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تقييم أنابيب الغاز المحومة بالقوس الكهربى باستخدام الرؤية بالحاسب

تعتبر الجودة هدفا من الأهداف الرئيسية لميكنة الصناعة، لذلك فقد أصبحت أنظمة الفحص الآلى جزءا رئيسيا من خطوط الإنتاج. وتزداد الحاجة إلى استخدام نظم الفحص الآلى لأن الفحص باستخدام العامل البشرى لا يؤدي إلى نتائج ثابتة، بالإضافة إلى الأخطاء الناتجة من العنصر البشرى. ونظرا للتطور الحديث في أساليب معالجة الصور الرقمية فقد أصبحت أجهزة الفحص الآلى تستخدم بكثرة في مصانع الإنتاج. ومن ناحية أخرى فإن التطور السريع في تكنولوجيا الإنتاج أصبح يتطلب استحداث أنظمة فحص آلى جديدة تتميز بالدقة العالية والكفاءة.

وتعتبر خطوط الأنابيب المستخدمة لنقل الغاز والزيوت الخام لمسافات طويلة أفضل وسيلة من ناحية الأمان ومن الناحية الاقتصادية. لذلك فإن فحص لحامات هذه الأنابيب يشغل حيزا هاما في مجال الاختبارات غير الإتلافية. وعلى مدى الخمسين سنة الماضية، تعتبر الاختبارات بواسطة أفلام التصوير الإشعاعى حجر الزاوية بالنسبة للاختبارات غير الإتلافية. وتعتبر أفلام التصوير الإشعاعى أكثر الطرق استخداما مقارنة بالطرق الأخرى، وتستخدم في كل الدول والأقطار وكافة المواقع. ويتم فحص عيوب اللحام من خلال هذه الأفلام بواسطة الخبراء والمتخصصين، إلا أن عملية قراءة وتفسير الخبراء للأفلام مهمة شاقة وعسيرة، وخاصة عند فحص عدد كبير من الأفلام التي يتم تصويرها لخطوط الأنابيب المنشأة على مسافات طويلة.

ومن المعروف أن كثيرا من الخبراء لا يكون لهم نفس الرأي عند قراءة نفس الفيلم. وكذلك فإن نفس الخبير ربما يكون له رأى في أول اليوم يختلف عنه في آخره. لذلك فإن استخدام أنظمة الفحص الآلى أصبح ضروريا، لأن هذه الأنظمة لا تعتمد في اتخاذ قرارها على عوامل شخصية. وفي نفس الوقت فإن قدرة الخبير على اكتشاف العيوب الصغيرة لاتصل إلى قدرة برامج الفحص الآلى على اكتشاف هذه العيوب.

وتهدف هذه الرسالة إلى بناء نظام للفحص الآلى للتعرف على عيوب اللحام في الأنابيب المحومة بالقوس الكهربى من خلال أفلام التصوير الإشعاعى، وذلك باستخدام كل من تقنية الرؤية بالحاسب الآلى ونظم الخبرة. ولإنجاز هذا العمل تم الآتى:

١- دراسة الأبحاث الحالية والسابقة في مجال الاختبارات غير الاتلافية، وتطبيقات أنظمة الفحص الآلي، ومعالجة الصور. كما تمت دراسة مستفيضة للمراحل الرئيسية لنظم الرؤية بالحاسب.

٢- تحديد وتعريف الأنواع المختلفة والشهيرة لعيوب اللحام، وتحديد أشكالها وأسباب ظهورها واختبارها طبقاً للعديد من المواصفات القياسية العالمية.

٣- دراسة الخوارزميات اللازمة للتعرف على عيوب اللحام في ثلاثة مراحل مختلفة هي (اكتشاف العيوب - تحديد شكلها - توصيفها). وقد تم تقديم خوارزمي جديد خاص بمعالجة الصور وتسهيل عملية التعرف على عيوب اللحام.

٤- تقسيم العيوب الشهيرة وتعريفها للحاسب من خلال المعلومات التي تم الحصول عليها من الخبراء في مجال التفثيش على اللحام وبعض المواصفات القياسية العالمية.

