Chapter

Interlinking Industry 4.0 and Academia through Robotics and Automation: An Indian Perspective

Prajwal Prabhu, Subin Raj and Abhra Roy Chowdhury

Abstract

Robots and automation systems are growing rapidly in the society globally with an annual global sales value of 16.5 billion USD in 2018 according to the International Federation of Robotics (IFR). They have found a commonplace not only in industries and service sector but also in households. This has attracted heavy investment by industries globally in the research and development of robotics and its applications. Understanding this rising trend in the industry and society, there is an obvious need for expertise and future workforce in robotics. According to the IFR report, India has recorded a growth of 39% in 2018 compared to the previous year in terms of annual robot installations. The annual report of the Confederation of Indian Industry (CII) in 2019 recommends robotics and automation as one of the prime areas of focus toward the development of national policies on Industry 4.0. One such interlinking initiative in robotics research and innovation has started at the Centre for Product Design and Manufacturing (CPDM) in the Indian Institute of Science (IISc). The project is designated under India's first Industry 4.0-compliant Smart Factory R&D platform in a unique academic set-up. It aligns with the policies of Govt. of India to boost vision Industry 4.0 for India's technological and economic transformation.

Keywords: Industry 4.0, robotics, automation, autonomous systems

1. Introduction

With the advent of industrial development, humans have witnessed its four phases starting from mechanized processes, mass production using electricity, assembly lines and now finally culminating to Industry 4.0. It is also commonly referred as Smart factory where the physical processes of factory are monitored by decentralized cyber-physical systems to take autonomous and individual decisions. The physical systems i.e. machines are configured with the Internet of Things (IoT), communicating in real time to each other and with human operators over the web representing another vital component called interoperability. Indian Institute of Science (IISc) has been developing a "Smart Factory called I4.0India@IISc" that will act as a Common Engineering Facility Centre (CEFC) at the Centre for Product Design and Manufacturing (CPDM), under the SAMARTH Udyog Bharat 4.0 program of the Department of Heavy Industries (DHI), GoI in [1].

The CEFC builds on the earlier work at IISc that initiated India's first smart factory R&D platform with seed collaboration fund from the various multinational and national companies worldwide. The CEFC intends to develop two contrasting factory platforms. One is highly automated, with data-intensive processing machines such as 5-axis CNC, metal additive manufacturing, metal laser routers etc. that are handled by Industrial robots, collaborative robots, automated guided vehicles, etc. The other platform is highly manual, with legacy machines with data layer, where handling is also carried out manually. The distinction is that all elements in both the Platforms (people, process, parts, tools and environment) are to be connected via IoT-based communication networks and data are stored and analytics carried out using cloud computing. The intent is to use the platforms as demonstration centers in which factories of the future will be explored to see their potential and challenges, and use the platforms for advancing research, innovation, training and support for practice. A major aim of this CEFC is to support Industry 4.0 in MSMEs of India by developing "advanced yet affordable" technologies and solutions for their use. The CEFC is supported by Tata Consultancy Services (TCS), Yaskawa, Faurecia, Toyota Kirloskar Motors (TKM) and Ashok Leyland as industrial partners who contribute with fully funded research projects. The CEFC is also supported by faculty members drawn from 12 departments of IISc as collaborators. A variety of research-intensive technologies are being developed at the CEFC for the benefit of industry. The technologies under development include smart resource bins for waste tracking, smart inspection systems, AR/VR-based digital twins and digital walkthrough systems, 3D printing systems for printing devices with embedded electronics, PCB assembly support systems, multi-modal robots, affordable door localization systems, etc. The CEFC is meant to serve the following purposes:

- Use of the factory with its two platforms as demonstrators for Industry 4.0 (development of platform should be completed in next 6 months)

- Utilization of the platforms for trying out new building blocks, technologies and solutions for their potential effects on KPI before committing investment on these.

- Playing with various combinations of the two platforms for creating different variants of factories of the future and seeing their impact on KPIs.

