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Modular Mobile Manipulators Task Allocation Auction-based Approach

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Abstract. The use of mobile manipulators for transport tasks has provided solutions to some flexibility problems in manufacturing systems. Mobile manipulators are mobile entities equipped with robotic arms for loading and unloading parts and a mobile base for transport. It can be modular, where the two entities work together or separately. The existing task assignment approaches for mobile manipulators do not take into account the balancing of robots especially when the robot can change their capacity thanks to their modularity characteristic. In this paper, we demonstrate the efficiency of the bidding mechanism for the assignment of task to robots in order to increase the balancing for the robots use.

Keywords. Mobile manipulators, Task assignment, Contract Net.

1. Introduction

The paradigm of mass production in factories was initiated by Henry Ford at the beginning of the 20th century on an assembly line. These lines have good yields, when it comes to producing the same part and when market demand for that part or product is high [1]. The current market trends need more variable and customized product, which cannot be ensured by these traditional production lines. The integration of flexible manufacturing systems (FMS) is a solution to cope with these changes. The conveyor systems used for transportation tasks are no longer suitable for FMS, especially with the requirements of flexibility [2]. Thus, in the Handling Material System (HMS), mobile manipulators are used for transport tasks to complement the flexibility needs of factories [3]. The mobile manipulators are made up of two intelligent elements (robotic arm and mobile base), which gives them a certain modularity. Several studies have focused on the use of these manipulators in the industry. These works mainly deal with the optimization of the number of AGVs to use and the advantage of having vehicles supporting several products at once (Multi-load) [4]; On vehicle routes and conflict resolution to ensure safe and efficient travel [2] [3]; On idle vehicles positioning and battery management [4]. Other researches focus on the assignment of tasks to manipulators [5] [6]. However, no research work has examined their modular aspect or the fact that they are two autonomous entities regard to the tasks assignment.

Based on the existing works in this field, we proposed a task assignment method regarding to transportation task proposal.

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The remainder of this paper is the following: the next section describes the mobile manipulators and their modularity aspects. A literature review on task assignment to mobile manipulators including our approach is outlined in the third section. The last section of the paper presents an experimentation on a real use case to compare the bidding based approach for several configuration of the robots to an existing one. The paper ends with a conclusion and perspectives for future works.

2. Modularity of mobile manipulators

Mobile robots are autonomous entities capable of moving from point A to point B to fulfil of mission assigned to them. They are used in several fields such as factories, military operations, medical, space exploration etc. When the field of application is industry, we refer to **AGVs** (Automatic Guided Vehicles). By adding a robotic arm on the AGV for loading and unloading operations, it becomes a **Mobile manipulator** [3].

The modularity of the mobile manipulators means that they can be divided into two classes (I and II).

- Class I, A mobile base with a robotic arm as an extension: The two entities are considered as a single entity. Communication is done through a single controller, the sequencer. This configuration is quite widespread and used, especially given the centralization of information.
- Class II, A mobile base and a physically separate arm: In this case, the two entities (mobile base and arm) are separated, each having its own decision-making unit. This configuration is necessary when the mobile base does not need the services of the arm, as in cases where loading/unloading is carried out by a human operator. The class II, is necessary also when the arm needs the service of the mobile base to be transported in a given location where the arm has to perform a handling operation (pick and place) for a certain duration.

3. Related work

Robotic tasks scheduling defines the "when", "where" and "how" a vehicle must perform tasks, including its routing [4]. A High-Level Entity (HLE) is generally in charge of the scheduling definition, to achieve and ensure the overall objective [7]. However, with the event of autonomous entities able to execute high-level order, the "how" is done locally at the bottom level (shop floor), in order to gain in flexibility and reactivity [8]. Several works were interested in task assignment of smart transport entities in industrial environment. Nevertheless, most of them limit transport entities to AGVs or, in the best cases, to mobile manipulators of class I. Zambrano [9] categorized the approaches allowing assignment into five groups: (1) the Contract Net (Auction/Bidding, negotiation between agents), (2) the potential fields (Attraction and repulsion), (3) the pull algorithms (Kanban) and (4) the stigmergy mechanisms (Ant colony, Birds flocks). We focus on the groups (1) and (2) (Contract Net and potential fields), which are commonly found in the literature on task assignment to transport entities.

