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Industry 4.0 remanufacturing: a novel approach towards smart remanufacturing

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INDUSTRY 4.0 REMANUFACTURING: A NOVEL APPROACH TOWARDS SMART REMANUFACTURING

by

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ABSTRACT

Smart remanufacturing has become more popular in recent years as a result of its multiple benefits and the growing need for society to encourage a circular economy that leads to sustainability. One of the most common end-of-life (EoL) choices that can lead to a circular economy is remanufacturing. As a result, at the end-of-life stage of a product,it is critical to prioritize this choice over other accessible options because it is the only recovery option that retains the same quality as a new product. This work focuses on the numerous technologies that can aid in the improvement of smart remanufacturing; in other words,the various technologies that can be utilized to simplify the process of smart remanufacturing, enhance quality, and increase customer trust.A modern approach towards smart remanufacturing has been discussed in this paper, with an aim to fill the gaps in the current remanufacturing process. 67 research papers from three databases are used for this review : Science Direct, Web of Science, and Scopus.

ACKNOWLEDGMENTS

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1. INTRODUCTION

Nowadays, technology, particularly information and communications technology (ICT) – is advancing at a breakneck pace, with many disruptive technologies such as cloud computing, the Internet of Things (IoT), big data analytics, and artificial intelligence appearing regularly. Exploiting these concepts and involving them in the remanufacturing process is called "Smart Remanufacturing". By converting remanufacturing processes to a smart level, these new technologies are infiltrating remanufacturing and functioning as essential enablers for the industry to handle contemporary difficulties such as increasingly personalized requirements and improved quality. Machines, if trained, can self-sense, self-act, and can also communicate with each other. Furthermore, these technologies enable the gathering and sharing of real-time production data, which may be used for quick and precise decision-making [66]. Smart remanufacturing can play a crucial role in the recovery of vital components and resources from the end-of-life (EOL) stage components in a lesser time and a cost-efficient way. The functional components extracted from these processes can be used in the manufacturing of new components on a need basis. For instance, several industries have struggled as a result of the negative impacts of covid-19 which are explained below.

For over the last half-century well-known companies, such as Toyota, employed Just in Time (JIT) and were able to stay ahead of the competition for a long period by holding stock only until it was needed, rather than building up a stockpile. Due to the sheer virus's quick spread in 2020, industries all over the world were forced to shut down, resulting in fewer consumer demand and less economic activity while most of us were on lockdown. Demand has skyrocketed as lock-downs have been eased. Supply chains were interrupted as a result many companies are still dealing with significant issues and are struggling to recover. This has caused havoc for manufacturers and distributors of goods, who are unable to create or provide as much as they did before the outbreak. The automobile industry was also affected due to the lack of computer chips, which are critical automotive components produced primarily in Asia. Automobile firms across the world have been forced to shut down assembly lines due to a lack of semiconductors. As a result, prices of all the goods have hiked post lockdown. In such situations smart remanufacturing can be a savior, firms can use resources from the EOL stage components and store them, which can be used for manufacturing components.

Currently there is no systematic framework for Industry 4.0 smart remanufacturing systems that can be clearly identified in both practice and academic research to guide future deployments.This thesis is motivated by these circumstances and provides a concept framework for Industry 4.0 smart remanufacturing systems, which includes themes like, remanufacturing, circular economy approach, machine vision, artificial intelligence, cyber physical systems, remote remanufacturing as aiding tools for smart remanufacturing. Finally a futuristic smart remanufacturing model is discussed which fulfills the gap that currently exists in the current remanufacturing method.

1.1. REMANUFACTURING-THE BEST RECOVERY OPTION

Remanufacturing is ranked the greatest option for recovering items in terms of economic viability and environmental stability [28]. Majority of scholars in this field have also defined it as the process of transforming nonfunctional, obsolete, or exchanged products into “like-new” conditions [17, 2, 55, 61, 22, 12, 5, 19, 26] with a reduced resource consumption and pollution [18].Both repair and remanufacturing operations are procedures aimed at recovering a product’s value during its life cycle but each technique is unique [32]. Only the visible issue is recognized and corrected during repair, whereas in remanufacturing, the entire performance is assured for a new life [19, 20] with a great detail of inspection and testing [29]. Figure 1.1 displays numerous treatment choices that are frequently used interchangeably but have substantial differences.

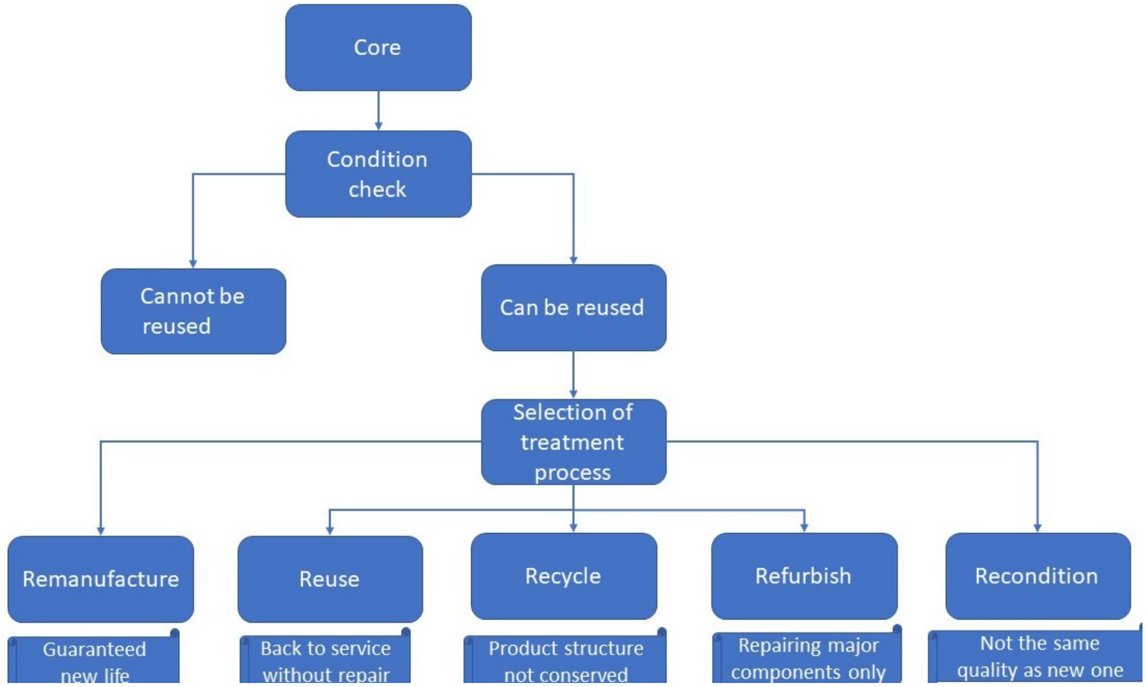

Figure 1.1. The idea behind this illustration is to clarify the misconceptions related to remanufacturing, reuse, recycle, refurbish and recondition

The other recovery options are refurbishing, reconditioning, and repairing. Refurbishing is the process of cleaning, fixing, and replacing major components to restore a product (e.g., a smartphone) to prime condition [44, 43]. Reconditioned products are frequently confused with remanufactured products. Although reconditioned products are returned to working order, they do not come with the same warranty as newly made products [19]. 16.7% of refurbished products are made from recycled materials [34]. Repairing as explained above is also often confused with remanufacturing, it is the process of correcting a product's flaw and restoring it to functional order [44, 29].

The concept of remanufacturing dates to the early twentieth century [20], but it was not until the 1990s that modern remanufacturing took center stage in the United States [22] after the emergence of environmental laws and regulations. The automotive industry saw a significant push in remanufacturing [4] as remanufactured products were much cheaper than the new components. Later remanufacturing has expanded to include ICT (Information and

Communication Technologies), medical equipment, tires[20],robots, airplane components, vending machines, copying machines, electronic products, toner cartridges, machine tools, cameras, office furniture, and other items[18, 11]. Remanufacturing is considered as a "win-win-win" [18, 36, 56] as it favors the:

- customer by providing the same product at a cheaper cost
- manufacturer by reducing the raw material and processing time and cost and
- It favors the environment by reducing waste disposal and reduction in resource consumption

When the price gap between remanufactured and new production is significant, the installed fleet is vast, remanufacturing becomes more attractive. This is the reason most Airplane parts are remanufactured on a schedule. Companies and organizations all over the world have begun to focus on sustainability, waste reduction, and energy consumption mitigation to reduce their environmental footprint [28, 55]. Furthermore, according to a few authors, few of the most compelling reasons to begin remanufacturing is a thorough understanding of the market need, laws, and environmental benefits for the product being remanufactured. If there is no market demand for the product, it is not worth the expenditure [5, 34].

In an era when everyone is tech-savvy and technophile, everyone is excited about the latest technology, and people often upgrade their gadgets, there are millions of tons of trash and a pressing need to dispose of it. This trash is known by a specific name "E-waste".The next section explains what E-waste is and why it is vital to reduce it.

1.2. E-WASTE

The term 'E-waste' refers to waste generated from or by electrical and electronic equipment like computers, wireless goods, and white goods. E-waste is a global problem with the increasing usage of electronic equipment, millions of tons of e-waste are discarded by UK households alone. Some of the equipment can be reused, recycled, or even remanufactured. But most of the e-waste ends up in landfills or incineration which is detrimental to the global environment [19] as shown in Figure 1.2 . Large quantities of e-waste are generated by different nations, and this is expected to increase as there is rapid innovation and development in science and technological fields.

