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APPLICATION OF AI TOOL IN PHARMACEUTICAL WAREHOUSE MANAGEMENT: A COMPREHENSIVE REVIEW

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Abstract:
The pharmaceutical industry's ongoing growth and changing supply chain dynamics have prompted the adoption of cutting-edge warehouse optimization solutions. Augmented Reality (AR) is emerging as a transformative technique for addressing the complex difficulties of pharmaceutical warehousing. This review paper dives into the use of augmented reality (AR) technologies in pharmaceutical warehousing, providing an in-depth analysis of its uses, benefits, problems, and future possibilities. The review begins by examining the various applications of AR in pharmaceutical warehousing, including order picking, inventory management and quality control, using case studies to demonstrate how AR improves accuracy, efficiency, and compliance in these critical areas. Additionally, the article examines the ergonomic benefits of AR in minimizing human error and increasing worker productivity. While emphasizing the benefits of AR, the review also notes the difficulties in implementing it in highly regulated pharmaceutical industries. Compliance with regulatory norms, data security problems, and initial financial investments are all thoroughly examined, with insights into potential solutions provided.
Finally, this review summarizes the current state of augmented reality applications in pharmaceutical warehousing, emphasizing the technology's critical role in transforming the industry's logistics landscape. With the help of a case study, it discusses future directions, pointing out opportunities for additional research and development in this promising sector. This review is a vital resource for understanding the possibilities of augmented reality in pharmaceutical storage as pharmaceutical companies seek to optimize their supply chain operations.

Keywords: Augmented reality (AR), Warehousing, Supply Chain, Pharmaceutical Supply Chain, Warehouse Management.

1. INTRODUCTION

Augmented reality (AR) is the real-time integration of digital information with the user's environment. Unlike virtual reality (VR), which generates a completely artificial environment, users of augmented reality (AR) encounter a real-world environment with generated perceptual information superimposed on top of it.
Augmented reality is used to either aesthetically alter natural environments or to give users with supplementary information. The fundamental advantage of AR is that it blends digital and three-dimensional (3D) components with a person's view of the real environment. AR has a wide range of applications, from decision-making to entertainment.
AR provides the user with visual elements, sound, and other sensory information via a device such as a smartphone or glasses. This data is superimposed on the device to create an integrated experience in which digital data influences the user's vision of the actual environment. Overlaid information can be used to supplement or disguise a natural environment[1].

1.1 How does Augmented Reality Works

AR projections can be seen on a variety of devices, including screens, glasses, handheld devices, smartphones, and headsets.

It calculates the position and orientation of the surrounding objects in real life in order for the computer-generated perceptual information to appear correctly. Typically, it goes as given in (Figure 1):

