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REGULAR ARTICLE

Power-Optimized Information Systems for Mobile Robotics in Physical Processes

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This paper explores the integration of Autonomous Mobile Robots (AMRs) in industrial settings, revolutionizing task scheduling. Focused on minimizing operational completion time, it delves into the physical processes within information systems. The study emphasizes the hardware, software, and robotics intersection, providing an overview of key AMR components and their role in task execution. Mobility, sensing capabilities, and interaction with the environment are crucial considerations for effective scheduling algorithms. Real-time data acquisition through AMR-mounted sensors informs scheduling algorithms, emphasizing the importance of accurate information. Data storage's pivotal role in maintaining efficiency is highlighted, stressing quick retrieval for rapid decision-making. The study examines central processing units (CPU) and arithmetic logic units (ALU) roles in processing scheduling algorithms, emphasizing the need for computational power. Communication processes, network communication, and data transmission reliability are paramount for coordinating multiple AMRs. Power supply and cooling systems' significance in sustaining AMR infrastructure is explored, addressing electrical power provision and environmental controls. Physical security measures and maintenance processes, including hardware and software updates, ensure peak AMR efficiency. In conclusion, this research illuminates the integral physical processes within information systems for AMR-based task scheduling, offering insights for enhanced efficiency in diverse industrial settings.

Keywords: Information System, Optimization of Energy, Autonomous Mobile Robots, Best First Search

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1. INTRODUCTION

The rise of Autonomous Mobile Robots (AMRs) in industrial and logistical domains has brought about a transformative shift. This study delves into the interplay of hardware, software, and robotics, focusing on AMRs' role in revolutionizing task scheduling to minimize operational completion time. Highlighting the significance of AMRs' mobility and sensing capabilities, the research emphasizes leveraging these attributes for efficient scheduling algorithms. Examining data input and processing stages, real-time sensor data acquisition is explored, underscoring its crucial role in optimizing task sequences. The study delves into the computational power of CPUs and ALUs, emphasizing their importance in processing intricate scheduling algorithms. Communication processes take center stage, addressing network communication speed and reliability as pivotal factors influencing scheduling algorithm effectiveness. Infrastructure considerations, encompassing power supply, cooling, and security measures, are scrutinized for optimal hardware conditions. The exploration concludes with a focus on maintenance, highlighting its critical role in sustaining peak AMR efficiency and minimizing operational completion time. In essence, the research provides a holistic understanding of physical processes within information systems, guiding organizations to optimize components and enhance efficiency across diverse industrial and logistical settings.

2. LITERATURE SURVEY

In recent years, the integration of Autonomous Mobile Robots (AMRs) in industrial and logistical settings

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has emerged as a transformative force, reshaping conventional task-scheduling processes. This research, as reflected in references [1, 2], delves into the intricate physical processes within information systems, seeking to minimize operational completion time through the strategic utilization of AMRs. The exploration spans the intersection of hardware, software, and robotics, emphasizing the role of mobility, sensing capabilities, and environmental interaction in developing effective scheduling algorithms [3, 4]. By providing an in-depth overview of key AMR components and their task execution functions, the study sets the stage for optimizing these robots' inherent capabilities to achieve operational efficiency and productivity improvements in diverse industrial and logistical scenarios.

As detailed in references [5, 6], the research extends to the data input and processing stages of task scheduling. Real-time data acquisition through sensors mounted on AMRs captures information about the surroundings and task statuses, underscoring the significance of accurate and timely data for optimizing task sequences. Furthermore, references [7, 8] highlight the pivotal role of computational power, examining the functions of central processing units (CPUs) and arithmetic logic units (ALUs) in processing complex scheduling algorithms. The study emphasizes the need for robust communication processes, as elucidated in references [9, 10], to coordinate multiple AMRs and ensure seamless task execution. Additionally, references [11, 12] underscore the importance of power supply, cooling systems, and security measures in sustaining the physical infrastructure supporting AMRs, safeguarding against unauthorized access, and preventing potential physical damage. Finally, reference [13] highlights the significance of routine maintenance and software updates in ensuring peak AMR efficiency, contributing to the overarching goal of minimizing operational completion time. Collectively, this research offers a comprehensive understanding of the intricate physical processes within information systems that are instrumental in addressing task scheduling challenges through AMRs.