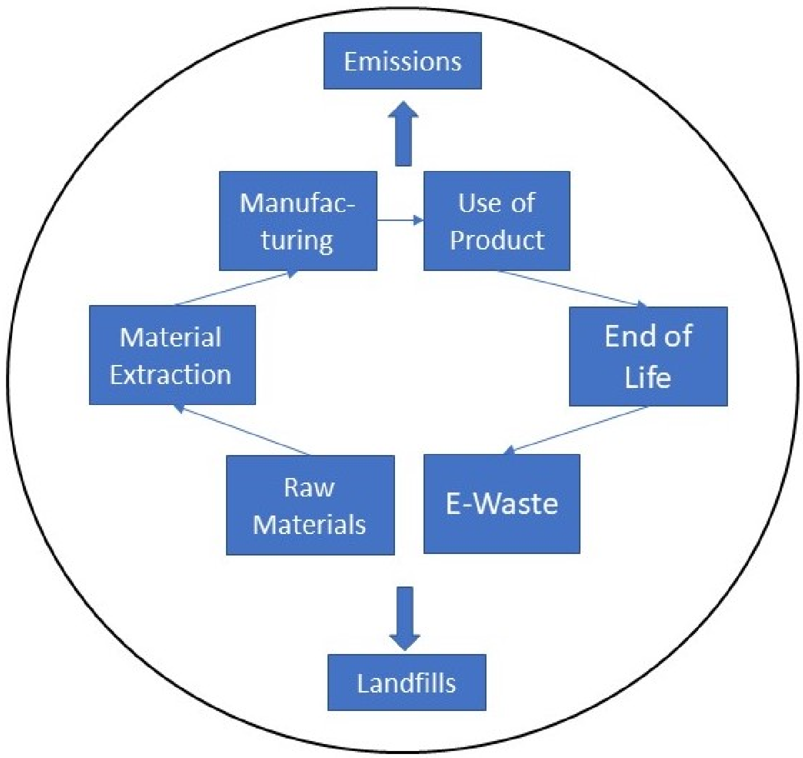

Figure 1.2. The resources for manufacturing the components are extracted from the nature, while manufacturing the products emissions like CO2 pollute the air, and once they reach end-of-life stage they are disposed back into the environment in the form of landfills

Smartphones are the most popular electronic items, and they are also the most quickly replaced. According to some estimates, there were 97 mobile phone subscriptions per 100 individuals in 2014 [43]. Studies show that TVs have the largest life span (13 years) while mobile phones have the shortest life duration (2 years) [39]. Rapid manufacturing on a wide scale may have unintended consequences. One such result of increased manufacturing is e-waste. Due to a decrease in the lifetime of electronic goods and a growth in the global market [17, 11, 47], a huge amount of e-waste is generated and managed on a global scale. Even when the phones are in good working order, consumers upgrade them every two years, according to the French Environment and Energy Management Agency (ADEME). According to a survey, over 30 million devices are sitting idle in drawers [40]. A slew of legislation has been enacted to minimize e-waste from a list of European priority waste streams as the severity of the problem grows. Original Equipment Manufacturers (OEMs) were compelled to return an equivalent number of used products for each new product sold [21], and such laws have incentivized OEMs to remanufacture their devices.

Electronic products contain scarce materials like gold, palladium, and toxic materials like mercury, lead, and cadmium [11]. The toxic minerals cannot be disposed of and the scarce minerals like gold and palladium can be restored and reused again. This collectively emerged as what is being called ‘Urban Ore’. The metals from these ores can be recovered using techniques like comminution, classification, and concentration [47] which are used in conventional mineral ores. The recycling process is not always very economical and recycled minerals perform unfavorably as they differ in composition and contamination when compared with virgin materials [44, 39]. It may require a little amount of extra work for cleaning the Urban ore but it reduces the raw material cost and also the e-waste generated.

The concept of reusing the resources we have instead of throwing them away is called the Circular Economy approach. The circular economy approach aims at using the products in a circular pattern rather than the linear trend of take- make- dispose approach as shown in Figure 1.3, which is explained further in the next section.

1.3. RE-MANUFACTURING – THE CIRCULAR ECONOMY APPROACH

The amount of e-waste generated is hard to dispose and there is an alarming need to reduce the waste. A new model for sustainable development has come into action. The circular economy model aims at reducing energy use and reducing waste disposal [63, 23]. It suggests changing the existing linear trend “take-make-dispose" [57], and using the materials in circulation rather than throwing them away [20]. This can be achieved through reusing, recycling, repairing, refurbishing, or remanufacturing [43]. It is an economic model that encourages closed-loop resource flow [29] where products are kept at their highest utility rate [32]. It is because remanufacturing constitutes a widely recognized enabler for effective and systematic implementation of circular economy that it is considered as the best solution [10]. In Figure 1.3, circular economy approach has been explained. The resources extracted from the nature are processed, used in manufacturing, and reused after recovery treatment.

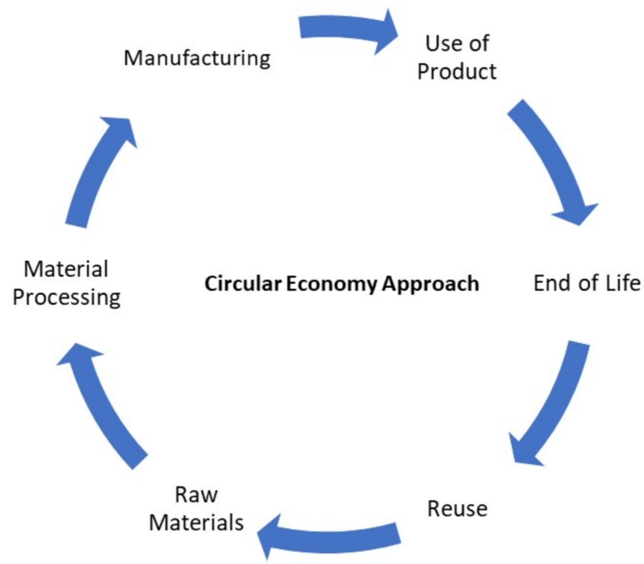

Figure 1.3. Remanufacturing enables the implementation of circular economy approach, As the figure explains once raw materials are extracted and a product is manufactured and, reaches its end-of-life stage, the components used to manufacture the product are reused further leading to circulation of the components in a closed loop

It is believed that this approach can create new business and job opportunities [23] in a profitable way in world economies [20, 57] and is believed to increase resource efficiency. It substitutes the EOL [62] concept with restoration and brings 80-90% savings in the consumption of raw material and energy consumption. Since this aims at reducing energy consumption and eliminating waste, it leads to a significant amount of reduction in CO_2 emission and thus affecting climate change in a positive manner. Thus, encouraging companies to take responsibility for the products they have manufactured and set up a remanufacturing plant leading to more job opportunities. There are further many other benefits of remanufacturing which are explained below.

1.4. BENEFITS OF REMANUFACTURING

According to studies, 85 percent of the weight of remanufactured products can be obtained by using components that perform similarly to new products but require less energy to manufacture [21]. Remanufacturing uses components from previously used product. Thus, the cost of purchasing raw materials is lower compared to when creating new products. Remanufactured products are estimated to cost 35-65% less to produce [56, 5, 20, 11], making the product more affordable. Remanufacturers claim that their prices are between 10% to 90% lower than new products, with most of them being around 50% lower [39, 15]. Job opportunities are also expected to be created by remanufacturing [39]. A remanufactured product uses 85 percent less energy than a new product [55].

Remanufactured products have the same quality and performance as new products, but at a fraction of the cost. The price stability is aided by these lower prices. It is beneficial to the environment and society in addition to the economic benefits [22]. Nigeria has demonstrated that remanufacturing can help their country's healthcare industry recover from its verism. They have successfully developed prototypes of body warmers, infant incubators, phototherapy lamps, and biomedical animal metabolic cages. Over and above the benefits, this might be a significant boon to developing countries, particularly in the area of health care [46].The latest environmental restrictions and increased energy prices play a vital role in encouraging firms to remanufacture their products [11]. The current level of energy and material consumption must be reduced to sufficiently mitigate climate change in a positive way [56]. There is also a need to minimize the rate of consumption of raw materials as seen in the previous section. Industrial greenhouse emissions are 30% of the total greenhouse gases and most of the energy is consumed in the conversion of natural resources and scrap into products [40]. Remanufacturing has the potential to reduce around 8,00,000 tons of CO2 emissions per year [11]. In a study, it was found out that greenhouse gas emissions are 60 times higher for producing a new product than for remanufacturing it. Manufacturing a new equipment/product consumes more energy compared to remanufacturing the same. Statistics say that the amount of energy consumed to manufacture a new washing machine and refrigerator is 30 times and 50 times more than remanufacturing it [61].

Few studies say that remanufacturing saves up to 16 million barrels [56] or over 8 million gallons [62] of crude oil every year. Not only large factories can save up to 105,000 Mega Watt-hours of energy, 240 tons of copper, 440 tons of Aluminum, and 2200 tons of steel [55] but also remanufacturing in the US alone can recuperate 50% of raw material. The above-mentioned reasons have driven many companies to follow the concept of "low carbon logistics" [61]. Research is still going on in this area and various institutes have collaborated on a worldwide level. Globally Recoverable and Eco-friendly E-equipment Network with Distributed Information Service Management' project, or 'GREENet' is one such research project which is a collaboration between various institutes in the EU and China. This involves the study of the status of remanufacturing and e-waste across the two global economies [19].

Table 1.1. Benefits of remanufacturing to customer and manufacturer

S.no	**Factors**	**Benefits**
1.	Cost to manufacture	35% - 65% <New [56, 5, 20, 11]
2.	Selling price to Customer	10% - 90% <New [39, 15]
3.	Energy required to remanufacture	85% <New [55]

Few studies say that remanufacturing saves up to 16 million barrels [56] or over 8 million gallons [62] of crude oil every year. Not only large factories can save up to 105,000 Mega Watt-hours of energy, 240 tons of copper, 440 tons of Aluminum, and 2200 tons of steel [55] but also remanufacturing in the US alone can recuperate 50% of raw material. The above-mentioned reasons have driven many companies to follow the concept of "low

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The benefits of remanufacturing exponentially increase when recent technologies like Artificial Intelligence (AI) and Machine Learning (ML) algorithms are used. The involvement of these technologies in remanufacturing is called "Smart Remanufacturing."

1.5. SMART REMANUFACTURING

Implementation of appropriate technology into a process can make it faster and more efficient. In today’s world, software application is crucial for human life. The goal of software development is to make people’s lives easier and more productive.[41]. The process of converting data from the manufacturing process into actionable information is referred to as smart manufacturing. Data is automatically collected using environmental sensors and equipment performance indicators in this method. Human or machine decision-makers receive data and make decisions based on their intelligence [16]. Artificial intelligence adoption is expected to have a massive influence in the Industrial Revolution 4.0, which is like the one that Henry Ford’s assembly line had over a century ago [1]. The concept of smart remanufacturing that connects networking, physical processes, and computation is Cyber-Physical systems. CPS is the intellectual framework by which one can implement a comprehensive reman operation. To set up a smart remanufacturing plant, technologies like computer vision and cyber-physical systems play a crucial role.