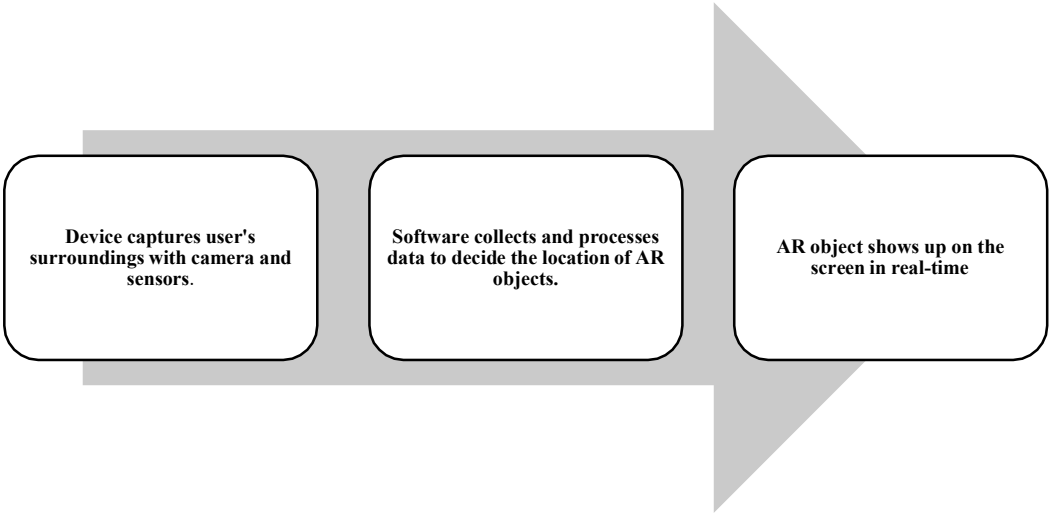

Figure 1: How does AR works

Depending on the type, AR can capture data from the user's environment using depth sensors, accelerometers, cameras, gyroscopes, and light sensors. They calculate the distance between objects, the speed of motion, the direction and angle of the motion, and the overall orientation in space. The data is subsequently analysed in order to display animation in a timely and relevant area[2].

1.2 Warehouse

A warehouse is a structure used to store commodities. Manufacturers, importers, exporters, wholesalers, transportation companies, customs, and others use warehouses. They are often enormous plain buildings located on the edges of cities, towns, or villages[3,4].

Loading docks are commonly used in warehouses to load and unload items from lorries. Warehouses are sometimes designed to load and unload goods directly from railways, airports, or seaports. Cranes and forklifts are frequently used to move items, which are typically placed on ISO standard pallets and then loaded into pallet racks. Raw materials, packing materials, spare parts, components, and completed commodities linked with agriculture, manufacturing, and industry can all be stored. A warehouse is known as a "godown" in India and Hong Kong[5].

1.3 Pharmaceutical Warehousing

Pharmaceutical warehousing is the methodical storing of medicines and medical supplies. The pharmaceutical sector deals with active compounds and volatile substances that need to be stored in controlled settings to be safe and viable. Receiving, storing, and releasing incoming items (including labelling and packaging), as well as releasing and distributing finished products, is the responsibility of a pharmaceutical warehouse. As a result, GMP guidelines are in place to ensure that materials are handled and stored correctly, while relevant documentation is kept[6].

GMP guidelines such as Good Distribution Practice (GDP) and Good Warehousing Practice (GWP) are critical to the quality of pharmaceutical products. A pharmaceutical product of excellent quality is pure, correctly identified, effective, and safe to use. These requirements are followed by pharmaceutical warehousing, which provides secure storage for pharmaceutical products such as medication, prescription drugs, and other pharmaceuticals[7].

1.4 Augmented Reality in Warehousing

Managing a warehouse entail dealing with complex procedures involving a multitude of moving components, including personnel, equipment, orders, and inventory. The majority of organizations still handle their warehouses in an archaic manner. Furthermore, due to existing management methods, supervisors encounter numerous obstacles, such as:

- Manual processes lead to unnecessary delays
- Orders are consistently put together wrongly
- It takes more effort and money to maintain an obsolete system
- Many returns become difficult to organize
- Labelling errors interrupt work and lead to sluggishness

The most effective option for dealing with such challenges is to use augmented reality (AR) in a warehouse. It may appear tough to transition to an automated warehousing system, but it is necessary. Here, an AR app can assist warehouse workers in getting real-time information about the things they are handling and their location within the warehouse via their smartphones or tablets. It is best to seek the assistance of an augmented reality app development company because they have the essential expertise, experience, and resources to produce high-quality AR apps that fit your business requirements. This will also save you time, money, and effort[8].

2. How Augmented Reality works in a Warehouse:

By implementing AR technology in your warehouse, the managers and readily inspect warehouse layouts. By using augmented reality glasses, whether alterations or experiments are conceivable. This is an excel information and making decisions about inventory changes and enhancem AR can be utilized to improve warehouse operations, logistics, and distri levels (Figure 2).

