Robot-enabled execution system for perishables auction logistics

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Abstract

Purpose – The purpose of this paper is to propose a concept of cloud auction robot (CAR) and its execution platform for transforming perishable food supply chain management. A new paradigm of goods-to-person auction execution model is proposed based on CARs. This paradigm can shift the management of traditional manual working to automated execution with great space and time saving. A scalable CAR-enabled execution system (CARES) is presented to manage logistics workflows, tasks and behavior of CAR-Agents in handling the real-time events and associated data.

Design/methodology/approach – An Internet of Things enabled auction environment is designed. The robot is used to pick up and deliver the auction products and commends are given to the robot in real-time. CARES architecture is proposed while integrating three core services from auction workflow management, auction task management, to auction execution control. A system prototype was developed to show its execution through physical emulations and experiments.

Findings – The CARES could well schedule the tasks for each robot to minimize their waiting time. The total execution time is reduced by 33 percent on average. Space utilization for each auction studio is improved by about 50 percent per day.

Originality/value – The CAR-enabled execution model and system is simulated and verified in a ubiquitous auction environment so as to upgrade the perishable food supply chain management into a new level which is automated and real-time. The proposed system is flexible to cope with different auction scenarios, such as different auction mechanisms and processes, with high reconfigurability and scalability.

Keywords Supply chain management, Multi-agent, Perishables auction logistics, Robot-enabled execution system

Paper type Research paper

1. Introduction

As the increasing attention paid by the modern consumers, food that is fresh, safe, nutritious, and palatable brings new opportunities to the supply chain management which represents the management of the food production, distribution, marketing activities, and recycling (Opara, 2003; Wang *et al.*, 2015). Thus, the perishable supply chain management (PSCM) plays a critical role in ensuring the demands. However, perishable products such as fruit, vegetables, seafood, etc. are very difficult to handle through traditional supply chain, for example, the vibration of trucks will cause mechanical damage to fruit and vegetables (Nakandala *et al.*, 2016).

Auction is widely used for fast trading of perishable products to achieve fair and transparent price, especially for perishable agricultural commodities such as fruits and fresh fish (Kambil and Van Heck, 1998). This trend remains strong in the Netherlands with transactions for 12.4 billion plants and flowers each year (*The New York Times*, 2014). Major third-party auction service providers such as FloraHolland have solved technological problems of dealing with millions of simultaneous biddings (www.floraholland.com). But logistics that fulfills the massive and lumpy auction demands is still challengeable (Qin *et al.*, 2014). The concept of auction logistics (AL) is thus proposed to transform and upgrade the PSCM using advanced technologies such as Internet of Things (IoT), robot-enabled processes, and cloud-based services (Huang and Kong, 2013; Zhong *et al.*, 2013; Qiu *et al.*, 2014).

Three phases are defined in the AL. The first phase is pre-auction consolidation on inbound goods from different farming suppliers. Auction orders can initiate the process in an auction logistics center (ALC). The second phase is auction studios where auction products are picked, traded, and dispatched by delivering the perishable products with trolleys. The third phase is post-auction sortation and packing on outbound goods based on customer orders. The logistics operations at the first and third phases are relatively mature while the second phase often creates the bottleneck under bulky auction demands in limited transaction windows.

Practically, most of existing auction execution activities are still relying on traditional manual operations or fixed material handling systems. It has been extremely labor intensive, often involving long distance of auction trolley movements at different positions. Such systems are structured with the limited flexibility which is unable to cope with lumpy auction demands (Huang *et al.*, 2015). Moreover, auction execution workflows change frequently in terms of different auction mechanisms. However, all auction tasks are centrally assigned by a traditional allocation method and it typically requires a huge and expensive effort to implement, maintain, or reconfigure the control application (Zhang *et al.*, 2015). Finally, due to the shortage of real-time interaction in the current auction ambient, the auction schedule and execution is often inconsistent (Kong, Chen, Luo and Huang, 2015a).

To address the above challenges, this paper introduces IoT-enabled cloud robots for auction execution. The cloud robots in auction execution can utilize their cognitive capabilities and share their knowledge by connecting themselves to cloud infrastructures (Kuner, 2010; Xu *et al.*, 2015). This study will contribute to the PSCM by the following aspects:

(1) using cloud auction robot (CAR) to achieve a new paradigm of goods-to-person in a ubiquitous auction execution environment;

(2) using a centralized, reconfigurable, and scalable cloud execution system for dealing with the global and complicated decisions in auction execution from workflow configuration, task allocation to auction navigation and control; and

(3) implementing and evaluating the proposed CAR-enabled execution system (CARES) via a case study.

In this research, a representative CAR-enabled execution model is presented in a ubiquitous auction execution environment based on the analysis of existing operations and challenges. Then, a CARES architecture is proposed by integrating three core services from auction workflow management, auction task management, to auction execution control. Finally, through a case study, the designed auction execution hardware and software systems are evaluated.

The remainder of the paper is organized as follows. Section 2 reviews the related and recent literature. Section 3 introduces the existing auction execution challenges. Based on the concept of CAR, an execution model is proposed with typical operation characteristics. Section 4 further describes the proposed backbone system for CARs management. In detail, the agent model of CAR, the cloud architecture and three core services are elaborated. A case study is then given in Section 5 with quantitative and qualitative analysis, and Section 6 concludes the whole paper and discusses the future works.

