NaSTech
JOURNAL OF NATURAL SCIENCES AND TECHNOLOGIES
2023, 2(2), pp. 232-237, DOI: 10.5281/zenodo.10354730

SHUTTLE-BASED STORAGE AND RETRIEVAL SYSTEM 3D MODEL IMPROVEMENT AND DEVELOPMENT

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ABSTRACT

The development of new design solutions for Radioshuttle will increase the storage density of heterogeneous goods, increase the efficiency and productivity of warehouse logistics, reduce the cost of renting warehouse space and reduce the negative impact on the environment, which makes this development extremely relevant and necessary in modern logistics**.**

Authors proposed to improve the designs of the Radioshuttle, through the use of the Mecanum Wheel. To test this, the authors designed a 3D model of a Radioshuttle with a Mecanum Wheel using Autodesk Fusion 360 while maintaining overall dimensions and a 3D model of rack structures.
Keywords: Shuttle, Storage, Retrieval System, Warehouse Management System, Warehouse 4.0.

1. INTRODUCTION

Shuttle-System is an automatic system for storing and moving goods in a warehouse, which is one of the elements of Warehouse 4.0 [1]. This system consists of special robotic devices called Radioshuttle, which move along rails on racks and rise along a vertical axis [2]. Radioshuttles can carry boxes or containers of goods and deliver them to operators at work stations. Using a Radioshuttle in a warehouse can significantly speed up order processing and reduce the time it takes to find and deliver items. It also improves inventory accuracy and reduces the need to manually move items, reducing the risk of errors and increasing efficiency. Radioshuttle can also be integrated with warehouse management systems such as Warehouse Management System (WMS) to streamline processes and increase productivity. The use of automatic systems for storing and moving goods is one of the key elements of Warehouse 4.0 and allows warehouses to become more efficient and competitive.

Using the Shuttle-Based Storage and Retrieval System has several advantages [3]:

- increased productivity: Radioshuttle allows you to automatically move goods in the warehouse, reducing the time it takes to process orders. This allows you to increase the productivity of the warehouse.
- space saving: Radioshuttle can help the warehouse use space efficiently due to its high storage density.
- error reduction: the use of Radioshuttle can reduce the number of errors associated with the manual movement of goods in the warehouse.
- improved inventory accuracy: Radioshuttle can be used with automatic scanning and inventory systems, which improves the accuracy of stock inventory.

However, there are some disadvantages of using the Shattle-Based Storage and Retrieval System:

- limited movement: the Radioshuttle design allows for the movement of goods within one rack; to move the Radioshuttle between the racks, you must use a forklift or a specialized "elevator" for the Radioshuttle;
- high cost: Radioshuttle is an expensive system, so implementation may be prohibitive for some warehouses.
- control complexity: Radioshuttle requires complex software to control it, which can lead to high costs for training and support of personnel.
- limited in product types: Radioshuttle may not be suitable for some types of goods, such as oversized goods or goods with a non-standard shape.

As a result, we can conclude that the development of new design solutions for the Radioshuttle is of great relevance in modern warehouse logistics. Increasing the density of storage of dissimilar goods can significantly reduce renting warehouse space cost and increase storage volumes. This in turn can increase the efficiency of warehouse logistics. Existing Radioshuttle designs have some limitations in the storage density of dissimilar goods, as they are structurally limited by the movement freedom degree within the racks, which limits existing storage methods. However, new design solutions may allow the Radioshuttle to handle a variety of product types, increasing versatility and storage density. In general, the development of new design solutions for Radioshuttle will increase the storage density of heterogeneous goods, increase the efficiency and productivity of warehouse logistics, reduce the cost of renting warehouse space and reduce the negative impact on the environment, which makes this development extremely relevant and necessary in modern logistics.