3. PHYSICAL PROCESS INFORMATION SYSTEM FOR ENERGY MANAGEMENT

The Pyramid model offers a widely accepted framework for categorizing information systems, presenting a hierarchical structure resembling a pyramid with three distinct levels: operational, middle management, and executive/senior. Illustrated in Fig. 1, each level corresponds to specific roles and functions. The operational level involves day-to-day tasks, the middle management level focuses on coordination and supervision, and the executive level is dedicated to strategic decision-making and leadership responsibilities. This model systematically classifies information systems, providing a clear and intuitive depiction of their diverse roles within different organizational hierarchy levels.

3.1 Operational Level

Operations managers play a critical role in daily business activities, making routine decisions like assessing the need for additional raw materials in the upcoming week. At the operational level, Transaction Processing Systems (TPS) and Process Control Systems (PCS) are utilized to facilitate these tasks

Transaction Processing System (TPS): Transactional Processing Systems (TPS) serve as vital tools for operational managers, tracking and managing automated or semi-automated transactions within an organization. They validate, sort, and update data from various interactions, enabling decision-making through the generation of summary reports.

Process Control Systems (PCS): Process Control Systems (PCS) are vital at the operational level, optimizing physical processes, particularly in areas like food preparation. PCS evaluates quality using sensor-derived data, empowering operational managers to enhance business processes. They find application in assembly lines for streamlined manufacturing and quality control

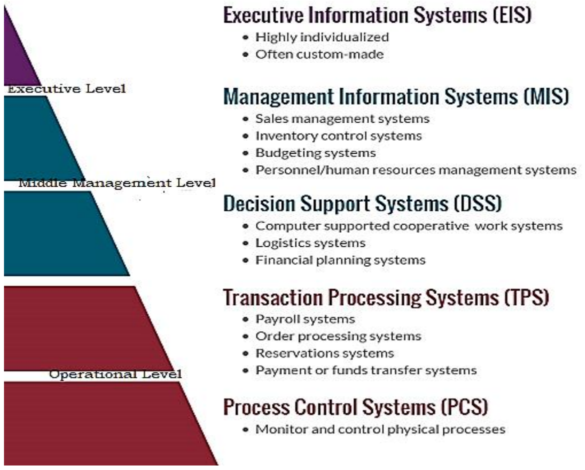

Fig. 1 – Pyramid Model for Information System

3.2 Process Control System (PCS)

Process control systems typically have various components that work together to control and regulate a process. These components include sensors, controllers, final control elements, and feedback elements are shown in Fig 2.

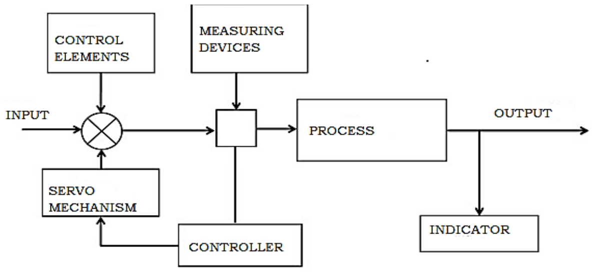

Fig. 2 – Components in Process Control System

3.3 Monitor and Control Physical Processes through AMRs

The synergy between Autonomous Mobile Robots (AMRs) and the Internet of Things (IoT) enhances AMRs' autonomy and connectivity. Through real-time communication with sensors and devices, AMRs utilize IoT to gather and share information, improving decision-making and task execution efficiency. This integration enables features like remote monitoring, predictive maintenance, and data-driven insights, contributing to intelligent and responsive robotic systems. In interconnected environments, AMRs navigate and collaborate more effectively, enhancing overall performance. The AMR prototype features an Arduino UNO as its controller, as depicted in Figures 3 to 7.