٥- بناء نظام متكامل يهدف إلى تصنيف العيوب التي يتم التعرف عليها، ومن ثم قبولها أو رفضها. ويتم ذلك باستخدام قواعد تصنيف إحصائية وتركيبية، وبعض القواعد الأخرى، بناء على المواصفات القياسية العالمية للتصنيف النهائي للعيوب.

٦- تم تقديم خوارزمي جديد لتصنيف العيوب أوماتيكيا تبعاً لنوع العيب، والعامل القائم بالعمل، والفترة الزمنية التي تم فيها اللحام.

ويمكن تقسيم نظام الفحص الآلي المقترح إلى قسمين هما:

١- الأدوات (Hardware): وتشمل جهاز حاسب آلي متوافق مع أجهزة (IBM)، ومثبت عليه أحد أنظمة التشغيل ويندوز، وكاميرا رقمية حساسة، وكارت لالتقاط صور أفلام اللحام (Frame Grabber)، ونظام إضاءة خلفي (Back lighting system) طبقاً لتوصيات معهد البترول الأمريكي (API).

٢- البرنامج المقترح: وقد تم كتابته بأحد لغات البرمجة الحديثة، وهي لغة (Visual C++) وتم تسمية البرنامج باسم (AutoWDI)، وهو اختصار للجملة:

Automatic Welding Defects Inspection.

ويوفر نظام الفحص الآلي المقترح نفس مميزات النظام التقليدي، بالإضافة إلى الدقة العالية، واختصار الوقت، وعدم ضياع تفاصيل الأفلام حيث يتم حفظها على وسائط التخزين الخاصة بالحاسب، وكذلك عدم الحاجة للخبراء لقراءة الأفلام. ويعتبر النظام المقترح وسيلة اقتصادية بالمقارنة بطرق الفحص الآلي الأوتوماتيكية التجارية. كما يعتبر التصنيف الآلي - تبعاً لنوع العيب والفني القائم بعملية اللحام وفترة اللحام - من أهم مميزات نظام الفحص الآلي المقترح. ومن ثم فإن النظام المقترح يمثل حلاً جيداً لفحص عيوب اللحام من خلال أفلام التصوير الإشعاعي.

وقد تم تقسيم هذه الرسالة إلى ستة فصول وثلاثة ملاحق كما يلي:

- **الفصل الأول:** يقدم ملخصاً للأبحاث السابقة والحالية في مجال الاختبارات غير الاتلافية، كما يقدم وصفاً تفصيلياً لأهم أنظمة الفحص الآلي الحديثة ومميزات كل منها.
- **الفصل الثاني:** يقدم هذا الفصل شرحاً للمكونات الرئيسية لأنظمة الرؤية بالحاسب الآلي.
- **الفصل الثالث:** يقدم هذا الفصل شرحاً للأشكال المختلفة لعيوب اللحام الموجودة في لحام أنابيب الغاز والبتروال الملحومة بالقوس الكهربائي، وكذلك وصفاً دقيقاً لأشكال هذه العيوب في أفلام الأشعة التصويرية المستخدمة في فحص واختبار هذه العيوب. وكذلك يقدم حدود القبول والرفض تبعاً لسبعة من المواصفات القياسية العالمية (API 1104, ASME, DIN, BS, ABS, AWS, and JIS). ويحتوي الملحق (أ) على المواصفات القياسية العالمية المستخدمة.
- **الفصل الرابع:** يقدم هذا الفصل المنهج العلمي المتبع وخوارزميات البرمجة التي استخدمت لتقديم البرنامج المقترح.
- **الفصل الخامس:** يقدم هذا الفصل المواصفات الفنية للأدوات المستخدمة لتكوين نظام الرؤية بالحاسب الآلي المقدم، مثل المواصفات الفنية للحاسب المطلوب، والكاميرا الرقمية، وكارت النقاط الصور. ويقدم هذا الفصل أيضاً بعض الاختبارات العملية التي استخدمت لاختبار النظام المقترح باستخدام عينات قياسية من الأفلام من شركة (AGFA) العالمية، وشركة المشروعات البترولية والاستشارات الفنية (إحدى شركات الهيئة العامة للبتروال بالقاهرة). ويحتوي الملحق (ب) على كتيب التشغيل للبرنامج المقترح.

- **الفصل السادس:** يقدم هذا الفصل ملخصاً لهذا البحث، كما يقدم التوصيات المقترحة للأبحاث التي يمكن استكمالها في المستقبل والمميزات التي يوفرها النظام المقترح.

