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Indian Society for
ISNT
Non Destructive Testing

The First International Conference on NDE 4.0 - April 2021 in Virtual Mode

The Second International Conference on NDE 4.0 – October 2022 at Berlin, Germany

And Now Proudly Announcing

The Third International Conference on NDE 4.0

to be held during

February 2025 in INDIA !

Watch this space for more details

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OBJECTIVE - This Journal of Non Destructive Tesing & Evaluation (JNDE) is published quarterly by the Indian Society for Non Destructive Testing (ISNT) for promoting NDT Science & Technology. The objective of this Journal is to provide a forum for dissemination of knowledge in NDE & related fields. Papers will be accepted on the basis of their contribution to the growth of NDE Science & Technology.

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PUBLISHED BY: Mr. Bikash Ghose - Managing Editor, JNDE

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LETTERS

PRESIDENT TALK

DIWAKAR JOSHI
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Greetings!

Sept 2022 issue of JNDE was well received by the readers; thanks to the Editorial board in releasing this issue in time.

I am happy to inform you that the Program Formulation and Management Board (PFMB) has been formed with the objectives of conceptualizing, formulating and various non-certification programs such as webinars, conferences, seminars etc. and to create platform for constant interaction with ISNT members, and meeting the requirement of industry, academia and research community. PFMB will interact with other international NDT societies, national technical societies to formulate and organize joint programs. You will get regular updates of these programs through JNDE.

NCB is in the process of promoting IS 13805 and ICN Examinations in the different industries. Our ICN scheme is getting aligned with revised ISO 9712:2021.

Training Management Board has started working for the development of course outlines, course materials, practical training books to standardize the training activity throughout the country. Presently, the Board has authorized four training centres for ICN and eleven training centres for IS 13805 (interim authorization).

The chapters are continuing with the webinars, workshops training programs and certification courseswhich are really worth appreciating.

Now we are nearing to the NDE 2022 mega event and I would like to meet you all there. This yearly conference is an opportunity for all. It involves technicians, managers, service personnel, buyers, sellers, students, and in short, anyone connected to the field of NDE. It showcases the latest technology, equipment and happenings in the field of NDE. It is a place to share knowledge and to network. The eager NDE person within you will be treated to a lavish feast of events which includes the Inauguration Talk, Exhibition Stalls, Plenary Sessions, Invited Talks, Quiz Competitions, Cultural Programs, Special Sessions with industrial interactions, and of course the Preconference Tutorials on carefully selected subjects. This is a place where NDE evolves!

ISNT made a proposal presentation to host the 3rdInternational Conference on NDE 4.0 (planned in February 2025) on October 18, 2022 during the ICNDT Special Interest Group (SIG) committee meeting; and the same was accepted by the members. The formal announcement was made during the Inaugural Session of the 2nd International Conference on NDE 4.0 which started in Berlin, Germany on 24thOct 2022. Thanks to Dr. K. Balasubramaniam and Dr. M T Shyamsunderto make it happen. Dr. Shyamsunder is also the Guest Editor for this issue of JNDE and you will enjoy the NDE 4.0 papers presented in this issue.

I thank all authors, the editorial board, advertisers and the whole team for keeping up the momentum!

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BIKASH GHOSE
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Another exciting JNDE issue with the theme of NDE 4.0, released on the eve of NDE 2022, is now in your hand.

India is making striding progress in Industry 4.0 and, inevitably, in NDE 4.0. ISNT is walking hand in hand with all, conducted a series of activities in this area over the years and now successfully bid to host the 3rd International Conference on NDE 4.0 in February 2025.

This issue presents four original papers on NDE 4.0 covering the basics of NDE 4.0 in the context of Radiography, use cases of AI & ML in inspection, principles for successful deployment of NDE 4.0 and Simulation Assisted Automatic Flaw Recognition using AI in NDE. The chapter activities section summarizes the activities conducted by various chapters in the last three months (Sep – Nov 2022).

The Mahatma Mandir Convention and Exhibition Center (MMCEC), Gandhinagar, Gujarat is ready to Host you for the Conference & Exhibition on NDE (NDE 2022) to be held during 24th -26th November 2022. Get an update and the post-event memoirs on the landmark event at www.isntnde.in.

My heartfelt thanks to all the advertisers and contributors of this issue who helped release the issue before time. Many thanks to Dr Shyamsunder for agreeing to be the guest editor for the special issue of JNDE on NDE 4.0.

Original research articles to JNDE can now be submitted through the online portal of JNDE http://jnde.isnt.in. The online version of JNDE will soon have the ISSN number, and it is planned to have the DOI number for each journal article.

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GUEST EDITOR'S TALK

DR.SHYAMSUNDER MANDAYAM
Guest Editor, JNDE Special Issue on NDE 4.0
Vice President, ISNT

ISNT's Journal of NDE's Special issue on NDE 4.0 is now in your hands. This issue has been specially crafted to introduce to our readers and the NDE community at large the exciting topic of NDE 4.0 which is emerging and growing at an extremely fast pace around the world. You are all aware that the ongoing fourth industrial revolution popularly called Industry 4.0 is based on digitisation, digitalization and digital transformation combined with several other elements of Big data, Analytics, Robotics, Internet-of-Things, Artificial Intelligence, Digital Twins and many others. NDE 4.0 is a key enabler for Industry 4.0 and will lead to an improved productivity, efficiency, reliability and safety of components / structures/assets during manufacturing and while in-service. Adoption of NDE 4.0 by the industry is a long and fruitful journey which has started but needs to be strongly supported, encouraged and motivated in all segments of academia, R&D and Industry. We have four very interesting papers for you in this issue covering different aspects of NDE 4.0 and will provide greater insights on the topic.

We are also delighted to share with pride that the 3rd International Conference on NDE 4.0 will be hosted by ISNT in India during February 2025 and will be a big boost for this emerging, globally relevant topic.

We hope you enjoy browsing this issue and the papers published along with our other regular features. Please share your feedback or suggestions.

Dr.Shyamsunder Mandayam
Guest Editor, JNDE Special Issue on NDE 4.0
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- Bench Units
- Ultraviolet Black Light
- Consumables & Essentials



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- Gamma Ray Projectors
- IR-192,Se-75, Co-60 Sources
- Linear Accelerator
- Digital Radiography
- Radiation Detection & Monitoring Devices






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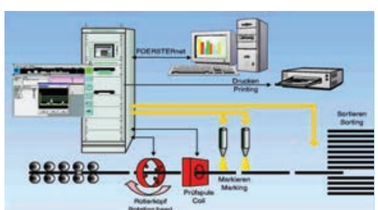
- Bar Testing
- Pipe Testing
- Piston Testing
- Component Testing


Eddy Current

- Sorting Equipments
- Component Testing Equipments
- Material Testing Equipments
- Portable Instruments

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Nov 2021/ TP

CHAPTER ACTIVITIES For the period from Dec 2022 to Feb 2023

BENGALURU

Technical Talk : Structural health monitoring of composite structure offline and online approach.

Speaker: Dr.Rajesh kumar NAL, Bengaluru

EC-Meeting conducted 10th Sept 2022

EC-Meeting conducted 01st Oct 2022

CHENNAI

In-house training on PT Level-II at NPCIL, GHAVP, Haryana from 5th September 2022 to 10th September 2022. Number of candidates attended the course and examination was 20.

Ultrasonic Testing Level-II course and examination was held on 13th September 2022 to 24th September 2022. Number of candidates attended the course and examination was 12. Mr.S.R.Ravindran was the course director.

We are planning to conduct MT & PT Level-II course and exam from 3rd November 2022 to 12th November 2022.

EC Meeting was held on 28th August 2022

EC Meeting was held on 1st October 2022

Ayudha Pooja function was held on 03.10.2022 at our office premises.

6th E-Newsletter – Sound Bytes were released on 1st September 2022.

KOLKATA

UT Level II Courses & Exam. Conducted Exam on 5th &6th September 2022. Candidates -05.

KOTA

Re-examination of Eddy current Testing level-II and Ultrasonic Testing level-I&II certification course (From 23.08.2022 to 24.08.2022)

MUMBAI

LPT II was conducted at NPCIL from 26th Sept – 30th Sept ,22 for 20 nos. candidates

LPT II was conducted at NPCIL from 03th Oct – 08th Oct ,22 for 20 nos. candidates

UT II was conducted at NPCIL from 03rd Oct – 14th Oct , 22 for 21 nos. of candidates

AGM was conducted on 24th Sep, 2022 at Acres club Chembur East, 112 nos. Attendees

NDTi -2022 : ISNT Mumbai organized a Seminar and Exhibition was organized by Mumbai Chapter during this year AGM, Technical programme titled NDTi- 2022 for Industrial Applications was organized for benefit of members on Sept 24th 2022 at Acres Club, There were Several talks during this programme. In addition, six exhibitors were given table space for displaying their products. The programme was well appreciated by all the members.

AGM was conducted on 24th Sep, 2022 at Acres club Chembur East, 112 nos. Attendees

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NAGPUR

Workshop on NDE at Butibori, MIDC Nagpur conducted.

We had conducted workshop on General NDE on Dt:- 29.04.2022 at M/s. Saitron Engineers Private Limited, Butibori Nagpur. Participants from various Industries attended the workshop.

Chairman Mr. Jeevan Ghime & Parag Pathak – Secretary given brief on forthcoming NDT Courses Scheduled for the year 2022-23.








PUNE

EC meeting No. 6 Conducted on dated 09.07.2022

One Life Member registered from ISNT Pune Chapter. (August)

One Corporate Member registered from ISNT Pune Chapter (September)

EC Meeting No. 7 conducted on dated 09.10.2022

AGM held on 12th of November 2022. Including Late L. M. Tolani memorial lecture

TIRUCHIRAPALLI

Proposed Courses in NOV. (Date to be confirmed):

a) LII Course in PT, MT, RT & UT

b) Training Cum Certification Course on Radiation Safety for Industrial Radiographer

Technical Talk

1. A better understanding on Diabetes and Obesity on 06.09.2022
2. ROYAL CHARTER DAY 2022, The Impact of 5G on human life in 21st Century on 13.09.2022
3. ENGINEERING IN THIRUKURAL on 20.09.2022
4. Artificial Intelligence and Robotics on 27.09.2022
5. Mind the Gap. Leave No One and Place Behind on 04.10.2022
6. Wire and Arc Additive Manufacturing: An Industrial perspective on 11.10.2022.
7. A Shared Vision for a Better World 18.10.2022.
8. Every Sunday-Webinar Planned.

TRIVANDRUM

During the period of September to November 2022, the chapter had conducted one EC meeting. The chapter discussed about the success of the event SENDAM 2022, NDE award nominations, Newsletter edition, AGM etc.

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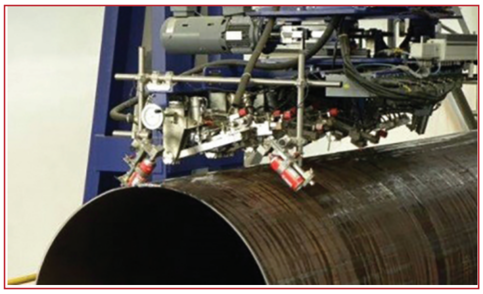

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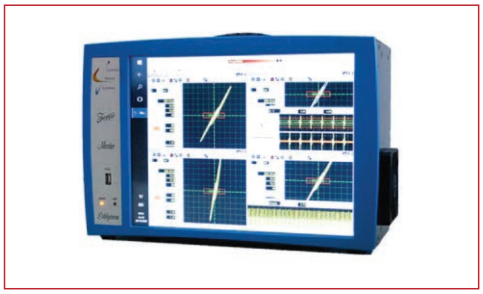

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VADODARA

Date: 10-September-2022

Technical Talk on Digital Radiography Solutions and Data Storage Solutions was organized by ISNT Vadodara Chapter on Saturday, September 10th, 2022 at at Vasvik Auditorium, Opp. GERI, Near Trident Complex, Race Course, Vadodara 390003 Gujarat, India. Mr. Santoor Girnekar - Product Lead and Mr. Krunal Sonawane - Regional Sales Manager from M/s. Fujifilm India Private Limited, Mumbai, presented the Technical Talk. The program was well appreciated by all the members who attended the program as well as by invitees.