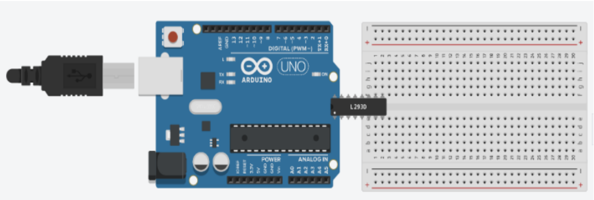

Fig. 3 – Arduino UNO, motor driver & Breadboard

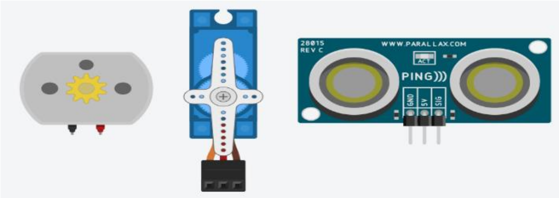

Fig. 4 – DC Motor, Servo Motor & Ultrasonic Sensor

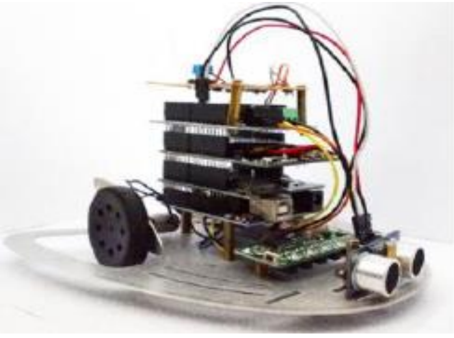

Fig. 5 – Prototype Assembly

Fig. 6 – Line Senor, Wi-Fi Module & LiPo Battery

Fig. 7 – Autonomous Mobile Robots at Industry 4.0

4. PHYSICAL PROCESS THROUGH AMRS

Task scheduling with Autonomous Mobile Robots (AMRs) optimizes task sequences for operational efficiency. AMRs, equipped with advanced navigation and sensing, adapt dynamically to changing conditions, prioritizing tasks in real time. The process aims to minimize operational completion time, utilizing algorithms considering factors like task urgency, resource availability, and optimal routes. The chosen Best-First Heuristic Algorithm prioritizes tasks efficiently, aligning with AMRs' real-time decision-making. This approach, focusing on dynamic scheduling, enhances operational efficiency and productivity in industrial and logistical settings.

4.1 Energy Management Model

This section presents a nonlinear Mixed Integer Programming (MIP) model centered around Autonomous Mobile Robots (AMRs) and job travel times, aiming to minimize Operational Completion Time (OCT) through the implementation of a First Search algorithm. FMS scheduling problems from Bilge and Ulusoy's model (1995) are considered, integrating key parameters and their effects. The scheduling process entails generating schedules for jobs moving through machines and utilizing tools across multiple machines. The objective is to minimize the OCT of all jobs, as represented by the MIP formulation:

Min $Z = Oij$
S.T

$$Z \geq C_{Nj} + Nj \text{ for all } j \text{ €} J$$

$$C_i - C_{i-1} \geq P_i + r_{ai} \text{ for all } I,\ i-1 \text{ € } I_j,\ j \text{ € } J$$

$$C_{Nj+1} \geq P_{Nj+1} + ta_{Nj+1} \text{ for all, } j \text{ € } J$$

$$Ci \neq C_h\ i \neq h, \text{ for all } i, h, \text{ € } Rk,\ k \text{ € } k$$

Operations Completions Time (OCT) $= Oij = Tij + Pij$

Variables

q_{rs} = {1= if Cr is less than Cs where r and s are operations of different jobs
= { 0 or else

β rs = {1= if Cr is less than Cs where r and s are operaations of different jobs’ s,r,s, € Rk
= { 0 or else

X_{hi} = { 1= if AMRs is assigned for the deadheading trip between trip h and i
= { 0 or else

X_{oi}= { 1= if AMRs is starts from L/U to trip i as its first operations
= { 0 or else

X_{ho} = { 1= if AMRs returns to the L/U station after completing trip h as its last assignment
= { 0 or else

C_i = OCT, T_{ai} = AMRs loaded trip CT.