- Using the factory as a springboard for supporting development of new innovations and start-ups for Industry 4.0 (1 start-up initiated, 10 existing start-ups already supported as planned)

- Creating Indigenous R&D capabilities in the area for India's Industry 4.0 by training researchers and developing deep tech knowledge. (11 PhD students and 20 researchers are being trained, over 20 technologies, tools and solutions are being developed with industrial significance)

- Providing awareness, training and education, especially high-end training to develop future leaders in manufacturing (over 500 people already trained, which is 2.5 times more than originally planned; a new MTech and PhD program in manufacturing initiated at IISc, an international conference on Industry 4.0 and Advanced Manufacturing I-4AM'19 initiated)

In continuation to this we have identified the opportunities and challenges for human robot collaboration in Industry 4.0 set-up. This is mentioned in subsequent sections.

2. Human factors in logistics and warehouse industry

A supply chain in a manufacturing environment involves manufacturers, suppliers, and other logistical entities that would entail dealing with the customers' requests. Modern management practices are designed to reduce the inventories; thus, warehouses play a crucial role in customer services and product availability. Logistical support provided to improve the warehouse order picking scenario would entail reduction of time in retrieving of the object and its successful shipment for delivery. Customer satisfaction in such a scenario would require for an efficient and flexible warehouse order handling processes. However, any small changes in the customer end of the supply chain would create a large ripple in the stock levels and orders along the supply chain also called as a "Bullwhip Effect." Increasing demand at the nth tier in a supply chain will be over-compensated by an even greater increase of the demand at the n+1th tier of the chain in [2]. As a result, the curve mapping the stock levels along the time looks similar to a whiplash, hence the name "Bullwhip Effect." Some of the key aspects of the human factors in the logistics industry are quantified as Perceptual Factor, Mental Factor, Physical Factor, Psychological Factor in [3]:

1. Perceptual Factor: Perception to new things will play a role to changing needs of warehousing environment. This will play a very important factor in determining the overall productivity of the warehouse. This factor will amount to 24.4% in the order picking process. Some of the key things that will affect in this factor would include information technology, ability to read, confusion created due to negligence and ability to accept new technology. It is of the utmost importance that the laborers are skilled to understand the upcoming technology that will reduce the overall burden of their work.

2. Mental factor: The mental factor in any order picking process will be of maximum importance and will amount to 45.2% in the order picking process. Some of the key aspects in this factor would be as follows: cognitive ability, ability to learn new technology will be a very important factor to ensure that the order picking process can be done in a very efficient way and will amount to 37.3%. Some of the other factors include behavior, training. To ensure the productivity of the warehouse, the laborers should have decent working environment where they are more receptive and learn modern technologies and new ideas that will improve the efficiency of the system.

3. Physical Factor: The physical factor in order picking process will amount to 16.3%. Some of the key aspects that will affect the order picking process are: Having an improper workload will lead to musculoskeletal diseases in the human beings causing back pain and fatigue. Further improper material handling may lead to material damages that will increase the overall cost in the production. It is of utmost importance that the workload of all laborers should be uniformly distributed, to avoid the breakdown of the warehouse machinery.

4. Psychological Factor: Factors like work environment, stress, monetary incentives also play a very important role in ensuring that human beings are motivated to do quality work and ensure that the order handling process runs in a very smooth and efficient way. Laborers should have proper incentives and can be in the form of monetary or otherwise, to ensure that they are motivated throughout to ensure that the productivity of the warehouse is not dropped.

3. Indian scenario for the human factors in logistical/warehousing industries

Logistical cost in Indian scenario accounts to 13–17% of the overall GDP, which is nearly double the GDP of the developed countries like US, France, UK, etc. in [4]. Main reasons for such high costs are due to lack of efficient transport systems. Further it is seen that there is a limited focus on robotics and automation which would reduce the majority of the human works. The main percentage of the logistical cost in India is borne by the end users. The future trends in warehousing industry would involve companies consolidating large warehouse spaces and developing futuristic technologies that would improve the warehousing operations leading to better and efficient productivity. A huge amount of flexibility can be incorporated by including human operators in the warehousing industry. Human being can react quickly to any operational changes or urgent requirements of the orders and maneuver in tight spaces that lead to efficiency in the order picking systems. Some of the key measures taken by the Indian government to improve the logistical scenario in India include the Creation of exclusive Warehousing Promotion Zones. Create logistics and warehousing policies separate from industrial promotion policies, Allocation of areas exclusively for warehousing within Industrial Parks, Setting up of Skill Augmentation Centers in [4]:

1. Creation of exclusive Warehousing Promotion Zones: To create modern warehouses and facilitate modern warehousing, need to create exclusive warehousing zones is stressed to develop modern warehousing infrastructures.