Date: 10-Septembre-2022

The 36TH Annual General Meeting of Indian Society for Non – Destructive Testing, Vadodara Chapter was held on Saturday, September 10TH 2022 online at 08.15 pm at Vasvik Auditorium, Opp. GERI, Near Trident Complex, Race Course, Vadodara 390003 Gujarat, India.

The AGM was followed by Dinner. The dinner was sponsored by M/s. Fujifilm India Private Limited, Mumbai.

Date: 30-September-2022

On 30-September-2022, Dr. Shyamsunder Mandayam Vice President –ISNT & Chairman –TMB visited Mr. R. Venkatasubramanian (Hon. Chairman ISNT Vadodara Chapter) and Mr. Prashant Barodia (Hon. Vice Chairman Vadodara Chapter). The agenda was promotion of NDT Training activities.

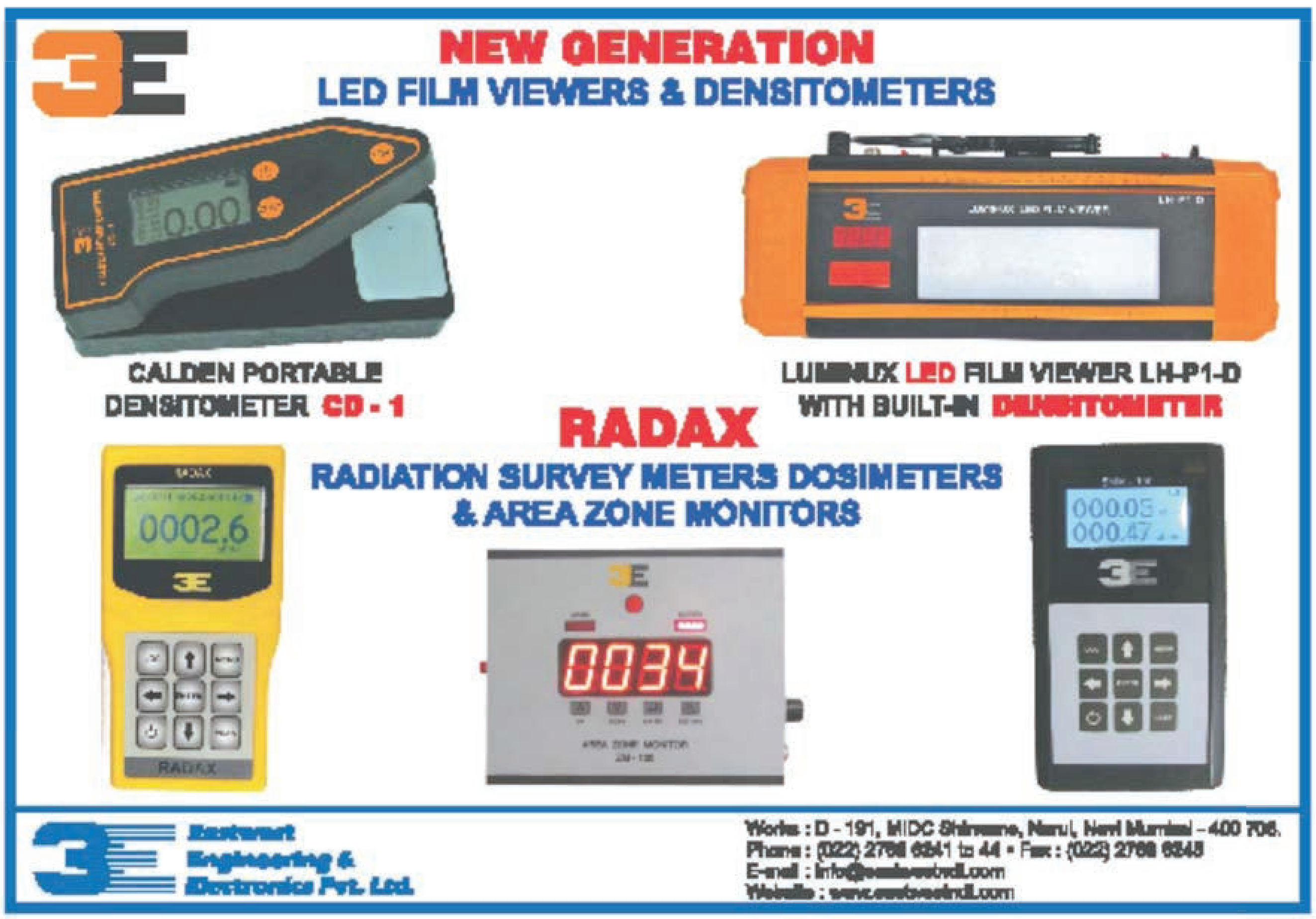
SUPPORT OF ISNT VADOARA CHAPTER TO NDE-2022 (HO EVENT)

GST Registration Number of ISNT Vadodara Chapter was shared with ISNT Head Office for invoicing and other related activities for NDE 2022.

SUPPORT OF ISNT VADOARA CHAPTER TO NDE-2022 (HO EVENT)

GST Registration Number of ISNT Vadodara Chapter was shared with ISNT Head Office for invoicing and other related activities for NDE 2022.

Audited balancesheet and accounting data of ISNT Vadodara Chapter have submitted head office



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Training Management Board (TMB) – ISNT

Over the last three decades, the training and certification activities of ISNT have been coordinated mainly by the National Certification Board (NCB) of ISNT, especially for the IS 13805 scheme, where BIS had authorized ISNT to be the sole body for this purpose. With NCB-ISNT getting formal accreditation by NABCB in accordance with ISO 17024 for initiating a new scheme based on ISO 9712 and having an international reach in the name of International Certification in NDT (ICN), it also became imperative that the training and the certification activities have to be operated independently to avoid conflict-of-interest and confidentiality issues. In view of this, ISNT has decided to form a Training Management Board (TMB) with the below-given objectives and scope,whose sole responsibility would be to manage all the training related activities and policies for the certification schemes of ISNT.The National Governing Council (NGC) of ISNT has formally approved the formation of TMBin the meeting held on 29th January 2022, and it was put in place immediately thereafter with a set of 15 members and 7 Ex-Officio members.

Objectives of TMB

Training

- Standardize and Harmonize the Content, Quality and Delivery of Training courses (leading to certification) being conducted by any authorized entity under the ISNT banner
- Key focus on Level 1, 2 and 3 certification courses being conducted by ISNT Chapters and Other Institutes
- Act as a nodal agency for addressing all NDT/Inspection related special Training needs of the Indian industry

Authorization of Training Centre's

- Streamline and create a Robust process to establish Authorized Training Centres (ATC) for IS13805 and ICN across the country (and abroad if needed) to help spread ISNT's schemes more widely

Scope

- Training activities related to IS13805 certification
- Training activities related to ICN certification
- Any Special Training programs of interest and relevance to be organized by ISNT based on current trends OR on request from Industry to help spread NDE Science and Technology across the country
- Developing, implementing and executing the method and process of Authorizing Training Centre's for both IS 13805 and ICN
- Establishing a self-sustaining model for revenue generation for continued operations and growth of TMB

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PROGRAM FORMULATION AND MANAGEMENT BOARD

PROGRAM FORMULATION AND MANAGEMENT BOARD (PFMB)

I wish to inform you that the Program Formulation and Management Board of ISNT (PFMB) has been constituted with Shri V. Manoharan as the Chairman, Dr. Deepesh Vimalan as Hon. Secretary and 14 technology/industry experts as members of the board.

PFMB has formed 4 technology groups –Radiological Imaging, Electromagnetic NDE, Thermal Imaging, and Acoustic NDE and Chairman for each working group were identified.

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Invitees

Dr. Paritosh Nanekar, Chairman-NCB
Dr. M.T. Shyamsunder, Chairman -TMB

Objectives

The main Objectives of PFMB are as follows:

- To conceptualize, formulate and organise various non-certification programs such as Webinars, Workshops, Conferences, Seminars etc. to create platform for constant interaction with ISNT members, meet the requirement of industry, academia and research community.
- To interact with other international NDT societies, National technical societies to formulate and organise joint programs.

Scope

- To plan and organise two annual conferences of maximum 2 days' duration (other than NDE) and execute through an organizing committee nominated by PFMB
- To conceptualize, formulate and execute programs such as Webinars, Workshops, Conferences, Seminars etc. of relevance to the NDT community to be organised by ISNT throughout the year across the country.
- To publicize the proposed program
- Develop and implement mechanism for executing the programs along with ISNT Chapters or independently (only if no chapter is interested).
- Create various topical working groups within PFMB and formulate programs as stated above for meeting specific requirement.
- To connect with various industries / institutes and formulate program to meet the specific needs
- Interact with international NDT societies (ISNT partner societies with MOUs) for conducting joint programs, pre-dominantly Webinars
- Interact with national technical societies for conducting joint programs
- Establishing a model for sustained revenue generation for continued operations and growth of PFMB

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TECHNICAL PAPERS

AI for NDE 4.0 – Recent use cases

Tuomas Koskinen, Topias Tyystjärvi, Oskar Siljama, Iikka Virkkunen
Trueflaw Oy
Tillinmäentie 3, tila A113, FIN-02330 Espoo, Finland
Email : tuomas.koskinen@trueflaw.com

Abstract

The use of machine learning in non-destructive evaluation (NDE) is a growing trend in the industry and a necessary development towards NDE 4.0. Beside academia, there are numerous case examples where machine learning is in use for actual inspections already. The main benefit of machine learning powered NDE is its reliability and repeatability to find flaws from the data. However, as the fundamental is in image recognition, machine learning can facilitate the inspection in general beyond just finding defects. These can be recognising the welds, image quality indicators and other features which the inspectors usually have to identify by themselves. In addition to reliability increase, automating these repeatable tasks increase the speed of data analysis considerably, saving inspector's time where it is most valuable. In this paper we review use cases where machine learning has been used in NDE and how these approaches benefit the end customer.

1.0 Introduction

Traditionally for mechanized NDE, inspector goes through all the data manually. This is a laborious task and usually takes a lot more time than the actual recording of the data. Naturally this data amount has been already limited by scanning only areas which are structurally most significant or are known to be under considerable loads or corrosive environments. However, there is still considerable amount of data to be evaluated by the inspector and the flaws are typically rare. Thus, the majority of the inspector's time is spent viewing data that contain no flaws. Furthermore, as inspectors' time is spent in data evaluation the final report is often limited to the bare essentials regarding data evaluation; pass or fail.

Machine learning (ML) changes this considerably. The ML model can go through the data and highlight the areas of interest. This leaves the inspector to only look and evaluate the possible flaw indications, skipping the looking of data which contains no indications. Moreover, ML can be used as an extra inspector where the procedure requires one or more inspectors to go through the data.

Previous research cases have covered ultrasonic data in welds [1] and noisy conditions [2]. Machine learning models have also been successfully in more challenging welds such as austenitic welds [3] and dissimilar metal welds [4]. The field progresses forward with modern ML models as [5] used modern U-net [6] for feature detection in radiographic images and [7] compared the effectiveness of other modern models such as ResNet and MobileNet with ultrasonic data.

In ultrasound NDE, ML has been used beside flaw detection in denoising of the signal to achieve higher image quality with autoencoders [8, 9, 10]. Naturally, this autoencoder approach has been used for increasing the efficiency of flaw detection with a ML model [11] and artefact detection [12].

Modern ML approaches have been proven to work in NDE for feature and flaw detection. Furthermore, they have proven to be versatile enough to process the recorded data even further. However, while the ML models are ready and capable for field use, the mindset needs to change in order to fully achieve all the benefits from NDE 4.0. As machine learning has enabled a great reliability and efficiency increase in the inspection itself, automation needs and data presentation needs to be taken even further. Traditionally, inspections have provided a report with a pass or fail evaluation where the data might not have been recorded. In [13] visions NDE 4.0 to be driven more toward data-oriented manner, where inspection and sensory data could be readily implemented to process monitoring. However, the transition needs to be gradual or the sudden requirement of cognitive demands and complete paradigm change might cause lack of acceptance or insufficient use [14].

In this paper we demonstrate the capability of modern machine learning models for ultrasonic inspection with two different model architectures, VGG16 [15] and U-net. Furthermore, we demonstrate the data presentation and reporting and how it evolves from traditional report to more interactive way of viewing the inspection results.