The design of a flexible environment through the best first search indexing of machines and tools remains unclear due to the known routing of each job. The primary objective is to minimize the Operational Completion Time (OCT) for all jobs, utilizing a Mixed Integer Programming (MIP) formulation in a nonlinear fashion.

4.2 Best First Search Algorithm

In Heuristic Search, Best-First Search (BFS) employs an evaluation function to explore the most promising contiguous node, prioritizing paths based on heuristic scores

Algorithms

1. Begin the process.
2. Initialize an open list with a single node.
3. Check if the open list is empty; if so, return and exit.
4. Extract a node, denoted as n, from the open list and move it to the closed list to avoid redundancy.
5. Expand node n by generating its successor nodes.
6. Examine each successor node to determine if it corresponds to the goal state. If a goal state is reached, stop the algorithm; otherwise, proceed to the next step.
7. Apply the evaluation function (f) to the successor node. Check if the node has been previously included in either the open or closed list. If not, add it to the open list.
8. Create a loop to repeat the algorithm from step 2.
9. Exit the algorithm.

4.3 AMRs Schedule Through BFS

To develop an expert system for scheduling Autonomous Mobile Robots (AMRs) using the Best First Search Technique, the focus is on the 1_5 configuration. This implies consideration of the 1st layout and the 5th task. The system will be designed to optimize the scheduling of AMRs based on the Best First Search algorithm, with specific attention to the 1_5 scenario

Step 1: Generate a spanning tree with open and closed nodes are shown in Tables 1 & 2.

Table 1 – Open Nodes

Node	Node Open
S	Start{S}
1	Open{1,3,5,7,10,13}
2	Open{3,5,7,10,13,2}
3	Open{ 5,7,10,13,2, 4}
4	Open{ 7,10,13,2, 4, 6}
5	Open{ 10,13,2, 4, 6,8}
6	Open{ 13,2, 4, 6,8,11}
7	Open{ 2, 4, 6,8, 11,14,9}
8	Open{ 2, 4, 6,11,14,9}}
9	Open{ 2, 4, 6,11,14,12}
10	Open{ 2, 4, 6,14,12}
11	Open{ 2, 4, 6,14,15}
12	Open{ 2, 4, 6,15}
13	Open{ 2,4, 6}
14	Open{4,6}
15	Open{6}
G	Goal

Table 2 – Close Nodes

Node	Node Close
S	Close {S}
1	Close {S,1}
2	Close {S,1,3}
3	Close {S,1,3,5}
4	Close {S,1,3,5,7}
5	Close {S,1,3,5,7,10}
6	Close {S,1,3,5,7,10,13}
7	Close {S,1,3,5,7,10,13,8}
8	Close {S,1,3,5,7,10,13,8,9}
9	Close {S,1,3,5,7,10,13,8,9,11}
10	Close {S,1,3,5,7,10,13,8,9,11,12}
11	Close {S,1,3,5,7,10,13,8,9,11,12,14}
12	Close {S,1,3,5,7,10,13,8,9,11,12,14,15}
13	Close {S,1,3,5,7,10,13,8,9,11,12,14,15,2}
14	Close {S,1,3,5,7,10,13,8,9,11,12,14,15,2,4}
15	Close {S,1,3,5,7,10,13,8,9,11,12,14,15,2,4,6}
G	Goal(G)

Step 2: Create nodes corresponding to individual tasks and assign heuristic function values to each node.

