SWARM ROBOTICS FOR INTELLIGENT WAREHOUSING: AN APPLICATION

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Abstract

Warehousing has become an important part of the supply chain of any business. With a rise in global business there is increasing pressure to modernize and improve the critical component of warehousing. This paper proposes automation of warehousing by using swarm intelligence. It describes the various key features that define a swarm of robots, the various control mechanism. This paper proposes a sample design of the warehouse robot and the warehouse layout. It proposes some key infrastructural changes in order to enable swarm intelligence. It proposes a model and unique control mechanism between the various stakeholders of the warehousing system. It also demonstrates improvements in some areas such as effective utilization of space, reduction in retrieval time, reduction in power consumption and overall improvement in efficiency.

Keywords: *Swarm Robotics, Warehousing, Centralized Control*

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1. INTRODUCTION

Warehousing is an important component of any global business forming a vital part of the supply chain mechanism. The criticality of the warehousing application has ensured its automation in order to produce reliable and predictable behavior over several indicators such as Average Retrieval Time etc. However, each of the warehousing robots tends to be independent machines which can perform only one task at a time or perhaps at best several tasks in quick succession. Each robot communicates only with a Central Command Centre and not among them. This results in bulky, expensive machines which reduce the overall performance of the system.

2. SWARM ROBOTICS

Designing a Robotic system has several challenges. One approach to the design is to create multi-purpose, complex and monolithic robots that are able to tackle the desired tasks alone [1]. This solution is simple but fails on factors such as robustness, flexibility and scalability. Adding to this is the complexity of redesign to incorporate new functions. An alternative to mechanism is to create a set of simple individuals with small and simple capabilities which collectively can perform the given task. This model is directly borrowed from the biological world of ants, bees etc. which use such “Swarm Intelligence” to accomplish tasks.

2.1 Key Features of a Swarm

Each Swarm is composed of many individuals. The individuals are relatively similar i.e. homogeneous. The individuals are relatively incapable. This means that they perform only a subset of the tasks meant to be taken up by the system. There is a high level of interaction among the individuals which are based on simple behavioral rules that primarily rely only on local information (Although, some systems rely on global information). The overall behavior results from a self-organized process, discovery and intensive co-ordination between individuals [2].

2.2 Swarm Control Mechanisms

Swarm Systems usually follow 2 distinct methods of control – Distributed or Localized Control and Centralized Control System [3].

2.2.1 Distributed Control Mechanism (DCM)

In a DCM, there is no central command center to serve as a hub of communication and co-ordination functions between the various swarm individuals. Each of the individuals relies on local information to decide on its behavior and its task allocation scheme. This is commonly used in Search and Discovery applications of Swarms as there is no global knowledge of the environment for the system to rely on. The environmental knowledge must be built bit by bit during the progress of the task. DCM is inherently local, distributed and scalable

There are two common ways of achieving communication in DCM. One such method is Self-organization - A process in which patterns at the global level of a system emerge solely from numerous interactions among the lower level components of the system. The other common method is Stigmergy which relies on communication through altering the environment. Stigmergy is used by ants which leave a trail of pheromones to act as a signal to other members following closely [4].

2.2.2 Centralized Control Mechanism (CCM)

A CCM relies on a centralized command center or a single elected leader from amongst the individuals to serve as the nerve center. All the individuals accept instructions from this center and report new found local information to the leader. The leader is primarily responsible for individual task allocation, updating the global environment etc. The main advantage of the CCM is that in scenarios where the global environment is known before hand, CCM reduces the total response time. In case of a DCM, some amount of response time is utilized in creating global scenario references by relying only on local information and local interactions between individual. However, the primary drawback is that the leader must have significant processing power in order to deal with larger swarms. Hence, there is a limitation in terms of scalability and flexibility of the swarm when it relies on CCM.

3. TYPICAL PROBLEMS IN WAREHOUSE

3.1 Space

A warehouse is meant to store a large number of goods and must therefore maximize on the amount of space allocated to storage as compared to other functions such as administration, spacing between racks for retrieval etc.

3.2 Retrieval Time

A good which is required to be dispatched from the warehouse must be retrieved from its exact storage location and brought to a dispatch/holding area as quick as possible

3.3 Storage Pattern Allocation

The System must follow an intelligent warehousing pattern in which goods which have highest retrieval must be stored very close to the dispatch/holding area. Several Optimization algorithms are already available to solve this problem

3.4 Power and Efficiency

A warehouse must use as little power as necessary for storage and retrieval of goods to enhance efficiency and profitability

4. DESIGN OF SWARM WAREHOUSE

Using Swarm Intelligence to solve some typical warehousing challenges involves designing a compliant warehouse layout as well as retrieval robots for automation of the entire process. The warehouse must be incorporated with additional infrastructure such as sensors, signaling networks for co-ordination of swarm individuals.

4.1 Design of Warehouse Robot

The Swarm enabled warehouse robot must be capable of carrying loads as per the goods specifications, which are to be established during the setup of the system.

Fig-1: Typical Warehouse Robot

4.1.1 Communication Module

The robot’s communication module can be comprised of short range protocol such as RF, Zigbee etc to leverage on local information. Additionally, a longer range protocol such as Wifi has to be incorporated in order for the robot to communicate with the Central Command Center. Using two separate protocols ensures that there is no network congestion and makes for a very scalable model.

4.1.2 Sensors Module

The robot must be equipped with IR Sensor to sense the proximity of other robots and obstacles in its path. It must have a pressure sensor to accurately determine the load it is carrying.