- **الملحق أ:** يوضح دليل استخدام برنامج (AutoWDI) المقترح.
- **الملحق ب:** يوضح المواصفات العالمية القياسية المستخدمة لقياس عيوب اللحام.
- **الملحق ج:** يوضح بعض التقارير التي يمكن الحصول عليها من البرنامج.

ABSTRACT

Quality is becoming one of the main automation objectives of industry. As a result, automated inspection systems have become an essential part of production lines. Automatic inspection is desirable because human inspectors are not always consistent evaluators of products. Due to recent developments in digital image processing, automated visual inspection is being extensively applied. On the other hand, the rapid development in production technology now requires the development of new accurate and efficient automated inspection systems.

Pipelines are considered the safest and most economic way of transporting gas or liquids over long distances. Weld inspection of oil and gas pipelines has always been one of the most important areas of non destructive testing (NDT). The film radiography method has been the cornerstone of NDT for the last 50 years. It is the most widely used method and the technique with which other methods are compared. Industrial radiography is carried out in every country, in every region and in all locations.

Although weld inspection of oil and gas pipelines is dependent on experts in inspection and decision making, the great number of control images, which has to be taken over very long distances, makes the detection of defects in pipelines difficult. The most difficult problem in the inspection cycle is the accurate detection of flaws in a given radiographic image. The human interpretation of radiographic films is a hard and difficult task when a great number of defects are to be counted and inspected. It is known that several experts do not have the same opinion on a given film, and even the same expert might have a different report at the beginning or the end of the workday. In addition, the ability of an expert to detect very small defects is not quite good, and difficult to reach to an automatic inspection system.

On the other hand, automatic inspection systems are more reliable because their decisions are not dependent on subjective factors, so these systems seem to provide good solutions for production inspection.

In this work, a new automated visual inspection system (using vision and expert systems) for defects identification in pipelines welded by shielded metal arc welding is developed. The recognition method is based on an identification tree, whose inputs are features and outputs are defect types. The knowledge gathered from radiographic expertise and different codes from international standards are used to build the recognition methodology. In addition to the advantages of the traditional radiography, the developed system offers many advantages such as giving more accurate results, eliminating any loss of image details due to film deterioration and eliminating the need for image interpretation by a skilled inspector. It is quite often economical in operation compared with commercial radiographic image enhancement systems. One of the great advantages of developed automated inspection system is that defect rates can be automatically classified according to the defect type, welder and welding date.

A review of the previous researches in the field of NDT, automatic inspection systems and image processing applications are introduced. A background on the main elements of the computer vision system is also introduced. In addition, the pipeline welding defects are identified and described. The acceptance limits according to specific codes are also introduced.

Many algorithms are used to build the developed system, so a novel algorithm for image enhancement and recognition welding defects is presented. Many image enhancement techniques are implemented such as gray level histogram, histogram equalization, histogram specification, noise reduction using filters, and feature extraction using boundary chain code BCC algorithm.

The defect recognition procedure consists of three steps: defect detection, feature extraction and recognition. An expert system is built to perform this task. It consists of two stages: the first stage is used to classify the defects into one of predefined defect groups. In the second stage, a set of classifiers (one classifier for each group of defects) that use statistical and structural rules are implemented for the final classification of the defects. The developed system supports most of the international standard codes (API 1104, ASME, DIN, BS, ABS, AWS, and JIS) for the acceptance criteria of weld defects. In addition, any new code can be defined easily to the system through a user friendly dialog box. An algorithm is proposed for automatic classification of defect rates according to defect type, welder and welding date.

The developed vision system is divided into two main parts, hardware and software. The hardware includes an IBM compatible personal computer with windows operating system, frame grabber as a capturing board and CCD (Charged Couple Device) camera. The software is developed totally in house to apply necessary image processing and computer vision algorithms to capture images and classify the defects automatically. The package is developed such that it can be used independently without referring to any other software. The developed software is written using Microsoft Visual C++ version 6.0 and it could run under any windows operating system. The suggested name for this software is *AutoWDI* (Automatic Welding Defects Inspection).