2. DEVELOPMENT OF A NAVIGATION SYSTEM FOR MAP BUILDING

New technologies introduction in Industry 4.0 concept led to the evolution of Warehouse Management Systems, which made it possible to reduce the response time to goods storage and retrieval, reduce warehouse volumes, while increasing the volume of stored goods, as well as automate all elements of the Warehousing Management System. Many companies are implementing modern automated solutions for Warehouse Management Systems using the Shattle-Based Storage and Retrieval System (SBS/RS). SBS/RS is a system consisting of an array of parallel storage racks in which the Radioshuttle moves [2]. Radioshuttle is an automated robotic platform for moving inside racks with a system for loading, unloading and moving goods. The most common Radioshuttles are shown in Figure 1.

a) b) c)

a) Toyota RadioShuttle [4]; b) Raymond RadioShuttle [5]; c) Rochiev RadioShuttle [6]

Figure 1. Radioshuttle

Warehouse Management Systems based on the use of Radioshuttle allows you to implement two methods of loading and unloading goods, which made it possible to increase the available storage space [7].

First - In - First - Out (FIFO) is the method of loading goods into the warehouse on one side (Input), and unloading on the other (Output) from the opposite side. The method of ensuring the principle of first in, first out consists of next: Radioshuttle sets the goods on the first line, as a result of which, if this product is needed, it will be shipped first. It installs the next product in the second cell, and so on. As a result, goods of the same content and purpose are stored on one line. This method allows you to implement a linear type of storage, an example is shown in Figure 2a. As you can see from the picture, item number one takes up the entire shelving line, and Radioshuttle places it in the first line for shipment.

Last - In - First - Out (LIFO) is the method of loading and unloading goods occurs from two sides (Input / Output). So, filling is carried out taking into account that one half of the rack (lines) will be occupied by one product, and the other half (lines) by another product. As a result, to ensure this loading logic, the following method is used, the product that was last loaded on the rack will be the first to be shipped. This method implementation example is shown in Figure 2b. This method allows you to create a cyclic loading, that is, goods numbered "two" and "one" are placed mirror to each other, as a result of which the goods will be removed in accordance with the proximity to the side of shipment (Input/Output).

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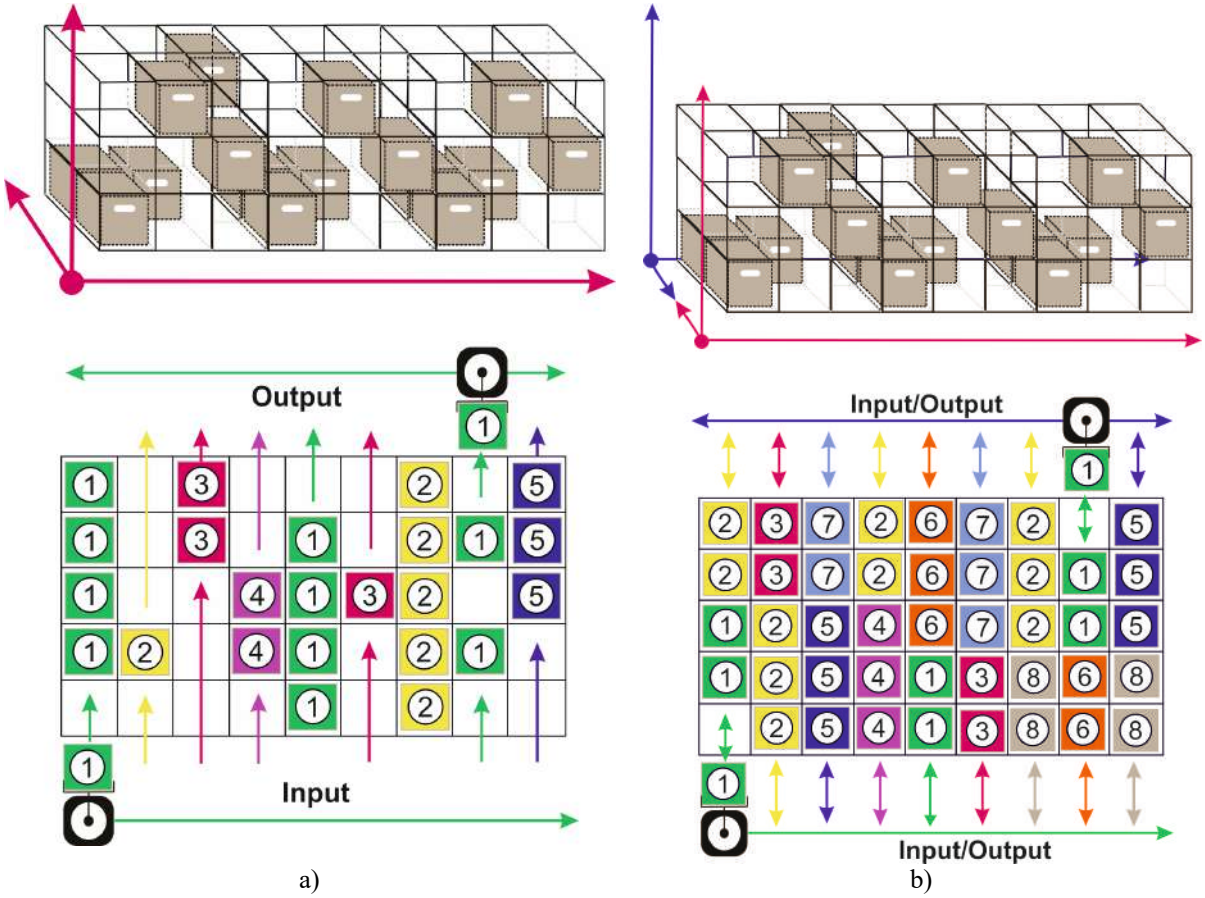