2. Literature review

2.1 Perishable Supply Chain Trading

A perishable supply chain is a network of enterprises that typically involves stakeholders of growers, auctioneers, wholesalers, retailers, and logistics service providers for perishable products whose value diminish over time (Cheng *et al.*, 2014). Fruits and vegetables are representative agri-food products in perishable supply chain. Recently, fruit and vegetable supply chains have faced additional complications due to some food-specific characteristics such as quality variations between growers, products freshness, and special packaging demands (Taylor and Fearne, 2006; Pieter van Donk *et al.*, 2008). Therefore, the pricing and logistics decision process involves lengthy consideration of many factors such as shorter delivery time, and the efficiency of PSCM often becomes a concern (Mendelson and Tunca, 2007).

Driven by the prospect of better matches between suppliers and buyers in perishable supply chain, auctions have been adopted to automate the process of buying, selling, or transferring products, services, and/or information. In auction markets, supply chain participants transact directly through a centralized intermediary (Garbade, 1982). Major auction intermediary such as FloraHolland have solved technological problems of dealing with millions of simultaneous biddings for flower transaction. The adoption of such practices could not only reduce the time suppliers spend at markets but also reduce the time buyers spend in bidding or bargaining for products.

2.2 Auction Logistics

Various visibility and traceability tools have been used to manage perishable food supply chain and related service operations (Buhr, 2003; Martínez-Sala *et al.*, 2009). Despite significant progress achieved by research and practitioner communities, major challenges still exist in applying agile logistics to facilitate auctions (De Koster and Yu, 2008). The concept of AL is thus proposed to ensure required throughput time with large trading volumes (Kong, Chen, Luo and Huang, 2015a). The following definition is developed using the definition of logistics management of the Council of Supply Chain Management Professionals: AL is that part of perishable supply chain trading that plans, implements, and controls the efficient, effective flow and storage of products, services and related information driven by the auction to meet customers and operators' requirements, considering the quality worsening of perishable products. Most key activities of AL are operated in a centralized ALC. Auction studios is the core of ALC where goods trading are taken place. For example, Dutch auction in the auction studio starts with a high asking price which is lowered until a buyer accepts the asking price by using a clock. In this way, millions of perishable products (e.g. fish, flowers, and fruits) could be sold and shipped quickly.

A generic cloud-enabled system architecture has been presented to enable adaptive decision supports for the configuration of auction studios/sessions, bidding synchronization between onsite and remote auction as well as the associated logistics activities in a typical ALC (Kong, Fang, Luo and Huang, 2015b). Qin *et al.* (2014) have introduced a modified class-based location policy to improve put system performance in AL with traditional person-to-goods method.

2.3 Robot-enabled warehouse automation system
Robotic warehouse automation solutions are commercially available (Caputo and Pelagagge, 2006). Examples include the well-known Kiva robots owned by Amazon (www.kivasystems.com) and AutoStore from Swisslog (www.swisslog.com). Wurman *et al.* (2008) introduced some aspects of Kiva management system that draw on artificial intelligence for pick-pack-and-ship warehouses. Its central controller is a warehouse execution system that orchestrates mobile robots and human pickers to fulfill orders (Dev Bahadur Poudel, 2013; Huang *et al.*, 2015). Gue *et al.* (2014) proposed a new paradigm "GridStore," a special variant of AS/RS by implementing decentralized control. Those robotic warehouse paradigms often appear to outperform traditional solutions in space requirements, investment, response time, emissions, and flexibility to layout/order changes (Furmans *et al.*, 2011). Nevertheless, a direct application of these solutions into AL is practically impossible and there are still some gaps worthy of discussion as follows:

- Although the robot-enabled warehouse automation is widely applied in the general warehousing processes such as order picking, the application in perishable auctions is limited. AL is more complicated and time-sensitive since it combines the general functionalities of warehousing process with an added perishable transaction process.

- The existing warehouse execution and control system is only developed and deployed for managing a kind or certain types of special equipment (Faber *et al.*, 2002). However, a typical ALC consists of a large variety of heterogeneous equipment, multiple information carriers, and communication standards. Therefore, system reconfigurability, usability, and scalability should be paid specifical attention with seamlessly accommodation of new services (Cheng *et al.*, 2012).

To deal with practical challenges and research gaps in AL, cloud robots could be utilized to support auction task offloading and information sharing. Cloud robots have potential to speed up many computationally intensive applications such as warehouse navigation (Riazuelo *et al.*, 2014). Cloud robots are also endowed with collective learning capabilities by collecting data from many instances of physical environments such as parallel planning and trajectory adjustment over many tasks (Berenson *et al.*, 2012). From the literature review, research and practices on CAR in the AL for PSCM are limited.

3. Overview of CAR
3.1 Current challenges in auction execution
An ALC has one or more auction studios. An auction studio consists of several auction clocks and AL (de)consolidation areas, each of which involves a variety of objects, such as operators, machines, materials, buffers, etc.