2. Create logistics and warehousing policies separate from industrial promotion policies: State governments are mandated to form separate policies for development of the logistics and warehousing industry so that the industries can grow to its full potential.

3. Allocation of areas exclusively for warehousing within Industrial Parks: Adequate storage facilities for raw materials and finished goods need to be provided in the industrial parks where the manufacturing facilities are provided.

4. Setting up of Skill Augmentation Centers: It is of the utmost importance to set up a skill augmentation center so that warehouses can be modernized to improve productivity and efficiency. Some of the modern technologies that can be included in the warehousing include using of cloud to access the warehouse inventories, deployment of drones in the warehousing industry. Using of IoT and automation can improve the overall performance of the system.

4. Need for autonomous mobile robot in manufacturing industries

Automation in the manufacturing industry will ensure that the end result will be achieved in a more effective way thereby reducing the human effort. Automated guided vehicles are the most extensively used robots in the industry; however, these lack the self-regulating mobility and need navigation lines along the shop floor. Further material handling while using the AGV will require human effort which in some cases will reduce the productivity. The need for human operators to undertake planning activities and the lack of real time feedback of the shop floor's inventory level will make the efficient flow of materials tough.

Autonomous mobile robots are machines designed to maneuver itself in an obstacle filled environment through the use of sensors and feedback. Due to its design it can be used in manufacturing industry thereby reducing wear and tear in different industrial components and improve the productivity. AMR's provide a wide range of advantages such as: reduced floor traffic, flexibility, reliability, self-regulating mobility etc. in [5].

The need for using the autonomous mobile robots in manufacturing environment is as follows:

1. To increase productivity and efficiency
2. To improve material handling
3. To improve the safety of human operators in high risk, stress environments
4. To perform repetitive tasks so that the human beings can concentrate on cognitive and creative tasks.
5. To enhance overall revenue by delivering order in perfect fulfillment rates and better customer satisfaction.
6. To reduce the factory traffic by navigating in tight and complex environments.

5. Human robot interactions in logistics/warehousing industry

Human machine interaction is one of the most crucial aspects of the warehousing industry. Since there is a collaboration between human and machine in the warehousing industry, efficient interaction between the two systems would ensure that the process runs in a smooth way in [6]. In an HMI system, machines relieve human from performing repetitive tasks, and human can focus on working in creative and cognitive tasks. Thereby such collaborations would improve the efficiency and reliability of the overall system. Human beings will not be able handle heavy objects in the warehousing industry. Such things will lead to the musculoskeletal damage in human beings and factor into improper material handling. The advent automation has reduced the burden on the human in the warehousing industries. However, there is a reduction of skill in the warehouse workers due to the increased workload on the human beings in [6]. Thereby creating a concept of adaptive automation where there is a continuous interaction between the human and machine considering the ever-changing needs of a logistics/warehousing setup.

Figure 1 shows the possible types of interaction in human machine system, which is adapted from "Formalizing Human–Machine Interactions for Adaptive Automation in Smart Manufacturing" [6].

In general, the possible human interactions that are seen in a warehousing environment can be classified as Human machine interaction, Human task interaction, Supervisor system interaction in [6].

Typical human machine interaction system would consist of human supervisor, several manufacturing cells that and each cell consists of human operator, machine and a human machine interface. The whole system can be viewed as a cell layer and supervisor layer. The interfaces at the cell layer are associated with the UIs for human operators who manipulate the machines to achieve the logistical goals and respond to unexpected situations either by reporting unanticipated events to the supervisor or performing the exception handling tasks issued by the supervisor.