3.1. Potential fields

Potential fields consists of the emission of a field into an environment in order to attract elements of common interest (Attraction) or to repel in order to avoid each other (Repulsion). In [10], an approach to assign tasks to AGVs in a dynamic environment based on potential fields is proposed. Fields are emitted by transport agents, idle AGVs are attracted by these fields. AGVs in turn emit repellent fields to avoid collisions when several AGVs are attracted by the same field. In [11] an approach based also on potential fields in which each resource can offer one or more services is proposed. Each service has its own potential field. The products are then attracted by the field corresponding to the service they need. Approaches based on potential fields therefore make it possible to solve scheduling and routing problems simultaneously [12]. However, the field flow is proportional to the distance where the emitting source is located. These methods have their limits then, when we are in large warehouses or factories. Especially if there are obstacles like walls for example. In other terms, the use of these approaches in an efficient way requires a particular configuration of the environment (open and relatively small space).

3.2. Contract Net

Contract-Net approaches are effective in solving allocation problems [12]. In this type of approach, a manager agent announces a proposal for job, contract agents evaluate the offer and then bid. The manager agent assigns the task, and finally the manager and the winner coordinate to perform the task. In [2], an auction-based assignment is presented. AGVs bid to obtain the transport of certain products. The allocation are made in relation to the AGV located at the shortest distance from the point where the product is taken. In this approach, it is not possible to perform several tasks in parallel [11]. The use of combinatorial bidding in [5], allows to overcome this type of problem. Thus in [5], a mobile entity can submit several bids at the same time to production tools in order to win the tasks of transporting products they offer.

Our approach is based on bidding, where a HLE generates a transportation order composed of three basic operations (loading \rightarrow transport \rightarrow unloading). Each resource responds to the order based on its class and estimates the associated delivery time (dt). The HLE selects the resource that minimizes the dt . When the whole tasks are assigned the HLE evaluates the solution and a genetic algorithm (GA) is used to optimize this solution. The optimization process is not detailed in this paper, reader can get more information in [13]. Each robot has an associated knowledge model, in which operations and total distance traveled are stored.

Table 3. Mathematical notations

Symbol	Description	Symbol	Description
j	Part index	R	Set of robots
m	Machine index	$dt_{jm'r}$	Delivery time of j to m' by r
m'	Next machine index	lt/ult_{jr}	Loading/unloading time of j using r
r	Robot index	$lt_{mm'r}$	Transport time from m to m' by r
J	Set of parts	pt_{jm}	Processing time of j by m
M	Set of machines	$tt_{mm'r}$	Transport time from m to m' by r

In the case where mobile manipulators cannot perform the whole task, a contract can be proposed to other resources. For example a mobile base can look for a contractor to load and unload parts.

Class I: the deliver time for the mobile manipulator is:

$$dt_{jm'r} = pt_{jm} + tt_{nm'r} + lt_{nr} + ult_{m'r} \quad (1)$$

Class II : Robotic arm can only offer a contract regarding these two situations:

Contract Offer for Non-Mounted arm :

$$contractTime^{NM} = \begin{cases} lt_{nr} & \text{if loading task} \\ ult_{m'r} & \text{if unloading task} \end{cases} \quad (2)$$

Contract offer for mounting arm :

$$contractTime^M = lt_{nr} + ult_{m'r} \quad (3)$$

The Mobile base has a dt depending of this defined contract time as follow:

$$dt_{jm'r} = pt_{jm} + tt_{jm'r} + contractTime \text{ where } \begin{cases} contractTime = contractTime^{NM} & \text{if non-mounted arm} \\ contractTime = contractTime^M & \text{if mounted arm} \end{cases} \quad (4)$$