1.5.1. Computer Vision. Computer vision, often known as machine vision, is a technique for obtaining digital information from a scene and applying it to various activities. In the manufacturing and remanufacturing industries, this technique, together with quality assurance is highly beneficial.The following are some of the key concepts that are frequently encountered while dealing with computer vision [58].

- The Internet of Things allows services to be provided by creating a connection between physical and virtual devices based on accessible data and communication technologies.
- Virtual Reality- Users can examine a 3D depiction of a product or environment using VR (Virtual Reality) technology, which employs computer-generated CAD images.
- Augmented Reality is a type of virtual reality in which computer-generated data is shown. According to a survey conducted across a variety of businesses, machine vision is critical in the field of quality assurance.

By implementation of machine vision as shown in Figure 1.4 , the quality and variety of remanufactured products tend to increase, which is further explained in the following paragraphs. With the introduction of Industry 4.0 and the IoT, there is a huge scope for automation in the remanufacturing sector. However, the IoT environment may also be vulnerable to cyber-attacks. As a result, extreme caution must be exercised when interacting with the IoT ecosystem. It can also affect assets, such as persons, as well as a variety of appliances, computer structures, and facilities that are widely used. Machine learning used for Computer Vision or Machine Vision is a process in which statistical techniques are used to uncover patterns in a set of data and provide the results to a computer, which then extracts the patterns on its own. This can be divided into three types: supervised, unsupervised, and reinforced learning. From our research reinforced learning is a good tool to train our model and achieve the best results in our scenario. These strategies can be employed in a variety of situations, depending on the need and application [42]. Digital technology has helped in providing value-added solutions for remanufacturing, it has helped in the development of the concept of the "Future Factory" for advanced manufacturing. The term "Future Factory" refers to the fourth stage of industrialization, in which a high level of automation in the manufacturing sector is achieved using information technology [63].

1.5.2. Cyber Physical System. Cyber-Physical Systems (CPS) is a combination of computation, networking, and physical processes. Embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice versa. CPS integrates the dynamics of the physical processes with those of the software and networking, providing abstractions, modeling, design, and analysis techniques for an integrated system [6]. Figure 1.4 briefly explains what a cyber-physical system in a remanufacturing industry would look like. The embedded computers and networks placed in the center of the diagram, monitor, and control the physical processes along with the feedback loops for each stage.

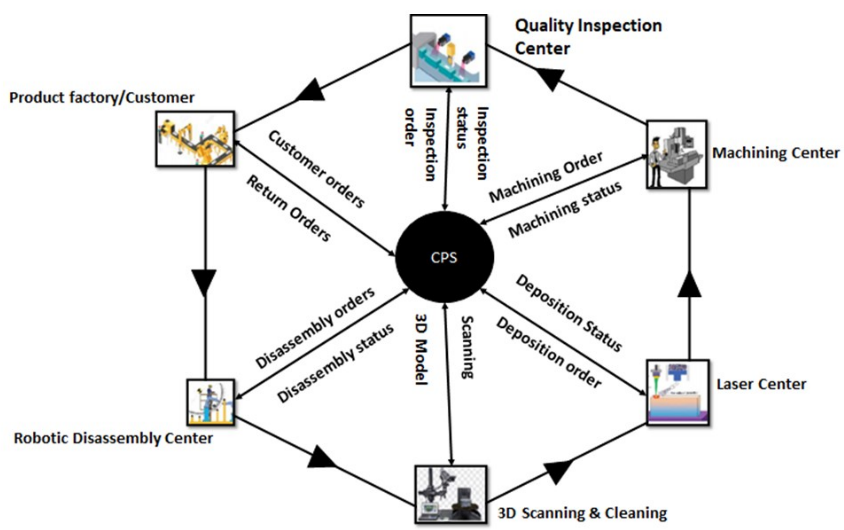

Figure 1.4. The futuristic model of smart remanufacturing is a part of cyber physical system and, all the operations are controlled by a computer.

After collecting the core, it is disassembled, the AI determines the status of the core, if it can be remanufactured or if it is a pure scrap. Similarly, all the machines can be controlled by using embedded systems and computers [59]. The figure explains that all the processes are connected to a computer and are managed through the computer. The idea behind a CPS is to automate the process by involving technology in it. The name itself says that a cyber-physical system is an approach to connect the culture of computers, information technology, and virtual reality to the physical factory. A smart remanufacturing system can also be known as a cyber-physical system on a broader scale.

Adopting the ever-growing information and communication technologies aided with Artificial intelligence has blurred the gap between the real environment and virtual environment making way for what is called sophisticated physical production system [1]. The main idea behind this is combining physical production and digital design so that personalized and diversified products can be produced [59].

2. BACKGROUND

Based on our research a bar chart has been created to depict the number of publications related to key concepts. Figure 2.1 displays the areas to which our review papers are related. From our research, Industry 4.0 has encouraged many companies to not just automate their process but also focus on remanufacturing their products.

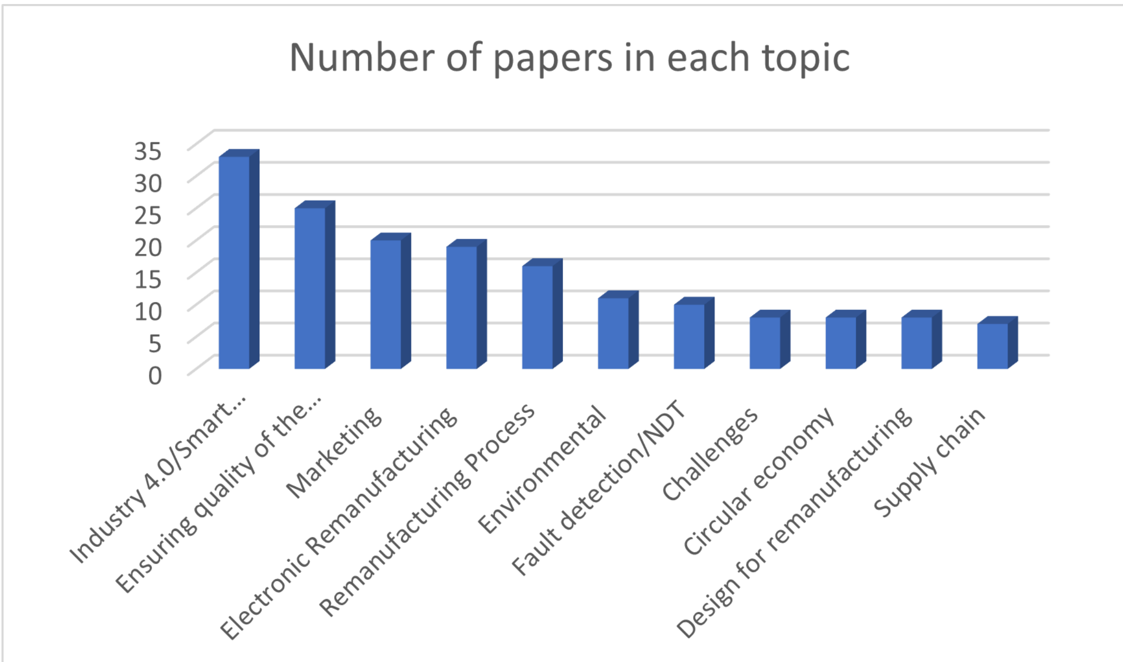

Figure 2.1. This Figure visualizes the frequency of concepts in different papers reviewed

All the key concepts and the papers which include these concepts are tabulated in Table 2.1, in order to summarize all the reviewed papers. Each row lists the key concept followed by the citations of the papers which include the concept.

Supply chain concepts in remanufacturing is an issue that has been discussed in the previous papers, which can be eliminated using forecasting analysis which our AI model could do. Nondestructive testing methods are also gaining importance over a period as manufacturers find it feasible compared to disassembling and testing the component.

Table 2.1. Concept and the related citations during literature review are noted

Concept	**Related citations**
Fault detection	[1, 53, 58, 33, 31, 54, 38, 48, 42, 37]
Remanufacturing process	[1, 5, 22, 19, 62, 55, 21, 20, 18, 12, 7, 17, 4, 30, 66, 8, 50]
Challenges	[4, 30, 56, 2, 1, 11, 5, 22]
Circular Economy	[29, 49, 28, 5, 15, 27, 32, 2]
Environmental / E–waste	[1, 49, 11, 5, 47, 34, 36, 10, 48, 15, 4]
Marketing	[29, 23, 49, 28, 11, 5, 57, 13, 16, 43, 10, 39, 63, 21, 7, 30, 26, 61, 32, 2]
Supply Chain concepts	[49, 5, 22, 13, 56, 61, 2]
Design for remanufacturing	[1, 19, 57, 55, 20, 18, 12, 8]
Industry 4.0/Smart Manufacturing	[46, 32, 52, 62, 3, 66, 27, 12, 42, 56, 9, 63, 48, 38, 14, 54, 10, 31, 36, 33, 40, 16, 13, 59, 6, 60, 65, 64, 53, 45, 23, 1]
Electronic Remanufacturing	[1, 28, 53, 47, 58, 22, 40, 43, 33, 31, 10, 25, 48, 44, 55, 56, 62, 32, 2]
Quality	[1, 23, 28, 53, 5, 47, 64, 65, 59, 57, 34, 54, 25, 55, 21, 18, 12, 24, 30, 26, 56, 27, 3, 32, 2]

2.1. CHALLENGES IN CURRENT PROCESS

Even though Remanufacturing is believed to have tremendous environmental benefits and economic benefits. It still must face a lot of challenges for implementation and acceptance in society. The problems start from the original equipment itself. Unique characteristics lead to complicated planning [4]. As we know that the first step in remanufacturing is the collection of used products and inspection, in this process it is uncertain to know the quality, quantity, and timing of the returned products [56, 55]. This is also said as uncertainty and variability in conditions of post used products/ core [27]concerning manufacturing systems [62, 39, 10, 25].