a) b)

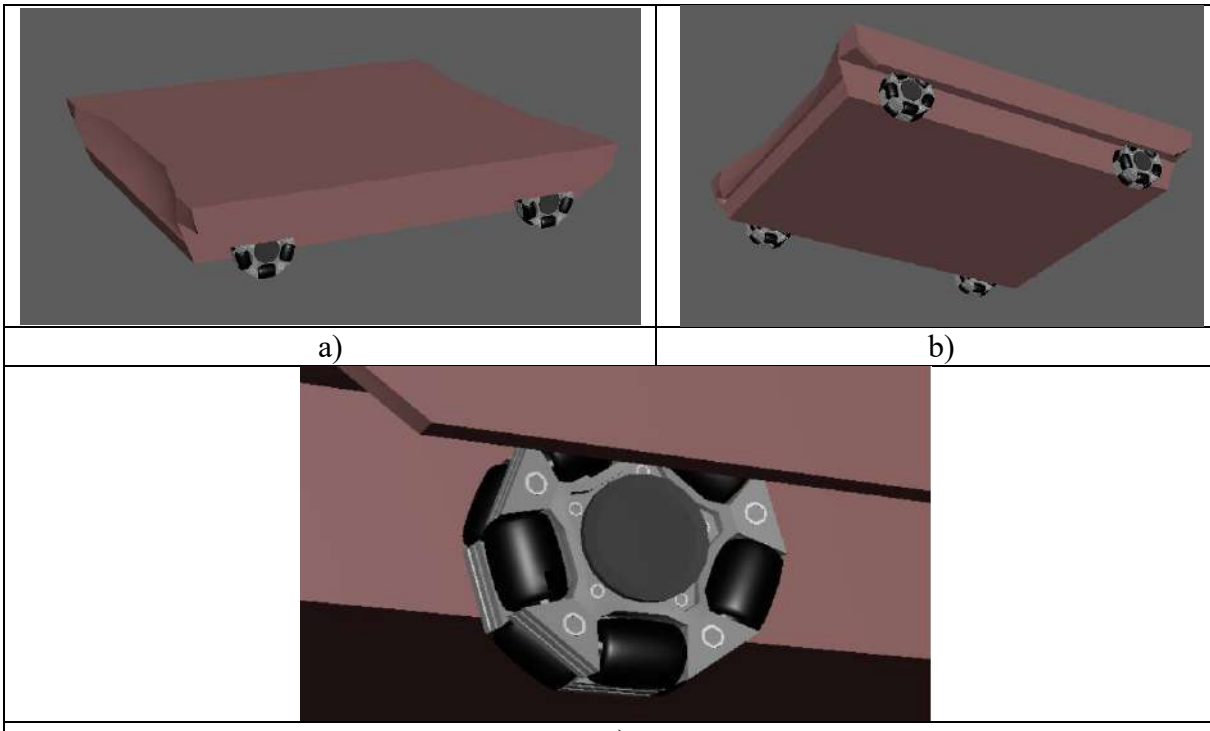
a) control method FIFO; b) control method LIFO