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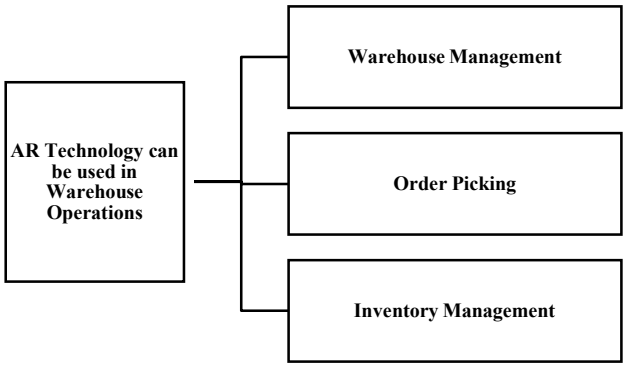

Figure 2: Application of AR Technology in Warehousing

2.1 Warehouse Management:

By boosting the efficiency and precision of various data collection operations, augmented reality simplifies warehouse management. Using barcode scanning systems powered by AR technology on mobile devices, warehouse managers and staff can easily:

- Find products
- Track delivery
- Enhance efficiency
- Streamline procedures

An efficient warehouse management system operation improves customer satisfaction and minimizes backorders and errors.

2.2 Order Picking:

Customers expect speedy delivery of goods and services in today's technology-driven society. As a result, logistics companies are constantly under pressure to optimize their order-picking procedures while maintaining income sources.

AR improves the accuracy and speed of various data capture methods, resulting in more effective warehouse management. It streamlines and improves workflows by utilizing barcode scanning solutions based on smart devices to locate products. A more efficient WMS operation leads in fewer backorders and errors, enhancing customer satisfaction.

2.3 Inventory Management:

One of the most important and difficult components of warehouse management is inventory management. The most time-consuming stage, however, is inventory checking.

Workers used to have to physically dash around the warehouse to see if product needed to be restocked, was ready to ship, or was in good shape. Traditional stocktaking procedures necessitated a lot of paperwork and took a long time. Furthermore, personnel have to go through extensive and costly training in order to generate the appropriate job results.

Because manual inventory management methods are time-consuming and error-prone, several large logistics companies spend considerably in barcode scanning devices.

While these technologies improve stocktaking methods and reduce errors, they are not very versatile and wind up costing a lot of money in hardware. Fortunately, barcode scanning devices can optimize your company's stock taking techniques by incorporating augment management[8].

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stock taking

3. Origin of Augmented Reality:

Despite all the claims about the novelty of this technology, the truth is that a more than 100 years ago.

Augmented reality has its roots in 1901, when Frank L. Baum created Maker[9] which may be regarded the prototype of what we know today as device was made consisting of a big electronic viewfinder that was used to about the people who were looking through it. Morton Hellig, a prominent filmmaker and inventor, built a device called Sensorama a little more than half a century after the invention of that instrument. This device used sound effects such as wind, seat vibrations, and surround sound to mimic a realistic 3D virtual reality experience. Hellig's invention allowed viewers to stroll around San Francisco by viewing film of the area, with extra aspects that made the experience as immersive as possible.

The phrase "augmented reality" was not coined until the 1990s. Boeing engineer Tom Caudell came up with the moniker after being inspired by the equipment used to repair airplane circuits[10].

This technology was called after the engineer Caudell, but its origin is credited to the inventor Louis Rosenberg, who constructed the first practical augmented reality system in 1992. Virtual Fixtures was a system that projected a robotic arm to the user as a guide for accomplishing specified operations[11]. Columbia University advanced the development of this system. There, a tiny group of scientists created the KARMA system. This technology included a virtual reality helmet with an HMD (Head Mounted Display) that projected a three-dimensional image that directed users through the operation of a printer. The goal of this invention is to do away with user manuals.

Since then, augmented reality has progressed dramatically, becoming a technology that is increasingly prominent in our daily life[12].

4. Application of Augmented Reality in Pharmaceutical Supply Chain:

Unlike virtual reality, which provides an immersive experience, augmented reality (AR) overlays digital information onto real-world objects, improving existing information with extra digital data. This implies that a warehouse operator can stroll around a facility and receive real-time warnings about whether equipment needs repair, stock restocking, or when routine maintenance is necessary. This can reduce costs by avoiding downtime.