2.2. EXPECTED CHALLENGES IN SMART REMANUFACTURING

For smart remanufacturing, having a proper internet connection is a major issue. The importance of internet connection lies in the fact that one should be able to access the machines and monitor them remotely. Another major challenge is concerning inventory management in remanufacturing systems. The traditional systems carry a wide variety of inventories like spares, new parts, finished goods, cores, and work-in-progress (WIP) inventories. They use strategies like Assemble-to-Order (ATO), Make-to-Order (MTO), and Make-to-Stock (MTS) methods to manage their vast inventories [49]. For remanufacturing that's not the case. It's much harder to do the forecast analysis and decide the demand for the product. As per the research, Reman-to-order is a better alternative to Make-to-Order, where remanufacturing takes place only when an order has been placed. This adds to the lead time and research is required in this field to get the best possibility to remanufacture a product with minimum lead time.

3. CURRENT STATE-OF-ART REMANUFACTURING PROCESS

Current conventional remanufacturing process is depicted in Figure 3.1. A core is placed through a series of processes and procedures to rebuild and restore its original functionality. The performance levels of the replacement part may be comparable to or better than those of the original [4] and the same level of warranty is also provided to the remanufactured part [26].

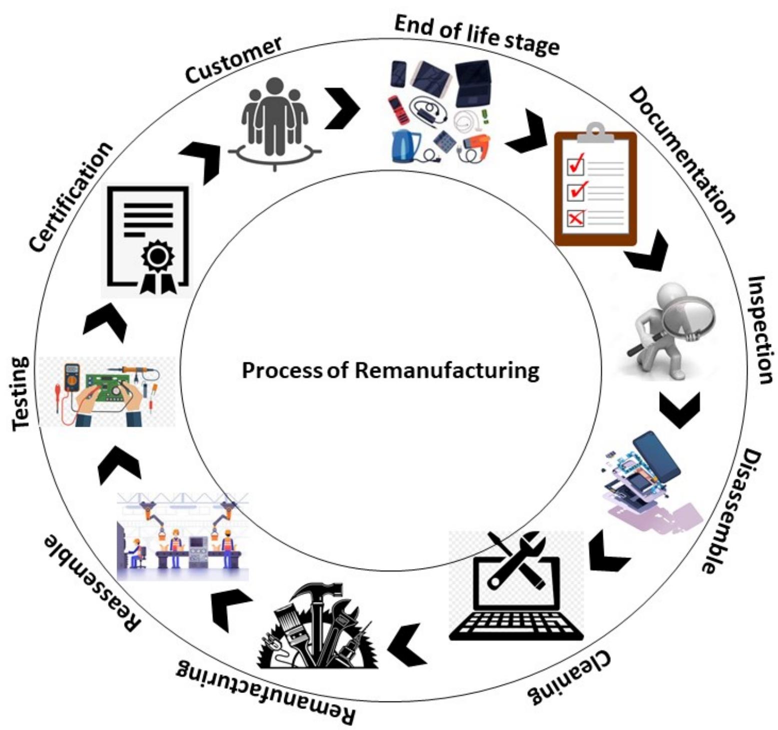

Figure 3.1. Remanufacturing consists of various stages which begins with inspection of the core, disassembling the core, cleaning it, remanufacturing and reprocessing it, reassembling, testing and it is good to be sold to the customer

In most of the papers remanufacturing has been classified into the following stages namely: inspection, disassembly, cleaning, repairing/replacing, reassembly, and testing [28, 55, 22, 20, 4, 11, 63, 8].The above mentioned stages in remanufactured are expanded in Figure 3.2.

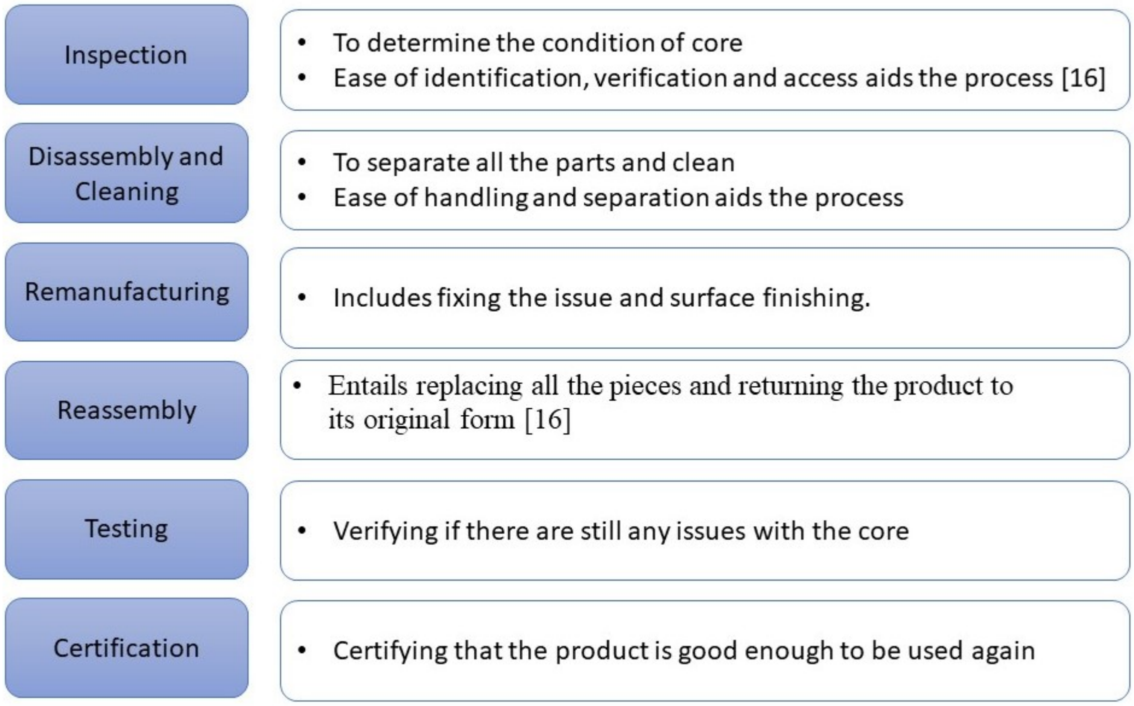

Figure 3.2. The various stages of remanufacturing are depicted and, each step is further discussed in the following paragraph

Inspection of the core-The first stage in remanufacturing is to determine the EOL of the core to determine its condition, and then depending on the condition determine the core's residual value to compare it to the remanufacturing costs [28, 4]. Ease of identification, verification, and access are some of the most important product qualities in this step. Disassembly-In the next stage, depending on the product's complexity, inspection and disassembly take place either concurrently or simultaneously. It is the same for basic high-volume products and advanced low-volume products. If the product is complex and the volume is high, it is sequential. During this process, the product should be easy to separate and handle. Identification, access, handling, separation, and wear resistance are all positive aspects of product disassembly [11].

Cleaning - Cleaning products with a lot of oil and heavy components is a big problem. In this context, technical advancement has been facilitated by the ease of access and resilience to wear [11]. However, our paper just focuses on remanufacturing electronic devices, and we do not have to deal with heavy components with a lot of oil on a major scale. Reassembly- is the following step, which entails replacing all the pieces and returning the product to its original form [4]. The product is then tested again to check if there are any further issues with the product. Certification- If no issues are found related to the core, and the quality of the product is similar to new product, it is certified. The restoration step of the remanufacturing process is the most important. Restoration planning, technology planning, and process planning are the other three crucial decision-making processes [28]. Original Equipment Remanufacturers are Original Equipment Manufacturers (OEMs) who remanufacture their products (OERs). The OERs suggest that remanufacturing a product can take a few days. If we employed creative and intelligent remanufacturing techniques, we could theoretically remanufacture a product in minutes. One such example is Liam, Apple's first recycling robot, which could recycle an iPhone every 12 minutes [40]. This shows a significant reduction in the time it takes to remanufacture a product using machine learning ideas.

3.1. FACTORS INFLUENCING CONVENTIONAL REMANUFACTURING

Few vital factors are to be taken into consideration while deciding if a product can be remanufactured. Certain studies dictate successful remanufacturing. The main decision-making aspects can be classified into the following four categories as shown in Figure 3.3:

Product characteristics: innovation rate, residence time, product residual value and re-manufacturability Demand-related factors: market size, market channel, pricing of new and remanufactured products, and the existence of a green segment. Process related

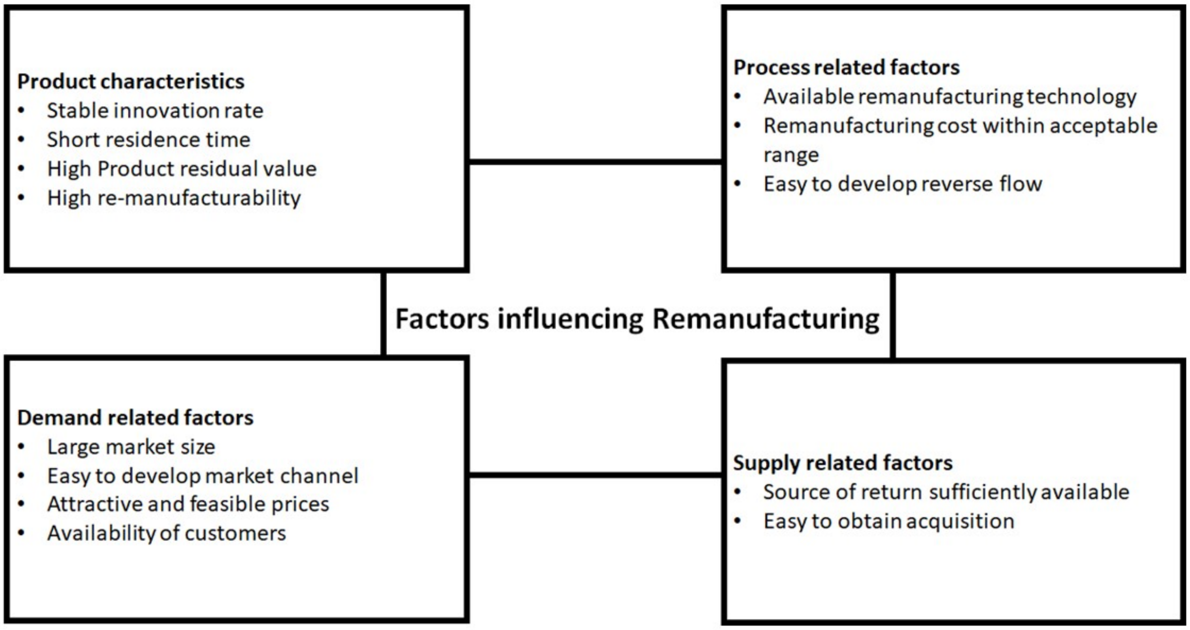

Figure 3.3. The factors that influence the conventional method of remanufacturing is depicted here

factors: remanufacturing technology availability, remanufacturing cost, reverse flow structure readiness Supply-related factors: acquisition price, source of return whether it is limited and poses as a constraint or unlimited [17].