2.0 Use Cases

For the use cases we go through four ML solutions for NDE. First the metro axle inspection with ultrasound, second control-rod drive mechanism inspection with time-of-flight diffraction, third dissimilar metal weld inspection with phased array ultrasound, and finally a composite inspection with ultrasound.

2.1 Metro axle inspection

For following case studies, the earliest model was taken into use in 2019, when first metro axle inspection was made with the aid of a machine learning model. The inspection is made with conventional ultrasound but with multiple probes. The data in new axles are simple, but as the axles wear during use, indications start to show from dents from rocks. Varying geometry makes the data interpretation challenging even for an experienced inspector. Due to these aspects, the use of simple amplitude threshold is infeasible, since the inspector needs to evaluate the indication and distinguish the signal from other indications.

A machine learning model was taught to detect cracks from the ultrasonic data. The model was based on a VGG-16 image recognition model. Thermal fatigue cracks were made into an axle specimen to generate initial data for machine learning. The data was augmented with virtual flaws to generate ample data and extra thermal fatigue cracks were manufactured for testing and validation of the model. The working model managed to reduce the inspection time considerably from multiple hours to an hour. While the increase in effectiveness was considerable, the reliability of the model was also significant.

The approach enabled data recording as previously, but in the data analysis the inspector was aided by the machine learning model and would only look at sections from the data which the model highlighted as seen in Figure 1. While the model did not point the exact location of the flaw it screened area of the data which the inspector would the evaluate and determine if the area contained a flaw. The final output of the model is a traditional PDF file, highly similar to normal inspection report. This output and functionality is industry 3.0 as there is no interaction in the report or automation for the data to be uploaded to a network for further storage and use.

Figure 1: Output for the axle inspection. Indications highlighted in red from the calibration axle.

1.2 Control-rod drive mechanism inspection (CRDM)

CRDM inspections in nuclear power plants are done with time-of-flight diffraction (TOFD) technique. Due to the geometry of the drive mechanism, there are a lot of indications that are not actually flaws. The data evaluation is challenging as the diffraction tip signal is difficult to detect when scrolling through a considerable amount of TOFD data. In addition, there can be noise from poor contact or similar deviations.

The approach was similar as with the metro axle case, since the model was based on the VGG-16 approach. The model would screen the data and highlight areas for the inspector to look at more carefully. As the inspector is no longer required to scour all the data as in Figure 2, the risk of missing a flaw by a mistake is reduced. This is particularly helpful since the data is required to be evaluated by multiple different inspectors, thus the time from one evaluation can be decreased considerably.

This model was put to a field trial, where number of qualification flaws were evaluated by the model and the performance was compared to a human inspector evaluating the same data.

The model was able to detect the same qualification flaws as the human inspector. No qualification flaws were missed by the human inspector or the machine learning model. However, there was a significant difference in the evaluation time between the inspector and the inspector aided by the machine learning model.

The output report seen in Figure 3 was an HTML document, where the results were highlighted for the inspector and the inspector could scroll through the vicinity of the indication to verify the result. Slight improvement toward NDE 4.0, but still the automation and system integration aspects could still be enhanced to achieve true NDE 4.0 performance

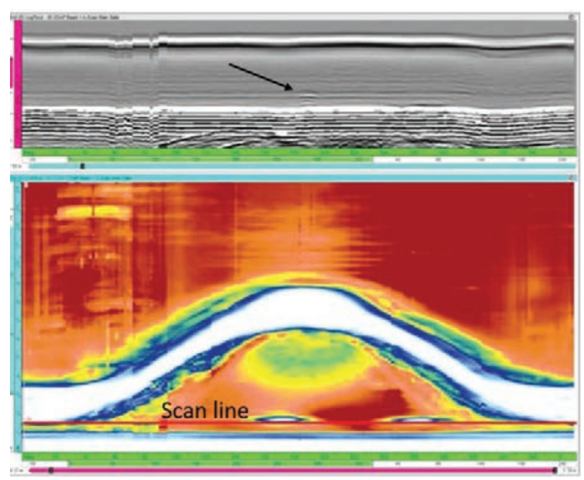

Figure 2: Traditional way of inspecting TOFD data

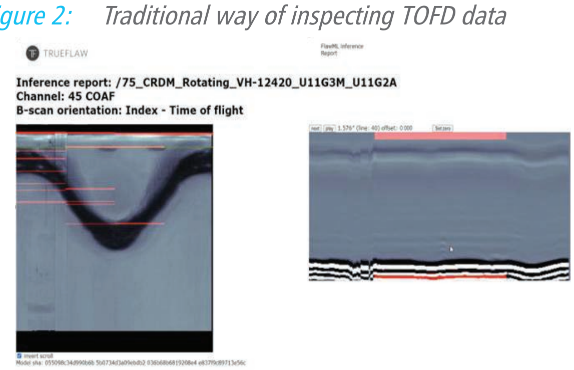

Figure 3: Indications highlighted by the ML model

1.3 Dissimilar metal weld inspection

Dissimilar metal weld (DMW) inspections are notoriously difficult inspections for ultrasound due to high noise and attenuation from the material structure. Moreover, these inspections are usually made in safety critical areas with high demand on reliability and low tolerance on false calls. Mostly these inspections are done with phased array ultrasound to gather enough information for flaw detection. As the data amount increases, so does the evaluation time. To reduce and ease the evaluation, different image and data processing methods are commonly used to help the inspector. One of these is merging the different angles obtained from phased array data to form a single merged ultrasonic image for the inspector to view. However, as the merge methods tend to leave artifacts and there is a possibility to lose data in the process, inspector usually needs to view the data completely.

For this case a U-net based semantic-segmentation model was used to detect flaws from the ultrasonic data and the output from the model can be seen in 4. In addition to detecting the flaws, the model could indicate the location of the flaw. By knowing the flaw location data analysis could be facilitated in such a way that an indication list would be presented to the inspector. This indication list would then show the actual indication in the data with pre-processed ultrasonic data. Then the inspector could readily measure the indication and move to the next one. As in the metro axle and CRDM inspection cases, the inspector would only evaluate the indications shown by the model, increasing the data evaluation speed considerably. Furthermore, the approach was more integrable with other systems as the result could be implemented to a regular inspection software as well if further analysis would be required.

1.4 Composite inspection

For the composite inspection the model was based on the VGG-16 approach. The target was to detect pores formed in the composite manufacturing. While ultrasound is ideal to detect pores and laminar defects from composite structures, the manual labour of the data analysis makes the pore detection and monitoring infeasible for human inspectors. Figure 5 demonstrates how the ML model has detected and highlighted the pores in the specimen.

As seen in Figure 5 there are numerous indications, thus it would have been infeasible for a human inspector to mark and track all the indications.

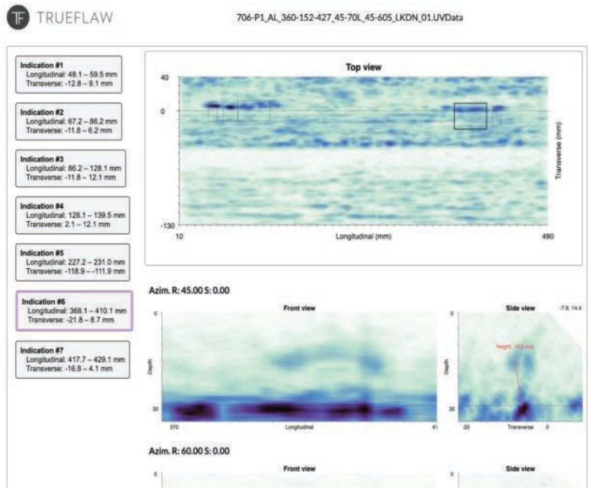

Figure 4: Result for DMW inspection from the ML model. Indication list on the left, which highlights the findings from the data. The height of the flaw can be measured easily by the inspector.

Once these indications are known they can be tracked over production batches for quality control purposes. Moreover, if pores pack as denser cluster they can be viewed as a defect. For the pore amount to be used in production statistics or monitoring, the data is possible to be integrated and implemented automatically to other production software to easily monitor the production parameters.

3.0 Discussion

The most recognizable benefit of these machine learning powered inspections is the efficiency. For most cases there is no need for the inspector to look at data that contains no indication about flaws or flaws, thus the result is promptly available.

Beside the considerable efficiency increase, the other significant benefit is the repeatability. Once the model has passed the qualification, the performance stays the same for future inspections. The performance stays predictable and there is no variation between evaluations. When compared to a human inspector, the performance of the evaluation is highly related to the inspector's skill but also how mentally fit the inspector is to do the evaluation endeavour.

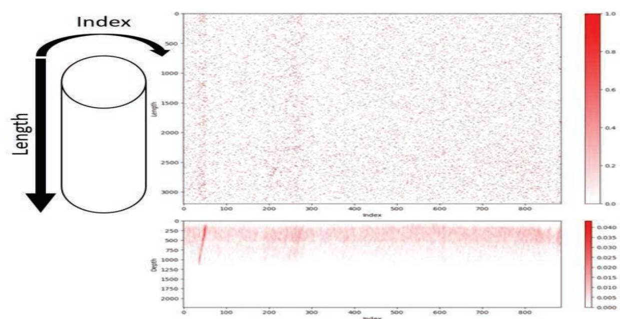

Figure 5: Composite inspection with a machine learning model. Areas marked in red are tiny pores from the specimen.

The repeatability is also highly linked to the overall reliability increase of the inspection. This reliability is measurable trough Probability of Detection (POD), which is well standardized practice in NDE [16]. POD elaborates the flaw size, which can be found the most feasibly, determining the critical flaw size. Auspiciously, missing of smaller flaws, is not significant comparing to a miss of a larger, critical sized one. Thus, the qualification effort needs to be set so, that the critical flaw size is found with high confidence. Through this high confidence, the inspector is always given the chance to evaluate the flaws within the scope of critical flaw sizes.

Once the inspector is given the chance to evaluate all critical sized flaws and possibly variety of smaller flaws the inspection effort is still highly controlled by the inspector. This enables the inspectors to use their time more efficiently by evaluating actual indications and not looking for them in the data, as they could miss some of the indications.

Finally, the ML opens completely new possibility for NDE by enabling larger variety of monitoring of the product. Features which are previously too laborious to monitor can now be implemented with ease with the aid of ML. This can either be implementing this monitoring to ongoing inspections or either inspecting the product with the goal of calculating porosity or other features. Furthermore, these approaches can be further integrated by automatically outputting the results in machine readable format for other systems to utilize and take advantage of.

4.0 Conclusion

Machine learning models have come to the NDE field and number of them are already in use. The models and approaches have matured to a point, where the machine learning models have passed the field trials in highly challenging data evaluations. Thus, the approaches are ready to increase the reliability of even the most safety critical industries.

The main benefit of utilising machine learning in NDE is the significant increase in efficiency, but also in reliability. When the inspector is able to focus to look at the data which is probable to have a flaw, the inspector's time is used more sensible way while still maintaining the control with the inspector.

Machine learning powered inspections also enable completely different approach to inspections in general. Once the data analysis can be automated, it enables monitoring of manufacturing in completely different scale than before, completely unreachable by manual data analysis.

Acknowledgements

The metro axle inspection was done in collaboration with DEKRA, CRDM and DMW inspection with EPRI and the composite inspection with Valmet. Their contribution is greatly appreciated.

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NDT 4.0 – Chance or Threat?

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Abstract

We are in the midst of a significant transformation driven by technology. In our everyday live this it becomes apparent through self-driving cars and artificial intelligence. The world around us is changing at a rapid pace – this also changes the way we produce products. Complete industries are transformed with major implications for professionals in this field. This transition is so compelling that it has been named Industry 4.0, the fourth industrial revolution. Also, our industry cannot escape the gravity of these fundamental changes. And the question arises – is this a threat or a chance? This paper will explain the fundamental principles and some specific examples from the field of radiography.

1.0 What is NDT 4.0?

The concept of NDT 4.0 is a subgroup of changes that are driven by the far bigger movement of Industry 4.0. It is important to understand where the term comes from [1]. The first industrial revolution happened between the late 1700s and early 1800s. During this period, manufacturing evolved from focusing on manual labor performed by people to a more optimized form of labor by using water and steam-powered engines and other types of machine tools.

