A Trust Model to Form Teams of Agentified AGVs in Workshop Areas

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Abstract
Smart Workshops are experiencing the need of a mobile intelligence for mining both learning patterns and knowledge from the wide sea of data generated by both mobile users and mobile technologies. Indeed, mobile intelligence would represent the ideal substratum for providing "agentified" robots with a plethora of advanced capabilities (e.g., visual recognition, fault detection, self-recovery) and, hence, with high-level functionalities, like production line control, asset movement, connectivity restore. Besides the operational plane, however, mobile intelligence can be successfully exploited also in organizational tasks, like the formation of temporary, ad-hoc teams for accomplishing a given target. The complexity of some industrial operations, indeed, often demands the involvement of several, heterogeneous group of robots and the adequate representation of the reciprocal trustworthiness represents a key pre-requisite. It holds particularly for the Automated Guided Vehicles (AGVs) which are increasingly involved in collaborative activities aimed to optimise storage, picking, and transport functions in a wide variety of workshop areas. Therefore, in this paper we define a trustworthiness model for agentified AGVs based on the mix of their reputation and reliability and we present an agent-based framework implementing the related team formation strategy. The improvements obtained in terms of effectiveness and efficiency from the AGV team are observed and measured through a simulation activity, in which realistic settings for an industrial applications have been considered.

Keywords
Trust, Smart Factories, Team Formation, Multi-agent System.

1. Introduction

AGVs, namely fully autonomous robots able to operate without manual intervention or permanent conveying systems, are increasingly present in Smart Workshops. Just to name a few motivational examples, AGVs are ideal for replacing workers in repetitive, unappealing jobs as well as they push both speed and accuracy in moving products from shelf to shipping over human limits. Broadly speaking, AGVs lessen labour requirements and promise improving

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effectiveness, efficiency and safety within the workshop area. In such a scenario, typical AGV applications include routine operations like the horizontal transport, storage and retrieval of materials as well as danger activities like clamp handling or extreme environmental conditions. In particular, AGVs result a critical enabling technology for agile production systems if devoted to collaborative tasks, such as the internal logistics ones. Therefore, the formation of temporary teams of heterogeneous AGVs is widely seen as an important advancement within the Industrial Internet of Things (IIoT) domain [1, 2, 3, 4]. However, establishing the criteria to rule such team formation process is challenging because of the mobility the AGVs, their different features (in terms of skills, autonomy, performances) and the potential lack of historical data or central shared repository. Therefore, more than exploiting structural or semantic similarities among team's partners, one can consider social properties existing among them for maximizing the probability of establishing positive interactions. In particular, a promising criterion consists in forming teams on the basis of the members' trustworthiness levels, namely the reliability shown in performing their own tasks and the reputation gained within the workshop area. Such two information, respectively, expressed in terms of efficiency and effectiveness, are usually embedded in a single measure named trust and can be shared within the workshop area (thus obviating the need of a centralized repository and also providing a higher fault tolerance, concurrency, etc.). To this end, a suitable solution is "agentifying" each AGV, leveraging on the widely established social, smart and cooperative attitudes of multi-agent systems (MAS) [5]. In particular, the agentified AGV can automatically updates its trust information and the MAS can implement a team formation strategy by ranking AGVs based on their time availability (i.e., the time they need to accept a new task) suitably weighted by the trustworthiness value which, in its turn, embeds efficiency and effectiveness information combined accordingly to the factory policies. On these basis, we present our framework, more comprehensively described in [2], that leverages on a distributed MAS (to bypass the need of a central management system and its associated overhead, typically unacceptable for most industrial tasks) and on a trust model based on the mix of AGVs's reputation and reliability. We tested our team formation strategy on a simulated agent-based scenario, showing that combining mobile intelligence, team formation, reliability, reputation, and trust information leads to a measurable improvement of the simulated workshop area in terms of high quality performance.

The outline of the structured is as follows. An overview about agent-based technology, AGV and trust is reported in Section 2. The proposed framework is presented in Section 3 while Section 4 introduces the outlined trust model. Section 4.1 makes a connection between the contributions of these two Sections (i.e., the main architecture presented in Section 3 and the trust model of Section 4), showing how the trust model can be exploited to perform a team formation activity on the AGVs of the smart workshop in a distributed way. The results of our experiments are discussed in Section 5. Finally, in Section 6 conclusions are drawn.