3.2. GAPS IN CURRENT REMANUFACTURING

Even though remanufactured goods are less expensive, more environmentally friendly, and have quality comparable to new components, they are not receiving the recognition they deserve. One reason for this could be the gaps in the present remanufacturing process. The existing remanufacturing process has many gaps that need to be filled in order to

Table 3.1. The Table depicts the gaps in current state of remanufacturing and the smart technologies available which can solve the issues

Gaps in remanufacturing sector	**Smart technologies that solve the issue**
Finding the intermittent faults [55]	Intermittent Fault Detector and Isolation System [55]
Components of core become obsolete [29,45]	Design for Upgrade [17, 2]
Risk during inspection [54]	Robots and remote remanufacturing [65]
Difficulty in disassembly [54]	Design for remanufacturing and design for disassembly [31]
Fear of Cannibalization [7]	It is equally profitable, reduce labor costs by installing robots [30]
The process of remanufacturing is different	Machine Learning models can be trained to make decisions [23]

make the remanufacturing process easier and the remanufactured items more appealing to buyers. Table 3.1 shows the existing gaps in current remanufacturing system and how the implementation of smart technologies can eliminate the issues.

The major challenges during the process of remanufacturing are:

Finding the flaws in the core component: The most difficult task is locating the flaw within the core. When tested, a few goods that have intermittent defects do not exhibit any faults. The flaws may only be detectable for a brief period of time, or there may be loose connections in the circuit. The component may or may not work. As a result, even after restoring the critical components, the gadget is not as functional as it should be. In such cases, a device that detects intermittent problems and loose connections is required to be installed, for a better detection of defects.

The components within the core can be obsolete: Gadgets are always being replaced by new models as technology evolves. The components of a device that is 5 to 10 years old are becoming obsolete, making remanufacturing the gadget problematic. As a result, the device is either discarded or demolished. Which brings us back to e-waste. As a result, only contemporary goods can be remanufactured, and older devices cannot be remanufactured effectively. Customers would rather buy a new gadget than a remanufactured device if there is no significant difference.The use of design for upgrade is one answer to this challenge. This approach intends to remanufacture gadgets by improving the design and components with the most up-to-date technologies available. As a result, luring customers by offering cutting-edge technology at a lower cost.

Risk factor while inspecting and cleaning: In the production sector, inspecting a device is considered a waste of time. It is, nevertheless, the most important stage of the remanufacturing process. Inspecting and cleaning are more difficult in the remanufacturing process due to the complexity of the product's design, as well as the risk of explosion or inhaling toxic fumes, particularly in electrical components like batteries. The design for remanufacturing and design for disassembly [30] facilitates easy remanufacturing by incorporating easy disassembly throughout the remanufacturing process. Robots and remote monitoring can be used to manage the risks of cleaning and inspecting electronic devices remotely.

Lack of trust in customers: Even after the awareness of e-waste and climate change, only few buyers are interested in purchasing remanufactured devices. This is due to a lack of awareness of remanufactured products and apprehension about their quality. The remanufactured products have the quality of a new product, but in order to get the trust of the client, the items need be certified for quality. Certified pre-owned vehicles are making a lot of money in the market as they have earned the trust of the buyers. To make an impact in the market, the process of remanufacturing devices must also be certified in terms of quality. This is achieved by completing post-remanufacturing testing and ensuring the device is defect-free.

Fear of cannibalization: Not many corporations are interested in remanufacturing their products because they are afraid about cannibalization[7]. However, they should understand that remanufacturing is profitable to company just as new ones because it reduces raw material costs and requires less energy to remanufacture the products. By applying smart remanufacturing processes, they may reduce labor costs by replacing most of the labor tasks with robots, while also enabling safety measures.

Remanufacturing every device is not same : Despite the numerous advantages of remanufacturing, there is a need to focus on raising public awareness. Only few individuals are aware of remanufactured equipment. Every device cannot be created in the same way, so it is vital to understand about the procedures for remanufacturing.The remanufacturing companies are also unaware of technological developments that can be implemented in the process to make it considerably simpler. If ML and AI are adopted in the sector, they will play a critical role. If the ML models are adequately trained, they will be able to make judgments depending on the set of rules presented, and come up with solutions on ’How to remanufacture a particular device’.

4. FUTURISTIC APPROACH FOR SMART REMANUFACTURING

Having discussed about the conventional remanufacturing process and various factors that affect it, it is time to discuss the futuristic smart remanufacturing model.The introduction of AR and VR has minimized the shortcomings of conventional remanufacturing as well as maximized technological progress.With smart robots and Cyber Physical Systems, smart machining can be achieved to capture the real time data and send it to a cloud based central system.By the deployment of various types of sensors, it is possible to achieve real time monitoring of the machines thus giving the ability to remotely monitor the firm. Smart monitoring not only provides a graphical visualisation of status of the firm but also gives alerts. IoT and CPS are the key concepts which enable smart remanufacturing.

Similar to the conventional remanufacturing process, this model also starts with collection and inspection of the core. The other stages are explained below and in Figure 4.1:

Core and Inspection: The core received for remanufacturing is scanned using an intermittent fault detector known as IFDIS ,(Intermittent fault detection and identification system) [31] to identify the defects that are very unstable , and hard to detect but affect the functionality of the core. Not all fault detectors have the ability to inspect the quality of core. A trained machine is more accurate in determining the flaws .Few intermittent defects show "No Fault Found", "Cannot Duplicate", "Retest OK", and "No evidence of defect", even when the core has defects in it. IFDIS helps in detecting defects with a 99 % accuracy.
Non Destructive Testing Methods: After determining the intermittent defects in the core and storing the points of defects in the cloud, a complementary non-destructive testing is performed which enables identification of issues without destroying the component.In regular remanufacturing process the core is disassembled for this inspection of the core.
Digital Twins and Decision Making: These processes are controlled and the data collected is stored in a centralized system which later helps in the decision making stage. The Artificial Intelligence and machine learning models which are trained using actual functional data of

the core determines the best way to remanufacture the core.The best decisions will then be applied to the digital twins of the core and feasibility is determined. This reduces the costs incurred in physical prototyping as well as fulfilling the job at hand.

Depending on the outcome from the above steps, a standard operation procedure on how to remanufacture the component is sent to the smart robots which perform remanufacturing process.With the help of sensors , AI , Web DPP (helps the companies to keep status updates)and the advancing technology operator/client has the ability to monitor the entire process. In addition they can send safety alerts, switch on and off the machine depending on the need. In the following paragraphs, each stage is explained in a detailed manner. Figure 4.1, summarizes the futuristic model of remanufacturing.

4.1. CORE RETRIEVING AND INSPECTION

Receiving the core is an important stage in the remanufacturing process. The original equipment manufacturer or the original equipment retailer provides the core to a remanufacturing firm. Each core and its components are given RFID (Radio Frequency Identification) [24] tags to enable unique identification.Figure 4.2 illustrates the difference in a setup where an IFDIS is installed (b) vs a setup where no IFDIS is installed (a). The probability of fault detection in IFDIS setup is 99% whereas where no IFDIS setup is approximately 50%.

Following the receipt of the core, the next critical step is to inspect it. This phase entails determining whether the gadget has any intermittent issues. Intermittent problems or abnormalities are often difficult to discover. In such instances, the malfunctioning gadget may be mistaken for a good one. Usually,when electronic boxes are checked for maintenance, they are usually found to be in good working order or to have no faults. They do, however, have sporadic flaws.

Sometimes the discontinuity is only there for a brief time and only manifests when they are under stress, such as vibration or a mixture of stresses. Cracked solder joints, rusted contacts, spring connectors, crimp connections, or hairline cracks in the circuit trace can all cause intermittent problems. A novel gadget created by [53] called the Intermittent fault detection and isolation system (IFDIS) is employed to solve this problem. The reason behind installing IFDIS in this remanufacturing firm is to eliminate the risk factor. In comparison to regular remanufacturing, incorporating the IFDIS in the process layout allows it to identify loose circuits and intermittent faults at an early stage. More than thousand electrical connection points can be interfaced with the IFDIS 2.0.

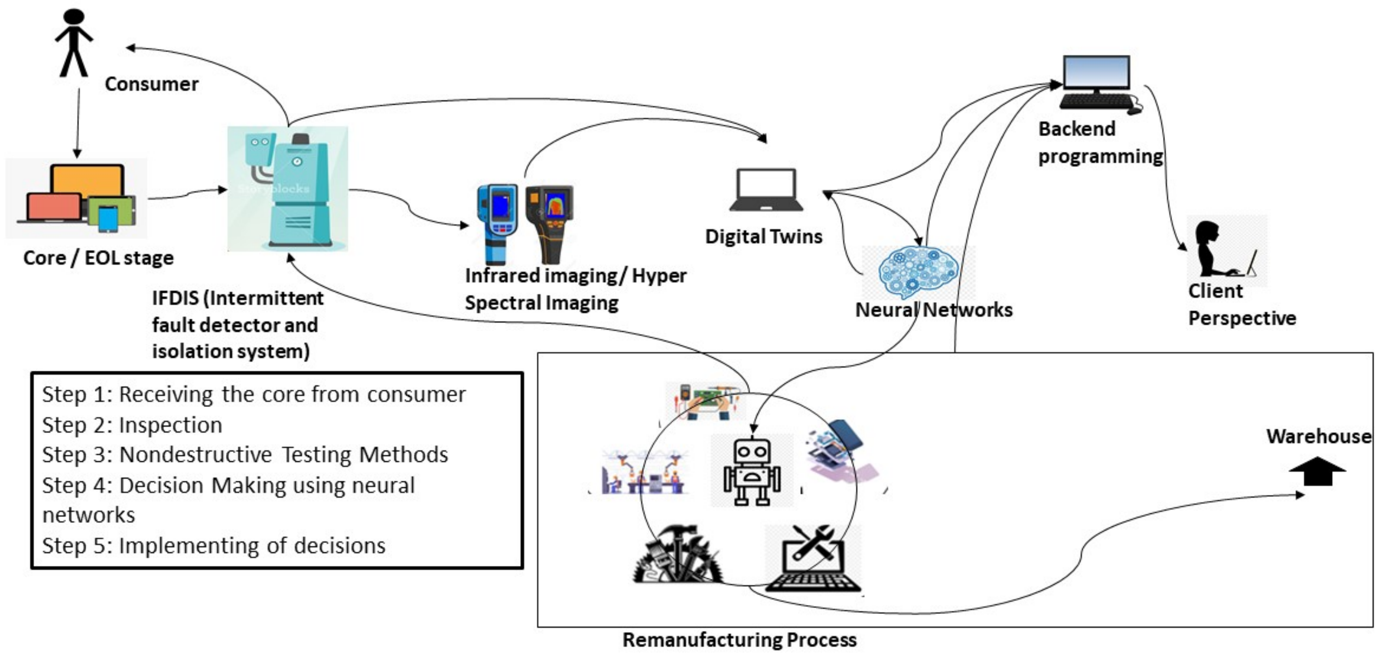

Figure 4.1. This method is believed to be the best feasible possibility of smart remanufacturing electronic devices considering the challenges faced by the current state remanufacturing process