It can also enable remote maintenance, which has been critical since the outbreak of the global pandemic. This can be important in preventing supply disruptions for a company with multiple sites that may not be close to an engineer.

AR can be a beneficial training tool, offering step-by-step digital instructions for complex, paper-based standard operating procedures (SOPs) that would otherwise need a significant time investment and risk of error.

It can even improve logistical operations by delivering additional information while scanning goods in transit, such as transportation directions and everything essential to rules and compliance[13].

5. How Augmented Reality will benefit Pharmaceutical Warehouse

Augmented Reality can benefit pharmaceutical warehousing in many ways as shown in the (Figure 3).

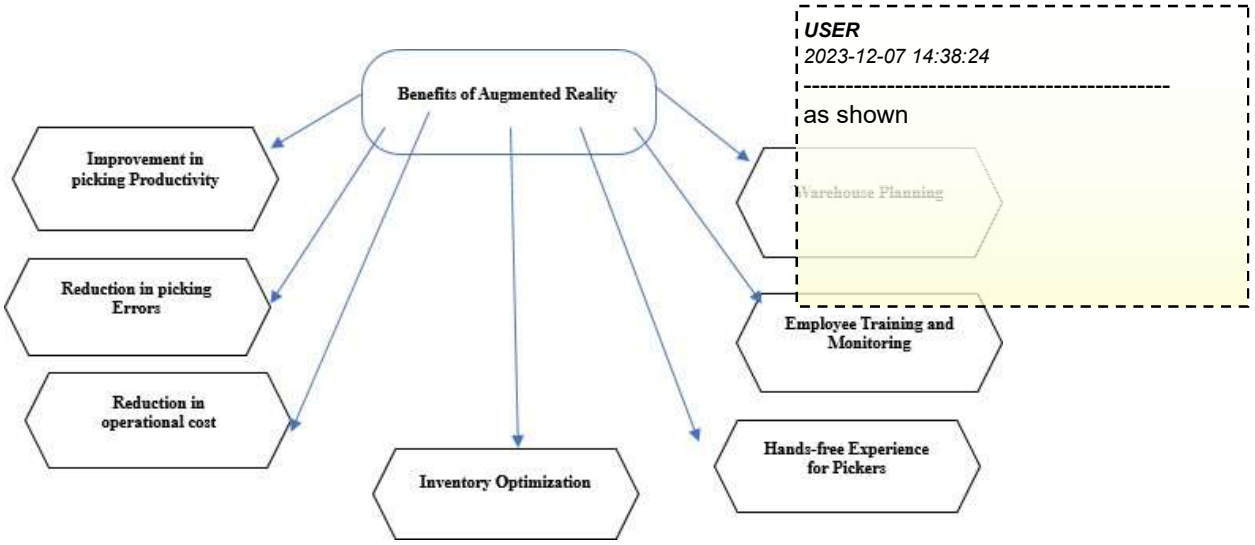

Figure 3: Benefits of Augmented Reality in Pharma warehousing.

Augmented reality has the potential to revolutionize pharmaceutical warehousing by improving efficiency, accuracy, safety, and compliance. Implementing AR technology requires an initial investment but can lead to significant long-term cost savings and operational improvements in the pharmaceutical supply chain.

- **Improvement In Picking Productivity**

Order selecting is one of the most expensive chores; extracting the right product from the right region and in the right quantity is a difficult game. Augmented reality headsets linked to mobile devices help workers through the selecting process, directing them to the best pick places in the least amount of time. AR systems with visual recognition will aid in the identification and confirmation of the goods. When the pick is finished, automation takes over and updates the entire system while also logging the activity.

- **Reduction In Picking Errors**

Warehouse picking is always prone to errors; augmented reality guides the employee through the warehouse to the correct item. As an authentication factor, the smart glass detects the item's barcode.