Figure 2.- SBS/RS Systems

As can be seen from Figure 2, the storage density is not high enough to allow maximum storage of two types of goods on one rack line for the LIFO control system and one for the FIFO, and these limitations are due to the design features of the Radioshuttle and rack designs. Based on this, the authors propose to use omnidirectional wheels (Mecanum Wheel) [8], which, compared to the classic wheels used in the Radioshuttle, will provide the following advantages:

- omnidirectional wheels allow Radioshuttle to move in any direction, which increases the maneuverability and flexibility of their work in the warehouse. This is especially important in conditions of limited space, when it is necessary to use the warehouse space as efficiently as possible;
- omnidirectional wheels allow to increase the load capacity of the Radioshuttle, as they provide an even distribution of weight on the wheels and increase the stability of the cargo container;
- omnidirectional wheels improve Radioshuttle handling and allow them to quickly change direction. This is especially important in conditions of high speeds and sharp turns, when it is necessary to ensure the safety of cargo and warehouse employees;
- the use of omnidirectional wheels reduces wear level and increases the life of the Radioshuttle, as the wheels evenly distribute the load on the surface and provide a smoother ride.

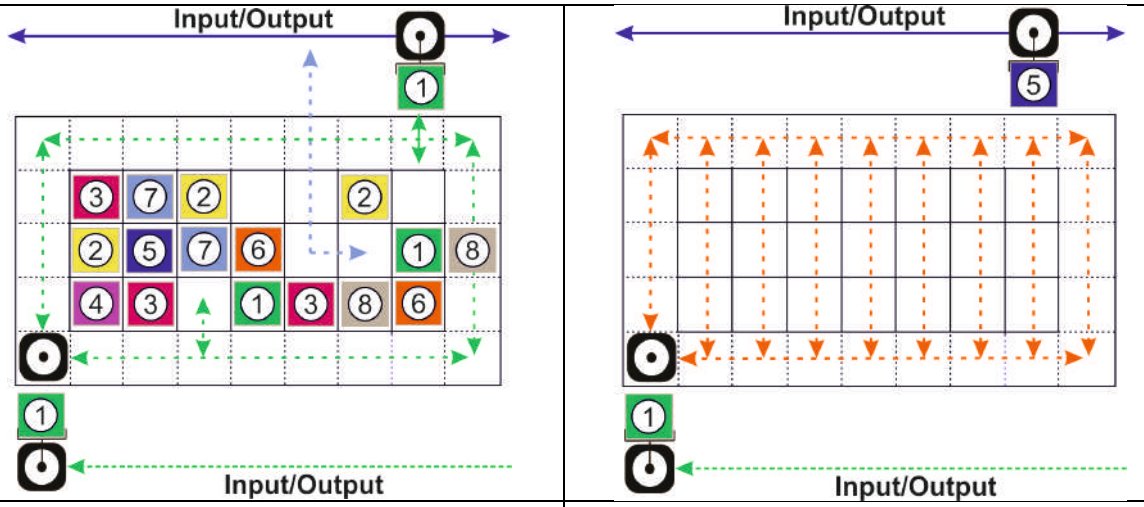
Thus, the use of omnidirectional wheels in the Pallet Shuttle System can significantly improve the maneuverability, load capacity, handling and service life of the Radioshuttle. This will increase the efficiency of the warehouse and ensure safer and more reliable storage and movement of goods. Based on these assumptions, an analysis of the designs of the Toyota RadioShuttle was carried out - as a prototype, on the basis of which a 3D model of the Radioshuttle with Mecanum Wheel was designed using Autodesk Fusion 360 while maintaining overall dimensions [9]. An example of the developed 3D model of the Radioshuttle is shown in Figure 3.