As shown in Figure 4.2, it not only detects defects, but it also interrogates and stores the wiring arrangement as specified. It lowers life cycle support costs and improves operational availability [54]. This also saves a lot of time because the issues are detected immediately. The IFDIS system is made up of a neural network that monitors the continuity of hundreds of circuit lines. This system shows the number of times intermittent faults have occurred, as well as the test history, which includes temperature, duration, and timeline information.

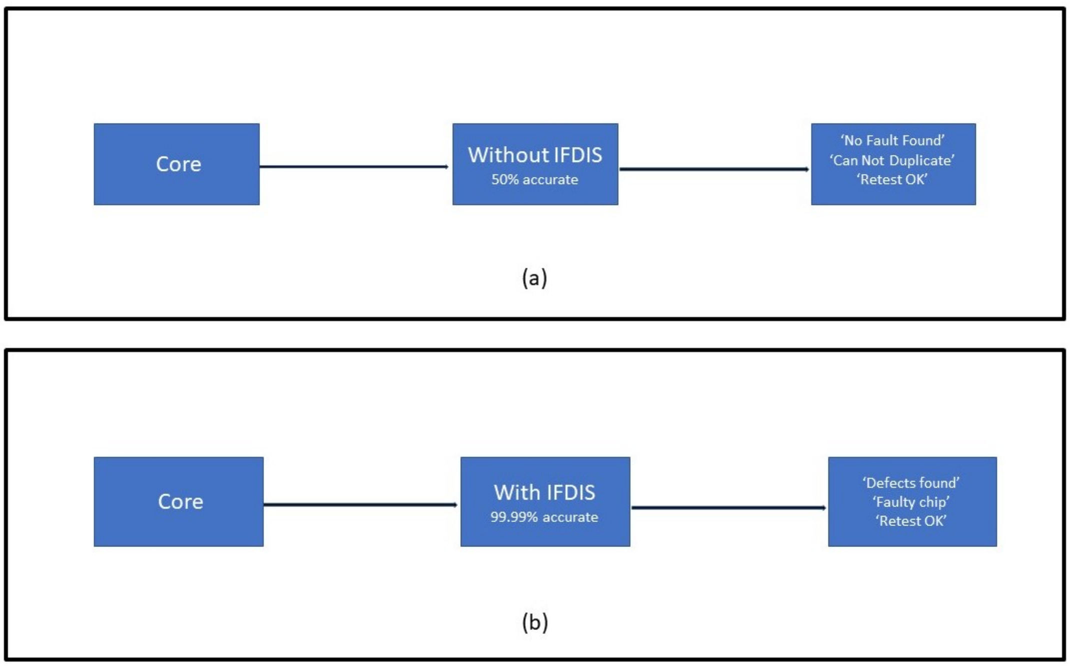

Figure 4.2. (a) A setup where no IFDIS is installed,(b) A setup where IFDIS is installed

This software gathers all data points when a problem is discovered and stores it on the machine where it is installed. The most significant benefit of this device is that it can detect defects that last for very small duration.After detecting the intermittent faults within the component. Using NDT methods other internal damages are inspected.

4.2. NON-DESTRUCTIVE TESTING

Identification of flaws to evaluate the quality of residual functionality and observable defects are critical phases in remanufacturing [55]. NDT methods are used to complement the IFDIS sensors, to help in diagnosing the core without disassembly of it. Nondestructive procedures are essential for finding and describing flaws without causing damage to the product. These also aid in the detection of faults such as loose connections or other out-of-spec conditions that prevent the product from completing its job. The common faults in electronics are in the chips, electrical connectors, and solder joints. A 2D imaging-based NDT helps to fast locate the defects and provide qualitative information. Techniques like x-ray micro-computed tomography scan, ultrasonic, scanning acoustic microscopy [33], scanning electron microscopy, liquid penetrant, and eddy current are used to access the internal defects in these sensitive components. Being able to analyze the problem within the component without disassembling it helps in getting an idea of the best possibility of how to process the component.

In this model, Infrared Radio Thermography [48] is used at this stage . The setup employs a camera with a large number of infrared sensors capable of detecting and measuring minute temperature variations. The image depicting these changes can be downloaded and seen on a computer, usually as a color or grayscale map. The camera is simply directed at the test component, and a temperature map is created from the thermal image. Variations in the temperature decay rate reveal flaws in the material. The machine determines which parts must be replaced with new parts based on the photos taken for a properly functional component and the core component. Data is captured and stored in this step [51] .

For the past 50 years, IRT has been used for electronic packaging [35], it has also been used for detecting breast cancer [9] and spreading swine flu and other viral diseases. The IRT method's basic working principle is to measure the heat luminance from a surface within the electromagnetic spectrum region corresponding to the infrared (IR) wavelength (2–14 m) and record the surface's temperature distribution.The purpose of installing NDT is to provide the necessary inspection and quality control to assure safety and dependability. Knowing the difficulties of evaluating composite materials, electronic connections and welds enables the AI models and the operators to appreciate the significance of finding the best solution for their needs.

Hyperspectral imaging (HIS) which is typically used to identify and classify different minerals on the earth's surface [31] could also be added to the process. This technology is used to identify the minerals used and estimate the cost reduction if they are replaced with other materials. Few other NDT techniques like Conventional X-ray radiography, neutron radiography, and liquid dye penetrant testing are discussed below.

Table 4.1. The various Non destructive testing methods and their capabilities as well as the technology used have been listed

Non Destructive Testing Methods	**Used For Inspecting**	**Technology Used**	**Benefits**
Conventional X-Ray Testing	Sealed or Potted assemblies, solder bridges	X-Ray	Do not need any extra preparation [48]
Neutron Radiography Testing	Plastics and Lubricants	Fast neutrons by decay of radio-active isotopes	Ability to reveal light elements such as hydrogen found in corrosion [48]
Liquid Dye Penetrant	Surface fractures, delamination in smooth surfaces	Penetrant dye	Sensitive to small interruptions [48]
Infrared Radiographic Testing	Electronic testing	Electromagnetic spectrum in IR wavelength	Allows large area to be tested in one go [48, 33]
Hyper Spectral Imaging	Classification of minerals	Hyperspectral sensing cameras	Operator needs no prior knowledge of the sample [30]
Scanning Acoustic Microscopy	Electronic devices	Reflected acoustic signals [31]	Depth of internal layers can be obtained [33]
Scanning Electron Microscopy	Material specimens	Electron beam induced current and cathodo luminescence	High resolution due to narrow electron beams[33]

4.2.1. Conventional X-ray Radiography. For engineers interested in determining the reason for failed assemblies, radiography is a popular and flexible technique. The engineer frequently needs to see inside or through an assembly but is unable to do so. Furthermore, there are numerous cases where disassembling the product might destroy the data required to assess the problem. When inspecting sealed or potted assemblies, this is frequently the case because forcing open the product would displace or destroy the components. In these cases, radiography is extremely useful. Based on the density and an atomic number of the item, X-ray radiography creates a shadow image. X-rays (and gamma rays) are exceptionally high-frequency electromagnetic waves. The slowing of high-speed electrons when they collide with a metal target in a vacuum tube is a frequent source of this radiation. This inspection methodology is frequently used to test potted assemblies for faults. Components and cables in the assembly can also be located using radiography. Assembly faults, solder bridges (solder is opaque to X-rays), or problems with automatic insertion equipment can all be revealed in this way [25, 48].

4.2.2. Neutron Radiography. Neutron radiography is a method that is still relatively young and underutilized. It has the potential to solve several production issues that no other NDT approach can. Low-atomic-number materials (such as plastics and lubricants) can be seen inside high-atomic-number materials (such as steel and lead) using neutron radiography. Thermal neutrons can be produced in a variety of ways. Fast neutrons are produced by the decay of some radioactive isotopes (for example, Californium 252). These neutrons are slowed to thermal speeds after traveling through a moderator such as heavy water (deuterium oxide) and can be employed in radiography. High-energy X-rays can also be used to produce neutrons by blasting a beryllium converter foil. Fast neutrons are also produced in this process, which must be reduced to thermal speeds using a moderator [48]. The neutron radiography dose levels are much below the damage threshold for even the most fragile semiconductors. This inspection methodology can also be employed without regard for the inspected product's safety. A detailed comparison of various techniques and applications are summarized in Table 4.1.

4.2.3. Liquid Dye Penetrate Testing. Liquid dye penetrant testing (LDPT) is a nondestructive testing (NDT) method for detecting surface fractures or delamination in otherwise smooth surfaces. A penetrant dye is applied to a problematic part after it has been cleansed. Capillary action draws the penetrant into existing surface fractures. After that, the excess penetrant is removed, and a developer is used. The developer pulls any remaining penetrate from the fracture to the surface, where it may be seen and photographed. A homogeneous, white background is also provided by the developer, which improves crack visibility [48]. In high potential (HIPOT) testing of solenoid coils, liquid dye penetrant testing is used. The exact position of the crack that caused the failure is determined by testing failed coils. In a potted circuit or assembly, this approach is also used to locate delamination between potting compound and incoming wires. On printed circuit boards, it can also be used to locate delaminated traces. The procedure's main drawbacks are that it's untidy and can only uncover defects that are surface connected [48].

