Implementation of IOT, Augmented Reality and Cyber Physical Systems in Tata Steel as part of Industry 4.0.

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Abstract— In the process manufacturing Industry, such as Steel Industry the entire supply chain is vertically as well as horizontally integrated. This is essential as the manufacturing processes are closely coupled and require just in time material flows from one stage of the manufacturing process to the next. Industry 4.0 leverages technologies such as Cyber Physical system and Augmented reality among other technology verticals such as Sensorization and Data Analytics. While a multitude of applications can be found for the latter, it has been a challenge to find applications for the former. This paper presents a few case studies wherein Augmented Reality and its associated technologies, leveraging on Cyber Physical systems and 3D modeling etc. have been effectively implemented in the Steel Manufacturing scenario in applications which have added value to the Bottom and Top Line of the company.

Keywords: Cyber Physical Systems, Augmented Reality, Digital Twin, 3D walkthrough, modelling, Remote diagnostics, Remote Trouble shooting, Gamification, Training and simulations, virtual twins, Internet of things, Laser guidance, remote control, laser positioning, operational safety, heads up display, Industry 4.0

I. INTRODUCTION

In the Process Manufacturing type of Industry, the entire supply chain is vertically integrated. It becomes essential for the profitability and even survival of such Industries in the competitive markets of the day to remain so. While the raw materials may arrive from geographically disparate locations, the supply chain set up is nose to tail to ensure just in time supply of materials to the next process chain upstream, till the end product, Steel in this case is realized. Maintaining large input and Output buffers are no longer realistic these days. Therefore, a modern steel plant has close knit horizontal supply chains and very mature IT and Automation verticals exerting close supervision and control of the process variations, proactive command, and control linkages which together ensure just in time supplies to various processes and production of materials at optimum cost and highest quality.

When the decision is taken on adopting Implementing Industry 4.0 in such industries many levels of mature Automation and Sensorization already exists and the Technology providers are hard pressed to find use cases for the technologies which can add real value to the organization in its bottom line, rather than remain a white Elephant acquisition or as a failed experiment as it often happens for many early adopters.

Technologies such as sensorization and Digitalization, Data Analytics etc. are familiar to process managers and can be assimilated into the existing Automation Framework, while Other Levers such as Digital Twins, Augmented Reality, Etc. have difficulty in finding realistic use cases and applications.

This paper presents three case studies where Augmented Reality and Cyber Physical systems have been successfully implemented in use cases which have benefitted the Value chain of the company.

II. USE CASE FOR CYBER PHYSICAL SYSTEMS

A. Caveats with Implementation of IOT and Digitalization and Rapidly evolving Technology.

Cyber Physical systems are defined as systems which integrate machine learning, algorithm-based decision making, heuristics, neural networks etc. coupled with electromechanical hardware, this is a transdisciplinary approach which culminates into an integrated, embedded control system and is propagated for use in Applications such as Robotics, Medical, industrial monitoring systems IOT (Internet of Things) etc.

Conventional use cases promoted by tier 1 vendors, market leader of these technologies is for Industrial Monitoring, Trouble shooting, Remote diagnostics, mobile or portable sensory networks and devices for control, analytics, and data acquisition etc.

However, many of these applications already exists in a vertically integrated Steel plant. The Functioning of a Steel plant requires a matured implementation of Standardized preventive and predictive maintenance practices as often established at remote areas , access to OEM experts are not feasible .Therefore over decades systems of standardization and maintenance, performance monitoring etc. have already been developed and established which ensure minimum MTBR/F(Mean Time Between Failure/Recovery) optimal spare management and standardized Operations procedure , training regimes which do not require expert supervision or intervention.

This may be contrasted with a Consumer Electrical goods company which may have 7-10 different Models/ variations of for ex. a mobile phone or a washing machine. These are with end users who do not keep spares or have any inclination of developing expertise in maintenance and repairs. For such cases, a remote trouble shooting/installation assistance program leveraging Voice Video connectivity and other IOT technologies may provide a cost effective and value-added services for the end user /consumer. However, such use cases may not be applicable in a process-based manufacturing industry which has standardized operations for decades and every minute of downtime / equipment failure has potential for losses greater than cost of the entire equipment itself.