4.2 Warehouse Infrastructure

The Swarm enabled warehouse layout is slightly altered to provide signaling and other infrastructure. The major difference is that various warehouse racks can now be placed much closer than before, leaving space only for one retrieving robot between the racks. At each junction a congestion sensor is placed which gives the number of robots between this junction and the next. Say between (3,2) and (3,3) there are 2 robots, then the congestion sensor would read 2. This provides for local routing information for each of the swarm individuals.

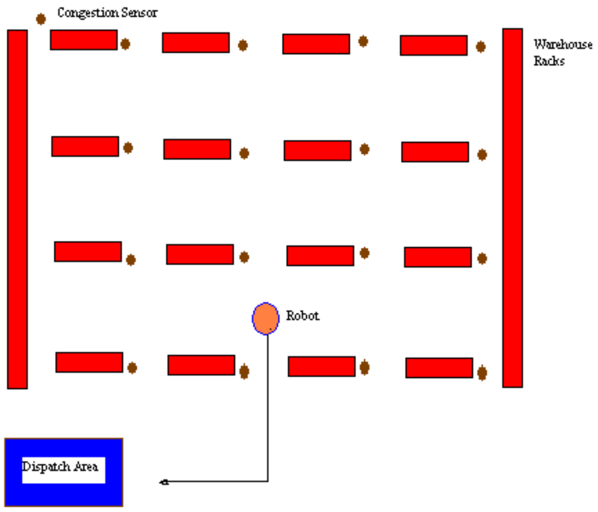


Fig-2: Swarm warehouse layout with congestion sensors

4.3 Control Mechanism

A mixed control mechanism is proposed for best results.

4.3.1 Dispatch Centre

The dispatch center acts as the centralized command center. When a good has to be retrieved, it issues the command to the mobile robot over the long distance communication protocol. It issues the command to either a free robot or to the one nearest to the location. The dispatch center is also responsible for tracking each of the swarm members using their periodic location updates. It is responsible for communicating the global layout scenario to each individual. It also performs readjustment of the storage pattern so as to further optimize the retrieval time.

4.3.2 Individual to Congestion Sensor

Once an individual receives a fetch command from dispatch, it must travel from its current location to the location of the fetch. The layout of the warehouse is already known to each individual and thus it can compute the shortest path and travels along this path. Along the path, the swarm individual communicates with the congestion sensor at every junction. If the path along the shortest route is congested with other individuals, it then recalculates the route. This avoids unnecessary delays during retrieval.

4.3.3 Individual to Individual

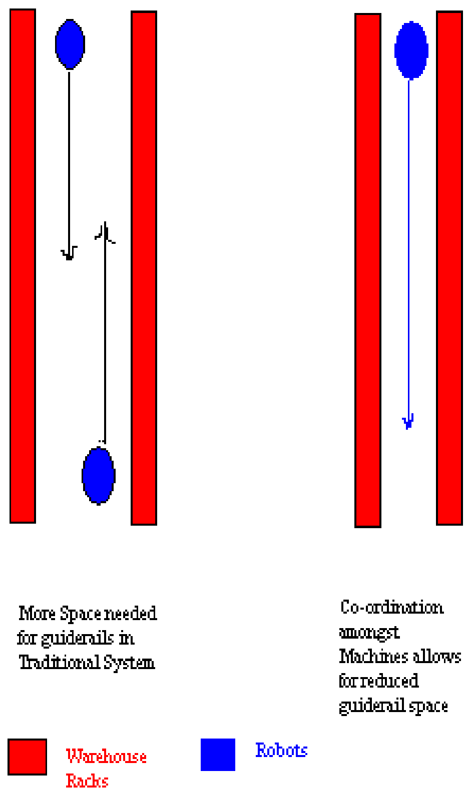
Each individual transmits its current location via the long range communication protocol back to the central command. It also transmits the current load it is carrying over a shorter range using short range protocol. This mechanism enables us to achieve reallocation of assigned duties and promoters greater efficiency. Say the dispatch has asked A to pick up an item of weight 20kg from a location X. A while on its path to location X hears over short range communication that another Robot B which is in the vicinity of X is currently carrying some load and can carry this additional 20kg load. A then dynamically reassigns its order of the item to B. Such dynamic reallocation leads to better utilization of resources and leads to shorter retrieval times

4.3.4 Individual to Dispatch

This control mechanism happens over long range communication protocols. Each individual updates the dispatch command center about its location, current order list and any dynamic reallocations if any.

5. ADVANTAGES

5.1 Space



Using intelligent swarm algorithms which have inbuilt congestion control and rerouting capabilities, it is possible to reduce the space between racks to a size small enough that only one individual can fit. This allows for greater utilization of space.

5.2 Retrieval Time

The dispatch center has the current location of all the individuals within the warehouse and allocates the fetching duties to robot closest to the location. This greatly reduces retrieval time. Additionally, dynamic order reallocation also reduces the time taken to fetch an order. It has the ability to reroute in case of congestion along the shortest route.

5.3 Power and Efficiency

The individual uses least amount of power in executing the order of the dispatch. This is achieved due to its ability to take the shortest route to the location, dynamic reallocation of orders.

CONCLUSIONS & FUTURE WORK

This paper presented a unique way to apply swarm intelligence to solve traditional warehousing problems. It provides a complete high level design specification and high level control and communication architecture for swarm based warehousing system. Future work in this area would involve developing a small scale model to implement the given algorithms and correct latencies in the system.

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BIOGRAPHIES

Kayala Rahul is currently in his 7th Semester at RVCE, Bangalore. His research interests include Swarm Robotics, Embedded systems, Internet of Things etc.