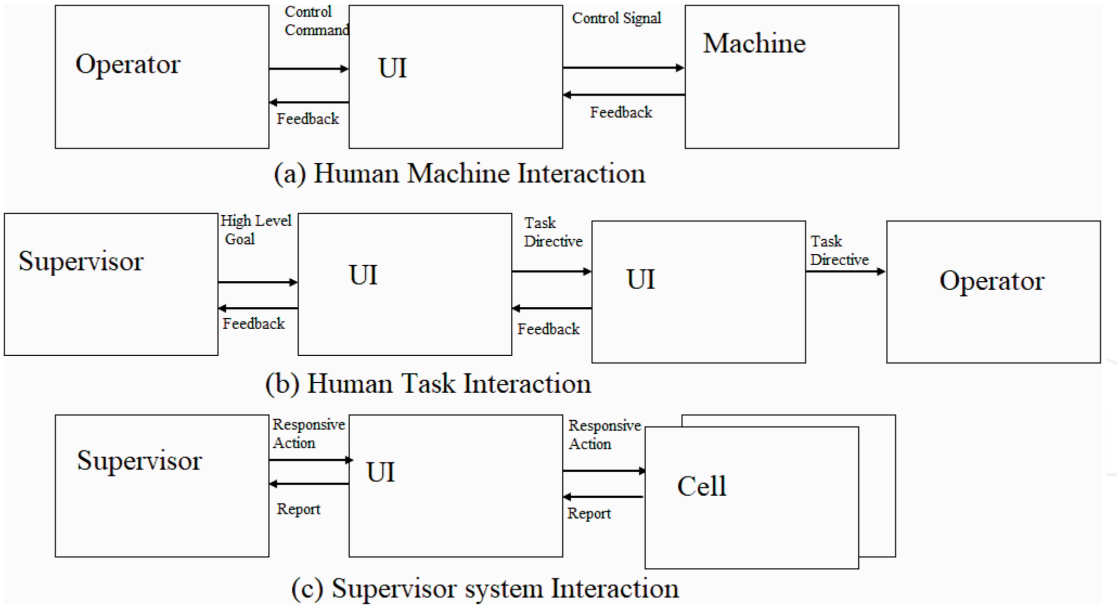

Figure 1.
Description for a human-machine system based on the type of interaction.

Information about machine state is delivered to the human operator through the interface and the operator controls the machine directly through his commands and suitably maneuvers the machine. The operator will notify the supervisor about any interrupts that may affect the overall performance of the system thereby allowing the supervisor to perform exception handling tasks. The interfaces at the supervisor layer are for a human supervisor in the human machine system. In normal scenarios the supervisor will monitor the key monitoring indices for logistical warehouses and maintain the task progress. In cases of exceptions the supervisor has to advice the operator to take the corrective actions. Exception handling task supportability is associated with responsive management concerning the uncertainty inherent in almost every logistical system. Designing of Human machine systems should take into account that human machine system has to assist humans or supervisor in coping with an unforeseen scenario. Due to a high degree of complexity, the problems of exceptions only by the means of autonomous robots will be a challenge, thereby creating the need for human involvement.

6. Present problems in autonomous navigation in factory set-up

Due to the complex nature of the AMR's, some of the key limiting factors that decide the acceptance of autonomous mobile robots in the manufacturing industry are in [4]:

1. Self-efficiency: It decides the ability of the user to adopt to new technology and perform given tasks under different circumstances. Some of the sub-factors include understanding the usage and application of AMR, ability to use the AMR without any assistance. It is highly necessary that human operator is well educated about the application of the AMR's so that upon interrupt, necessity suitable changes can be incorporated to the systems without bringing the whole production to a standstill.

2. Performance expectancy: Since the AMR comprises of many sensitive electronic components, the reliability of the overall system and the performance

of the said system will dictate the productivity in the usage of AMR's in the industry. Further due to the lack of regular maintenance schedule will bring down the performance expectancy of the robot.