Currently, based on predefined and fixed auction plans, auction executions are conducted through a crowd of staffs from products receiving, auction trolley loading and consolidation to auction transaction with associated internal distribution. Figure 1 presents the processes in a typical auction environment. First of all, auction products are unloaded from the delivery vehicles and randomly stored at the receiving zone. They are categorized and loaded into trolleys with same quality grade level. Loaded trolleys are then manually put-awayed to the pre-auction
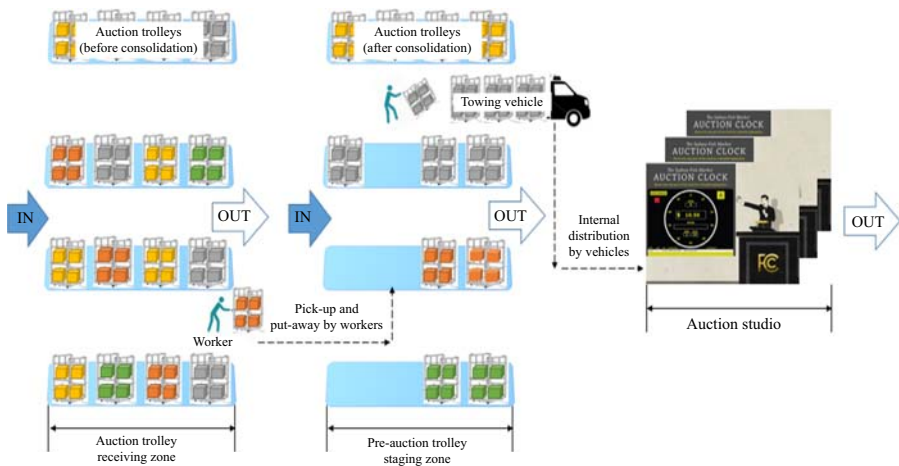
Figure 1.
Typical auction
environment

trolley staging zone. Loaded trolleys are batched and sequenced to a train based on specific auction requirements. Second, once the trolleys are chained together, each train can only be moved into the appointed auction session. Finally, traded trolleys are sent to the post-auction stage (e.g. sorting and packing) and towing vehicles are returned back for the next delivery.

Typically, there are several operational challenges in such manual auction environment:

(1) Repetitive and tedious material handling operations are based on manual working fashion which is with low efficiency, high instability, and error prone. Moreover, real-time information (e.g. trolley location) cannot be collected to support bidders, auctioneers, and logistics team for decision makings.

(2) A specific fixed space of pre-auction trolley staging zone is set. That thus takes much more time and costs.

(3) It lacks effective scheduling and control methods for auction execution so that the vehicle congestion increases during internal distribution.

(4) It is also difficult to scale up the existing facilities when auction businesses expand. The existing system is unable to deal with fluctuated demands at peak seasons and becomes under-utilized during off-peak periods.

With the increasing daily number of auctions, the existing inefficient logistics operation mode will lead to unsatisfactory bidding experience, and therefore the loss of onsite bidders since some perishable products are prone to deterioration. Therefore, an advanced AL system with high modularity, scalability, agility, and reconfigurability is needed.

3.2 The conceptual model of CAR

Mirroring the definition of cloud asset (Xu *et al.*, 2015), CAR refers to a cloud controlled autonomous robot in the auction floor that is augmented with the capability of perception, communication, and mobility. Through utilizing sufficient cloud computing and storage resources, CARs could handle the mass data collected during the whole process of auction execution. Basically, CAR consists of two parts: hardware and software, and its concept model is depicted in Figure 2.

The hardware also called "smart transportation unit" consists of industrial robot and smart devices like RFID readers. Each CAR is equipped with sensor, auto-localization, and local
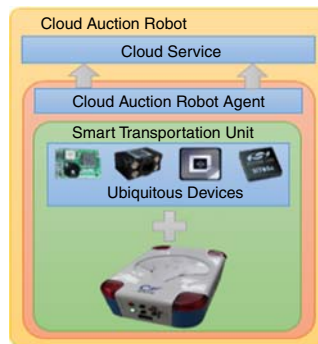
Figure 2.
The conceptual model
of cloud auction robot

navigation subsystems running independently and informing regularly its execution system
about the status of each task (i.e. position, problem found, or task finished). The software refers
to the "CAR agent" that is used to wrap and represent smart transportation unit in the cloud.

Based on the conceptual model, a representative auction execution scenario with CAR is
exemplified in Figure 3. Movable auction trolleys that can be lifted by small, autonomous
CARs are used. A few rows of auction trolleys are randomly staged on the floor and aisles
are set aside for moving trolleys back and forth by CARs. The auction execution procedures
from trolley pick-up, put-away, consolidation are all processed by CARs. A CAR can deliver
multiple auction trolleys. The CAR-based operations have several characteristics:

(1) Distinguishing from the traditional person-to-goods method in AL, a new paradigm
of goods-to-person (goods are brought to human operators who complete order
picking, put-away and possibly have to distribute trolleys to fixed positions at
auction studio) can be achieved through the proposed execution model.

(2) The space for trolley consolidation and internal distribution (the fixed pre-auction
trolley staging zone) can be significantly reduced. Moreover, it is flexible to scale up
the existing facilities when auction businesses expand.

(3) CARs' queueing sequence can be dynamically adjusted with the real-time
auctioneers' instructions. Hence, it can adapt to bidders' fluctuating behaviors
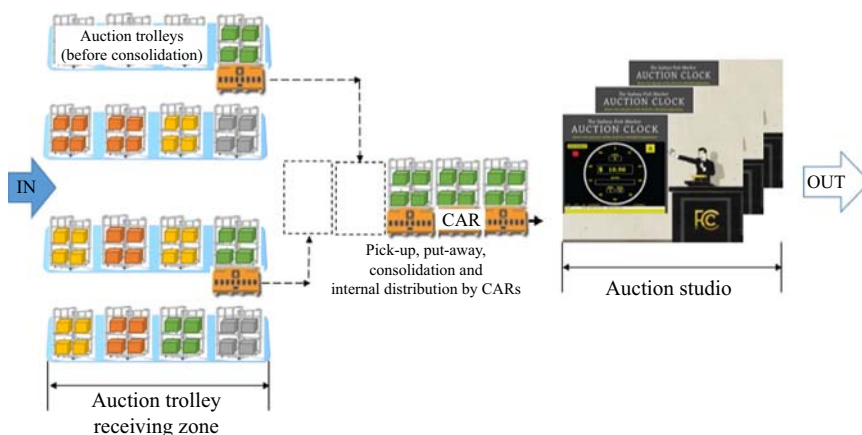through operation synchronization between auction and logistics department.