Another issue with rapid deployment of continuously evolving technology is the issue of obsolescence. For example, Cell phone manufacturers are competing with themselves to put new and better models in the market rapidly. In a matter of few months the latest product is deemed obsolete and replaced by the more

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improved and superior product. These leads to flooding of market with technology and product where the bugs have not been ironed out totally. The Process Manufacturing industries have been made intrinsically vulnerable by adopting these strategies. Rapid and profligate Sensorization brings a challenge of Data Acquisition, storage and Telemetry which warrants further investment. Migration from IP4 to IP 6 may well require making an entire functional IT Switching infrastructure obsolete, Adopting Cellular and Wireless technology like Lora WAN and Cloud computing exposes the entire IT infrastructure and Automation Systems of a industry vulnerable to external threats and a fickle technology platform with non-guaranteed service levels and availability.

III. Criterion for Technology and Use case selection

With the caveats mentioned earlier, Technological levers have to be boot strapped to fit new and existing use cases which can add value to the Processes and systems.

Some Criteria for selecting such use cases could be

1) Seamless integration with existing IT/Networking platforms and infrastructure.
2) No additional over heads in adopting the Technology, such as those which may require making existing systems obsolete and create disruption in existing processes akin to sewing an entire coat around a button instead of the other way around.
3) Which should not require any disruption of existing supply chains, statutory systems, or key process parameters.
4) Should not require exhaustive retraining of large number of workforces and in activities where hand eye co-ordination, muscle memory type of skill sets are required, the adopted technology / method should not disrupt the operations.
5) The adopted system should have a tangible, measurable, replicable, time bound impact on the performance measure being improved.

Taking the above criteria into consideration 3 uses cases were identified and Augmented reality and Cyber Physical technology was tried out successfully for these.

IV. Case-1. Augmented Reality and Cyber Physical system in a Fabrication shop

Augmented Reality technologies in conjunction with Cyber Physical systems were deployed in a workshop where structural fabrication work is done. Here the nature of work is discrete, made to order, workflow.

Augmented reality and Cyber physical technology levers are used to trouble shoot the manufacturing equipment such as lathes and provide proper tooling guidelines, provide work orders to the operators and enable the quality inspectors and experts to inspect the job during fabrication and post manufacturing stages.

A. System Overview

The system to implement the Augmented reality-based workshop management system was deployed in the following manner. (See Fig.1)

Several Nano Web Servers cum access points were deployed throughout the Workshop area ensuring proper coverage in all working areas of the workshop.

These Nano servers were configured from Rasberry Pi /Orange pi[1][2] embedded controllers /microcomputers. These acted as a Hotspot access point as well as repository of web pages for the Human Machine Interface (HMI) for the various operators and maintenance crews.

Fig. 1.0: Architecture of AR and IOT enabled Workshop

Near the Machines themselves on a pedestal Heads Up displays (HUD)[3] were mounted. These provided screen mirroring of the mobile phone screen of the authorized operators and crew onto a larger heads-up display which could be gesture controlled. This would enable them to interact with HMI without removing their safety gloves and PPE (Persona Protective equipment).

The nano servers were daisy chained to the plant network and there on to a server which contained updated manuals, work orders, archived history, spare lists updated from the plant store keeping system etc.

On the equipment NFC and RFID [4] tags were mounted to ensure hands free connection to the nearest hotspot, while opening the exact HMI webpage required for that operator without requiring operator to do any operation or data entry on their devices to access the pertinent information.

Temperature, current, humidity sensors connected over a LoRa (Long Range) WAN [5] (Wireless Area Network) telemetry system which provided real time health of the equipment, with background IFTT (If -This -Then-That) logic in the server interpreting this data and determining heuristically if the machine was safe to operate or required auto escalation to the maintenance team for effecting urgent repairs.

3D fully interactive Digital twins of the machines crated beforehand using 3D scanning camera from M/s Faro [6] and on software platform such as Unity3D by expert professionals. (See Fig.2)

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Fig. 2.0: 3D interactive scan of Equipment using Faro Laser scanner

B. *Use case scenarios*

1) *Machine Operator*

The expert Lathe machine operator would approach the equipment assigned to them. Scanning a NFC (Near Field communication) or QR (Quick Response 3D)[4] code (in case their mobile phone does not have NFC) they are quickly connected to the nearest nano server , which authenticates them based upon the device Radio Unique ID.

They are taken to an HMI which tells them,

1) If the machine is serviced recently and safe to use.
2) The list of jobs to be done, the orders which are incomplete,
3) Materials and drawings and tools required for these etc.
4) Link to connect over video to the supervisor or expert

This HMI is displayed on a nearby HUD which is mirroring their Mobile device using Miracast dongle. (see Fig.1)

Fig. 3.0: Screen shot of AR enabled Workshop

They can navigate these pages using gestures [9] by their fingers and hands and do not require to remove their gloves or glasses at any stage to interact with the HMI.