4.3. DIGITAL TWINS AND DECISION MAKING

The digital twin is a virtual representation of the physical product as designed and maintained, complemented by real-time process data and analytics based on accurate configurations of the actual product as shown in Figure 4.3 [13]. Virtual models are conceptual, but real-time and operational data is a digital depiction of real physical events. Real-time operational and asset data are required by analytics systems that define the status and behavior of the performance-based digital twin and allow optimization and process improvement.

The information gathered in the first two processes is applied on the digital twins to find the optimal remanufacturing solution using AI. This helps in determining how to remanufacture, upgrade, and cost-effectively remanufacture the product. Digital twins are used because they remove the need for prototypes and save a lot of time.

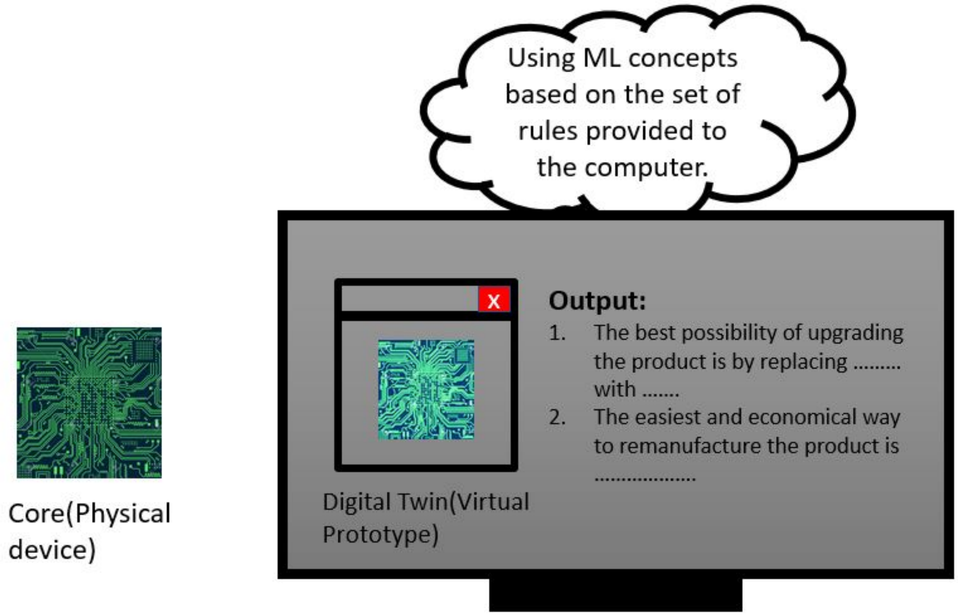

Figure 4.3. The core is on the left side of the image and a digital twin is displayed on the monitor screen. Using ML concepts based on the set of rules provided to the model, it figures a right way to remanufacture the device.

4.3.1. Digital Twin and its Implementation Today. The digital twins relies heavily on today's superior virtual simulation technology. They simulate and evaluate the functionality of product designs simultaneously with comprehensive simulation platforms, allowing designers to validate their designs as they go. Real-time sensor data is utilized to populate simulation applications that subsequently emulate the physical product and enable design improvements in the context of the digital twin [52].

To enable automation, data interchange, and joined-up production processes, as well as de-risk product roll out, the digital twin plays a critical role in smart remote remanufacturing as well. Employees in the industry can monitor processes in real time, offering early warnings of potential breakdowns and enabling for real-time performance optimization and evaluation with little productivity loss [65].

A digital twin is used, to anticipate downtime, adapt to changing circumstances, test design enhancements, by simulating actual assets, frameworks, and activities to create continuous data. It generates a simulation model that has the ability to update alongside or in place of a physical counterpart by combining technologies such as artificial intelligence, machine learning, and software analytic with data. This enables the business to evaluate an entirely computerized development cycle, from design to deployment to decommissioning.

Since, not all the concepts of remanufacturing are known and a lot of new concepts can be discovered. The machine comes up with the best possible solution based on a set of rules, and procedures provided to it. In the next few sections , the various technologies that have been used for upgrading the product and remanufacturing a product are discussed.

4.3.2. Upgrading the Product. In this stage the core is remanufactured. A link is established between design for manufacturing and design for remanufacturing. Design for manufacturing is a widely used concept across all the industrial applications to address the possible challenges in early phases and rectify them [63]. Design for remanufacturing is a similar approach believed to play a prominent role in reducing the challenges. Another important concept to attract customers is by using Design for Upgrade. When the market life of the component/product is very important for a technological change, then there is a need to design for upgrade. It can also fall into the Design for Multiple Life-cycles[12]. The technology/appearance of the appliances made design for upgrade more relevant to the remanufacturing sector. This type of practice to upgrade the product to meet the customers' requirements also prolongs the product life in the market. Final concept related to design which helps in remanufacturing the product involves identifying when the optimum life span of the product/component has been reached is called design for optimum life [12].

Process or product optimization is a data-intensive operation involving a large number of historical data sets. It is difficult to determine what factors result in the highest product quality. Manufacturing and quality engineers constantly run dozens of Design of Experiments to optimize process parameters, but it can be costly and time consuming. In this approach, the models and operators determine the optimal process recipe for various products using AI's quick data crunching speed. AI constantly learns from all production data points to continuously improve product parameters, hence suggesting on the best ways to upgrade the product.

4.3.3. Neural Networks and Remanufacturing. A neural network structure is designed to replicate a human neural system using a weighted sum of inputs.The development of Neural Networking is motivated by a desire to comprehend the principles of the human brain and to create machines capable of executing complicated tasks that conventional computers are incapable of performing. Neural network approaches can help to advance the creation of intelligent centers in which sensing, pre-processing, and decision making are combined into a single unit as shown in Figure 4.4 below. Neural networks are best suited for tasks that need human-like interface and decision-making, rather than sequence automated computation. The most likely applications for neural networks are those involving categorization association reasoning. Despite its roots in human learning mechanisms and widespread expectation that human-like cognitive AI was well within reach, perceptron research was impeded by its inability to grasp even the most basic logic and insurmountable computing complexity. Especially the invention of deep learning (DL), along with the advances in sensing and computational infrastructure allowed ML/DL models to be established [65]. These strategies are based on generalization, which means they deduce the general description of a class based on the behavior of individuals within that class. The expectation of AI has also shifted to a more concentrated perspective of enabling analytics, in which AI technologies serve as a supplement to the domain expertise of human specialists in the factory rather than as a replacement.

IBM developed Deep Blue, a chess-playing robot [9]. The Bayesian structure of Deep Blue allowed its programmers to examine the computer's decision-making afterward and find out why it had chosen to act in a certain way. Deep Blue is an example of explainable AI, meaning that its decisions are transparent and easy to understand for later designers.

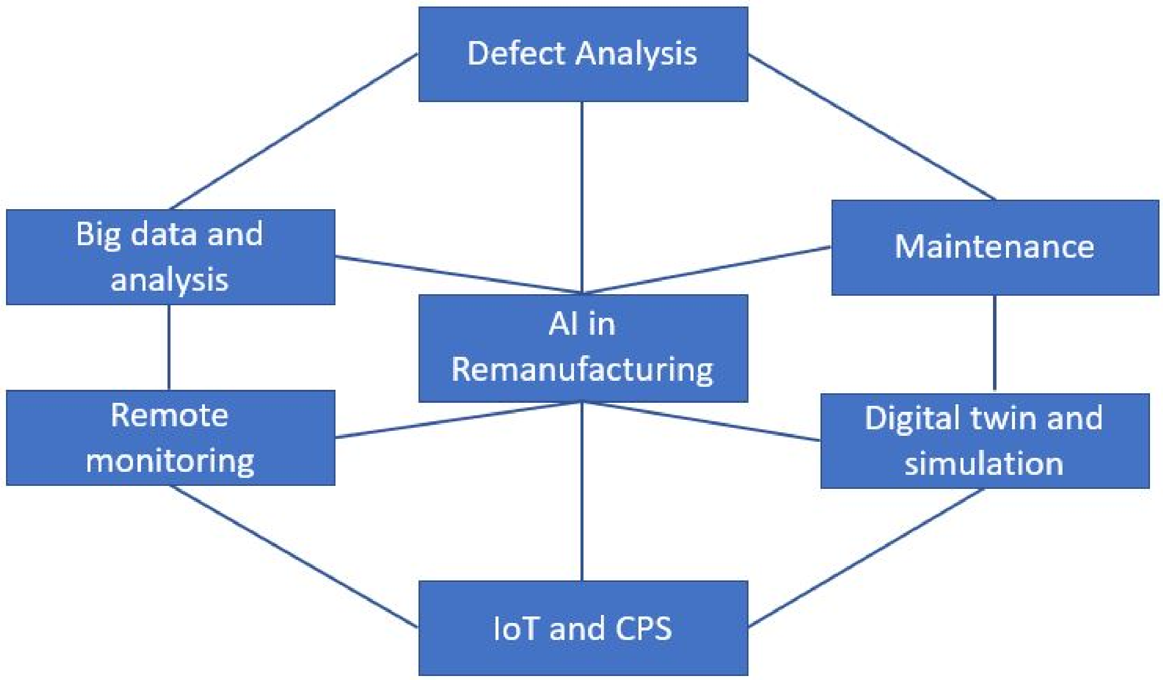

Figure 4.4. How AI in remanufacturing is beneficial is depicted in this figure

Technology, on the other hand, has advanced significantly. Reinforcement Learning involves agents making random decisions in their environment and learning how to choose the best one out of many to achieve their goal and play at a superhuman level. In Reinforcement Learning algorithms like Monte Carlo Tree Search, Policy and Value Networks are combined [9]. The Policy Network is a network that learns to give a specific output by providing a specific input to the game. The policy network's optimal policy determines which actions should be taken in the current state to maximize reward [9, 38, 45, 14]. This policy network technology is used to train the AI model to make decisions using these advancements. The AI is provided with a set of rules on how to determine, how to remanufacture a device based on its condition. Once the machine is trained based on the set of rules provided to the AI, with the help of optimal policy, the AI performs permutations and combinations and provides the most feasible solution. Implementation of these best feasible solutions on digital twins to check their functionality is a the next step. Functional models are then sent to a robot which manages the operations at remanufacturing level in the plant.