a) Radioshuttle 3D model top view; b) Radioshuttle 3D model bottom view;
c) Mecanum Wheel 3D model

Figure 3. - Radioshuttle 3D Model with Mecanum Wheel using Autodesk Fusion 360.

Based on the features of the Mecanum Wheel, which allow movement in any direction without the need to turn it is proposed to modernize the SBS / RS design, to enable the implementation of the improved Radioshuttle movement not only parallel to the racks, but also perpendicular to the entire plane of the "floor" of storage. To do this, it is necessary to improve the design of the racks, in order to realize the possibility of moving the Radioshuttle both parallel inside and perpendicular to adjacent racks within the same plane. Based on this, the following scheme for moving the improved Radioshuttle based on the Mecanum Wheel is proposed, as shown in Figure 4.



a) controk system ; б) Radioshuttle movement scheme basing on Mecanum Wheel

Figure 4. – Improved Control and Movement Model of the Radioshuttle in the SBS/RS system

As can be seen from Figure 4, the improved control and movement model of the Radioshuttle in the SBS / RS system, unlike the classic solution, allows you to implement the following features:

- movement in any direction: Radioshuttle, can move in any direction without the need to turn. This is especially useful when maneuvering in tight spaces, which will allow you to flexibly move cargos inside the racks for loading / unloading;

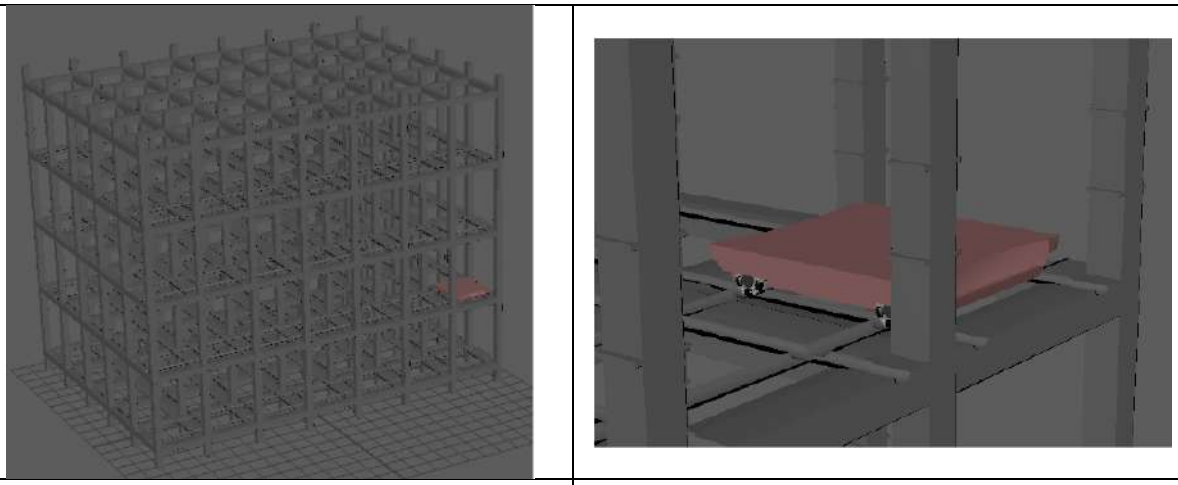
- lateral movement: allows the Radioshuttle to move sideways, which will allow you to move goods in a narrow space, as well as move to adjacent racks, within the same "floor";

