. For the 1st x-ray device they were:

$$\Delta DAP = 5.82 \cdot 20\% = 1.164\ \mu Gy{\cdot}m^2$$

$$DAP_{min} = 5.82 - 1.164 = 4.656\ \mu Gy{\cdot}m^2$$

$$DAP_{max} = 5.82 + 1.164 = 6.984\ \mu Gy{\cdot}m^2$$

$$\lambda_{min} = (4.656 - 3{,}1567)/ 395{,}44 = 0.004$$

$$\lambda_{max} = (6.984 - 3{,}1567)/ 395{,}44 = 0.01$$

In the Fig.13 it is shown the x-ray device Nr.1 criterion λ tolerance limits corresponding to the equations.

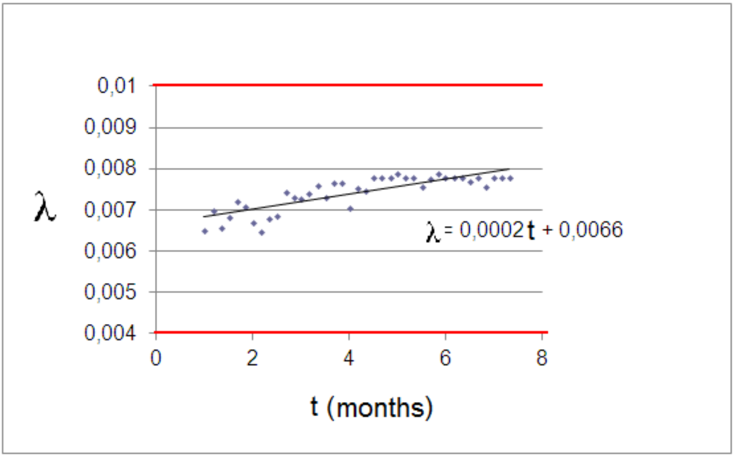

Fig.13 Criterion λ limits for x-ray device Nr.1

From the given graph can be concluded that the criterion λ increases with time. Now, using the criterion of λ with time relationships (Trendline) formulae it is possible to calculate the time (T), the criterion λ exceeds the maximum permitted limit:

$$T = (\lambda - 0.0066)/0.0002 = \mathbf{17} \text{ months} \qquad (17)$$

As you can see, this x-ray device will require maintenance after 17 months.

Similar calculations were performed for all investigational X-ray devices (for example fig. 14 and 15).

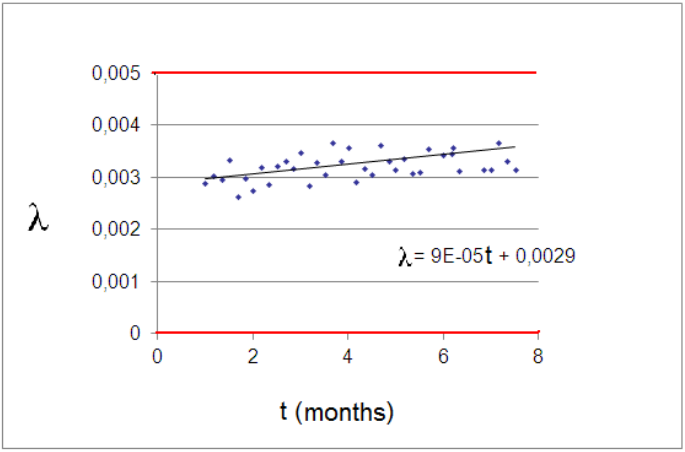

Fig.14 Criterion λ limits for x-ray device Nr.2

$$T = (\lambda - 0.0029)/0.00009 = \mathbf{40} \text{ months}$$

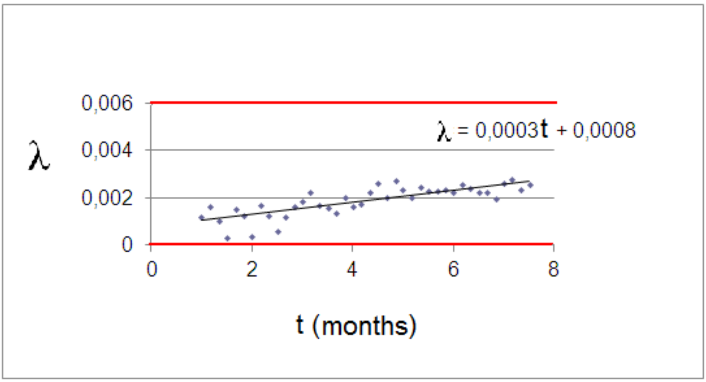

Fig.15 Criterion λ limits for x-ray device Nr.3

$$T = (\lambda - 0.0008)/0.0003 = \mathbf{17{,}3} \text{ months}$$

Based on the results of clinical approbation was offered method (sequence) used to work in the clinic.

ALGORITHM OF THE METHOD FOR CLINICAL USE

1) choose the manual mode on x-ray device;
2) choose the following x-ray tube parameters: 81kV; 188mA;
3) choose the x-ray beam collimation 7x7cm; SID = 100cm;
4) make an exposure;
5) write down the DAP value;
6) save the acquired x-ray image in DICOM format, burne the data on CD;
7) transfer data to TIFF format;
8) repeat steps 1-6 nine times more, using the same digital detector;
9) cut out a 100x100 pixel large area of each obtained x-ray image center using the translucent monitor template;
10) digitize the obtained data;
11) calculate criterion λ for each obtained area;
12) calculate the average λ;
13) calculate the average DAP value;
14) write down obtained average values;
15) make all above procedure at least 1 time per month;
16) using the obtained results determine the minimum and maximum of λ criterion for X-ray device;
17) follow the changes of criterion λ during time;
18) evaluate when the next service maintenance for x-ray machine would be required

In cooperation with the Riga Technical University Department of Computer Science, a software for data processing directly in DICOM format is developed.

CONCLUSIONS

1) For the first time is developed a new „method for evaluation digital x-ray device radiation stability" that is based on x-ray photons generation fundamental Poisson distribution.
   The method is designed to determine the frequency of digital x-ray device routine quality monitoring and maintenance (regulation).
2) Kolmogorov - Smirnov criterion is used as an indicator of digital x-ray device operational sustainability of the complex way. Kolmogorov - Smirnov criterion enlarges if:
   - ✓ melts x-ray tube focus
   - ✓ increases or decreases the nominal voltage
   - ✓ decreases the nominal current
3) The developed method was practically verified in clinical conditions during 8 months in 6 hospitals, using 7 x-ray devices. The method is effective. There is positive feedback from clinics.
4) Usage of the method could help to:
   - ✓ save resources for digital x-ray device quality assurance (because to accomplish an objective digital x-ray device quality performance test several expensive measuring equipment and specially trained personnel is required. In addition, all of these devices need to be calibrated on a regular basis, that make it costly for quality checks of process);

- ✓ raise up the quality of medical diagnostic X-ray services (because using the method medical staff are able to timely notice discrepancies of x-ray device work and to provide the necessary maintenance, eliminating inaccurate diagnosis and unnecessary patient dose increase);
- ✓ everyday watch digital radiography device radiation changes

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