Step 3: The sequence of operations according to the algorithm can be derived from tables 1 and 2.

{1-3-5-7-10-13-8-9-11-12-14-15-2-4-6}

Step4: The identification of the maximum operational completion time in the given arrangement is determined through two Autonomous Mobile Robots (AMRs) with distinct constraints, as outlined in the table below

Step 5: The initial assignment of both vehicles is done randomly for the first two operations. Starting from the third operation onward, a heuristic is employed to choose one of the two vehicles.

Node	Mac. No	Veh. No	Veh Prev Loc	Prev opes Mach No	Veh ode trip	Proc time	OCT
1_1	M_1	AMR_1	LU	LU	6	10	16
2_1	M_2	AMR_2	LU	LU	8	10	18

Step 6: Determine the vehicle's previous location and its Ready Time (VRT).

AMR_1 @ M_1, AMR_2 @M_2

Step 7: Vehicle assignment for the next Operation

Next Node: 3_1: Machine M1
Vehicle Locations AMR1 @ M_1, AMR2@ M - 2
Next Operation Machine No: M_1
Previous Operation Machine No: L_U
AMR1 Travel Time: M_1 to L_U to M_1
AMR1 Initially with 6 minutes of travel time
6+M_1 to L/U travel time + L/U to M_1
=6+12+6= 24 Travel time of AMR_1 for Task 3_1
AMR2 Travel Time : M_2 to L_U to M_1
AMR2 Initially with 8 minutes of travel time
8+M_2 to L/U travel time + L/U to M_1
=8+10+6= 24 Travel time of AMR_2 for Task 3_1

Note: If Both vehicle travel times are the same select the first vehicle as a priority so for the next operation So, for node 3_1 AMRs are 1

Next Node: 4_1: Machine No: M2
Vehicle Locations AMR1 @ M_1, AMR2@ M - 2
Next Operation Machine No: M_2
Previous Operation Machine No: L_U

AMR1 Travel Time : M_1 to L_U to M_2
AMR1 Initially with 24 minutes of travel time
24+M_1 to L/U travel time + L/U to M_1
=24+12+6=42 Travel time of AMR_1 for Task 4_1
AMR2 Travel Time : M_2 to L_U to M_1
AMR2 Initially with 8 minutes of travel time
8+M_2 to L/U travel time + L/U to M_2
=8+10+8= 26 Travel time of AMR_2 for Task 3_1
So, for node 4_1 AMRs is 2 with travel time 26.

Next Node: 5_1: Machine M2
Vehicle Locations AMR1 @ M_1, AMR2@ M - 2
Next Operation Machine No: M_1
Previous Operation Machine No: L/U
AMR1 Travel Time : M_1 to L_U to M_2
AMR1 Initially with 24 minutes of travel time
24+M_1 to L/U travel time + L/U to M_1
=24+12+6=42 Travel time of AMR_1 for Task 5_1
AMR2 Travel Time : M_2 to L_U to M_1
AMR2 Initially with 26 minutes of travel time
26+M_2 to L/U travel time + L/U to M_2
=26+10+6= 42 Travel time of AMR_2 for Task 5_1
So, for node 5_1 AMRs is 1 with a travel time of 42

Next Node: 6_1: Machine M1
Vehicle Locations AMR1 @ M_1, AMR2@ M - 2
Next Operation Machine No: M_1
Previous Operation Machine No: L_U
AMR1 Travel Time : M_1 to L_U to M_2
AMR1 Initially with 42 minutes of travel time
42+M1 to L/U travel time + L/U to M_1
=42+12+6=60 Travel time of AMR_1 for Task 6_1
AMR2 Travel Time : M_2 to L_U to M_1
AMR2 Initially with 26 minutes of travel time
26+M_2 to L/U travel time + L/U to M_1
=26+10+6= 42 Travel time of AMR_2 for Task 6_1
So, for node 6_1 AMRs is 2 with a travel time of 42