They can indicate job completed, have audio video conference with supervisors, requisition of more items, work orders etc. through this interface.[10]

2) *Machine Repair and Maintenance team.*

1) They are similarly authenticated
2) They see the last service details on their HMI screens
3) They see availability of Spares and online health parameters captured from the Sensors through LoRa WAN devices.
4) They can have voice and video call with the experts who have a digital twin of the machine available online.
5) The experts can virtually dissect the machine using the 3D models of the machine created using 3D scanners from Faro and Unity Software. (See Fig 3.0 and 4.0).
6) Disassembly of the machine can be done virtually by expert on the digital twin, while the field operators reads this information on HMI.
7) The field maintenance operator gets instructions from expert, location of spare parts, and assembly/disassembly details and manuals on their HMI displayed on HUD.

Fig. 4.0: AR Enabled Workshop in 3D

V. Case-2. Training of Locomotive Operators Using Wearable Technologies.

Tata Steel has several kilometers of captive railway tracks where in process materials including molten iron from various Blast Furnaces are transported to the Steel Making shops on special refractory lined containers on wheeled carriages called Torpedo Ladle Cars. The Torpedo Ladles cars are weighed on weighbridges en-route to the Steel Making shops and again weighed after emptying their Hot Metal in the steel making shops. By this means molten iron production is captured.

Up till a few years ago the rake transporting the Hot Metal was guided by 2 ground crew, while the loco operator operated the diesel locomotive from inside the cabin. One ground crew walked beside the driver cabin in line of sight of the driver while the other walked ahead of the rake which could be as long as 70 meters, if 2 Torpedo Ladles were being transported together.

This practice is followed, as the Diesel Locomotives cannot generate enough torque while pulling the rake from front, as each Torpedo ladle filled with Hot Metal weighs 500 Tons. When pulling the rake, the wheels of the loco skids on the rails. Now as the width of these torpedo ladles are more than the width of the loco, the loco driver cannot see obstacles on the track ahead.

The ground crew walking alongside sees the signals flagged by the ground crew walking ahead and accordingly

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signals the driver. Therefore, the reaction time required of the driver receiving signal from the ground crews are quite high. The ground crew ahead also operates the track points to the route that is to be followed. Therefore, in this method rake proceeds at a slow walking pace.

Few years ago, a radio remote control system was implemented so that the loco could be operated remotely. The driver now operates the loco standing on the last Torpedo ladle with clear visibility of the obstacles ahead, and only one ground crew is now required to operate the track points. Further benefits achieved after implementing this is that turn around time /travel times have decreased, as now instead of walking pace the rake can be driven up to 9kmph.

This further benefits by preserving the latent heat of the molten iron, thus conserving energy required to reheat it during conversion to steel process [7].

In the remote operated Locomotives to ensure safety of the driver and the rake several safety features and emergency systems have been installed [8]. Push buttons at the side of the rake can be pressed by anyone in case the remote control fails, and rake starts rolling. Similarly, emergency conditions where the radio link fails, operator is incapacitated, the electronics malfunction etc. have been considered (as per SIL-3 and PL-d standards) and several standard operating procedures have been developed which require fast reaction time and alertness from the operator in pushing certain buttons in particular sequence. See Figs. 5 and 6.

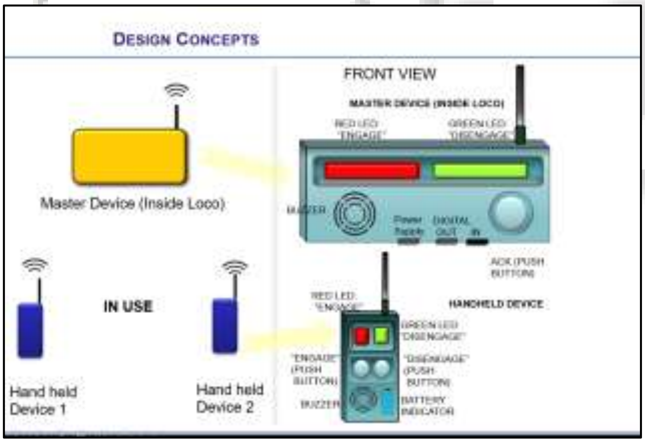

Fig. 5.0: Mockup of Various buttons on a Loco Controller

It is not possible to safely replicate these emergency conditions and complicated safety procedures on the field and many times operator panicked or reacted in a slow manner causing derailment.