In the early part of the 20th century, the world entered the second industrial revolution with the use of electricity in factories. The introduction of electricity enabled manufacturers to increase efficiency and helped make factory machinery more mobile. It was during this phase that mass production concepts like the assembly line were introduced to boost productivity. The legacy of Ford is a great example of that period.

Starting in the late 1950s, a third industrial revolution slowly began to emerge, as manufacturers began incorporating more electronic—and eventually computer—technology into their factories. During this period, manufacturers began experiencing a shift that put less emphasis on analog and mechanical technology and more on digital technology and automation software.

The fourth industrial revolution is characterized by connected computer systems through the cloud, the Internet of Things (IoT), Smart Factories, Big Data, Artificial Intelligence (AI), autonomous robots, predictive maintenance and additive manufacturing (AM). The adoption of these technologies lead to substantial improvements in productivity and efficiency. As its implementation are not an evolution but rather a revolution of the traditional manufacturing paradigm it is considered as disruptive. Especially, professionals on the shop floor face fundamental challenges and have a steep learning curve ahead as the new tools require a completely different skillset.

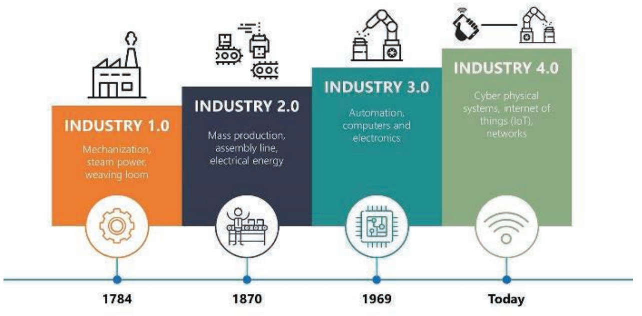

Figure 1: Evolution of Industry 4.0

2.0 The impact on NDT

Figure 2 shows the different fields of Industry 4.0. This section will assess some of them and provide real examples where they already impact NDT today. Due to space constraints this assessment cannot be holistic, but it should provide a good overview.

First, we will investigate robotics and simulation, allowing tedious handling tasks to be automated. This allows higher throughput, lower inspection costs and higher process safety. Figure 3 shows an example solution where three robots work in harmony to inspect airducts and pipes used in the aerospace industry. While two robots do the part handling, one robot has a C-Arm with the X-ray components mounted on it. This way cycle time could be brought down from several hours to a few minutes. When an operator brings a part, he scans a barcode and the system automatically loads the right parameters and part holders. All images are archived under the serial number and full traceability is given and image quality is always supervised as the system performs an automatic long-term performance evaluation according to ASTM E2737 [2]. New programs can be programmed offline by the CAD/CAM simulation tool. This way the system can be utilized 100% for production and does not need to be shut down for engineering purposes. This increases utilization by a big amount.

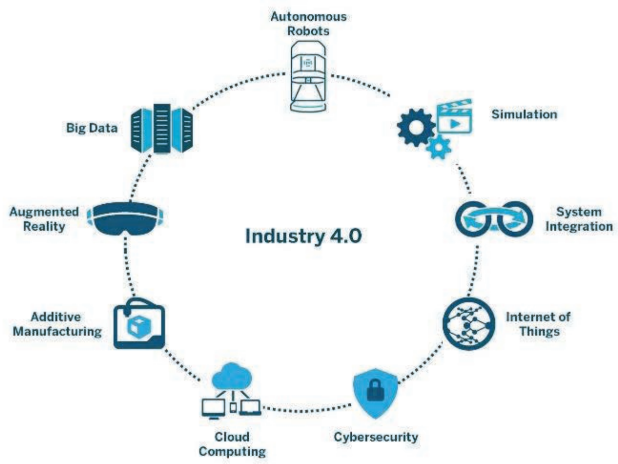

Figure 2: *Fields of Industry 4.0*

Figure 3: *Robots working in harmony in the aerospace industry*

The next big segment of Industry 4.0 is Artificial Intelligence (AI) and big data. This is also known as Automated Defect Recognition (ADR) in Radiography [3]. Indications, like porosities, cracks or inclusions, are automatically detected, measured and evaluated against the inspection criteria. Already widely adopted by the automotive industry we finally see other industries like aerospace following. During the transition period it makes sense to adopt an assisted defect recognition strategy, where an AI supports the human operator by cross checking his readings. This approach is also called supervised learning in data processing and allows rapid training of the underlying AI system. As soon as enough data is collected that correlates decisions by the operator and the AI companies can build the required proof for qualification of the ADR system by using probability of detection (POD) methods. With increasing computational power AI unfolds is strength. Figure 4 shows an example where ADR was used to evaluate a digital radiograph of an automotive casting part.

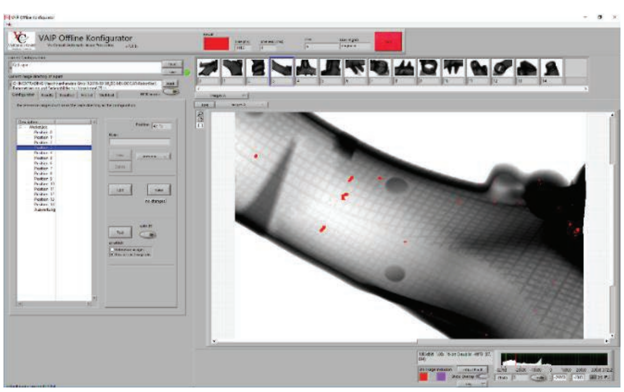

Figure 4: *ADR in automotive industry*

When looking into Additive Manufacturing (AM) our technology plays a big role. Industry experts identified that Computed Tomography (CT) [4] is probably the only technology that can inspect complex AM parts to qualify them for safety critical environments. Figure 5 shows a scan of a tensile probe; the upper part shows the horizontal cuts and the lower part the vertical cuts. By acquiring substantial amounts of digital radiographs and computing them into a 3D model we can gain information about parts like we have never been before. In manufacturing it is all about the digital twin – what people do not realize is that NDT can supply the perfect digital twin!

The last part we will assess is Cloud connection and system integration. With today's technology it becomes possible to connect systems in factories. If desired even complete factories around the globe. Today it is possible to have image acquisition locally (on the so-called edge) and interpretation centralized in an excellence center. This could be a solution to the lack of qualified personnel that many companies face. Standardized interfaces on machine communication like OPC UA allow systems to interact.

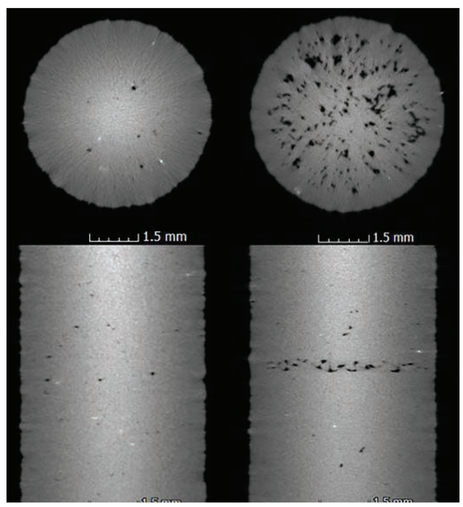

Figure 5: *Scan of a tensile sample*

Currently NDT is only seen to ensure quality, but it can do so much more. Let us assume the example of a casting company. Every 20 seconds they manufacture one aluminum casting. Sometimes process parameters get out of bound and parts with flaws (porosities) are produced. The company performs digital RT to prevents these parts from being delivered. In the past the X-ray inspection has been on the end of the line with a substantial delay of sometimes days between the two stations. By moving the two stations much closer together the manufacturer has two advantages: Less value-added steps being performed on flawed parts. More importantly the X-ray system can communicate with the casting system to "warn" it that the scrap rate goes up. This way the casting process engineers can correct parameters in order to get back to the desired quality. This way NDT has just saved the company a lot of money.

All those measures alone pose significant gains in efficiency, but they compound each other if done together. Just assume the robotic system above that is installed in factory A and B. As there is a lack of qualified inspection personnel in that region the company decides to transfer all images to factory C, which is its NDT excellence center. Image interpretation is performed centrally for all other locations. At the same time, it is ensured that there is a baseline for inspection quality. All data is archived in a local data center and an AI is constantly being trained. The smarter the system gets the more help do interpreters get, which further improves the interpretation quality. This simple example shows the powerful impact that robotics, cloud connection, system integration and AI can have on our industry.

Quote: *"Data is the oil of NDT 4.0" - Lennart Schulenburg*

3.0 How does this affect me?

The world has never been more complex, as supply chains are spanning around the world and we see the rise of big scale automation on the shop floor and beyond. Especially Western economies face a growing competition from lower cost countries that are quickly catching up in terms of technology. Many other departments of our companies are already transformed by the digital disruption and robots have become a valued colleague in many areas. In every sector from automotive to aerospace the impact of automation is clearly visible. Companies understood that they are in a global competition these days and that just continuing to do it the way we always did it will have severe consequences.

NDT traditionally shows a substantial inertia towards change and there are good reasons for it. In the end all of us are responsible for the quality of the output that leave our companies. Our work is far too important for thoughtless experiments with technology. As the guardians of quality, the NDT industry created a strong network of rigid standards and regulations. On the downside, these rigidities are now slowing us down significantly. Recently, a supplier of the aerospace industry discovered substantial cost savings by roughly factor ten if he would switch from X-ray film to digital radiography, robotics and computer numerical controls. The return of interest (ROI) was amazing and it would help the company to stay in business against its new competitors from Malaysia. Unfortunately, the project had to be abandoned as it was discovered that the parts were governed under a standard established in the 1970s. Such situations are quite frequent in our industry and destroy a huge amount of value that could be captured for our companies and countries.

Even such stories happen frequently, our industry sees a huge transformation. Especially, in industries that have less rigid quality requirements, like automotive, embraced the new technologies. One of Germanies leading automotive manufacturers adopted inline Computed Tomography (CT) to inspect rotors for electric motors. The system uses an industrial robot for part handling and artificial intelligence for the interpretation of the images. The skillsets required for the operators – completely different than in the past.

4.0 How to be prepared for the future ?

The initial question was chance or threat. There is no single answer to this as it is highly context dependent. This movement will, one way or the other, change our industry fundamentally and there will be a need for adoption. This process will stretch over the next five years and pressure will be increasing in that time. Nevertheless, this is no reason to panic or activism. We all must remember that our first and foremost job to ensure part integrity and to prevent faulty parts going on the market. This should never be jeopardized by efficiency improvements or new technology. Therefore, it is needed to develop a strategic change roadmap with realistic milestones and contingency measures. A careful process analysis will reveal low-hanging fruits that can be easily approached.

It is also very important to not take two steps at a time. Moving straight from film (2.0) to a fully automated robot system (4.0). The right step would be to first switch from film to digital RT (3.0), then establish new processes, techniques and qualify all operators. The next step would be to then carefully automate and digitize further process steps.

5.0 Does digitization take my job?

There is a big fear that robots, AI and automation will take our jobs. This fear is mainly driven by misleading media articles and futuristic movies. Even though the new technology can do amazing things, they do not even come close to the capabilities of the human brain. We will not see these systems replacing professionals in NDT any time soon. There should be a paradigm shift in the perception of these helpers. Robots help us to move parts and reduce the amount of physical labor. The cloud makes archiving and processing results much easier, while AI helps us to improve our evaluation capabilities. No doubt, our jobs will change and the activities we perform will be more computer heavy. This requires requalification and learning of new skills. In the end, every machine needs a human to supervise it! Let's just think about the other industrial revolutions like electrification – it happened, and we still have jobs. It is more important to approach this new technology with openness and to embrace the chances it has for us. The biggest threat would be to wait for the things to come and get disrupted by others that adopted them earlier.

