DEVELOPMENT OF DIGITAL FLUOROSCOPIC PROTOTYPE FOR MANUFACTURING INDUSTRIES

PEMBUATAN PROTOTIPE SISTEM FLUOROSKOPI DIGITAL UNTUK INDUSTRI MANUFAKTUR

Demon Handoyo, Agus Cahyono, Kristedjo Kurnianto, Andeka TS

Centre for Nuclear Facility Engineering-BATAN *dehandoyo@yahoo.com*

ABSTRACT

Many X-ray applications in non-destructive testing have provided lots of benefits for manufacturing industries. A number of shortcomings of the use of film to capture images and the cost of digital radiography equipments are quite expensive, so a low-cost equipment that can generate clean and clear images is really expected. This paper describes the manufacturing process of this hardware prototipe, whose cost is estimated around seventy million rupiahs. Based on the engineering principles, a prototype of digital fluoroscopy consisting of radioscopy box, conveyor belt, and controlling instrument has been completed. The design uses fluorescent screen, mirror, and digital camera to record and transmit the images of test specimen to a computer for image processing. A LabVIEW-based program has been built for conveyor control, camera control, image recording, image storing, and image processing. Calibration and image enhancement processes have improved the quality of the images obtained. The success of the development of this equipment is represented by the highly clean and clear quality of the generated images so that they can be easily interpreted by human eyesight.

Keywords: prototype, digital fluoroscopy, digital radiography, manufacturing industries, X-ray, non-destructive testing

ABSTRAK

Aplikasi sinar-X pada pengujian tak-merusak (nondestructive test/NDT) telah memberi banyak manfaat dalam dunia industri manufaktur. Sejumlah kelemahan dari penggunaan lapisan film untuk menangkap citra dan harga perangkat radiografi digital yang relatif mahal membuat perangkat yang mampu menghasilkan pencitraan secara jernih dan jelas dengan harga yang rendah sangat diharapkan. Makalah ini menguraikan kegiatan pembuatan prototipe perangkat keras tersebut, yang biayanya diperkirakan sekitar tujuh puluh juta rupiah. Dengan menerapkan prinsip-prinsip kerekayasaan (engineering), prototipe fluoroskopi digital yang terdiri atas kotak fluoroskopi, konveyor sabuk atau sabuk berjalan (conveyor belt), dan perangkat kendalinya telah berhasil dibuat. Desain perangkat keras ini menggunakan layar fluoresen, cermin, dan kamera digital untuk menangkap dan meneruskan citra benda uji ke sebuah komputer untuk pengolahan citra. Suatu program perangkat lunak yang berbasis LabVIEW untuk pengendalian konveyor, pengendalian kamera, dan pengambilan serta penyimpanan dan pengolahan citra juga telah dibangun. Tindakan kalibrasi dan peningkatan citra (image enhancement) dikenakan pada citra yang diperoleh. Keberhasilan pembuatan prototipe alat ini direpresentasikan oleh kualitas citra yang dihasilkan yang jernih dan jelas sehingga dapat secara mudah ditafsirkan oleh pandangan manusia.

Kata kunci: prototipe, fluoroskopi digital, radiografi digital, industri manufaktur, sinar-X, uji tak-merusak

A. INTRODUCTION

X-ray, which was discovered by W. Roentgen in 1895 in Germany, has been applied widely nowadays in various areas, starting from medicine to industry, to inspect the inner part of an object. In industrial application, X-ray is used in non-destructive testing (NDT) to detect and identify defect or crack present in, for example, welding, casting, forging, concrete, composite material, and many more. Basically, the use of X-ray in NDT is conducted by transmitting X-ray beam into a test specimen and measuring the remaining incident radiation after traversing it (IAEA, 2013).

The incident radiation of X-ray beam penetrating through a specimen can be conventionally detected by using film. However, the use of film to capture the X-ray incident radiation has some shortcomings, i.e. the need of relatively long exposure time, nonreusable radiographic film, the need of film processing facility, subjective radiographic interpretation, and more. These disadvantages of film-radiography could then be overcome after the invention of digital detectors, which have potential capability to replace the film and change the radiology technique. The detector utilizes an application and computer-based methods (Ewert, Zscherpel, & Bavendiek, 2017; Patel, 2005).