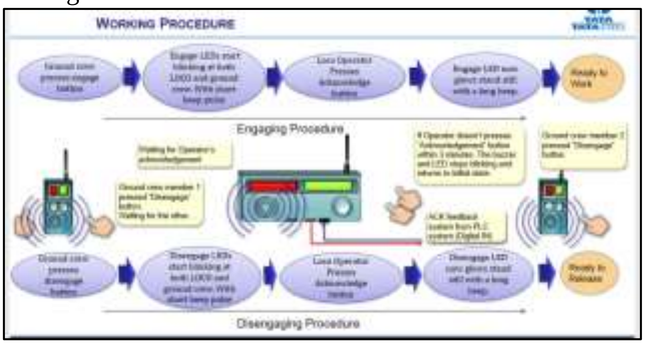

Fig. 6.0: Sequence of steps to follow in an emergency event

To train these operators on the emergency conditions a 3D model of the loco and railway tracks can be developed by 3D software developers. These 3D Scenes developed in Unity 3D software provide a realistic and immersive experience to the trainee operator. These are played in an Oculus Rift S device (See Fig.7) worn by the operator to give them a realistic and immersive experience. The actual buttons and Emergency procedures can be played, and operator practices various scenarios while in a safe environment so that mind muscle connection, good reflexes and muscle memory for handling such events get developed and ingrained in a classroom environment.

Fig. 7.0: Oculus Rift S device to Train Operators

VI. LASER GUIDED POSITIONING OF TORPEDO LADLES UNDER BLAST FURNACE TROUGH.

As mentioned in the prior use case, Molten iron is collected in Torpedo ladles, which are poured into the opening on top of the ladle from an opening underneath the Blast Furnace, called a trough. Alignment of the two openings is crucial, otherwise spillage of molten metal will cause destruction of life and property. This operation is extremely dangerous for the ground crew as he must stand very close to the trough opening and is exposed to the blast furnace gases which may escape from the trough. The alignment may also be affected by parallax errors during eye estimation.

A system using RFID to identify the Rake length and visible Laser beams to guide the Loco operator to align the Torpedo opening with the Blast Furnace trough mouth has been developed [11]. This reduces the time required to align using flag or hand based signaling and makes it safe for the ground crew. (See Fig. 8.0)

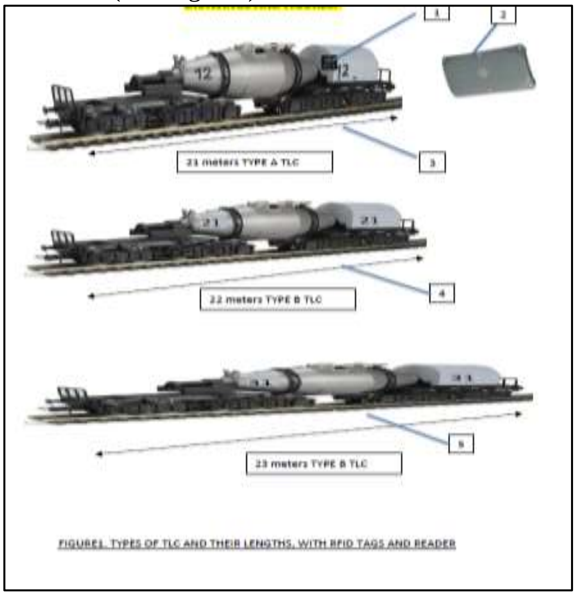

Fig. 8.0: RFID technology used to identify Rake Length

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The System is architected as indicated in Fig 9.0

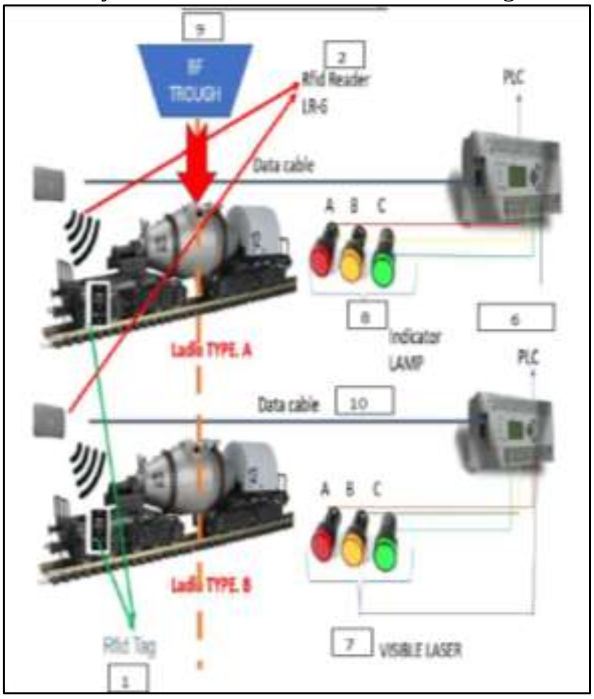

Fig. 9.0: Architecture of the Laser Guidance system.