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Principles for Successful Deployment of NDE 4.0

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Abstract

Digital Transformation is at the heart of the current industrial revolution, and it won't spare the non-destructive evaluation (NDE) sector. It is changing the value proposition of inspection processes from 'an undesirable quality check' to a 'much-needed source of data, information, and knowledge' from manufacturing to service life maintenance. Non-destructive assessment has changed significantly from the early days of 'enhancing human senses' to 'equipment that can assess the condition' and remotely support sustainment decisions. The current trends in cyber-physical technologies offer new possibilities wherein the inspectors will be able to see the anomaly on a digital twin before it can be detected on conventional NDE equipment, by fusing data from multiple sources and leveraging the history captured in digital threads. To convert such a possibility into reality, organizations need to embark on a journey where the endpoint is not very clear. This puts a set of guiding principles, a compass, at the heart of execution to make correct choices, help prioritize processes, and minimize the possibility of conflict.

This paper provides a structured model of twelve principles in three synergistic perspectives with a responsible foundation. They are designed to serve as a guide to meaningful development, deployment, and leveraging of the next generation of inspection systems, as well as creating, capturing, and distributing value from the data they generate.

KEYWORDS: Industry 4.0, Digitalization, Inspection reliability, Digital Transformation, Roadmap, Value Creation, Innovation.

1.0 Recap of NDE 4.0

1.1 Historical Evolution

Historians split recent times into three industrial revolutions: mechanization (steam power), technical (electric power and mass production), and digital (computing and microelectronics). The world of NDE has seen a parallel: first - tools to sharpen human senses, second - wave applications to view inside the components, and third - digital processing and automation.

As the industry goes through the fourth revolution powered by interconnections and enhanced digitalization, NDE is also on a new horizon with the addition of information transparency, technical assistance, machine intelligence, decentralized decisions, and much more. The line between non-destructive evaluation (NDE) and the fourth industrial revolution is getting blurred since both are sensory data-driven domains. This multidisciplinary approach has led to the emergence of a new capability for non-destructive evaluation, now termed NDE 4.0. The NDT community is coming together once again to define the purpose, chart the process, re-align the organizations, and address the adoption of emerging technologies.

NDE 4.0 is defined as a *Cyber-physical Non-Destructive Evaluation; arising out of a confluence of Industry 4.0 technologies and traditional NDE physical methods, to enhance inspection performance, decision making for safety and quality assurance, as well as provide relevant data to improve the design, production, and maintenance* [1,2].

This fourth revolution integrates the digital tools (from third) and physical methods of interrogating materials (from second) in a closed-loop manner reducing human intervention and enhancing inspection performance. Within the context of the physical-digital-physical loop of NDE 4.0 [3,4,5]; digital technologies and physical methods may continue to evolve independently, interdependently, or concurrently. The real value is in the concurrent design of an inspection system through the application of Digital Twins, Digital Threads [3,4], and an expanded perspective of the human role in NDE evaluation processes. This provides the ability to capture and leverage data right from the materials themselves and from the manufacturing processes up to the stages of usage and in-service maintenance, creating value across the ecosystem [3].

1.2 Need for guidance today

In [1] the digital technologies relevant to NDE were covered in a design thinking approach. In [3] the value proposition of NDE 4.0 for various stakeholders in the eco-system was discussed and in [4] the core technologies to enable NDE 4.0, like Industrial Internet of Things, Digital Twin, and Cyber-Physical Loops. Those publications covered the WHY and WHAT for NDE 4.0. An extensive description in the context of NDE has been published in the book "The World of NDE 4.0" [6]. The state-of-the-art in NDE 4.0 has recently been captured in the Handbook of NDE 4.0 [7]. All these publications create a suitable vision of the future of NDE and a good indication of personalized sets of seemingly complex technologies suited for specific industries or geographies. What is missing from the published literature on the topic is HOW to plan it out that makes business sense.

There is an extensive suite of digital technologies [1], and their impact is reasonably well understood as standalone pieces. However, their combination adds to the complexity of the technical systems and uncertainty in the business environment. Nonetheless, the synergies and value embedded in their combination are worth the extra effort of a deeper understanding of the principles, perspectives, and mindsets required to manage uncertainty and complexity.

The enormous leap in technology application and value realization tied to the fourth industrial revolution or digital transformation [8] can also be termed as massive transformation purpose (MTP). This is easier said than done. It requires leadership commitment, serious planning, and investment over a sustained period. It requires a roadmap that defines the HOW, starting with actions now and here. An explicit need for such guidance has also been highlighted by the recently formed Special Interest Group on NDE 4.0 (SIG NDE 4.0) within International Committee for NDT (ICNDT). This paper provides a set of guiding principles adopted from Industry 4.0 and interpreted in the context of inspection systems.

2.0 The Three Facets of NDE 4.0

Different NDE practitioners and managers see NDE 4.0 differently. To reduce the confusion, we must classify various facets of NDE 4.0 from the digital adoption perspective. This clarity emerges when we accept an intermediate step (digitalization) between digitization (Industry 3.0) and digital transformation (Industry 4.0).

2.1 Digitalization of NDE

Initiatives directed at the application of Industry 4.0 principles, technologies, and frameworks to improve and expand the realm of NDE solutions available in the world. Examples: Autonomous drone/robotic NDE for bridges, towers, pipelines; and Digital RT/UT/ET along with Augmented Intelligence for integrity assessment of in-service high-risk assets, such as Turbine parts.

2.2 NDE of Digitalized Systems

Initiatives directed at the application of existing NDE principles, technologies, and frameworks to create and mature solutions for Industry 4.0 needs, pains, and gains. Examples: Manual UT/ET at the end of an automated manufacturing line, or Digital RT/UT for an additively manufactured part after printing, or PT/UT/ET of an autonomous drone or a surgical robot.

2.3 Digital Transformation of Industry/NDE

Initiatives directed at integrated development of digitalized NDE capabilities within digitally transformed systems to fully deliver the promise of Industry 4.0. This is not to be viewed as a mere combination of the above two, rather it should be seen as a seamless integration of both, a digitally transformed industry that integrates digitally transformed NDE solutions. Those NDE solutions are a combination of hardware, embedded software, platforms, and enriched human participation through new digital competencies. Example: NDE technologies integrated within smart manufacturing for inline quality assurance with no human intervention; or In-situ real-time NDE within additive manufacturing process to control the process for part quality assurance; or NDE and SHM digitally fused to assure service performance and safety.

3.0 A Dozen Principles for NDE 4.0

Figure 1 shows the twelve principles that can serve all three facets of NDE 4.0. They are categorized into four buckets corresponding to three perspectives (a) infrastructural, (b) value enhancers, (c) outcome, and a responsible mindset that makes up the foundation across the other three.

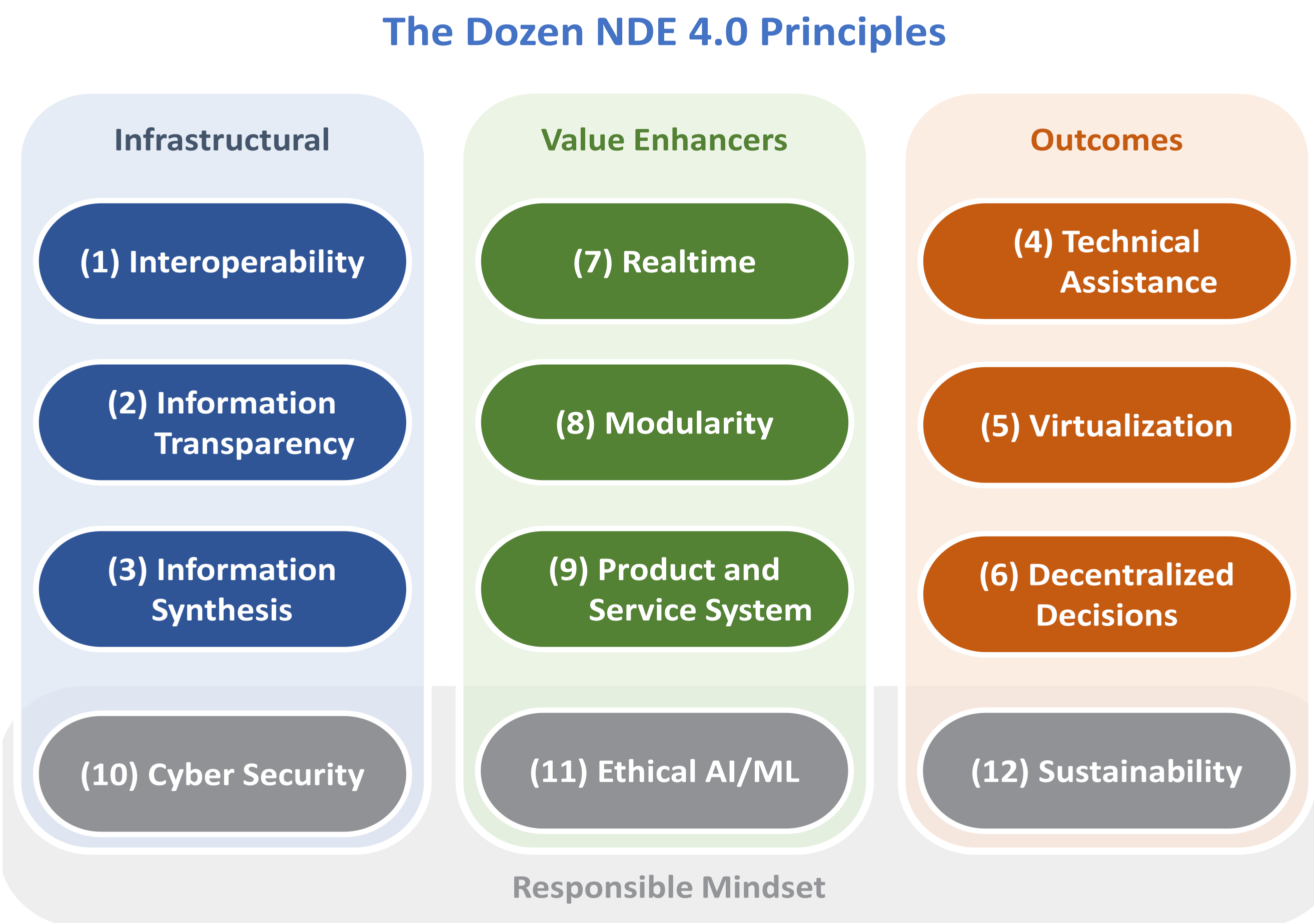

Figure 1: *Key NDE 4.0 principles derived from the Industry 4.0 philosophies, industry expectations, and technology trends to provide guidance in selecting, developing, and integrating technologies, products, data, services, and competencies, for a myriad of purposes.*

2.1 Interoperability

The ability of systems (assets, instruments, sensors, devices, inspection equipment) to connect and communicate with each other via the Internet of Industrial Things (IIoT).

There are three main types of interoperability. (a) Syntactic interoperability: where two or more systems can communicate and share data, thus allowing different types of software to work together. This happens even if the interface or language is not the same. (b) Structural interoperability: this defines the data exchange format, which specifies the standards used to format messages sent from one system to another. This is essential for users to be able to understand the information's purpose clearly. (c) Semantic interoperability: two or more systems connect and share data that each system understands in a meaningful way.

2.2 Information Transparency

The ability of systems to share information (with semantic interoperability), facilitating interpretation, training, and visualization.

The transparency afforded by NDE 4.0 technologies provide operators, inspectors, and NDE engineers with vast amounts of useful information needed to make appropriate decisions, in time. It begins with interconnectivity, which permits the collection of large amounts of data and information from all points in the manufacturing process and service life usage, thus aiding quality, safety, and design improvements. Transparency also helps identify key areas that can benefit from innovation and improvement.

2.3 Information Synthesis

The ability of systems to synthesize information obtained from the materials, environment, and usage history, of several comparable assets and provide intelligent forecasting.

Information synthesis is all about gathering and analyzing information to gain valuable, actionable insights. Conducting this kind of activity and sharing knowledge across time and location leads to advancements guided by purpose. It goes beyond summarizing or reporting; it goes to connecting and interpreting information obtained from diverse sources referenced within a relevant context.

2.4 Technical Assistance

The ability of systems to assist with inspection automation, workflow management, decision-making, and traceability.

NDE 4.0 shifts the role of humans from an inspector of assets to a problem solver and decision maker for the sustainment of assets. Assistance systems are designed to support inspectors and engineers that need to make informed decisions to address urgent needs for operation or maintenance, regardless of whether it's corrective, preventive, or predictive, on short notice. This could be on an asset or from a remote location.

2.5 Virtualization

The ability of systems to create virtual models of themselves and of other assets in their environment that can facilitate the creation of digital-twins, threads, and weaves.