This reduces the scope of errors and improves operations by shortening processing time and increasing system correctness. Furthermore, automation entirely automates item tracking while preserving accuracy and relevancy based on real-time inventory data feeds, boosting visibility and quality control of your warehouse operations.

- **Inventory Optimization**

Manual inventory management systems are continually challenged and too slow, which is why augmented reality glasses can improve the supply chain by optimizing stock procedures. With these technologies, employees may successfully gaze at various objects while the smart glasses scan and record barcodes. Once the instructions have been recorded, the team can directly follow them and sort goods with speed and accuracy. Inventory optimization can be simplified even further by integrating with existing ERP systems, allowing fresh data to be quickly shared with all staff.

- **Reduction In Operational Costs**

Considering the applications of augmented reality-based collaboration and process improvement in operations and overall process management. The increased precision and efficiency of warehouse operations eliminate all of the extra costs associated with locating, order picking, and tracking, saving numerous manhours and company resources. Warehouse managers may virtually test proposed tactics with augmented reality glasses, ensuring that businesses remain flexible and plan order placement with effective space usage. Warehouse managers can also save time and effort by not having to train new personnel.

- **Hands-Free Experience for Pickers**

With AR systems, employees may select things while keeping their hands free because the list is displayed in the headsets. Furthermore, as each item is selected, the system uses optical barcode readers to confirm the correct item and informs the employee of the next most logical item to select. As a result, the employee can work effectively and efficiently while ensuring system accuracy and minimizing mobility within the warehouse. Being hands-free improves safety and gives significant benefits for lengthier processes.

- **Employee Training and Monitoring**

Virtual introductory and training sessions for new staff can be conducted using augmented reality glasses. This will aid in seamless onboarding and promote team collaboration by acquainting them with corporate operations. This interactive type of instruction allows them to practice several times without delaying or interfering with ongoing procedures. Employees can also be watched in order to increase their awareness and avoid mistakes in warehouse operations.

- **Warehouse Planning**

Warehouse operations must be planned to attain maximum efficiency for any firm to succeed. Warehouse managers can now plan and test their processes using smart glasses and data-driven automation. To put it another way, normal activities need product inspection, allocation, assembly, packaging, dispatching, planning a complete warehouse strategy, and verifying its viability. It also provides value-added services such as sharing insights and monitoring all operations to ensure precise service delivery[14].

6. Future Regulatory Positioning of Augmented Reality in Pharma Supply Chain

The future of augmented reality in the pharmaceutical supply chain looks promising, with continued advancements that enhance efficiency, quality control, and transparency. As technology matures and becomes more integrated into supply chain operations, it will contribute to safer, more reliable, and more efficient pharmaceutical distribution. To better understand this by analysing the case study

describes how XYZ MedTech, a leading medical equipment manufacturer, used augmented reality (AR) technology to improve their warehousing operations.

CASE STUDY - Enhancing Medical Device Warehousing with Augmented Reality

This case study describes how XYZ MedTech, a leading medical equipment manufacturer, used augmented reality (AR) technology to improve their warehousing operations. XYZ MedTech hoped to improve inventory management, eliminate errors, and increase overall productivity in the storage and retrieval of medical items by introducing AR

Client Profile:

Company: XYZ MedTech (a pseudo name)

Industry: Medical Device Manufacturing

Challenge: Improve warehousing efficiency and reduce errors in medical device storage and retrieval.

Solution: Execution of Augmented Reality for warehousing.

XYZ MedTech collaborated with an augmented reality technology supplier to create and execute a bespoke augmented reality solution for their warehousing operations. The following were the primary implementation components:

1. **AR Headsets:** Warehouse workers wore AR headsets that presented relevant information in their field of vision, such as product names, quantities, storage locations, and any specific handling guidelines.
2. **Inventory Tracking System:** An integrated inventory tracking system was built, allowing the AR headsets to access real-time warehouse inventory data.
3. **Spatial Mapping:** The AR system mapped the warehouse's physical layout, providing a digital depiction that assisted personnel in locating the relevant storage areas.