Next Node: 4_2: Machine No: M3
Vehicle Locations AMR1 @ M_1, AMR2@ M - 1
Next Operation Machine No: M_3
Previous Operation Machine No: M2
AMR1 Travel Time : M_1 to L_U to M_2
AMR1 Initially with 42 minutes of travel time
42+M_1 to M2 travel time + M2 to M_3
=42+6+6=54 Travel time of AMR_1 for Task 4_2
AMR2 Travel Time : M_1 to M2 to M_3
AMR2 Initially with 42 minutes of travel time
42+M_1 to M2 travel time + M_2 to M_3
=42+6+6= 54 Travel time of AMR_2 for Task 4_2
So, for node 4_2 AMRs is 1 with a travel time of 54

Next Node: 4_3: Machine No: M4
Vehicle Locations AMR1 @ M_3, AMR2@ M - 1
Previous Operation Machine No: M_3
AMR1 Travel Time : M_3 to M_3 to M_4
AMR1 Initially with 54 minutes of travel time
54+M_3 to M_3 travel time + M_3 to M_4
=54+0+6=60 Travel time of AMR_1 for Task 4_3
AMR2 Travel Time : M_1 to M3 to M_4
AMR2 Initially with 42 minutes of travel time
42+M_1 to M3travel time + M_3 to M_4
=52+8+6= 66 Travel time of AMR_2 for Task 4_3
So, for node 4_3 AMRs is 1 with a travel time of 60

Next Node: 5_2:
For node 5_2 AMRs is 2 with travel time 58

Next Node: 5_3:
for node 5_3 AMRs is 2 with travel time 87

Next Node: 6_2:
for node 6_2 AMRs is 1 with a travel time of 73

Next Node: 6_3:
for node 6_3 AMRs is 1 with a travel time of 112

Next Node: 1_2:
for node 1_2 AMRs is 2 with travel time 107

Next Node: 2_2:
for node 2_2 AMRs is 2 with travel time 125

Next Node: 3_2:
for node 3_2 AMRs is 1 with a travel time of 128

After completing a loaded trip, the vehicle is prepared for its next assignment, and the Vehicle Lead Time (VLT) of the current trip is then considered as the Vehicle Ready Time (VRT) for the subsequent trip. This heuristic iterates through this process for both Automated Guided Vehicles (AGVs) at each operation, ultimately assigning the vehicle with the lower VLT. Table 3 provides a numerical representation of the outlined steps and The operations schedule depicted in Fig. 8 & 9 is visually represented through the Gantt chart.

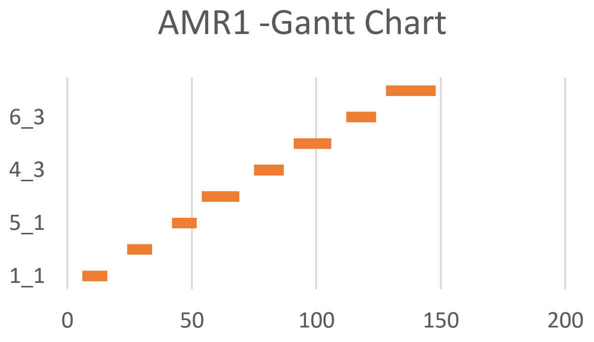

Fig. 8 – AMRs 1 Idle time and Working time

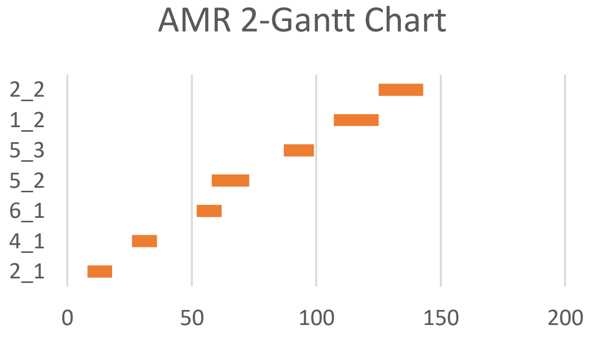

Fig. 9 – AMRs 2 Idle time and Working time

Table 3 – The determination of Vehicle Lead Time (VLT) for assigning a vehicle to a specific operation involves a calculated process