2. Background and Related work

Multi-AGV systems have been recently adopted in the IIoT domain [1] to perform key activities like real-time monitoring, connectivity restore and collaborative control. Authors of [6, 7, 8], for example, illustrate some benefits provided by AGVs, in terms of reliability, efficiency and safety, for the whole smart workshop area. If the advantages coming from the exploitation of teams of AGV are well-established, the discussion about the better criterion leading the team formation process is still open. Indeed, more than conventional approaches based on geographical locality/social closeness or similarity (in terms of goals, skills, etc.), trustworthiness represents a novel, viable approach for dynamically and effectively grouping AGVs. Likewise, the agent-based computing (ABC) [5] is an enabling paradigm for information processing in dynamic, decentralized and scalable environments, where the entities exchange data to be automatically combined for outlining the global better setting (for example, resource allocation or scheduling problems). In particular, works like [9, 10] attest how trust systems have been widely implemented in the past through the ABC paradigm. Focused on the IIoT, our proposal relies on these research steps with the exploitation of AGVs which are enhanced through the multi-agent technology and are fully integrated within the trust system.

Along such research direction, a number of related work exist at the state-of-the-art[**?** 11]. For example, Authors of [12] and [13] sponsor the formation of group of both autonomously and cooperatively agent-based smart industrial devices for accomplishing tasks like controlling the materials handling and factory scheduling to automate the factory environment and its activities. In [14], instead, an agent-based controller is deputed to find the optimal, collision- and deadlock-free motion planning of its associated AGV. In the context of the Supply Chain Management, a real case study [15] showcases a framework integrating neutrosophic Decision Making Trial and Evaluation Laboratory technique with an analytic hierarchy process to effectively deal with uncertain and incomplete information. A recent work of Wan et Al. [16], instead, illustrates a combined solution exploiting simultaneously an OLE (Object Linking and Embedding) for process control technology, a software defined industrial network, and a device-to-device communication technology to achieve efficient dynamic resource interaction and management (to this end, an ontology modeling with multi-agent technology is used). The trustworthiness of potential partners is estimated in [17, 18, 19, 20] through reputation systems based on first and second-hand information/observations, while in [21, 22, 23, 24, 25] by mainly analyzing the evolution of social relationships over time. In BETaaS [26], instead, a more comprehensive approach is presented, with a complex trust model for Machine-to-Machine applications taking into account factors like security, QoS, scalability, availability and gateways reputation. In [27, 28], finally, cloud-based solutions to form groups of agentified industrial devices on the basis of their reliability and reputation values are presented.

With respect to these contributions, in our proposal the effective team formation is performed by means of a trustworthiness measure whose implementation (and the preliminary information exchange it requires) is enabled by the exploitation of the multi-agent technology in the entire framework, as detailed in the next Section 3.

3. Our Scenario

We consider a Smart Workshop adopting a swarm assembly approach with teams of coworkers for reaching the desired production goals in the required time. The considered scenario is modeled as follows:

- workshop's activities are performed by both human and AGVs, present in variable num-

bers depending on the adopted processing technique;
- for each activities (e.g., welding, transportation, connectivity restore), there exists a specific kind of AGVs;
- AGVs differ with each other for efficiency (depending on their model, age, sensing capabilities, usury, etc.) and effectiveness (e.g., skills and so on) values;
- the agent of each AGV supports its physical counterpart for the working activity within the team of coworkers;
- a special *Manufacturing-Manager* (MM) agent is in charge of managing the production-lines and, in particular, of updating the measures of performance of the workshop agents and accordingly forming the "best" team/teams of AGV coworkers based on their trust measures;
- the MAS allows distributing the information load over the entire set of AGVs, thus avoiding the need of a unique, centralized repository.

In details, let W be the workshop area of our smart workshop and let SC be the daily set of customers requiring to the smart workshop the assembly of a customized item. Each customer $c \in SC$ has a reference to a MM agent, aiming at building for each item the best team/teams of AGVs capable of optimizing the production process in terms of performance. The MM periodically updates those two measures for each agent and, consequently, computes and updates the trustworthiness measure, (see Section 4). The MM saves a copy of these values in its internal memory, while each agent that has interacted with the MM saves a local copy of its measures. Therefore, when the agent will interact in the future with a novel MM, it will transmit the information about its efficiency, effectiveness and trustworthiness, as a sort of references.

4. The Trust Model

In this section, we introduce the trust model used to consider the performance of AGVs in a smart workshop. In this context, we define the following measures: the AVG *effectiveness* (γ) represents the customer satisfaction for the AVG's job; in other words, it is the reputation that an AGV has in the customer community; the AGV *efficiency* (λ) represents the capability of complying with the product assembly constraints (e.g., time); in other words, it is the reliability with respect to the production-line operation; the AGV *trustworthiness* (τ) is a single trust measure that considers performance to properly guide the AGV team formation processes.