Virtualization allows a "copy" of the physical system to be created digitally by merging sensor data acquired from monitoring assets and inspection equipment with virtual simulation models. The virtual view through a 3D interface helps to monitor physical materials, structure, and processes, allowing operators and managers to better manage growing complexity, and achieve their purpose.

2.6 Decentralized Decisions

The ability of systems to make decisions on their own and perform inspection tasks independently; and to seek human intervention in case of exceptions, interferences, or conflicting objectives.

Interconnection and information transparency permits inspectors and engineers to make decisions both inside and outside of production or maintenance facilities. This ability to combine local and global information at the same time helps to drive better decision-making and increase overall productivity.

2.7 Realtime

The ability of systems to generate and retrieve datasets in real-time to support or substantiate decentralized decision-making processes.

For high-value continuously operating assets such as power plants and transport systems, the concept of real-time condition monitoring is not new. It however becomes essential to fully leverage decentralized decision-making processes and is enabled by transparency and interoperability.

2.8 Modularity

The ability of systems to flexibly adapt to different requirements by virtue of design characteristics.

Essentially, modularity offers advantages in the move to digitized inspections by promoting greater flexibility, interconnectivity, interoperability, data-sharing, and information transparency, allowing much higher levels of technical support and decentralized decision-making.

2.9 Product Service System (PSS)

The ability to synergistically merge a specific set of products and services to create, capture, and distribute enhanced value for purpose.

Digitalization helps to realize product-service integration as business models providing higher profits through a supplementary set of added values. It comes in various forms. (a) Function-based PSS: where you add new functions to increase product value in the competing market, through real-time remote monitoring and technical assistance services. (b) Evidence-based PSS: where you periodically use big data analytics to achieve the purpose.

2.10 Cyber-security

The ability of systems to protect themselves from disruption or misdirection, and protect the data from theft, damage, or unauthorized disclosure.

While the implementation of NDE 4.0 appears to solve many issues, new cybersecurity concerns may be introduced. The use of sensors and remote access may provide entry points for hackers, cybercriminals, or industry competitors to gain access to inspection systems and even assets. Before implementing new technologies, a cyber risk assessment must be performed to provide a full understanding of the system's cybersecurity needs and capabilities. NDE system developers and users should understand the benefits and the potential cybersecurity risks implementing NDE 4.0 may introduce. Cybersecurity standards generated by organisms such as ISO or NIST are valuable resources to enrich and strengthen the security of NDE 4.0 solutions.

2.11 Ethics

The ability of the systems to reduce bias, warn users when operating outside design parameters, and shut down before causing any harm.

NDE 4.0 technologies with automation, robotics, data traceability, and workflows can help reduce many of the existing concerns in NDE and human factors that create difficult situations. However, Artificial Intelligence and Machine Learning require some additional precepts to the existing Code of Ethics. We must address the concerns around responsibility and accountability of decisions made by machines learning from multiple sources. Can smart machines outthink us and, if they can, whether we should worry about this? Are our traditional business practices of privacy and confidentiality compatible with other principles of information transparency and synthesis? A sound ethical foundation is paramount for any NDE 4.0 solution created, regardless of the decision processes being guided exclusively by human intervention or supported by digital technologies.

2.12 Sustainability

The ability of systems to self-optimize energy consumption and data generation for sustainability.

Just like ethics, sustainability and sustainable development need conscious effort. Digital transformation affects materials and their energy life cycle depending upon how the engineering community approaches design optimization. Data generation and storage are having a profound impact on carbon footprint. Digital technologies shall also be used to minimize and compensate for the impact of the digital transformation of NDE processes and systems.

4.0 Application of these principles

The list of dozen items above is not to be treated as a compliance checklist. But a reference for awareness, education, and guidance applications.

4.1 Organizational Alignment

One of the challenges leaders face is keeping the organization aligned and focused on meaningful actions. A set of guiding Principles helps them with this desire. As we are getting more and more dispersed globally, delegating authority and responsibility across cultures, it is important for managers to have clarity on what is acceptable and preferred. These dozen principles make a useful leadership tool.

4.2 Building a Strategic Roadmap

NDE 4.0 is a transformation journey. You need a roadmap in pursuit of a purpose, with sustained leadership commitment, and a dashboard to track execution. All this requires changes in governance and mindset. A set of principles help align various facets of organizational change and reduce conflict through the transformation. This has been extensively covered in a recently presented paper [9] and also published as a book [11].

These principles can help with assessment processes before and alignment after a merger/ acquisition. Hence, these dozen principles also make a useful management tool.

4.3 Developing New NDE Products and Services

These principles help define requirements for the new product and service systems. There will be times when it will be difficult to meet all of them concurrently. In such situations, principles help make the right choices, prioritize the proper selection of alternatives, and reduce internal conflict. These principles are becoming increasingly important to fully support the innovation management process [12,13].

4.4 Regular NDE Activity

Digital Transformation is sweeping every sector. We all talk about it from our own experiences and perspectives, and look at it with different emotions, from anxiety to enthusiasm. The non-destructive evaluation as a cross-sector industry is neither immune nor trendsetting in this rapidly evolving change. One common area of concern for managers is where to start and how to progress, with limited resources and unlimited uncertainty in this vast and increasingly complex ecosystem.

These principles enhance the value extracted from NDE 4.0 activities, be it in-production inspection on the shop floor or Inservice inspection of a high-value asset.

4.5 Talent Development

In the dawn of NDE 4.0, training and workforce reorientation play a central role in shaping the professional path of new talent, providing stability and development opportunities for active practitioners and contributing to preserve and transmit the accumulated knowledge of experienced generations of NDE practitioners.

Industry 4.0 is compelling to revise the roles of NDE practitioners, trainers, and mentors who are immersed not only in the accelerated technological advancements but also in profound social, environmental, and cultural transformations [14,15]. NDE itself is transitioning from a niche role as a quality control support instrument to an invaluable knowledge-generating process for creating value through substantial improvements in business sustainability, quality, and safety [3].

This profound transformation is shaping how Education 4.0 for Industry 4.0 will deliver disruptive modifications in education models, training processes, certification schemes, and support tools. These principles shape those instances and transform how we recruit and develop NDE practitioners in alignment with an NDE 4.0 roadmap.

4.6 Adopt and Adapt

When you look deeply, you will see the intent behind the organized structure to support the applications. These are focused on the responsible use of technology for a profound transformative purpose. With that in mind, you are welcome to tailor this set to your business situation, your supply chain, your customer expectations, and your desire to push innovation. You can even add some of your own to the mix. Dropping any one of them permanently is not advisable.

5.0 Summary and Outlook

NDE 4.0 is a case of a massive transformation in a specific realm of human activity. It shall require that digital technologies be integrated into the inspection systems, the digitalization of workflows, and the integration of NDE workflows within value streams. This paper is all about a fundamental framework of principles that help align an organization through the transformation, while creating new products and services.

NDE 4 0 must be viewed as a journey and not a project or a single deliverable goal. It could take a few years, depending upon the organizational internal and external context, resources, and commitment to sustainable growth through change. Where does the journey end will not be clear in the beginning, but you will know when you get there.

To some, the world of NDE 4.0 appears overwhelming, but a roadmap that breaks down the holistic view into achievable goals provides a means to successfully take on this journey. When the end is not clear, the set of guiding principles become a very important, acting as a compass or a navigation instrument to arrive at a good destination.

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Simulation Assisted Automatic Defect Recognition (SimADR) for NDE4.0 Inspection Datasets

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Abstract

The paper highlights a new paradigm using simulation-based analysis that employs physics-based models in parallel processing using GPU for rapid generation of synthetic data sets. This paper discusses the development of a Simulation Assisted ADR (Automatic Defect Recognition) using the physics-based simulation models of the different NDE/NDT imaging modalities as well as Deep Learning (DL) and/or Machine Learning (ML) models. Our **approach addresses the classic issues during the implementation of DL/ML approach to Radiography and Ultrasonics based NDE/NDT data interpretation that includes lack of sufficient apriori data as well as biases in the data sets, among others. Here, using the limited experimental/field NDE/NDT data sets that are available and by deriving critical statistical distribution parameters from this data set, the stochastics of the simulation models are determined. Thereby, the simulated data sets are generated using numerical simulations along with the variations in the different parameters during experimental/field data acquisition. This process allows the generation of simulated data sets in large quantity that augments the smaller data sets obtained experimentally. This rich data set is subsequently utilized to train the DL models and provide reliable ADR algorithms. Weld and AL casting radiography data sets from Digital X-ray Images and PAUT (with FMC/TFM) are both used to demonstrate the SimADR approach.**

***KEYWORDS*: PAUT, Digital X-ray, Radiography, ADR, Simulation, Assisted**

1.0 Introduction

Digital X-ray and Phased Array Ultrasound imaging inspection technologies have been well documented in the field of industrial and medical applications. The use of digital X-ray imaging has been further enhanced by techniques such as Computed Tomography (CT) that have the capability to expand the conventional 2D imaging modalities into 3D volumetric imaging. Similarly, the Phased Array Ultrasonic Imaging technology (PAUT), particularly with the FMC/TFM mode, has vastly improved the ability to image, characterize, and size defects.

The ability of the advanced NDE imaging technology has reached very significant maturity permitting the operator to provide advanced insights into the state of the component, and more importantly, into the root cause analysis of the anomaly formations during manufacturing as well as prediction of the effect of these anomalies on performance of the components. While these advancements do represent a significant enhancement of diagnostic capabilities, the trade-off has been the large volume of data and the time consumed for processing this data set as well as the analysis of the processed data. This trade-off has led to requirement of additional well-trained manpower, faster processing instruments, and consequently its implementation in a post processing mode rather than the preferred in-line diagnostic mode.

Several researchers explored the identification of defects from radiographic images using different techniques and approaches [1-2]. Artificial intelligence 45 and computer vision methods can be used to aid in analyzing the X-rays and provide an indication of the examined material's diagnosis. There has been a lot of effort to build and construct computational tools focused on image processing, computer vision, artificial intelligence and other related tools with the aim of encouraging radiograph analysis and thus improving the robustness, accuracy and speed of the inspection process [3-4]. Owing to the exponential increase in the capability of the processing algorithms as well as the computing power of the hardware the implementation of sophisticated image classification, object detection, and image segmentation of welds are advancing significantly.

The development of deep Convolution Neural Networks (CNN) has led to major improvements in several tasks related to image processing. Ferguson et al [4] demonstrated the defect detection system of the deep learning model Mask RCNN that uses the transfer learning technique exceeds the state-of-the-art performance on the GDXray [5] datasets of X-ray images of both casting and welds. In this work, we present the accomplishment of an automated defect recognition (ADR) system that uses deep learning algorithms to improve the effectiveness of the automated data analysis. The defect detection system used in this work is based on Mask Region-based CNN [6] that simultaneously perform object detection and image segmentation.

The application of the phased array ultrasonic testing (PAUT) has becoming common in the field of non-destructive evaluation (NDE) for faster scanning and better visibility of the scanned sample [7]. While manufacturing the welds, the weld flaws occur inherent to the structure, and some are due to the improper choice of process parameters. Inspection of welds are challenging due to the massive structures containing thousands of welds, and a few are inaccessible. The PAUT overcomes this challenge by allowing to inspect large regions from a single location, which gives an advantage to inspecting the components with limited access and complex surface geometry. The Total Focusing Method (TFM) is a sampling of PAUT [8]. The TFM is an image reconstruction technique that uses Full Matrix Capture (FMC) ultrasonic signals to construct a fully focused image [9]. This technique characterizes the weld flaws better when compared to conventional PAUT [10]. In the process of identifying defects, it is difficult to place the transducer on the weld area due to an uneven bead surface. Hence instead of using the normal ultrasonic wave beam, the angular wave beam with a multi-skip wave path is used to inspect the welds. At a given point in time, the transducer receives ultrasonic signals from different wave paths, such as direct TFM, half-skip TFM, and full-skip TFM [11]. The mode conversion takes place at the back wall and at the flaw location, and this mode converted ultrasonic signals are used to generate high-resolution TFM imaging. These reconstructed TFM images are examined by NDT experts to characterize weld flaws and qualify them. As it involves the processing of bulk images by NDT experts, there may be chances of human errors while identification of the defect and the inability to distinguish among themselves. AI, robustly identifies object detection and classification tasks through feature extraction [12].