Node	Mac.No	Veh.No	Veh Lod Trip	Proc time	Make span
1_1	M_1	V_1	6	10	16
2_1	M_2	V_2	8	10	18
3_1	M_1	V_1	24	10	34
4_1	M_2	V_2	26	10	36
5_1	M_1	V_1	42	10	52
6_1	M_1	V_2	52	10	62
4_2	M_3	V_1	54	15	69
4_3	M_4	V_1	75	12	87
5_2	M_2	V_2	58	15	73

5_3	M_4	V_2	87	12	99
6_2	M_2	V_1	91	15	106
6_3	M_3	V_1	112	12	124
1_2	M_4	V_2	107	18	125
2_2	M_4	V_2	125	18	143
3_2	M_3	V_1	128	20	148

The operations schedule depicted in Fig. 8 is visually represented through the Gantt chart.

5. CONCLUSION

This study delved into the physical processes within information systems to address task scheduling challenges through the minimization of operational completion time, employing Autonomous Mobile Robots (AMRs) and the Best-First Search (BFS) heuristic algorithm. The integration of AMRs and BFS algorithm showcased the potential for enhanced efficiency in diverse industrial and logistical settings when compared with FCFS % of energy deviation is 10.34, SPT % of energy deviation is 14.99 and LPT % of energy deviation is 11.69 for configuration 1. By leveraging the physical aspects, data processing, communication, and security measures, organizations can develop robust systems. Future research could explore advanced algorithms and technologies, refining the coordination between AMRs, and addressing scalability challenges for broader applications. Additionally, investigating the environmental impact and sustainability aspects of deploying AMRs in various industries could pave the way for more eco-friendly solutions. As technology evolves, the ongoing exploration of novel strategies and advancements in hardware components can further optimize task-scheduling processes and propel the integration of AMRs into mainstream industrial practices.

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Енергооптимізовані інформаційні системи для мобільної робототехніки у фізичних процесах

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У цій статті досліджується інтеграція автономних мобільних роботів (AMR) у промислові умови, що революціонізує планування завдань. Орієнтований на мінімізацію часу завершення операцій, він заглиблюється у фізичні процеси в інформаційних системах. Дослідження наголошує на перетині апаратного, програмного та робототехнічного забезпечення, надаючи огляд ключових компонентів AMR та їх ролі у виконанні завдань. Мобільність, можливості зондування та взаємодія з навколишнім середовищем є вирішальними факторами для ефективних алгоритмів планування. Збір даних у режимі реального часу за допомогою встановлених датчиків AMR інформує алгоритми планування, підкреслюючи важливість точної інформації. Підкреслюється ключова роль зберігання даних у підтримці ефективності, наголошується на швидкому пошуку для швидкого прийняття рішень. Дослідження розглядає роль центральних процесорів (CPU) і арифметико-логічних пристроїв (ALU) в алгоритмах планування обробки, підкреслюючи потребу в обчислювальній потужності. Комунікаційні процеси, мережевий зв'язок і надійність передачі даних є найважливішими для координації кількох AMR. Досліджено значення систем живлення та охолодження в підтримці інфраструктури AMR, звертаючись до забезпечення електроенергією та контролю навколишнього середовища. Фізичні заходи безпеки та процеси обслуговування, включаючи оновлення апаратного та програмного забезпечення, забезпечують максимальну ефективність AMR. У підсумку, це дослідження висвітлює інтегральні фізичні процеси в інформаційних системах для планування завдань на основі AMR, пропонуючи ідеї для підвищення ефективності в різноманітних промислових умовах.

Ключові слова: Інформаційна система, Оптимізація енергетики, Автономні мобільні роботи.