In a controlled smart workshop, we assume that there are no malicious agents therefore it is not necessary to implement countermeasures against unsuitable behaviors (e.g., collusive, complainer, alternate, whitewashing and so on).

$\gamma \in [0, 1] \subset \mathrm{R}$ considers the feedback f_{eed}, with $k \in [0, 1] \subset \mathrm{R}$, released by the customers to the AGV. More formally, γ is computed as:

$$\gamma^{new} = \beta \cdot \gamma^{old} + (1 - \beta) \cdot f_{eed} \tag{1}$$

where $\beta \in [0, 1] \subset \mathrm{R}$ is used to award a certain relevance to f_{eed} in updating γ with respect to its current value.

$\lambda \in [0,1] \subset R$ is calculated on the basis of objective measures (k) (e.g., the time required to complete a task) that can be combined in a single measure $\rho \in [0,1] \subset R$, with $\rho = f(k_1, \cdots, k_n)$. More formally, λ is computed as:

$$\lambda^{new} = \alpha \cdot \lambda^{old} + (1 - \alpha) \cdot \rho \tag{2}$$

where $\alpha \in [0,1] \subset R$ is a parameter giving more or less relevance to ρ in updating λ with respect to its current value.

τ combines *Efficiency* and *Effectiveness* to achieve a unique synthetic measure for a specific AGV. This trust model is the linear combination of reliability measures used with considerable results in our previous papers [27, 29] but contextualized in other multi-agent domains. Our proposal is adequate given the supposition that, if an increment of efficiency $\Delta\lambda$ (resp. effectiveness $\Delta\gamma$) produces an increase of trustworthiness $\Delta\tau$, then the percentage ratio $\frac{\Delta\tau}{\Delta\lambda}$ (resp. $\frac{\Delta\tau}{\Delta\gamma}$) should be the same for any increment of $\Delta\lambda$ (resp. $\Delta\gamma$). In Section 5, the experiments show that the linear model correctly reproduces the simulated scenario. More formally, τ is computed as:

$$\tau = \eta \cdot \lambda + (1 - \eta) \cdot \gamma \tag{3}$$

where $\eta \in [0,1] \subset R$ gives more or less relevance to λ with respect to γ; η is set considering the factory policies in terms of performance. In our experiments (see Section 5), we have utilized a value $\eta = 0.4$ to give more importance to the effectiveness with respect to the efficiency.

4.1. Team formation

We recall that our trust model allows the team formation considering both present and past AVG results, in terms of performance. Each MM agent categorizes AGVs on the basis of the time need to accept a new task, called time availability TA, weighted on the τ value which embeds performance information combined accordingly to the factory policies. Therefore, AGV teams are formed by each MM selecting the top classified in this ranking. The set $G = \{g_0, g_1, .., g_n\}$ executes a distributed algorithm, where g_0 is the MM agent and g_i is the i-th AGV agent. The algorithm is composed of five steps, called the *formation assignment*, the *request*, the *response*, the *selection*, and the *team formation*. The response step is executed by each agent g_i, $i = 1, .., n$, instead the MM agent g_0 performs the formation assignment, request, selection and team formation steps. In detail, the five steps operate as follows:

1. **formation assignment:** g_0 receives by its administrator (i.e., a human manager or a workflow process) the assignment to form a team. Then, g_0 produces as inputs for the step:
   - the agent's number z needful for the team formation;
   - the maximum waiting time t_{max} before starting the team formation;
   - the minimum trustworthiness τ_{min} required to an AVG for joining the team.
2. **request:** g_0 forwards a request to each agent g_i, $i = 1, .., n$ to obtain its time availability TA_i, representing the time that g_i needs to accept the step, and its trustworthiness τ_i.
3. **response:** an agent g_i computes the required values before providing a reply:

- TA_i based on the other steps in which it is previously involved;
- τ_i by combining efficiency and effectiveness (see Section 4).

Recall that each agent a_i continually updates the two measures according to both the time utilized to finish their steps and the feedbacks received by the customers. Then, TA_i and τ_i are sent to g_0.

4. **selection:** g_0 continuously monitors the list R of the responses received by the AGV agents, containing the pairs (λ_i, γ_i); for each $i = 1, .., n$, g_0 calculates the following score:

$$R_i = TA_i \cdot \tau_i \quad (4)$$

Hence, g_0 deletes from R all those agents g_i whose $TA_i > t_{max}$ or $\tau_i < \tau_{min}$ because their AGVs are not eligible to perform the team formation. Also, g_0 stores R ordered by a decreasing value of the score R_i.