Validation of bidding solution:

$$\sum_{j \in J} \sum_{m \in M} \sum_{r \in R} dt_{jm'r} * X_r \leq dueDate \text{ where } \begin{cases} X_r = 1 & \text{if } r \text{ is operation winner} \\ X_r = 0 & \text{Otherwise} \end{cases} \quad (5)$$

4. Experimentation

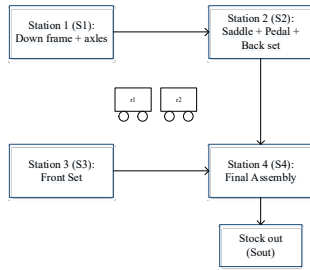


Table 2. Operations details

Operations(O)	Route	tt
O ₁	S1 → S2	22.64s
O ₂	S2 → S4	17.84s
O ₃	S3 → S4	32.03s
O ₄	S4 → Sout	11.82s

Figure 1. Assembly workshop of tricycle

The Figure 2 describes a workshop composed of four manual assembly stations (S1, S2, S3, and S4). The final objective is to assemble and deliver tricycles in a stock out (Sout). Transport resources (r1 and r2) are in charge of transferring products from different stations. Three configurations are simulated to resources: (1) Class I, r1 and r2 are mobile manipulators; (2) Class II.1: r1 and r2 are mobile bases without arm, loading and unloading are performed by different arms; (3): Class II.2: r1 and r2 are mobile bases without arm, loading and unloading are performed by human. The transportation time (tt) for each transport operation are illustrated on the Table2.

4.1. Test case

The purpose is to test the efficiency of the Bidding Based Approach of Assignment (BBAA) by making a comparison with an approach commonly used in industry namely the Dedicated Resource Based Approach (DRBA). The latter aims to dedicate one specific transport resource to a transportation task in order to avoid routing conflicts.

Based on Table 2, for the DRBA the r1 is allocated to perform the O₁ and O₂, and the r2 for the O₃ and O₄. An algorithm is developed on python to implement the BBAA.

4.2. Results

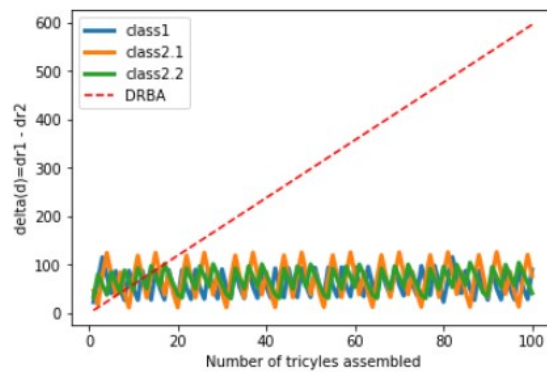


Figure 2. Workload variation between mobile robots

The delta (d) indicates the workload repartition between resources. A good distribution of workload reduces the usury and energy consumption of robots, which ensures a better battery life. A low delta (d) demonstrates that the workload is well distributed and tasks are well assigned. The BBAA then provides a better distribution of tasks for several configuration of the robots (three different configurations). The figure 3 shows this affirmation with the assembly simulation of one hundred tricycles. The variation of the workload stays constant at some point during all the process of tricycles assembly for the BBAA (Class I, Class II.1, and Class II.2) but for the DRBA it increases.

5. Conclusion

This paper deals with the problem of task assignment for modular robots in flexible manufacturing system. The modularity of mobile manipulators allows them to be more flexible, but makes their control and task assignment more complicated. We tested a method based on bidding of transportation tasks (loading, transport, and unloading) by proposing their associated time depending on their configuration (Classes I or II).

A testing scenario was defined and results show the efficiency of the proposed method with different configurations of the robots.

Next work will focus on the optimisation of the efficiency of the bidding process in order to reduce the variability of the system.

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