2.0 Approach

2.1 X-ray Data Sets

The key technology in this work for X-ray based datasets is the development of advanced Simulation assisted Automated Defect Recognition (SimADR) algorithms for flaw detection, classification, and characterizations of different types of Castings and Weld Defects. These castings and weld joints are likely to develop flaws at the interfaces and inside the weld due to perturbations in the process variables and consequently its manifestation in the final products are inherent in a mass-manufacturing environment due to several reasons. Several forms of simulation software have been developed over the past few years for radiological applications [13-16]. In this work, the method is based on creating a radio-graph database with different potential defect characteristics using a simulation model based on ray casting and using this to train a deep-learning algorithm. The Sim-ADR system is proposed to enhance the detection and identification of the defects from the X-ray images of castings and welds. Fig-1 presents the Sim-ADR development flowchart. The proposed system consists of three main stages; a pre-processor, a simulation engine for X-ray images (Sim-Xray), and Artificial Neural Network based Automatic Defect Recognition (ANN-ADR). Each stage consists of a variety of processes and communicates correctly with the input of the next stage before the final identification report is obtained. In the following subsections, the functionality of each stage is described in more detail.

The Pre-processor unit prepares the radiographic image for the annotation task by enhancing the defect features in the image. The 16-bit X-ray image input first goes through a normalization step. Algorithms to enhance the images are

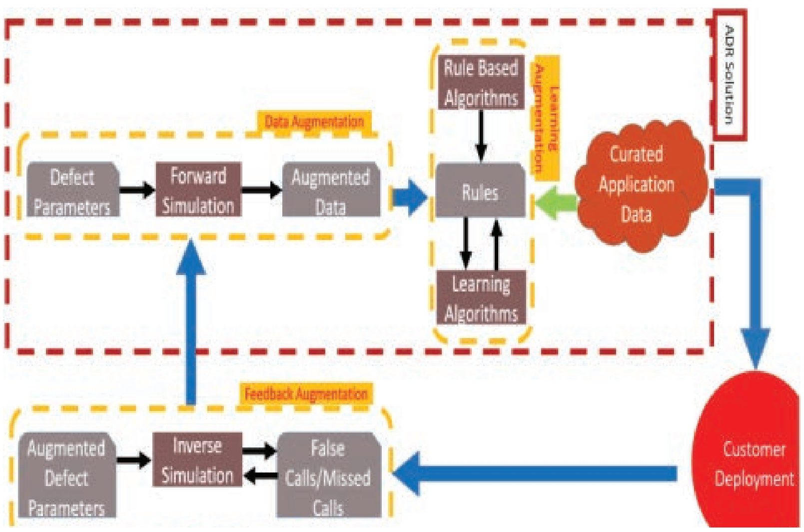

Figure 1: SimADR system Development Flowchart

implemented using a combination of many Image processing filters like Sharpening filters, Contrast Limited Adaptive Histogram Equalization (CLAHE), and FFT-Low Pass filters, such that the defects are clearly seen for the annotation. In the Annotation toolbox, the defects are marked using the built-in annotation features like magic-wand, contour, and circulation, and the annotated data are stored in a suitable format to train the Neural network. This is followed by automatic segmentation of defect region and annotation using the defined rules. On the successful verification of the annotations by the Radiography Expert, the annotated images are sent to the ANN-ADR module. This approach has been discussed elsewhere with more details [17]

2.2 PAUT with FMC/TFM Data Sets

The SimADR approach for PAUT data sets is similar to X-ray data sets, as shown in Fig. 1. However, the simulation-assisted weld TFM imaging is generated through fewer finite element (FE) simulation followed by the deployment of generative adversarial network (GAN) algorithms. These augmented images are used to train the neural network in the standard process [18-19]. The syntheses of the required high-resolution image dataset by implementing AI-based frameworks such as GANs [20]. The deep convolutional generative adversarial networks (DCGANs) [21] is a variant of GANs, which is a convolutional neural network (CNN) based framework. The DCGAN uses a complex algorithm to generate new images, which come from the training data sets distribution. However, the generated new images are similar to trained images but different in terms of varying defect patterns, clusters, and locations. In this framework, two separate CNN network architectures exist and compete with each other during the training of the networks. These neural networks are trained in an adversarial manner to generate imaging data by mimicking distribution from the real training images. Thereafter, the new imaging samples are generated from the trained AI network [22]. In this process, the AI-based model generates the training data sets several orders faster than classical FE simulations. Hence, the AI-based simulator can provide a vast volume of imaging data sets with comparatively reduced computational resources and time.

Subsequently, for ADR, we have used a convolutional neural network (CNN)-based framework, such as the YOLOv4 model [23], to detect and classify the weld flaws using the AI/FE generated simulated datasets. This algorithm scans the entire image at once to predict the outcome, which is a faster end-to-end deep learning object detection CNN-based model. The single pass image makes the YOLOv4 model faster and can be used in real-time automated defect recognition. Over a while, a series of advancements have taken place to improve the YOLO network performance [24]. The model divides the entire input image into a grid of cells and then predicts the bounding boxes and class probability of these boxes. The network generates multiple bounding boxes for a single defect. However, using the non-maximal suppression algorithm for an individual box for each defect in an image. Before training the ADR model, the AI/FE datasets need to convert to a specific YOLOv4 model acceptable format. Therefore, each defect in every training data sets image has to be annotated with a bounding box and the class of the defect. The transfer learning technique is used for YOLOv4 model training instead of random initialization of the network hyperparameters because the model has been pre-trained with various shapes in the training data sets. Although the YOLOv4 model is pre-trained, a large volume of training/testing datasets is required to teach the network of the different classes, sizes, and locations of the defects in the welds. For more details, kindly see the publication by authors elsewhere [22].

3.0 Results and Discussion

3.1 X-ray Data Sets

The x-ray radiography images were obtained on two types of test samples (a) Aluminum Cast, and (b) Steel welds. Fig. 2 shows the result obtained from using SimADR algorithm using the SimXRAY software as the modeling tool. The color represents the different categories of porosities in the casting as per ASTM 2422 standards.

The results presented in Fig. 3 shows the influence of the simulated data sets on the performance of the SimADR algorithm for the AL casting data set. In this work, the ground truth used was over 54,000 of the experimental images that were available. While this is not common for such a large number of annotated images to be available, this particular example allowed for the comparison of the pure experimental versus simulated data sets.

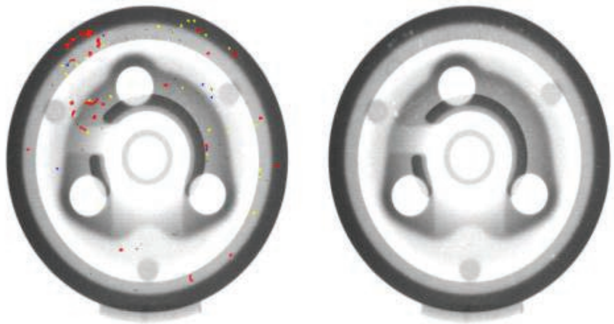

Figure 2: The SimADR result on an AL casting digital X-Ray image showing the ADR on the left from the raw data on the right.

The ratio of the number of simulated data vs experimental data was varied and evaluated. It was observed that, as expected, the POD Accuracy was improving with the number of data sets used in the training of the SimADR AI engine. Accuracy of 95% was obtained for this Al cast sample. The false positive (false-call) rate was also found to decrease significantly with an increase in the number of data sets used.

A similar approach was employed using the SimXRAY simulation software for the development of a synthetic data set for the as-welded sample. Here, the weld bead geometrical feature was captured using laser scanners, and a weld bead stochastic model was developed and used in addition to the stochastic models used for modeling the other parameters such as defect geometry, alignment, noise, etc. Fig. 4 shows the SimADR output with the defects mapped on the weld region as well as the raw radiographic image used.

3.2 PAUT with FMC/TFM Data Sets

As discussed in section 2.2, the FEM models were used to generate datasets for creating the FMC/TFM datasets for two types of volumetric defects, such as the cluster of porosity and the cluster of slag inclusions.

Single and multiple defect case studies were considered. A typical simulated image for slag inclusion is shown in Figure 5. The datasets used for training the SimADR engine comprised a small set of experimental data and a larger set of simulated data. The trained SimADR engine was tested on many real weld scenarios. Figure 6 illustrates an

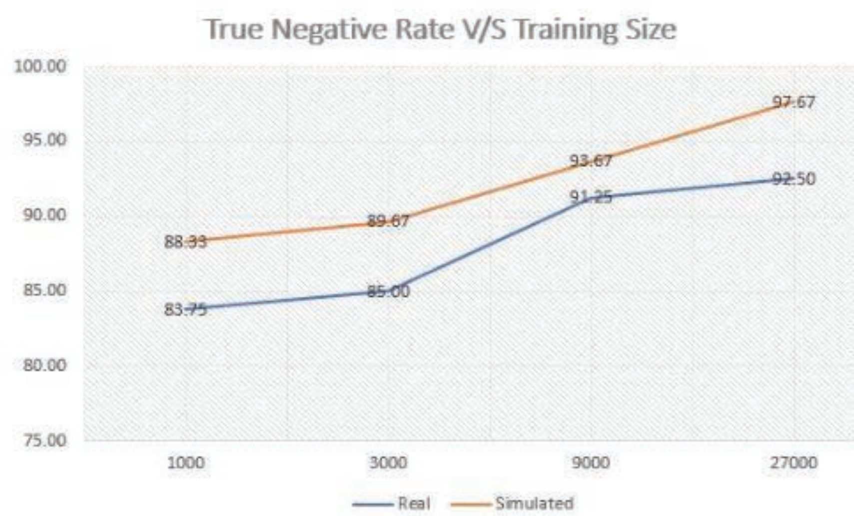

Figure 3: *The plot shows the influence of levels of simulation data sets used in the SimADR for the images on the AL casting test sample shown in Fig. 2*

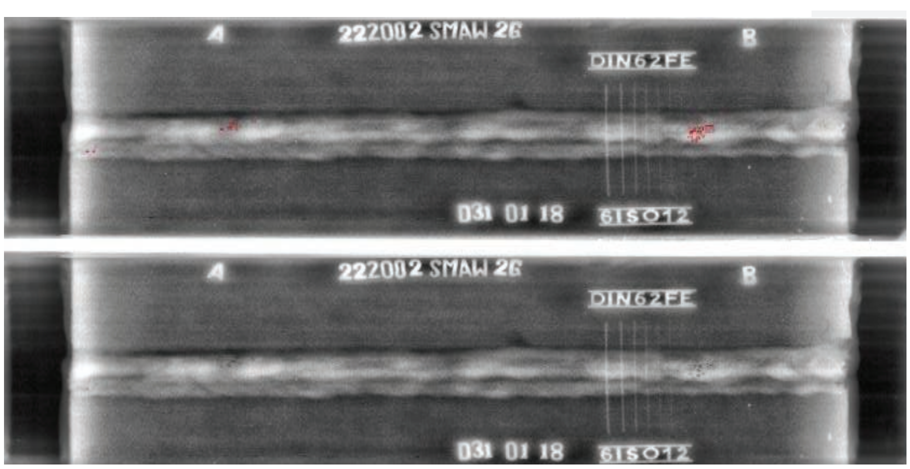

Figure 4: *The SimADR result on a steel weld sample digital X-Ray image showing the ADR on the above image that was obtained from the raw data image below.*