The proposed vision system offers the following capabilities:

1. It is capable of detecting and classifying most of weld flaws (11 types) in a given radiographic image.
2. In addition to the advantages of the traditional radiography, it saves time and eliminates the need for image interpretation by a skilled inspector.
3. It eliminates any loss of image details due to film deterioration by transferring the image to more stable storage media.

4. It supports most of the International standard codes (API 1104, ASME, DIN, BS, ABS, AWS and JIS) to classify the defects and to take the acceptance decision.
5. The defect rates can be automatically classified according to the defect type, welder and welding date.

This thesis is divided into six chapters and three appendixes as follows:

- Chapter 1:** Introduces a literature review of the previous researches in the field of RT, vision system applications, automated inspection systems and image processing applications.
- Chapter 2:** This chapter explains a background on vision systems.
- Chapter 3:** This chapter covers the general discontinuities in pipeline welding. The illustrations are very valuable on the job site for assisting film interpreters in describing discontinuities on radiographs, identification, acceptance limits for specific code. The codes are explained in appendix (B).
- Chapter 4:** This chapter introduces the methodology and the main programming algorithms used to build up the *AutoWDI* package. The output reports from the developed system in appendix (c).
- Chapter 5:** This chapter illustrates the hardware setup for developed vision system and introduces the technical specifications for each hardware component such as PC, the frame grabber, and the CCD camera. It also discusses the results to verify the capability and the validation of the developed vision system. The user's manual of this package is fully explained in appendix (A).
- Chapter 6:** This chapter introduces the conclusions of the work and the recommendations for further researches.

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Assessment of Gas Pipelines Welds -Welded by shielding Metal Arc welding- Using Computer Vision Techniques

A Thesis Submitted to
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For the Degree of
Doctor of Philosophy
In Industrial Engineering

By

Eng. Hani Ibrahim Shafeek Soliman

Assistant Lecturer in the Mechanical Engineering Department
Higher Technological Institute Ramadan Tenth City

Supervisors

Prof. I.M. Elewa

Mansoura University - Faculty of Engineering
Production Engineering and Mechanical
Design Department

Ass. Prof. A. A. Abdel-Shafey

Mansoura University - Faculty of Engineering
Production Engineering and Mechanical
Design Department

Dr. E. S. Gadelmawla

Mansoura University- Faculty of Engineering
Production Engineering and Mechanical
Design Department

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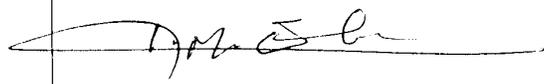
Supervisors

Researcher Name: Hani Ibrahim Shafeek Soliman

Title of Thesis: Assessment of gas pipelines welds -welded by shielded metal arc welding- using computer vision techniques

	Name	Position
1	Prof. Ibrahim Mohamed Elewa	Mansoura University, Faculty of Engineering. Production Engineering and Mechanical Design Department.
2	Ass. Prof. Ahmed A. Abdel Shafey	Mansoura University, Faculty of Engineering Production Engineering and Mechanical Design Department.
3	Dr. Elamir Samy Gadelmawla	Mansoura University, Faculty of Engineering Production Engineering and Mechanical Design Department.

SIGNATURES

	Name	Signature
1	Prof. Ibrahim Mohamed Elewa	
2	Ass. Prof Ahmed A. Abdel Shafey	
3	Dr. Elamir Samy Gadelmawla	

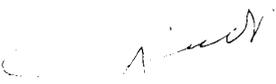
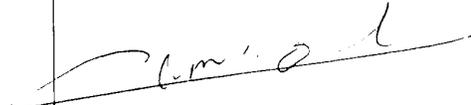
EXAMINATION COMMITTEE

Researcher Name: Hani Ibrahim Shafeek Soliman

Title of Thesis: Assessment of gas pipelines welds -welded by shielded metal arc welding- using computer vision techniques

No.	Name	Position
1	Prof. Monir Mohamed Koura	Ain Shams University, Faculty of Engineering Design and Production Engineering Department.
2	Prof. Mohamed Nasr Shabarah	Mansoura University, Faculty of Engineering Design and Production Engineering Department.
3	Prof. Ibrahim Mohamed Elewa	Mansoura University, Faculty of Engineering. Design and Production Engineering Department.
4	Ass. Prof Ahmed A. Abedel Shafey	Mansoura University, Faculty of Engineering Design and Production Engineering Department.