Utilization of digital detector with good imaging performance is one of factors affecting the success of NDT application using X-ray. Digital detector includes a system based on charge-coupled device and on amorphsilicone flat-panel detector (Yorkston, 2003). These two types of digital detector have high efficiency and generate much better image quality than that produced by film radiography (Yorkston, 2003). The advantages of digital radiography are precise recording, high flexibility of characteristic display, and easy image transmission from one location to others through communication network (Yaffe & Rowlands, 1997). Digital radiography has also been implemented to automatic production line in automotive industry (Skerik, 2017). In this application, digital radiography that is not influenced by magnetic field is equipped with image intensifier to obtain good image quality.

However, disadvantages of digital radiography have been identified. Spatial resolution of its image recording system is lower than that of film/screen radiography. This low spatial resolution affects overall spatial resolution of radiographic testing. Consequently, in detecting a tiny defect, film/ screen radiography is still much better than the digital one. In particular, the sampling frequency in digital radiography becomes a limiting factor in determining the spatial resolution of digital radiography system (Ewert et al., 2017; Davidson, 2006). Further development in digital detector technology apparently, especially in image acquisition and diagnostic image quality, will materialize in the near future (Lanca & Silva, 2009).

Nowadays, the upper limit of image quality is determined by inhomogeneity of

the inspected object material, not by detection technique anymore. High contrast sensitivity will compensate low spatial resolution (effective pixel size) (Zscherpel, Ewert, & Bavendiek, 2007). On the other hand, due to high investment cost on the use of digital radiography, transition from film to digital radiography should be well reconsidered as, maybe, it is not the best option (Harara, 2008). Therefore, a low-cost and simplified digital radiography is really expected. Related to this alternative, a research project under the coordination of the International Atomic Energy Agency (IAEA) to optimize the digital radiography technique, including the accuracy of data processing, spatial resolution, and contrast sensitivity, has been performed (Ewert et al., 2017).

To fulfil that expectation, a low-cost fluoroscopic technique, while still has high spatial resolution and sensitivity, is proposed. Such fluoroscopy technique can be achieved using fluorescent screen. It is achievable since its technology can be easily mastered and the size, thickness, and flexibility of the fluorescent screen can be easily handled (Kim, Cunningham, Yin, & Cho, 2008). This paper describes the development of such fluoroscopic technique using a fluorescent screen that can emit visible light when exposed by X-ray radiation. The fluorescent screen capturing the test specimen image can be viewed by direct observation or recorded by a camera (fluoroscopy).

B. THEORY

1. Radiation Attenuation Principle

Industrial radiography applied to non-destructive testing technique basically employs radiation attenuation principle in material. X-ray beam with an initial intensity I_0 will have intensity I after traversing material with thickness x and attenuation coefficient μ , as indicated by Equation (1) (IAEA, 2013). For monochromatic radiation, linear attenuation coefficient μ is assumed constant.

$$I(x) = I_0 e^{\mu x} \tag{1}$$

Therefore, X-ray attenuation traversing an object having different thickness or containing



Figure 1. Intensity Attenuation of X-ray After Traversing An Object with Different Thickness

defect will be different. In addition, higher X-ray energy will lower intensity difference (ΔI) of X-ray traversing an object with different thickness, as shown in Figure 1.

In this engineering development, X-ray traversing the material is captured by a fluorescent screen, containing cesium iodide (CsI) and gadolinium oxysulfide (Gd₂O₂S). The physics of the fluorescent includes emission of visible light by a molecule or atom that is excited due to X-ray incident. The efficiency of fluorescent process (η) is expressed as the ratio of the number of emitted photons to absorbed photons, as indicated by Equation (2) (Babeti, Chiritoiu, Maria, Popescu, & Dorobantu, 2012).

$$\eta = \frac{\text{The number of emitted photons}}{\text{The number of absorbed photons}}$$
(2)

2. Image Processing

In industrial radiography, image processing is required to improve image quality. One of techniques commonly employed is image enhancement. This technique includes several steps, i.e. point, spatial, and transformation operations.