Figure 3.
CAR-enabled
representative
execution scenario

4. CARES

CARES is a centralized cloud platform to manage the parallel execution of autonomous CARs. As a bridge between CARs and CARES platform, smart IoT gateway is designed to manage heterogeneous assets (Fang *et al.*, 2013). Smart IoT gateways are capable of making online control of CARs. Once operation disturbances are detected, real-time information will be rapidly fed back to decision makers for replanning or rescheduling. CARES can also facilitate sharing of data for CARs' learning by collecting data from many instances of physical trials and environment, and therefore more intelligent performance can be achieved.

4.1 CAR agent

To manage CAR, (CAR-agent) is proposed. CAR-Agent is a software agent that is used to wrap the physical part of CAR and represent it as autonomous software agent in the cloud. As a typical software agent, it is built upon The Foundation for Intelligent, Physical Agents (FIPA) specification. With their properties and parameters abstracted as attributes of CAR-Agents, and functions and behaviors as services, CAR-Agent serves as a mirror of auction robot and could run in parallel and independently. In addition, CAR could be easily controlled remotely by invoking the corresponding services of its CAR-Agent.

Figure 4 shows the logic framework of CAR-Agent. Generally, CAR agent model can be divided into three layers. The bottom is the physical layer that consists of sensors and actuators. Sensors are responsible for collecting the real-time data. Actuators control the basic actions of CAR. The second layer is control layer which has two main functions. First, it provides data processing service for the real-time data collected from the physical layer, and sends the processed data to the upper layer for decision making. Second, it interprets the planning information and generates concrete workflow as well as control command for the execution of CAR. Information layer is responsible for high-level decision making. The tasks are first analyzed based on the real-time status of CARs and predefined knowledge stored in knowledge base. Then, the local path planning for each allocated task could be made with intelligent anti-collision capability. Particularly, this logic model builds a close loop for the task execution, which enables CARs to flexibly and robustly work in the changing environment.
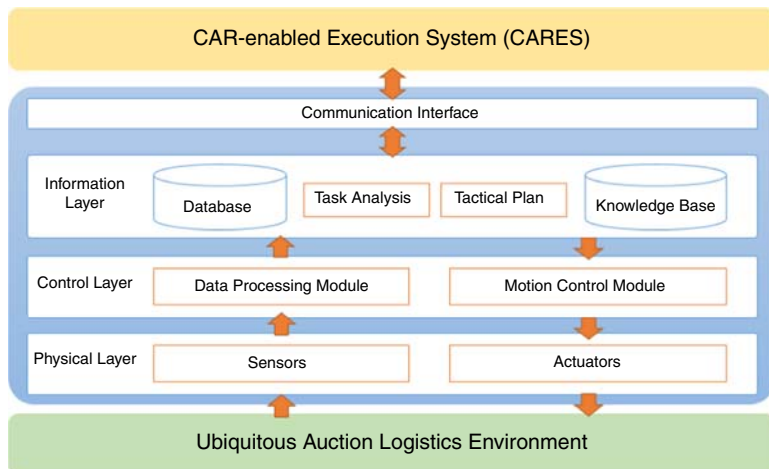

Figure 4.
Logic model of cloud auction robot agent

4.2 System architecture

CARES is essentially a multi-agent system, following FIPA (2004) specification. CARES deals with the scalability and reconfigurability of CAR-Agents. CAR can be added or deleted, and their configuration properties can be adjusted without affecting each other. Moreover, it manages behavior and workflows of CARs (agents) in handling the real-time events and associated data. Figure 5 presents the supportive cloud databases or repository and three core cloud services in the proposed layered architecture.

CAR agent manager contains four key components: agent management system (AMS), agent directory facilitator (ADF), lifecycle manager (LM), and message transportation system (MTS). AMS maintains a directory of agent identifiers and their transport addresses. It is responsible for handing agent requests, and providing global control for CAR-Agents, including their evolvement, scheduling, etc. ADF provides yellow page services for CAR-Agents. CAR-Agents can register one or more services with ADF, and query ADF for services provided by other agents. LM offers complete and systematic lifecycle management for agents in terms of requisition, installation, execution, relocation, maintenance, and disposals. MTS is the default communication method between agents. All the interactions and communications between agents and services are done by MTS.

There are three supportive cloud databases or repositories that are virtualized as cloud services to be shared by cloud users, including cloud asset agents and applications in the upper layer. One is execution database for collection of real-time operation and sensory data. The other two parts are knowledge repositories that provide basic control supports and knowledge resources, such as CAR routing strategies, etc.