SIGNATURES

NO.	Name	Signature
1	Prof. Monir Mohamed Koura	
2	Prof. Mohamed Nasr Shabarah	
3	Prof. Ibrahim Mohamed Elewa	
4	Ass. Prof Ahmed A. Abedel Shafey	

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ABBREVIATION

ABS	American Bureau Shipping
ADC	Analogue-to-Digital Converter
API	American Petroleum Institute
ASME	American Standard of Mechanical Engineering
AVI	Automatic Vision Inspection
AWS	American Welding Society
BS	British Standard
BT	Burn Through
CR	Computed Radiography
CT	Computed Tomography
DAC	Digital-to-Analogue Converter
DIN	Deutsch International Norm
DWT	Discrete Wavelet Transform
E	Elongated Shape
FCR	False Call Rate
FFT	Fast Fourier Transform
HB	Hollow Bead
I	Irregular Shape
IF	Incomplete Fusion of Root Pass
IP	Inadequate Penetration Without High-Low

ABBREVIATION

IPD	Inadequate Penetration Due to High-Low
IU	Internal Undercut
JIS	Japanese Industrial Standard
L	Large
LUT	Lookup Table
NDT	Non Destructive Testing
PWB	Printed Wiring Board
R	Round Shape
RC	Root Concavity
ROIs	Regions of Interest
RT	Radiographic Test
SMAW	Shielded Metal Arc Welding
SP	Surface Porosity
TOFD	Time Of Flight Diffraction

NOMENCLATURE

IW	Inside Weld
A _{min}	The Area of the Minimum Enclosing Rectangle
A _r	The Area of Region
CW	Center of Weld
EW	Edge of Weld
h	The Height of Defect
L _a	Aggregate Length
L _i	The Length of an Individual Indication of Defect
L _w	The Length of Weld
M _{ij}	Center of Mass Where i and j Nonnegative Integers.
M ₀₀	Center of Mass Where Substitute 0 for i and 0 for j
P	Perimeter
R _i	Rectangularity Measure
U _g	Geometric Unsharpened
U _i	Inherent Unsharpened
W	The Width of Defect
X _{max}	Coordinate of the Lower Right Pixel
X _{min}	Coordinate of the Upper Left Pixel
Y _{max}	Coordinate of the Lower Right Pixel
Y _{min}	Coordinate of the Upper Left Pixel

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ABSTRACT

Quality is becoming one of the main automation objectives of industry. As a result, automated inspection systems have become an essential part of production lines. Automatic inspection is desirable because human inspectors are not always consistent evaluators of products. Due to recent developments in digital image processing, automated visual inspection is being extensively applied. On the other hand, the rapid development in production technology now requires the development of new accurate and efficient automated inspection systems.

Pipelines are considered the safest and most economic way of transporting gas or liquids over long distances. Weld inspection of oil and gas pipelines has always been one of the most important areas of non destructive testing (NDT). The film radiography method has been the cornerstone of NDT for the last 50 years. It is the most widely used method and the technique with which other methods are compared. Industrial radiography is carried out in every country, in every region and in all locations.

Although weld inspection of oil and gas pipelines is dependent on experts in inspection and decision making, the great number of control images, which has to be taken over very long distances, makes the detection of defects in pipelines difficult. The most difficult problem in the inspection cycle is the accurate detection of flaws in a given radiographic image. The human interpretation of radiographic films is a hard and difficult task when a great number of defects are to be counted and inspected. It is known that several experts do not have the same opinion on a given film, and even the same expert might have a different report at the beginning or the end of the workday. In addition, the ability of an expert to detect very small defects is not quite good, and difficult to reach to an automatic inspection system.

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الإشراف

أ.م.د. / أحمد عبد الحميد عبد الشافى

أستاذ مساعد بقسم هندسة الإنتاج والتصميم الميكانيكي
كلية الهندسة – جامعة المنصورة

أ.د. / إبراهيم محمد عليوة

أستاذ بقسم هندسة الإنتاج والتصميم الميكانيكي
كلية الهندسة – جامعة المنصورة

د. / الأمير سامى جاد المولى

مدرس بقسم هندسة الإنتاج والتصميم الميكانيكي
كلية الهندسة – جامعة المنصورة

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