Point operation is carried out by modifying image histogram to achieve the expected characteristics. It includes intensity adjustment, histogram, and thresholding. Spatial operation in digital image processing is performed by using two-dimension convolution kernel and consists of low-pass filter, median filter, and high-pass filter. In transformation operation, an image is transformed to a domain suitable for enhancement process. After being enhanced, the image is transformed back to the initial spatial domain for further process or display.

C. METHODOLOGY

The development of fluoroscopic image recording prototype for industry basically follows engineering principles, consisting of defining design requirements, developing conceptual design, basic design, detail design, and construction. Once the basic design is completed, its evaluation is carried out to find out whether the design requirements are fulfilled. Figure 2 depicts these engineering steps.

The conceptual design of this digital fluoroscopy is shown in Figure 3. The image recording system comprises a conveyor, a fluorescent screen, a mirror, a camera, and an industrial computer. X-ray produced by an X-ray generator is directed to a test object placed on the sample table, which is a conveyor. The image of the traversing X-ray is then captured by a fluorescent screen. The image is reflected by a screen and recorded by a digital camera that is connected to a computer for data processing. Therefore, there are three components constructed, i.e. fluoroscopic box, conveyor, and data processing system.

The development of this fluoroscopic prototype includes two types of work, i.e. construction of hardware system (fluoroscopic box and conveyor) and development of a software program to control the conveyor, camera, and data acquisition, storing, and processing. Equation (1) and (2) are used to



Figure 2. The Methodology of Development of Digital Fluoroscopic Prototype for Industry

estimate the shielding thickness in order to protect operator from X-ray radiation exposure as well as to determine the distance of test object from X-ray generator.

D. RESULTS AND DISCUSSION

The development of this digital fluoroscopy prototype is performed using the design developed by Bundesanstalt für Materialforschung und prüfung (BAM) – Federal Institute for Materials Research and Testing, Berlin (IAEA, 2013). This equipment is required to be able to operate easily and meets the specified safety requirements. In addition, a quality assurance has been applied and BATAN Standard SB77 must be fulfilled. Moreover, this prototype has experienced a field test in an alloy wheel factory in Surabaya, East Java, for twenty-four hour operation two months. It withstood in harsh environment and showed reliable performance. The prototype also indicated safe operation as no radiation exposure to the operators was found.

1. Hardware

The hardware of this fluoroscopy consists of fluoroscopic box and conveyor. The fluoroscopic box employs SS304 material as casing and filter for the screen installed. In this fluoroscopic box, there are a fluorescent screen, a digital camera, and a mirror. The function of this fluorescent screen is to project the specimen image traversed by X-ray. The digital camera is used to capture



Figure 3. Conceptual Design of the Digital Fluoroscopic System

the image displayed by the screen. The mirror is meant to reflect the image generated on the screen to the digital camera for recording.

Digital camera is an electronic device that is very sensitive to X-ray. Therefore, to prevent the camera from being easily damaged, it is positioned not in line with the X-ray beam path. The camera records the indirect imaging from the fluorescent screen, but from the mirror that is installed in a tilted position under the screen, as shown in Figure 3. Moreover, to avoid the camera from being exposed by the X-ray beam, the camera is protected by lead. This fluoroscopic box is indicated in Figure 4.

The other equipment constructed is a conveyor to make the test specimen move toward and leave the beam region. The conveyor (shown in Figure 5) employs a stepper motor to move the conveyor belt. The stepper motor is controlled and run by a LabVIEW based code specifically developed for this project.

Actually, there are three techniques to control the conveyor movement, i.e. stand alone, wifi controlled, and serial control using bluetooth. For this project, stand alone control is used for the sake of process simplification. By this control technique, the test specimen has been able to be moved and halted for 5 minutes in the beam area. Then, the conveyor moves



Figure 4. Fluoroscopic Box

again to bring the test specimen away from the beam area. Figure 6 shows the conveyor control module of the digital image recorder.