Cloud service layer is built to manage decision support services in cloud for auction execution such as workflow management service, task allocation service, auction navigation, and control service as well as local applications deployed at gateways. It contains several built-in services, at the same time, allows user to add other new applications which comply with the required protocol through several setting steps.
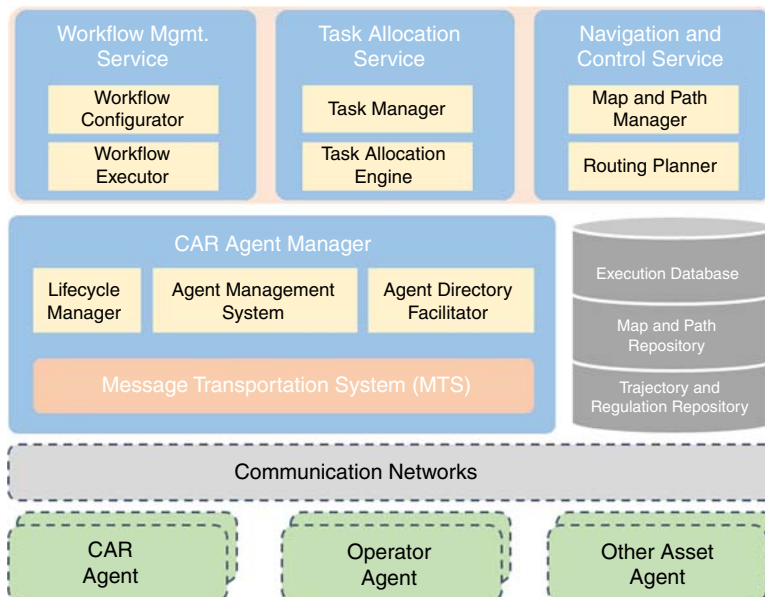

Figure 5.
Architecture
of CARES

4.3 CARES core services

4.3.1 Workflow management service. Different from traditional production processes (Zhang *et al.*, 2010), auction execution workflows varied from different auction mechanisms. In this case, for example, supposing a simple task execution under Dutch auction is conducted by a robot formation with five auction robots (i.e. CAR A, B, C, D, and E). CAR A and B are equipped with flexible manipulators and responsible for auction products picking and auction trolley loading in the pre-auction trolley staging zone. The rest of CAR robots undertake the subsequent delivery of loaded trolleys across the specified auction studio. However, once the auction mechanism and process requirement changes, the workflow will be reconfigured accordingly. CARs' queueing sequence should be dynamically adjusted with the real-time auctioneers' commands. Considering those emergency situations in auction, the matching process of workflow with physical assets should also be done in a very short period of time.

To fulfill these requirements, CAR-enabled workflow management is worked out along with the following three steps. First, ALC resource managers define the workflows according to the process planning, and indicate the requirements of CAR-Agents that would be involved. Generally, different auction mechanisms probably have different execution processes. Second, each activity in the workflow search works for the qualified and available CAR-Agents automatically. Mapping relationship between the executable activity and CARs (agents) is established. The workflow facility in CARES also provides graphic interfaces (i.e. workflow configurator) for related decision makers to edit the workflow. Third, the selected CAR-Agents will be invoked through the internet, and actions could be taken according to the predefined parameters. Workflow execution engine not only facilitates the execution of CAR-Agents according to the defined workflow and logic, but also monitors, coordinates, and controls these agents during the auction execution. Since every CAR is published as a cloud service, it could be found and invoked by different workflows. Meanwhile, the domain specific knowledge could also be easily transferred to the selected CARs as rules, so that it could easily adapt to new working scenario and execute immediately after being invoked.

4.3.2 Active auction task allocation service. After auction workflows are well defined and configured, task manager in CARES provides real-time auction task allocation service. Before the actual execution, all the auction tasks will form a task pool at first regarding the task status and execution requirements. Then, each CAR will automatically send its real-time status and request of the auction tasks when it is available. The CARES continuously interacts with the CARs and checks their real-time status using an automated form of "negotiation" so that the optimal auction tasks will be assigned to the optimal CARs. The task allocation engine follows the rule that only one optimal task is selected and assigned for one CAR at each time. Moreover, CARES wants less robot to be used to complete maximum tasks. This decreases the crowd of robot in the auction floor and eases the obstacle detection problem. The key benefit of such active task allocation approach is that if the actual execution is disrupted or reorganized in some way, the same negotiation process still takes place and hence the system is relatively robust to change. In addition, the process of real-time task allocation is simplified as far as possible by using the concept of task pool that it only needs to determine the optimal sequence of tasks in the task pool (Zhong *et al.*, 2013).

4.3.3 Auction navigation and control service. Before implementing the proposed auction execution, the auction floor should be placed with fiducial markers and other sensors during the system installation. Using sensors as node, a grid of path is constructed by interconnecting these sensors between the storage location in the pre-auction trolley staging zone and the auction studio. The CARs' local navigation system involves a combination of dead reckoning and cameras that look for these sensors. Map and path manager in CARES will help to guide the CAR motion from one position to another from the global perspective.

After tasks allocation, the responsibility of finding optimal path to the destination is assigned to the CAR through routing planner. The workflow of auction execution can be explained as follows, which presents a sequence of processes/activities to be taken along a time sequence: the CAR receives information (e.g. the coordinate of task locations) about the required tasks from CARES. Taking into account the global route, each CAR calculates its own local path to reach its goal and monitors its surroundings looking for unexpected obstacles along the planned path. Based on sensor data and an environment model, each auto-localization subsystem of CAR updates its estimated position and informs these data to the local navigation subsystems. The local navigation subsystem compares the current position with the desired one. If the CAR deviates from the route, the local navigation subsystem will send commands to correct its orientation for returning the planned route. If the local navigation subsystems verify that the route has exceeded the limited runtime, the CAR will communicate with CARES and its neighboring CARs while recalculating and ensuring conflict-free routes. During the whole process of auction execution, CARES continuously interacts with the CARs to notify the possible collisions, traffic jams, etc. Meanwhile, CARES regularly verifies the progress of all tasks.