4.4. IMPLEMENTING THE DECISIONS

AI techniques provide several important benefits such as robustness, reconfigurability, and responsiveness. After the decision is made, the AI passes down this information to the remanufacturing robot [65]. The remanufacturing robot performs actions accordingly and continues the next step in the process.

4.5. ROBOTS THAT REMANUFACTURE

Disassembly :The core is disassembled by robots to remove the non functioning parts and parts with intermittent faults with the help of data collected in the first two steps (IFDIS and NDT). Cleaning: The next step is cleaning in which the core is internally cleaned using brushes installed on the robot. Cleaning is a challenging and tedious job as the operation has to be precise without damaging the integral components. The other significant advantage of using a robot is cleaning of hazardous components.

Reprocessing: In this step the core can be remanufactured by replacing non functional components. One other possibility in this step is to upgrade the product using superior parts and make it more attractive to the consumers.

Reassembly: After remanufacturing the core the robot reassembles all the components and the remanufactured product is checked for further defects.

The robots which perform the remanufacturing operation are instructed with the following steps. Figure 4.5 briefly illustrates different operations performed by robots in a remanufacturing setup.

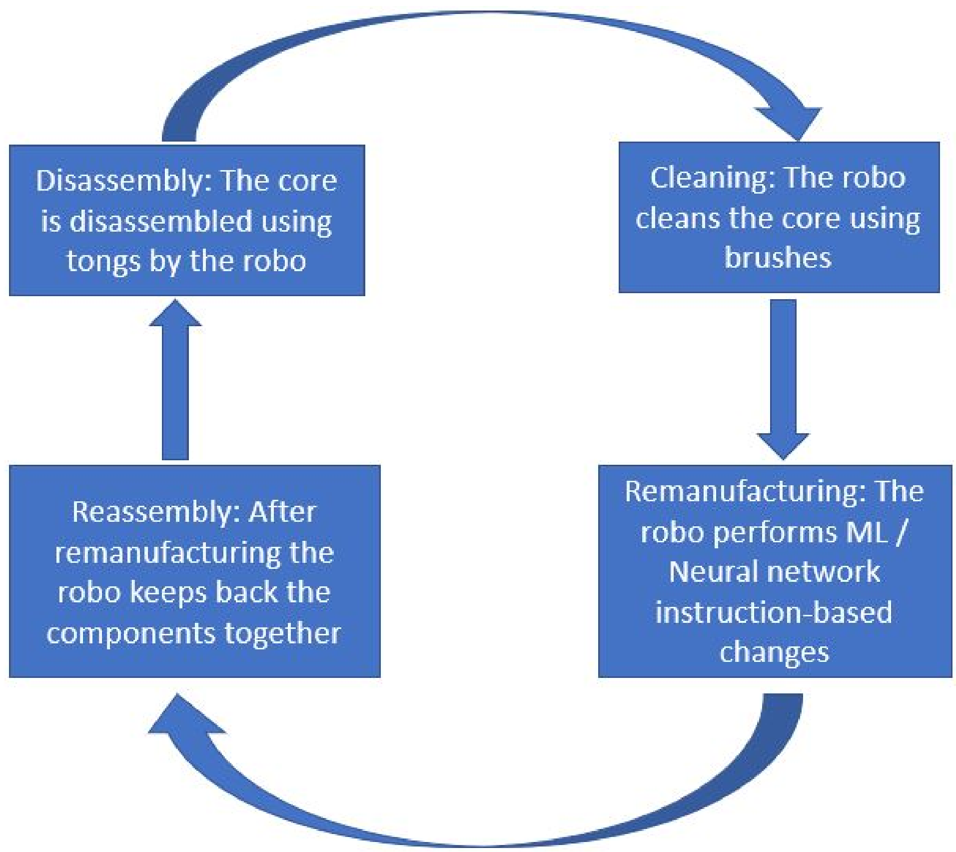

Figure 4.5. The robots are installed in remanufacturing process to make it simpler

4.6. REMOTE MONITORING AND CONTROLLING

The idea of remotely monitoring the process and controlling the robot is to manage distant assembly and disassembly operations at cheaper cost with higher productivity using cyber manufacturing or Cloud manufacturing [59, 60]. This technique is also gaining importance in rescue operations. In distant robotic assembly, keeping track and sensing play a crucial role. The Remote robot manipulations have both real-time monitoring and adaptive control capabilities to be responsive to unpredictable changes. To reach this requirement a system that keeps track of customers and machine tools distantly via a combination of mobile phone network and internet is introduced. To give a tough competition and maintain practicality, an inexpensive web-based method to perform real-time monitoring and distant robot control has a great demand as a substitute to tele-operations that are dependent on allotted communication channels. Real time control is a major issue for any cyber-physical system, capable of web-based remote monitoring and control, distributed process planning, remote machining, and assembly. The Internet is the main source of connection for a cyber physical system. A schematic of remote control manufacturing is presented in Figure 4.6.

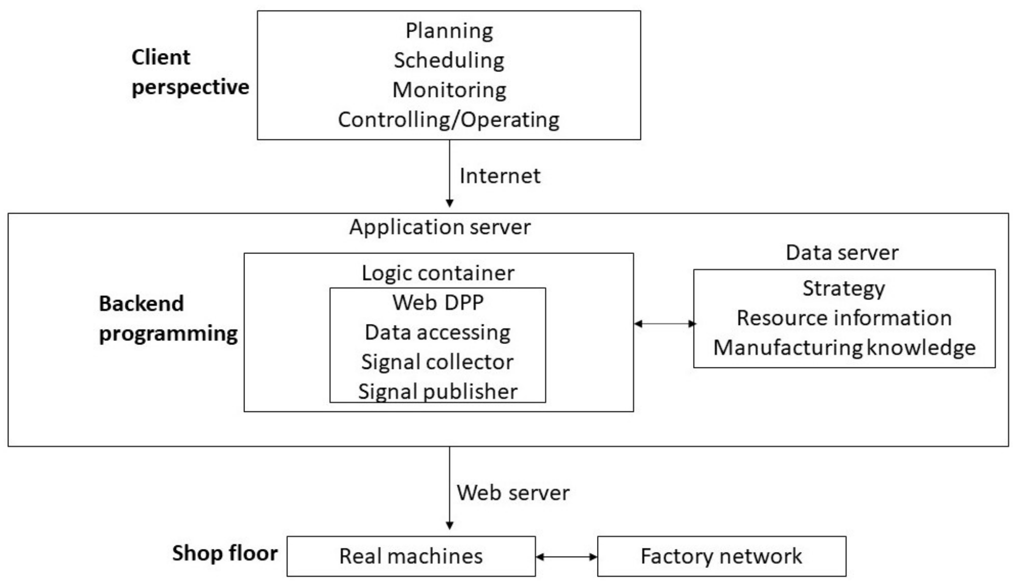

Figure 4.6. The remote remanufaturing setup is shown

The flow chart above gives a brief idea about the concept of remotely controlling the machines. A web server connects the shop floor to the program. From the sensors data is retrieved and stored in the data server , where resource information is stored. The Web DPP makes sure that the data received is up to date. All the stored data , and manufacturing knowledge are stored in the back end. The client can plan, schedule, monitor and operate the machines. All the information and knowledge is stored in the data server. The medium of communication is via the internet [60]. Depending on the distance, if the distance between the operator and the firm is within 12 kms, LoRA [3] can also be used in this case.

4.7. BENEFITS OF REMOTE REMANUFACTURING

Technology is progressing at an alarming rate. Incorporating remote control into the remanufacturing industry is an excellent idea. The facility can be operated by anyone, regardless of the location. This restricts human interaction while dealing with potentially hazardous experiments. The majority of the work in the remanufacturing business is done by machines. The gadgets are now controlled remotely.

In industrial automated manufacturing, remote control provides advantages. Its usage in industrial automated production can boost production efficiency, eliminate manufacturing process faults in real time, decrease costs, and increase the enterprise's survival and development.

It offers cost advantages in industrial automated manufacturing. The use of remote control technology in industrial automated production can effectively strengthen the automation system's functions, improve production efficiency in the industrial production process, and reduce investment costs, thus benefiting the enterprise's management level and economic benefits[51].

Meanwhile, it promotes enterprise management information by transforming an initially difficult automation control program into the integration of basic control systems with definite relevance for the organization's production and development. Remote monitoring and control has numerous social benefits for industrial automated manufacturing.

4.8. WAREHOUSE MANAGEMENT

Depending on the core supplied and the demand, using forecasting the demand is predicted and depending on the requirement the products are remanufactured. If the supply is more than demand, the functional components are retrieved from the core and are sent to the warehouse. When the demand is more, the components stored at the warehouse can be used again for the remanufacturing process. In situations where there is shortage of resources similar to the one during covid-19 crisis mentioned in the introduction , these components are a viable option for manufacturing as they are in pretty good quality.

5. CONCLUSION

Some of the key take away points from the above work are: Smart remanufacturing helps to address the gaps that exist in conventional remanufacturing system. Employing IFDIS sensors for intermittent fault detection helps in identification of defects that are very unstable in the orders of nanoseconds. Complementing IFDIS with non-destructive evaluation in inspection stages helps the remanufacturers in preventing disassembly cost and losses that may incur in disassembly of the core. Including trained AI models in decision making allows in saving time and generate results that are very reliable. Employing digital twins for trail and error tests in restoring the core is an innovative step that enables to be assured of the restoration process without investing on physical prototypes.Finally, remote smart remanufacturing which helps in controlling the operation from any part of the world enables more dexterity and flexibility in terms of remanufacturing a component. It also prevents potential hazardous environments involved in remanufacturing certain electronic devices.

6. FUTURE WORK

There is a huge scope of research in smart remanufacturing. There is a need to figure out how to include various digital twins in a single software and find how various components can be remanufactured under the same plant without any complications. This whole process can be broken down to product specific models.

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