Image recording of the test specimen is conducted using IP digital camera TP-Link TL-SC4171G. The function of this camera is to monitor visually the performance of electronic hardware of the fluoroscopic image recorder module. IP Camera TP-LINK TL-SC4171G has two indicators, Power LED and Ethernet indicator that lights when its connection is on. IP Camera TP-LINK TL-SC4171G is completed with a built-in microphone to allow audio visual



Figure 5. Conveyor of the Digital Fluoroscopy



Figure 6. Conveyor Control Module of the Digital Image Recorder

recording. Camera control, image acquisition process, image storing, and image processing are carried out by the use of a LabVIEW-based code.

2. Software

The hardware of fluoroscopic system is controlled through an interface system developed specifically for this project. The interface of the control system is an interface software to access the arrangement of a sliding table movement. The interface of this control system is an essential part for the engineering development of fluoroscopic image recording for manufacturing industries. Interface and communication system built for the module of fluoroscopic image recording hardware prioritizes operation reliability principle and has user friendly human-machine interface with cost-effective financing.

For the image acquisition, a software code based on LabVIEW has also been developed. This program consists of several parts, i.e. preparation for image acquisition, acquisition and storing of fluoroscopic images, and image processing. This program should be operable easily, ergonomic, communicative, and reliable. The setting of the digital camera is illustrated in Figure 7. All programming steps, either related to image processing or conveyor control, are performed using a personal computer. The image acquisition process is started with a command start to X-ray machine. After X-ray traverses the test specimen, the generated image is captured by the fluorescent screen and recorded by the digital camera. The data obtained from this digital camera are then stored in the computer. When these processes have been done, the conveyor moves and brings the test specimen away from the beam area.

3. Calibration and Image Processing

The images resulted from the test of fluoroscopic hardware prototype are calibrated by reducing bad pixels, dark current, and applying flat plane correction. For image calibration, one frame of dark image and three frames of bright images are required. The image calibration comprises several steps, i.e. preparation of fluoroscopic equipment, image acquisition without X-ray exposure to generate dark image, and image acquisition without test specimen with X-ray exposure to produce bright image by variation of X-ray voltage (50–70 kV) and current (40–50 mA), text file creation for image correction, and the application of ISee software package for calibration. Figure 8 shows an image without



Figure 7. Front Panel of the Digital Camera Setting



Figure 8. Comparison of Sample Images between without Calibration (a) and with Calibration (b)



Figure 9. Comparison of Sample Images between Without Image Processing (a) and With Image Processing (b)

and with calibration. Image without calibration shows darker at the edges than at the center, while image with calibration gives equal brightness. It is obvious that calibration can generate clearer image.

Moreover, radiographic images should be treated with an image processing. It is a signal processing with image used as an input and transformed into other image using a particular technique. Image processing is conducted to correct the error of image signal due to signal and acquisition signal and to improve image quality. Image processing has been performed using image enhancement technique and ISee software package. Figure 9 shows the comparison of test specimen image without and with image processing. The maximum size of the specimen is 20 cm \times 20 cm \times 20 cm. This figure indicates that image enhancement technique generates image with better clarity. Therefore, improved image quality can be easily interpreted by human visual system through either image manipulation or analysis.

E. CONCLUSION

Engineering development of fluoroscopic prototype for manufacture industry has been successfully carried out. This hardware is quite essential in non-destructive test using X-ray exposure. The testing results of this prototype indicate that this device can function satisfactorily and produce images with high clarity. The construction of this prototype requires about seventy millions rupiah, which is very much lower than the price of digital radiography that costs from Rp350 millions for detector flat panel and Rp1.6 billions for imaging plate. The quality of the generated image reflects the potential application of this low-cost fluoroscopic equipment in manufacture industry.

ACKNOWLEDGEMENT

The authors would like to deliver lots of thanks to Ir. Sigit Budi Santoso and Drs. Kushartono of the Center for Isotopes and Radiation Application—BATAN for their continuous support to this work.

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