5. Case study
To verify the effectiveness and efficiency of the proposed solution, a prototype of the system has been developed, with a test bed of CAR-enabled fruit auction execution.

5.1 Test bed for CARES
A test bed has been set up in the laboratory environment (around 50 square meter) to simulate the operating mechanism of auction execution. The general structure of the test bed is shown in Figure 6(a). Basically, the test bed has three working zones. The first one is auction studio. It contains two independent auction sessions via developed e-auction clocks. Different auctions cloud be made paralleled. The second working zone is pre-auction trolley staging zone. It serves as the buffer for storage and consolidation of all the goods that are waiting for auction. All these goods are well graded, categorized, and loaded in the auction trolleys. After each trolley retrieving, the available staging place could be automatically replenished until all assigned tasks have been completed. The third working zone is the CAR parking lot which is the base for all the idle CARs. Due to the limitation of experimental space, only 50 mimic auction trolleys are selected in the test bed. The simulation data used for the auction trading are based on the empirical measurements from our collaborating company. Other key parameters are summarized in Table I.

Currently, we have finished phase one of the simulation test bed for CARES in the lab, including hardware and software, as seen in Figure 6(b). From the hardware deployment perspective, the ground is labeled by black lines as the main guide path in the test bed so that robots can move automatically according to the commands send from the proposed CARES. In addition, two types of robot are deployed in the test bed. One is a fetch and freight robot with intelligent manipulator. It is responsible for picking up goods from the trolley staging location, putting these goods on its own trailer, and then delivering them to the auction studio. This robot has two infrared sensors so that it could move according to the lines on the ground. The other two are mobile auction robots, which are also line-tracking robots. From the software deployment perspective, the prototype of CARES has also been developed. To work with the application programing interfaces given by these robots, the system was developed under Java Runtime Environment, and could cover all the working processes in auction execution.
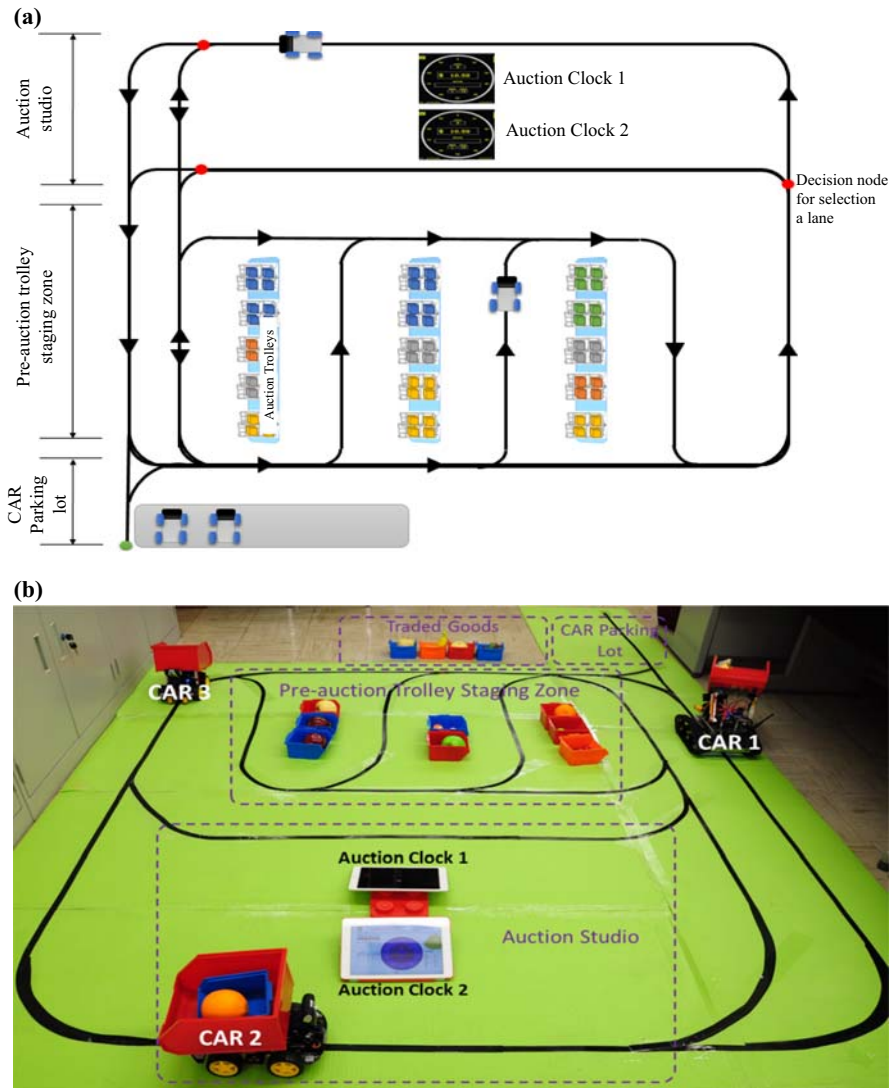
Figure 6.
Deployment of a
robotic environment
for fruit auction
execution

Notes: (a) Layout design of the test bed for CARES; (b) simulation test bed for CARES in the
university lab (Phase 1)

Two server computers are deployed to simulate the cloud environment in our
laboratory, and several mobile devices, including iPad and smart phones are used for
onsite controllers.