5. **team formation:** when t_{max} is reached, g_0 examines R and releases the following response to its administrator:
   - the list of the first z agents of R, if the cardinality of R is greater than or equal to z.
   - a failure message, otherwise.

All this steps are independently performed by the agents of the set G without the need of a central repository of the trustworthiness information regarding the AGVs. This choice allows to increase the efficiency of our model because the central repository management would imply a continuous updating of the AGV information with a consequent overhead for the internal communication network.

5. Experiments

The proposed industrial scenario has been simulated by a multi-agent system supporting the cooperation of AVG in a production site. To this aim, a significant number of workdays has been simulated by assuming that a random number of customer orders must be processed on each of the simulated workdays. Moreover, we assumed that the manufacturing process is organized in a serial way by production islands and in each production island one or more customization of the products are carried out according to the customers' order. On each island, the production process is carried out by a team of three smart AGVsc, denoted by heterogeneous performance, capable of autonomously operating.

In more detail:

- the heterogeneity of AGVs implies different skills and performance and, therefore, they will differ from each other also in terms of time required to complete the task assigned to them;
- given the different capabilities, AGVs will receive individual appreciation (i.e., the feedback f_{eed}) from the customer who placed the order for the customization work done.

As already described in Section 3, each production line is associated with an MM agent, who supervises the assembly of the items ordered by customers. In particular, each MM will interact with the software agents associated with AGVs to arrange the best AGV team for each specific production island (e.g., manufacturing task) at a given time with respect to both each specific order of a customer $c \in CS$ and the availability trustworthiness of each AGV. At the end of each production task, the parameters of reliability (*lambda*), reputation (*gamma*), and trust (τ) are updated for each AGV.

The simulation has regarded a single smart production line for which the following parameters have been adopted: *i*) 60 working days; *ii*) 8 working hours for workday; *iii*) 150 customers' orders per workday; *iv*) 25 production islands[1] for each production line; *v*) 4 serial customized manufacturing tasks for each item and for each island; *vi*) 400 AGVs are active on the production-line, in other words 100 AGV for each of the 4 required manufacturing task to realize for item and for island. The parameters introduced above will drive both the operation of the production line and the response of the AGVs. In order to realize, to the best of our possibilities, a simulation as realistic as possible we have configured our production line adopting the most common parameters in use in some European factories that assemble cars.

Some preliminary tests have been carried out to suitably set the trust framework and, as a result of these tests:

- the parameters λ and γ were both initially set to 1.0 in order to assign maximum trustworthiness when reliability information is not yet available for then updating the AVG reliability based on subsequent experience;
- the parameter τ was initially set to 1.0;
- the parameters α and β were initially set to 0.95 (remember that λ and γ are updated through the feedback received over time in order to take into account even small variations in terms of performance)
- the parameter η (exploited to update the τ) were set to 0.4 conformly the criteria presented in Section 4.

Different scenarios were simulated by varying the performance of AVGs uniformly within suitable ranges of domains with the goal of forming efficient and effective AGV teams based on trustworthiness criteria. For this purpose, we considered the most critical scenario in our set of simulations, which is given by a combination of maximum performance loss varying from 5% to 25%. The results of these experiments are depicted in Figures 1 and 2.

Figure 1 depicts the changes in the parameters λ, γ and τ for the considered simulation period. It is evident how the proposed framework is able to produce significant advantages in terms of the plotted parameters. More specifically, note that the benefits in terms of λ (i.e„ γ and τ) were evaluated incrementally based on the sum of the differences in efficiency (i.e., effectiveness and trustworthiness) measures of the AGV teams formed by applying the strategy proposed in Section 4.1 versus those that would have been formed based on temporal availability alone. Therefore, the results of this experiment show that our proposed trust framework allows improving both efficiency and effectiveness of the production line.

In contrast to the benefits described above, one must keep in account that the adoption of the proposed trust framework also has a cost in terms of average daily loss of time (in seconds)

[1]Remember that each production island is devoted to realize on or more (customization) tasks and an item will leave its current production island only after each manufacturing task of that island will be ended.

for AGV, which is depicted in Figure 2. This is due to the fact that the proposed strategy for forming teams is optimized with respect to the AGV's trust score (i.e., it takes into account AGVs' performance and time availability) and not on the basis of the only AGVs' time availability. This means that not the AGV with the best time availability is selected, but the one with the best placement resulting from a weighted average between performance and time availability (see section 4). More simulations have been performed to evaluate this "loss" of time, arriving to simulate also a complete year, achieving values that are always around the minute, on average compared to all the AGVs. This average time loss can be considered negligible in light of the improvement achieved in performance.