3. Perceived risks: AMR's are prone to a traffic collision due to hardware failure, software failure which will often lead to improper material handling, thereby creating a scene of uncertainty towards performance and productivity. Such incidents usually end with a financial loss to the manufacturers.

4. Intentions to use: Intention of the use of AMR's is governed by users and the end application. If the technology is used as per the purpose of its creation then it will lead to easing out of work, thereby boosting the industries. Due to the software functionality of the AMR's once if the steps involved in the manufacturing process is trained, it will retain these steps thereby reducing the intensity of the work.

5. Privacy: Breach of private information through hacking of the software used will lead to wrong marketing, scrutiny, etc. vehicle to vehicle communication will involve transferring of vehicular data in order to have better productivity but however leads to breach of privacy. So, privacy of data will be important in the autonomous environment to ensure that the data generated by the systems will not get into the wrong hands.

6. Reliability: The reliability of the AMR's will mainly depend on the following factors: precision, accuracy, safety, security. Some of the sub-factors include getting confused due to extenuating circumstances of the everchanging needs of the warehouse, precision and the accuracy with which the system responds to the changing needs of a manufacturing industry, mean time between failure.

Further there are other constraints that limit the overall performance of the AMR's in the factory setup in [7]:

1. Getting the software correct so that the robot can navigate the factory setup autonomously and do the complex tasks in an efficient way.

2. Gathering enough real-world data so that the robot can accommodate the real-world changes in the factory setup.

3. Creating precise motion control so that the robot can maneuver in tight spaces and material handling is done in an efficient way.

4. Reducing the false positives that may occur by training the robot in enough real-world scenarios and distinguishing the data obtained between the actual data and the false positive ones.

5. Present Solutions Used for Autonomous Navigation in Factory Set-Up.

One of the evident problems that may be seen while using an AMR is the process of motion planning for an unstructured environment like a warehouse where there are continuous upgrades of the warehouse technology and thereby will be constant updating of the maps. In such a scenario where the start and the finish points are fixed, the motion planning will be complex. There are infinite possibilities for achieving the trajectory for a given start and finish. The best way would be to use a probabilistic approach to generate the trajectory using the concept of least action. The concept of least action will use the simple fact that the best possible path out of the infinite possible paths from a start point to the finish point would be the one that consumes the least energy in [8]. The principle of least action will generate a best possible path out of the infinite possibilities that are available from starting point to finish point considering all of the infinite paths that are possible. While using the concept of least action all of the possible paths are discretized for a small interval that is decided by the user, and the trajectory generated for this discretized instant for all the paths will be a straight line as shown in the **Figure 2** that is selected in [9].

To find the energy of each of the infinite path that is essential in the computation of the least action, there will be a Lagrangian that is defined for all the paths that will be a function of time in [8]. Further an action function is defined, which will be an integral of the Lagrangian for the path from start to the finish.as per the Eq. 1. The main objective would be to minimize this function, so that the best optimal path is generated.

$$S = \int_{ti}^{tf} L\, dT \tag{1}$$

where S = the action function that is defined for a given start and finish.

L = Lagrangian that is defined over the path which is the difference of the kinetic and the potential energy and is the function of the time.

ti = start time.

tf = finish time.

The Lagrangian for the system is defined as

$$L(x,\dot{x}) = K(\dot{x}) - P(x) \tag{2}$$

where $k(\dot{x})$ = overall Kinetic energy for the path.

P(x) = overall Potential energy for the path.

The physical significance of the action function would be that, the function would eliminate the infinite path which is not practical and will keep only the paths that make sense, from where the optimal path is selected. Further by discretizing the path for small instants can be useful for the process of real time obstacle detection in the environment and generating a trajectory that can be obstacle free. The path taken by the system that is generated through the concept of least action will give the complete history of the path that is taken to achieve the required goal which means that path taken by the robot is dependent on the path that the robot has taken