5.2 Execution control with CARES
The system execution processes can be divided into three phases: workflow management
phase, task management phase, and execution control phase. Their working logic is shown
in Figure 7. Generally, two major flows are involved in the process. One is control flow.

Parameters	Value
Average auction rate	1 trolley per 10-20 seconds
Total number of trolleys	50
Average percentage of trolleys with multiple transactions	80%
Total number of bidders	4
Number of pre-auction staging zones	3
Number of robots	3
Number of manual operators	3
Travel speed and acceleration/deceleration of robots in movement	2.5 m/s, 1.5 m/s^2
Travel speed and acceleration/deceleration of manual operators in movement	0.9 m/s, 0.3 m/s^2
Time for dropping off or picking up a trolley by a robot	2 s
Time for dropping off or picking up a trolley by a manual operator	7 s
Average distance of a round trip	
Staging zone 1-AC1-CAR parking lot	26 m
Staging zone 2-AC1-CAR parking lot	23 m
Staging zone 3-AC1-CAR parking lot	20 m
Staging zone 1-AC2-CAR parking lot	34 m
Staging zone 2-AC2-CAR parking lot	31 m
Staging zone 3-AC2-CAR parking lot	29 m

Table I.
Parameters used in
simulation of test bed

Figure 7.
Execution process
of the simulation
case under the
proposed system

It contains the management strategies, working rules, and control parameters, which flows
from the workflow management phase, to task management phase, and finally to the
auction execution phase. The other flow is the feedback data flow. It contains the real-time
sensing data collected from the onsite execution robots, and flows from the bottom phase to

the upper phase. In this way, a closed-loop could be formed to enable the dynamic and robust control of various involved robots. The detailed working processes of the three execution phases are as follows.

5.2.1 Phase 1: workflow management. This phase is done by auction managers at auction studio. It is responsible for generating concrete workflows for different auctions according to the requirements. The input of this phase is the detailed requirements for each auction, and output is a well-structured workflow. Three basic steps are included in this phase as follows:

- define the basic information for an auction working scenario, such as its proposed auction session, goods for auction, amount, quality grades, and so on;
- configure detailed auction parameters, such as auction mechanism, auction places, auctioneers, and so on; and
- after the auction has been well defined and configured, a well-structured workflow for the auction could be generated automatically according to the predefined format, and then it will be released to the next phase.

5.2.2 Phase 2: task management. This phase is done automatically by the CAR-enabled auction execution system. It is responsible for generating concrete tasks for CARs according to the requirements of the auction workflow. The input of this phase is the well-structured workflow, and output is the assigned tasks for each robot. The main working steps of this phase are listed as follows:

- make detailed analysis for the workflow, and generate sequenced tasks/activities lists for executing the workflow on real-time basis;
- according to the requirements of tasks/activities and the real-time environmental status, the task execution plan is made automatically; and
- based on real-time status of each robot, the system would optimize the distribution of tasks, and then release them to corresponding robots with detailed information.

5.2.3 Phase 3: execution control. This phase is done by various CARs, and their corresponding control modules. It executes the released tasks and keeps updating their real-time execution status to the upper layer. The input of this phase is the released tasks, and the output is the executed tasks and the real-time status of them. This phase also contains the following three steps:

- Make detailed analysis for the received tasks. According to their requirements, and the real-time status of the environment, generate an optimized execution sequence for these tasks.
- Make detailed execution plan for each task, such as local routes and corresponding collision avoidance actions, based on the environmental information, and the real-time status of itself and other CARs.
- Execute the task and report its real-time status to the upper layer.

5.3 Discussion

5.3.1 Quantitative improvements. Before the CARES implementation, each auction studio has conditioned eight working hours per day. Each trolley needs ten sheets of paper-based documents for manual consolidation and the cost of each sheet is one cent. According to a random task list sent from CARES, the auction execution for mimic 50 trolleys is extracted to demonstrate the system performance. Table II shows the rudimentary comparison results

from manual-handling operations, robot-handling operation, and estimated improvements in physical emulation.

Through using the robots, the trolley picking time could be greatly saved, as these robots and trolleys are designed for automatic operations, and the routes are optimized according to the real-time position of robots and goods. In addition, the CARES could well schedule the tasks for each robot to minimize their waiting time. Hence, the total auction execution time is reduced by 33 percent on average. Space utilization (referring to the trolley buffering turnover capacity) for each auction studio is improved by almost 50 percent per day. Auction execution data are available for managers without delay after the CARES implementation. The amount of paperwork is also cut down greatly, resulting in a paperless operation environment. Smoother task handling and cooperation, accurate and timely data and better-informed execution decisions are also achieved.

Figure 8 analyzes the total execution time of both human-operating system and manual-operating system for different amounts of auction trolleys. The time curve of human-operating system slightly climbs in the early stages and has a rapid growth after 35-trolley amount is achieved. This is because traditional person-to-goods method is still adopted in the existing manual-operating system. Goods are brought to human operators who complete order picking, put-away and possibly have to distribute trolleys to fixed positions at auction studio. The whole system bottlenecks may appear when a relatively large auction order size arrives. In contrast, the time increase of robot-operating system is slightly slow. It is also observed that the difference between human-operating system and manual-operating system grows larger with the increase of auction trolleys. It thus implies that CARES could easily improve the auction execution efficiency and the effect will be more obvious if auction businesses expand.