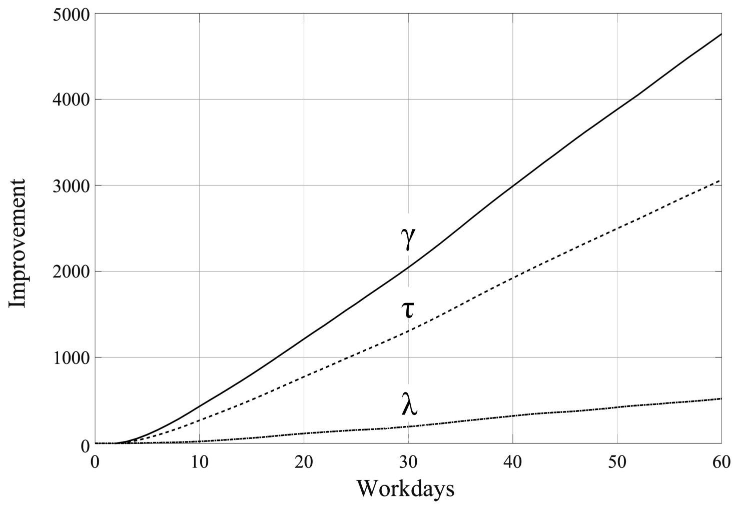

Figure 1: Advantage given by the trust framework in terms of λ, γ and τ.

6. Conclusions

The inherent complexity of many industrial activities demands for the cooperation of multiple, heterogeneous robots. In particular, teams of "agentified" AGVs with different capabilities are suitable candidates to accomplish both routine and extra-ordinary tasks by, simultaneously, improving the performance within a workshop area. Reliability and reputation are two enabling factors for establishing trust among AGVs: therefore, in this paper, we have presented and tested a trustworthiness model and an agent-based framework to support the automatic formation of virtual, temporary teams of highly performing, mobile intelligent devices. The preliminary results obtained on a simulated industrial scenario with realistic settings have shown a measurable improvement in the teams composition in terms of both performance and appreciation. The implementation of the outlined agent-based framework, a parametric study of the trustworthiness model to achieve its best configuration and the introduction of management techniques for handling unpredictable events potentially affecting the team formation represent our future research directions.

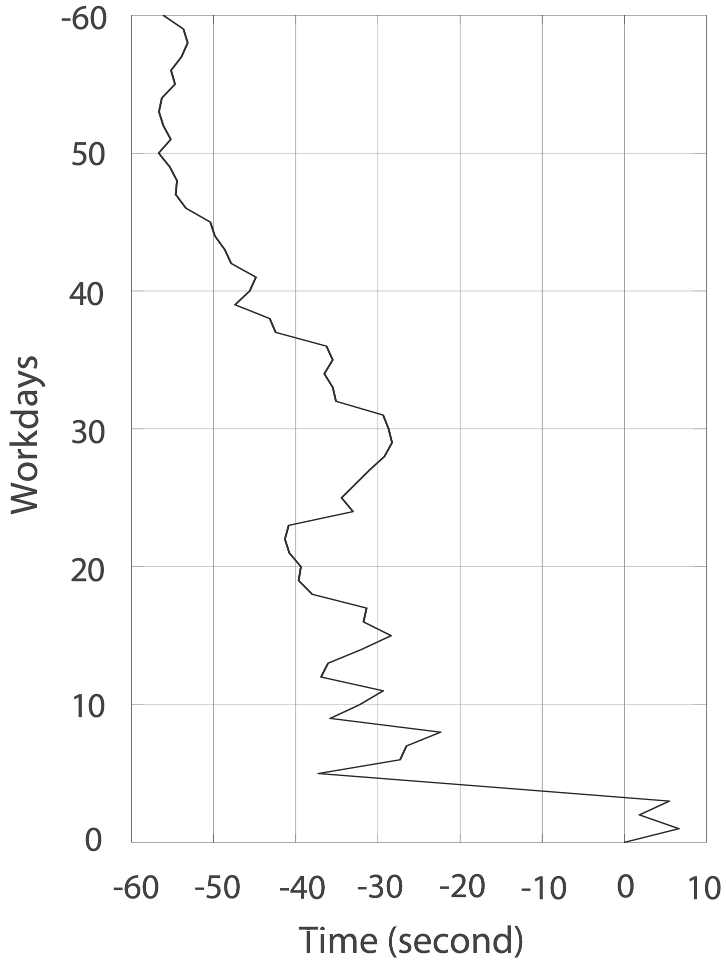

Figure 2: Average time “loss” for AGV.

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