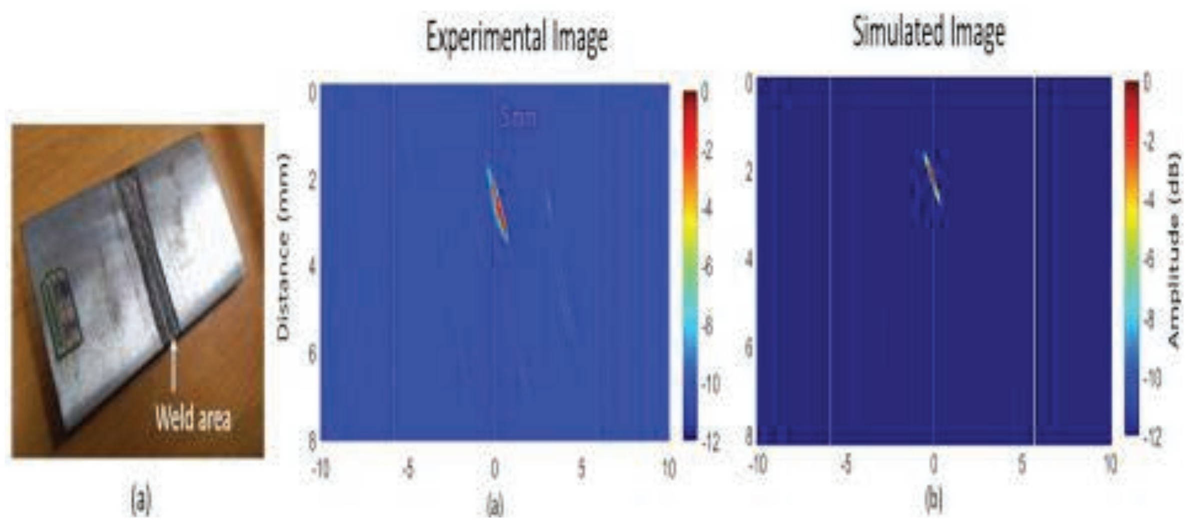

Figure 5: *Simulated PAUT TFM Image of a butt-weld with a cluster of slag inclusion (a) Welded Sample, (b) Experimental image, (c) Simulated image.*

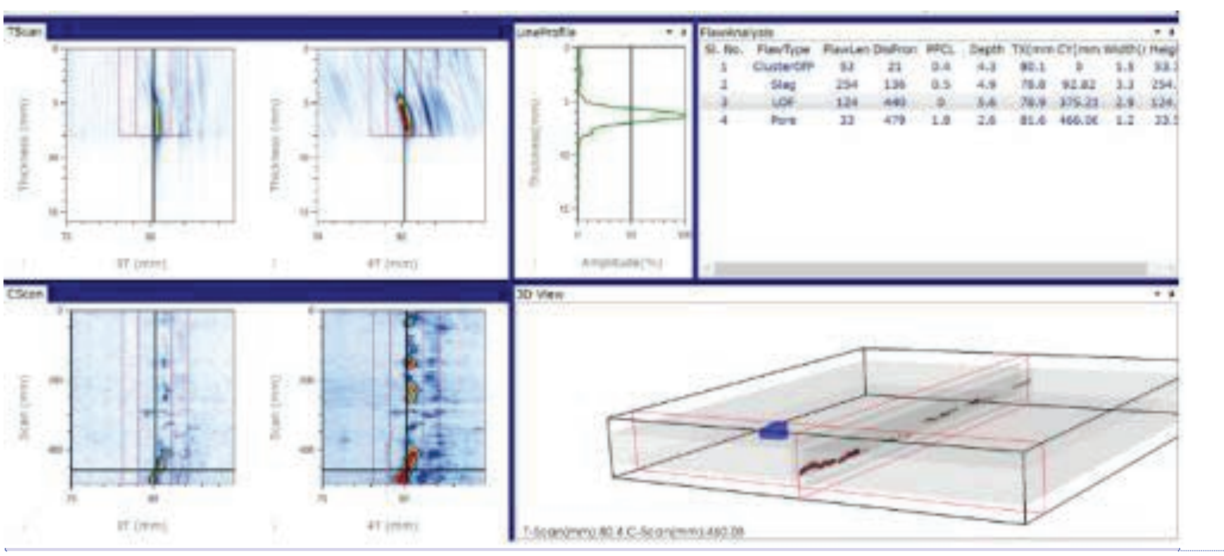

Figure 6: *Screenshot of the weld data using SimADR with a B and C-scan representation on the left and the ADR result table on the right for a V-Weld with a 3D visualization plot.*

example of one such welded structure of 1 m long inspection result. Using the SimADR engine and the FMC/TFM data sets, it was feasible to not only detect the defects but also to classify and size defects.

4.0 Conclusions

Physics based simulations were employed for the generation of synthetic datasets for both digital radiography and Phased Array Ultrasonic Testing (PAUT) with FMC/TFM. The SimADR engine were trained and found to successfully provide automation in the interpretation of the datasets. Of the several case studies that were evaluated, Al casting and Weld inspection applications were demonstrated.

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NDE PATENTS

Dr.Shyamsunder Mandayam

Through this feature every quarter, we intend to provide you a snapshot of some latest and important patents in the world of NDE. We also intend to use this feature to encourage the Indian NDE community to file more patents based on your innovations. We will be happy to provide guidance and assistance in different ways – Answering queries, Conducting Tutorials and webinars, One-on-one discussions, Networking with Intellectual property experts, etc.

Need help understanding, What are Patents? Why to Patent? When to Patent? What is the Patenting Process? …… Please feel free to reach out to me by email at mandayam.shyamsunder@gmail.com

Here we list below a few interesting patents related to a mix of different modalities in ***NDE and Inspection.***

United States Patent 11,131,635

Infrared detection camera

Inventors: GuptaMool C, Edrington Alexander C, Harp James I, Marsh Waverley D, ShenGuoqing Paul

Assignee: LASER & PLASMA TECHNOLOGIES, LLC (Hampton, VA)

An infrared detection camera for the inspection of coated substrates. A corrosion sensing instrument is handheld, portable, battery powered, compact and lightweight. The camera performs nondestructive, real time imaging of corrosion and defects beneath painted metal or plastics or composite surfaces. The device includes a user-friendly computer interface for real time imaging and image storage capability and is typically used for detecting early stage corrosion beneath painted aircraft aluminum surfaces. The handheld device has a front "open air" imaging port which is designed to be placed in soft contact against the painted surface to be inspected by the instrument. The device includes an infrared camera and infrared lighting to capture an image of the surface. The captured image is transferred to a computer and analyzed to locate imperfections below a coating on a surface.

United States Patent 10,823,703

Real-time fusion of ultrasound and eddy current data during non-destructive examination

Inventors: Kollgaard Jeffrey R, Holmes Tyler M, Georgeson Gary E

Assignee: The Boeing Company (Chicago, IL)

Apparatus and methods for real-time fusion of data acquired using ultrasonic and eddy current area sensors during nondestructive examination. The ultrasonic data is acquired using an array of ultrasonic transducer elements configured to enable the production and display of a C-scan of a small area. The ultrasonic transducer array may be one- or two-dimensional. The eddy current sensor can be a single pair of induction coils, a multiplicity of coil pairs, or a coil configuration in which the numbers of drive coils and sense coils are not equal. The eddy current sensor is able to provide data about the test material, such as material thickness or conductivity, to complement the ultrasonic data or enable auto-setup of the ultrasonic inspection device.

PATENTS

United States Patent10,732,149

Laser ultrasound scanning for visualizing damage or irregularities

Inventors: IhnJeong-Beom, Georgeson Gary E, Motzer William Paul

Assignee: The Boeing Company (Chicago, IL)

Methods and systems may be configured to integrate data from fixed nondestructive inspection sensors positioned on a test specimen and data from laser ultrasound scans of the test specimen, in order to monitor and track damage and stress indications in the test specimen in real-time during mechanical stress testing of the test specimen. Data from the laser ultrasound scans may identify emergent areas of interest within the test specimen that were not predicted by stress analysis, and further allow for reconfiguration of the test plan in view of the emergent areas of interest, without having the stop the test. Laser ultrasound scans may be performed on the entire test specimen, with high-resolution scans being performed on emergent areas of interest. Thus, stress indications, or stress effects, in the test specimen may be measured, identified, and tracked in real-time (e.g., as growth is propagating) in a test specimen undergoing structural tests.

United States Patent 11,340,195

Methods and systems for pipe wall thickness detection

Inventors: LiuShuangwen, Liu Lei

Assignee: Zhejiang Future Technology Institute

The present invention discloses ultrasonic nondestructive methods for pipe wall thickness measurement at high or low temperatures. An ultrasonic detection device comprises a first and a second ultrasonic waveguide. The waveguide length is selected according to the surface temperature of a pipe under inspection. A first piezoelectric plate causes generation of a plurality of ultrasonic excitation signals which is transmitted to the pipe through the first ultrasonic waveguide. The plurality of ultrasonic excitation signals has different group speeds when traveling along the first ultrasonic waveguide. The reflected ultrasonic wave signals are collected and transmitted to a second piezoelectric plate by the second ultrasonic waveguide. The pipe wall thickness is calculated using an ultrasonic wave signal which has the highest group speed. The first and second waveguides are arranged parallel and side by side. An isolation plate is disposed such that the first and second waveguides go through the plate perpendicularly.

United States Patent 11,287,400

Large-panel ultrasonic on-machine non-contact scanning thickness measurement equipment and thickness measurement method

Inventors: Wang Yongqing, Liu Haibo, Li Te, Lian Meng, Liu Kuo, Jia Zhenyuan

Assignee: DALIAN UNIVERSITY OF TECHNOLOGY (Dalian, CN)

A large-panel ultrasonic on-machine scanning thickness measurement equipment and method is disclosed. A GNCMT is adopted as the measuring machine main body on which a measured large panel is clamped and conducts scanning measurement motion; a non-contact ultrasonic measurement device is installed on the spindle of the machine tool for realizing transmission and acquisition of ultrasonic signals; a coupling liquid circulation system with the functions of multi-layer filtering, flow monitoring and regulation is set up; a jet flow immersion coupling mode is adopted on the surface of the measured large panel, and micro-emulsion cutting fluid is used as compatible coupling liquid of ultrasonic on-machine thickness measurement; and the coupling liquid is recycled, purified and stably supplied circularly. The thickness measurement equipment has high multi-function integration and reliable performance. It is easy to operate and highly automated, which effectively realizes nondestructive, accurate, efficient on-machine wall thickness measurement of the large panel.

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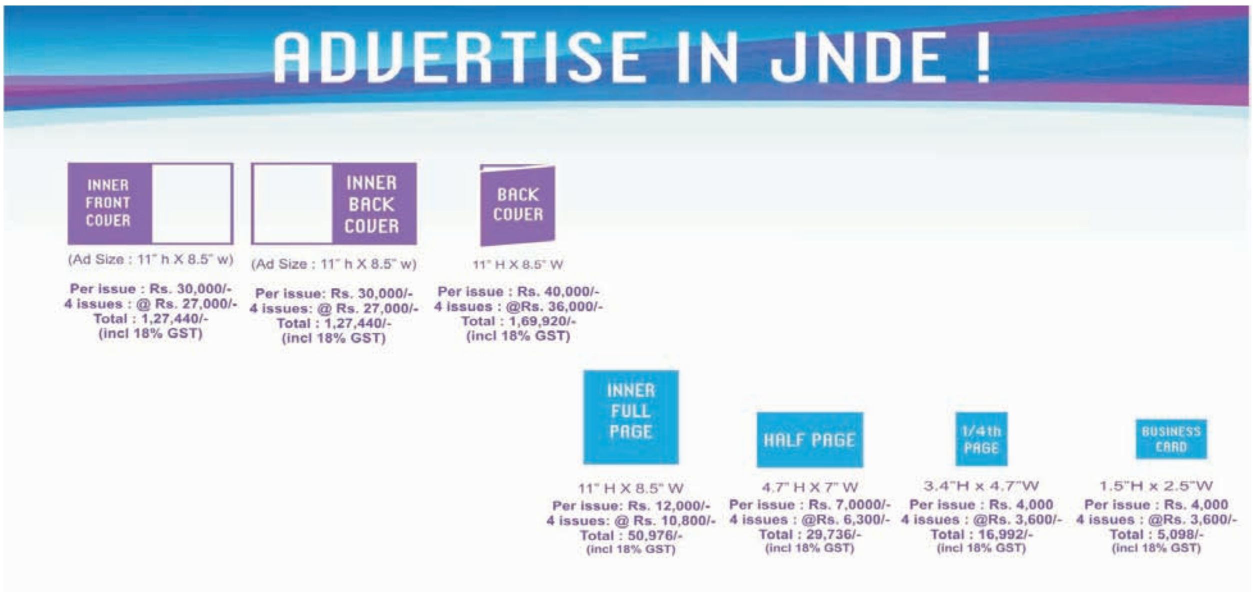

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