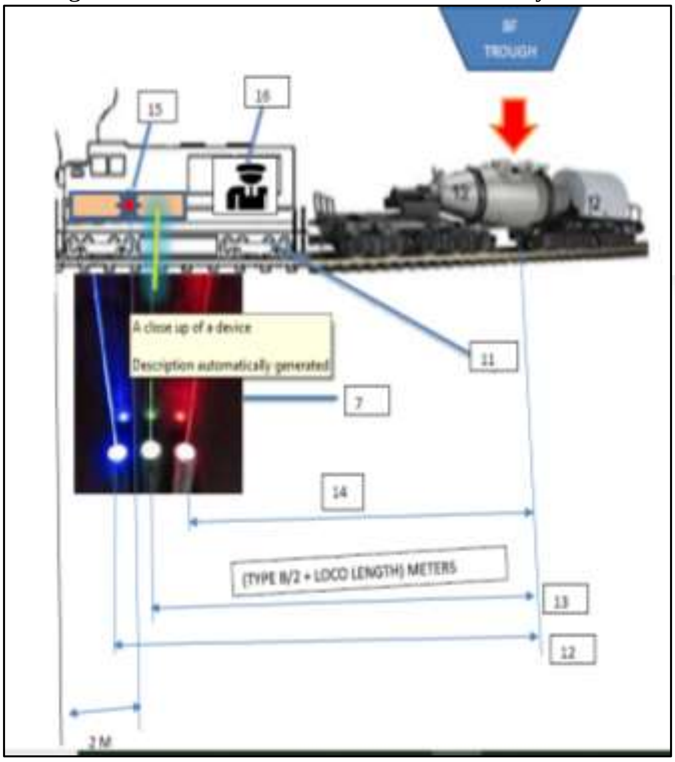

Fig. 10: Operational Philosophy of the Laser Based Positioning system.

The Loco operator looks for the bright Laser spot on the side of the engine Cowl, while operating the Loco with a remote or from inside the cabin. When the visible Laser gets Positioned on the target [12], operator halts the loco. As the offset lengths of the Torpedo and Furnace openings have already been calibrated and Laser source has been positioned according to these calculation, the Alignment is therefore accurate up to +/- 10 cm which is well within the acceptable values. (See Fig 10.0 for the operating Philosophy).

VII. CONCLUSION AND WAY FORWARD:

Augmented reality (AR) technology is the common thread between the three use cases which have been developed. The portfolio of associated soft and hard technologies functions by enhancing one's current perception of reality. With the help of advanced AR technology, the information about the surrounding real world of the user becomes interactive and digitally manipulable. Artificial information about the environment and its objects can be overlaid on the real world. By contrast, virtual reality replaces the real world with a simulated one. the platform which delivers the Enhanced, contextual content, consists of: -

1) Database Server and MIS. A Backend Server/MIS system with AR applications developed as a repository of contextual data such as manuals, walk through, check lists and other relevant information. This is delivered to the end user in the field, appropriately on demand.
   The Server /MIS system also monitors the AR user's location, audio/visual feeds, and other sensory inputs from user
2) Telemetry and Data communication Network.
3) Wearable technologies and Interactive and immersive visualization systems for AR.
4) Creating 3D environments using 3D scanning cameras and software such as Unity 3D .

These technologies are in their nascent phase and it will take some more time and research before they can be widely deployed at low cost in Manufacturing and Process industries in a meaningful way,

These Technologies will emerge in the forefront in Industry 4.0 and Digitalization initiatives undertaken by global industries such as Wearable technologies for augmented reality and immersive visualization - To experience augmented reality, the end user requires suitable devices which can transmit the user's location, position, sensory feedback etc. and in turn receive contextual content on devices such as Handheld computers, Tablets, and smart phones and smart glasses.

It is also envisaged that immersive visualization systems will enable a support team to see live video feeds from the field along with data from the gauges and sensors to enable rapid diagnostics.

- To achieve this, technologies in forefront will be
- HUD (Heads up displays) & transparent emissive displays, First Person Viewing systems.
- Miniaturized electromechanical Sensors, Micro- CCTV streaming systems and wearables.
- Data Acquisition Systems, Telemetry and Personal Area networks.
- In the end it remains up to the end user to leverage these technologies in a productive, cost effective, meaningful way.

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