- smooth movement: provide smooth movement, which reduces shock and vibration, which can lead to damage to the cargo;

- low noise level: Mecanum wheels have a low noise level when driving, which makes them especially useful for use in buildings where it is necessary to reduce noise levels;

- control: Mecanum wheels are controlled using special software algorithms that allow you to accurately determine the direction of movement and speed.

Using Autodesk Fusion 360, we will design a 3D model of an improved SBS / RS system, taking into account the solutions proposed above. A fragment of the developed 3D model of the SBS/RS system is shown in Figure 5.



a) b)

a) SBS/RS system 3D model general view; b) Radioshuttle 3D model inside the rack

Figure 5. - SBS/RS Improved System 3D Model.

Based on the above improvements of the SBS/RS system, the authors have developed the following method of loading and unloading cargos with an attempt to minimize movements [9]. To do this, it is proposed to use the method of combinatorics and group theory. In particular, it is planned to use a group of permutations, which allows you to change the location of goods in the cells in the warehouse of the SBS / RS system. For each cell, we will determine its coordinates $M_n(x_i, y_i)$, as well as the contents of the cell, and then carry out the loading according to the following algorithm:

- we find a free cell, which is closest to the desired position in the warehouse;
- with the help of Radioshuttle we move to this cell;
- if it is necessary, we move other cargos to free the desired cell;
- put the cargo in the desired cell.

To extract the cargo, we will perform the following actions:

- find the cell in which the desired cargo is located;
- with the help of Radioshuttle we move to this cell;
- remove the cargo from the cell;
- if it is necessary, we move other cargos to fill the vacated cell [10].

During developing a method for loading and unloading cargos in an SBS/RS system using Radioshuttle, mathematical models can be used to determine the best order for moving cargos with a minimum investment of time and energy. To do this, you can apply optimization algorithms that are based on finding the shortest path or on routing. For example, Dijkstra's algorithm can be used to determine the shortest path between cargo cells or the A* algorithm can be used to route a Radioshuttle between cells. You can also use combinatorics to determine the best sequence for moving cargos. For example, you can break a task into subtasks and determine the best order to complete those tasks. In this way, the need to move the cargos in the opposite direction can be avoided and the overall time of loading and unloading the weights can be reduced. In addition, machine learning methods can be applied so that the system automatically determines the optimal sequence of actions depending on the specific

working conditions. For example, you can use neural networks to train a system to make optimal decisions based on a large amount of data about the movement of goods in the system [11].

Thus, the use of mathematical models, optimization algorithms, combinatorics and machine learning methods can help develop an efficient system for loading and retrieving cargos in an advanced SBS / RS system using Radioshuttle.

3. CONCLUSION

As a result of the research, it was proposed to improve the designs of the Radioshuttle, through the use of the Mecanum Wheel. To test this assumption, the authors designed a 3D model of a Radioshuttle with a Mecanum Wheel using Autodesk Fusion 360 while maintaining overall dimensions and a 3D model of rack structures. A special feature of the developed rack design is the implementation of the possibility of moving the Radioshuttle not only parallel to the racks, but also perpendicularly along the entire plane of the storage “floor”, which will allow you to move goods in a narrow space, as well as move to neighboring racks, within one “floor”. In general, the development of new design solutions for SBS / RS systems will increase the storage density of heterogeneous goods, increase the efficiency and productivity of warehouse logistics, reduce the cost of renting warehouse space and reduce the time for unloading / installing goods, which makes this development extremely relevant and necessary in modern logistics within Warehousing 4.0.

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