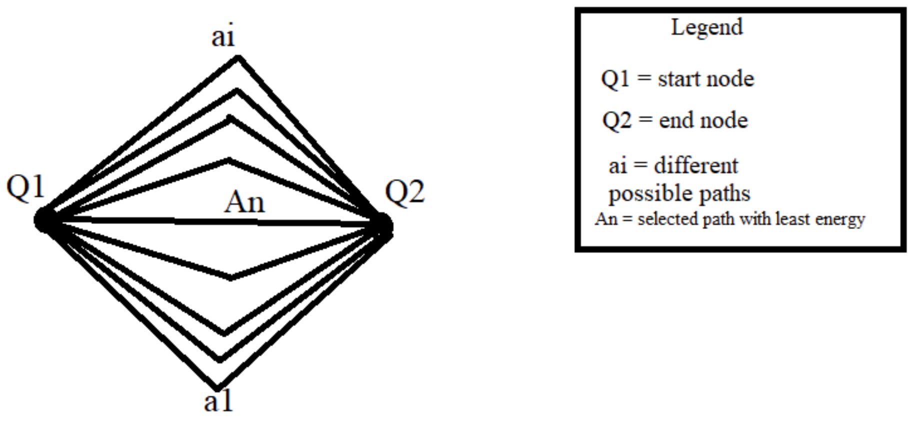

Figure 2.
Infinite possible paths that are possible for a given start and finish.

previously. The simplicity of this approach makes it more useful in using the proposed method in complex environments. So, the institute looks at incorporating the concept of least action for the motion planning of autonomous mobile robots that is developed at the common engineering facility center. The technology developed at the common engineering facility center is discussed in the paragraphs below.

The present solutions those are developed by the industry keeping in mind the different problems like the software complexity, performance, flexibility in the harsh conditions of a warehouse environment are as follows in [11, 12]:

1. Goods to person picking robots: companies like IAM, robotics, gray orange and blue offer mobile robot solutions that are loaded with modern technology and add new efficiency to the tasks done in factory setup. These robots can be programmed to have flexible routes in the factory set-up and requires less infrastructure to set up. The computer interface is friendly and easy to understand. Thereby the human machine interaction happens in a smooth way.

2. Self-driving forklift: Linde's new automated forklift consists of navigation lasers, 3D camera and visual and acoustic warning indicator that enables to move safely around human workers. The company also includes the feature of detection of real-time obstacles and adjust suitably. These things can work in fleet thereby optimizing the performance of the warehouses. These are being used in Kerala, Gujarat, Madhya Pradesh for different industries like electronics, consumer. The system further is mainly used as an artificial intelligence solution to the said product and has been installed in the manufacturing setup at ITC.

3. Autonomous inventory robots: FETCH's tag surveyor consists of three RFID mounted for optimal coverage and has reliability and consistently detect the products up to 25 feet away, thereby reducing the manual inventory count. Typically, the initial cost for such robots will be high due to complexity of the system. However, the run time costs will be reduced as the labor required to do the inventory will be reduced. This technology is in research stages currently in India and companies like iFuture robotics are at the forefront to develop a cost-effective solution.

4. Amazon air prime: This is the advanced delivery system developed by AMAZON that is used to deliver the products to customers through the means of UAV's. The drones usually make their way through automated tracks and lift on to open sky and autonomously deliver to the customers. This was first implemented in 2016 in the UK and based on the success the company looks to expand the trial on a larger scale.

5. Robomart: It is a self- driving store that focuses on transferring of goods that are pre bought online. Robomart is designed to be completely autonomous but also has the additional feature of being completely electric.

Some of the current solutions that are incorporated in IISC's smart manufacturing CEFC facility are shown in the **Figures 3**–**5**.

Figure 3 shows the robot arm that is used to distinguish and sort things from the conveyor. The robot has an interactive human machine interface through which suitable instruction to the robot can be provided. The instructions provided are codes that can be suitably uploaded to the interface. Further the stabilizer provided to the robot arm will ensure the smooth operation of the robot. **Figures 4** and **5** shows the

Figure 3.
Yasakawa Robotic arm used for to pick and sort different items from a conveyor.