How it Works:

Product Storage: When a new batch of medical devices arrived at the warehouse, employees scanned the products and identified their storage locations using AR headsets. The AR technology then guided them to the appropriate shelves by displaying visual clues and guidance in the headset.

Inventory Retrieval: When it was time to retrieve a medical device, the AR system gave the quickest route to the storage site, decreasing the time spent searching for goods. It also assured that the right item was chosen.

Real-time Updates: Any changes in inventory were quickly reflected in the AR system, ensuring that warehouse personnel always received the most up-to-date information.

Safety Compliance: The AR system contained safety reminders and recommendations to ensure that medical devices were kept and handled in accordance with regulatory standards.

Results:

The implementation of augmented reality in ABC MedTech's warehousing operations yielded several positive outcomes:

Error Reduction: Inventory management errors, such as misplacements and improper product retrievals, were greatly decreased.

Efficiency Gains: Warehouse employees reported a significant boost in productivity as a result of AR-guided operations that optimized their responsibilities.

Real-time Inventory: Real-time inventory tracking increased overall inventory management and minimized the danger of stockouts or overstock situations.

Conclusion:

Augmented reality has improved efficiency, reduced errors, and ensured compliance with safety rules at XYZ MedTech's warehousing operations. By adopting AR technology, the company has not only improved inventory

6.1 Future

Regulatory bodies are likely to issue more precise guidelines in this area as technology improves and becomes more popular. The likely guidelines would include the following points.

- The use of AR in product warehousing must emphasize compliance with current regulations governing pharmaceutical products, logistics, and warehousing from relevant regulatory authorities such as the USFDA, EMA, and others.
- There may be data privacy and security concerns when employing AR technology, especially if the AR system involves capturing or transferring patient information or sensitive data. Data protection regulations will have to be followed.
- Manufacturers and warehousing facilities may be required to validate and document the use of AR technologies in their processes. This may include validation studies, system performance documentation, and maintaining records in line with regulatory criteria.
- Throughout the warehousing process, including any interactions with AR systems, product labelling and traceability must be maintained.
- Regulatory authorities may perform audits or inspections to ensure compliance with applicable requirements. Companies should be ready to demonstrate how they employ AR technology securely and in accordance with these laws.

Finally, businesses should stay up to date on any new guidelines or regulations pertaining to warehousing AR applications and change their processes accordingly.

7. CONCLUSION:

Finally, the use of augmented reality (AR) in pharmaceutical warehousing offers a big step forward in modernizing and optimizing pharmaceutical supply chain operations. This cutting-edge technology provides a slew of benefits that directly improve the efficiency, accuracy, and safety of pharmaceutical storage and distribution.

AR improves warehousing processes by offering warehouse staff with real-time, context-aware information. This includes visual signals, inventory data, and navigation help, all of which lower the risk of errors and improve order fulfilment speed. The capacity to overlay digital information onto the physical world simplifies operations like stock verification, picking, and packing, resulting in lower operational costs and more productivity.

Furthermore, AR helps to maintain product integrity and patient safety by ensuring that temperature-sensitive medications are maintained at suitable temperatures. If environmental conditions differ from set standards, warehouse personnel can receive immediate alerts and visual indicators via AR, allowing for timely corrective steps.

AR integration improves quality assurance and regulatory compliance efforts in an industry where precision, compliance, and traceability are critical. It provides a solid framework for documenting and tracking, making audits and reporting easier.

In summary, AR is a transformative technology for pharmaceutical warehousing, delivering tangible benefits in terms of efficiency, accuracy, and safety. Its implementation not only aligns with industry trends but also positions pharmaceutical companies to meet the evolving demands of a complex and highly regulated marketplace. As technology continues to advance, the pharmaceutical sector should embrace AR as a strategic investment for the future of warehousing operations.

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