Figure 4.
Autonomous mobile vehicle/Hanhwa Cobot.

autonomous robot used for material handling process throughout the factory setup. There magnetic tapes that are provided along the floor of the smart factory which will guide the robot through the different parts of the factory. Further the robot is provided with obstacle detection system that will simply stop if the robot senses an obstacle along the path of motion. Further to ensure the safety of the human

Figure 5.
Autonomous mobile vehicle/Hanhwa Cobot system collaborating with robotic arm for material handling process.

operators there are emergency brakes that are provided to the system. The motion path for the robot can be suitably programmed according to the requirements and can be uploaded to the interactive human machine interface.

7. Conclusion

The growth of any country is dependent on the investments that the country makes in the manufacturing and the technological upgrade. This report deals with how the technology, the advent of Industry 4.0, and demands of the Indian market make India a viable choice. There are many viable entities like China, which act as a main competitor by the fact that it spends around 53% of the GDP in the manufacturing. There is a high level of foreign direct investment that the government of China has encouraged to improve the manufacturing and warehousing scenarios. However, there are certain limitations like the lack of good infrastructure for the manufacturing industry, IPR violations, etc. that the industries face making China not a viable option for companies to look at. In such a scenario, the Indian markets emerge as a suitable alternative where the service sector accounts to high amount of the overall GDP of the country at around 53% in [10]. Additionally, the affordability of the technology, the initiative taken by the Indian government makes it a suitable alternative for the companies to look at. Further concept of IOT is looked at as an important factor and is expected to capture close to 20% of the overall IOT share of the globe. Government of India looks at the initiatives of green corridor, setting up of isolated warehousing environments and make in India initiative encourages company to setup shops in India. Due to these initiatives India looks at leapfrogging the world's major players like China, Germany, USA as a major technological player for the industries to look at. Further for any industry to succeed the labor has to be skilled which India has in abundance. This report looks at the different concepts that may affect a typical warehousing scenario and how it affects the overall performance. Human machine interaction will play an important factor in determining the efficiency of the process. Further as a prospective solution the concept of least action is proposed where there is an optimal solution from the infinite paths. The proposed theory is simple and can be used for real time obstacle detection for a complex environment. The proposed concept can be looked at for a multi-robot system and IOT can be used for better control of the proposed robotic system in the warehouse.

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References

[1] Common Engineering Facility Centre (CEFC) IISc, Bangalore; Centre for Product Design and Manufacturing (CPDM), Department of Heavy Industries (DHI), Project Brochure report

[2] Brauner P, Runge S, Groten M, Schuh G, Ziefle M. Human factors in supply chain management. In: Yamamoto S, editors. Human Interface and the Management of Information. Information and Interaction for Learning, Culture, Collaboration and Business. HIMI. 2013. Lecture Notes in Computer Science. Vol. 8018. Berlin, Heidelberg: Springer; 2013

[3] Grosse EH, Glock CH, Neumann WP. Human Factors in Order Picking System Design: A Content Analysis. Elsevier; 2015. pp. 320-325

[4] Available from: https://content.knightfrank.com/research/677/documents/en/india-warehousing-and-logistics-india-warehousing-market-report-2018-5326.pdf

[5] Available from: https://www.roboticsbusinessreview.com/supply-chain/autonomous-mobile-robots-changing-logistics-landscape/

[6] Joo T, Shin D. Formalizing human–machine interactions for adaptive automation in smart manufacturing. IEEE Transactions on Human-Machine Systems. 2019;**49**(6):529-539

[7] Available from: https://www.therobotreport.com/autonomous-navigation-design-challenges/

[8] Available from: https://cds.cern.ch/record/101498/files/Thesis-1942-Feynman.pdf

[9] Available from: https://www.physics.mcgill.ca/~hilke/719.pdf

[10] Available from: https://www.gita.org.in/Attachments/Reports/India%E2%80%99s%20Readiness%20for%20Industry%204.0.pdf

[11] Available from: https://www.dhl.com/content/dam/downloads/g0/about_us/logistics_insights/dhl_trendreport_robotics.pdf

[12] Available from: https://www.supplychaindive.com/news/4-types-of-autonomous-mobile-robots-and-their-warehouse-use-cases/529548/