Item	Human-operating system	Robot-operating system	Estimated improvements
Total auction execution time for 50 trolleys (minute)	22.4	15	~33%
Space utilization for each auction studio per day (trolley buffering turnover/m^2)	21.4	32	~50%
Cost of daily paperwork (RMB)	~1,000/auction studio	Paperless	Paperless
Auction execution data capturing and entry	Delay	Real-time	Real-time
Level of false trolley pickup, delivery and drop off	High	Low	Low

Table II.
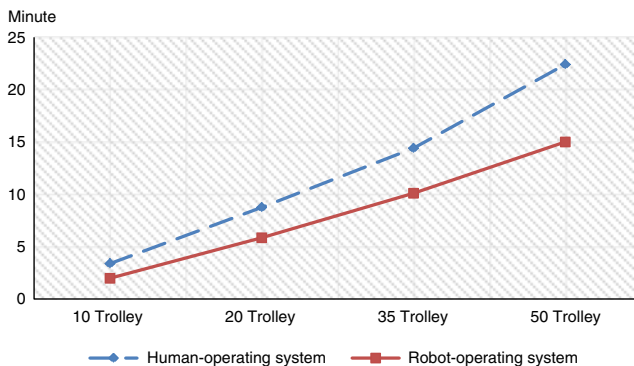System comparisons and estimated improvements in the physical emulation

Figure 8.
Systems performance evaluation under varied trolley amounts

5.3.2 Qualitative improvements. For qualitative aspect, there are several improvements. First, the system is flexible enough to cope with different auction scenarios. In the simulation, several different types of auctions are involved. The system is able to handle different working logics, and the mixed auction scenarios to maintain an acceptable output. For example, CARs' queueing sequence can be dynamically adjusted with the real-time auctioneers' instructions. Using the proposed system, operation synchronization between auction and logistics department could be enabled.

Second, the system is flexible to scale up when auction businesses expand. In the simulation, adding one or more robots to the existing running system is tested and the added robots could be easily configured and participated in the working processes. Meanwhile, the system can also well handle the situation when the amount of auction demands increases greatly (e.g. during valentine's period) with high reliability.

Third, the system standardizes the decision-making procedures through a rich set of services, which are developed as interactive explorers for end-users to fulfill their daily operations. It can also enhance the coordination among different decision-making parties through seamlessly integrating auction planning, scheduling, execution, and control in the light of the real-time sharing and feedback of IoT-enabled operation and sensory data. Therefore, the decisions based on individual and subjective experience previously could be greatly lessoned.

6. Conclusions

As auction markets become increasingly IT-reliant, distributed, and agile-demanding, there are valid reasons and perhaps requirement for auction intermediary to embrace the massive use of cloud robots in a ubiquitous auction environment. Effective management of them is always of great importance for the PSCM. To manage these robots more flexibly and accurately, this paper proposed a concept of CAR and its execution models. Besides, to facilitate parallel execution of autonomous CARs and to fulfill the massive and lumpy auction demands through the cloud, CAR agent model and the supportive CARES cloud platform are designed. CARES integrates three core services from auction workflow management, auction task management, to auction execution control. Furthermore, a demonstrative test bed is also given to verify the effectiveness of the proposed concept.

The contributions of this paper can be concluded as follows. First, this paper innovatively proposes a new paradigm of goods-to-person auction execution model based on CARs. It helps adapt to the increasing daily number of auctions. Besides, from the managerial point of view, this paradigm also shifts the management of traditional manual working to automated execution with great space and time saving. Second, a scalable CARES management platform is proposed based on the integration of various technologies. With CARES, CARs can be easily added or deleted, and their configuration properties can be adjusted independently. Moreover, it manages workflows, tasks, and behaviors of CAR-Agents in handling the real-time events and associated data. Third, the proposed system is flexible enough to cope with different auction scenarios with high reconfigurability. Once the auction mechanism and process requirement changes, the workflow will be reconfigured accordingly via workflow management service. Besides, using active task allocation and navigation services, CARs' queueing sequence could be dynamically adjusted with the real-time auctioneers' commands.

In the future, this work could be further extended in three aspects. First, considering the specific situation in auction execution, corresponding decision making models should be further explored to evaluate the impacts of products category size, storage assignment scheme and the length of auction trolley chain on the proposed CAR-enabled execution models. Second, Big Data Analytics tools for mining frequent trajectory pattern and knowledge of CARs is critical for determining the accurate plans and layout optimization of ALC. Third, the concept

should be taken into some real-life auction execution cases to make more sophisticated performance measurement of our proposed concept. Furthermore, other significant process in ALC could also be involved such as post-auction sortation and package operations.

References

Berenson, D., Abbeel, P. and Goldberg, K. (2012), "A robot path planning framework that learns from experience", *IEEE International Conference on Robotics and Automation*, pp. 3671-3678.

Buhr, B.L. (2003), "Traceability and information technology in the meat supply chain: implications for firm organization and market structure", *Journal of Food Distribution Research*, Vol. 34 No. 3, pp. 13-26.

Caputo, A.C. and Pelagagge, P.M. (2006), "Management criteria of automated order picking systems in high-rotation high-volume distribution centers", *Industrial Management & Data Systems*, Vol. 106 No. 9, pp. 1359-1383.

Cheng, M., Luo, H., Zhong, R.Y., Lan, S. and Huang, G.Q. (2014), "Cloud-based auction tower for perishable supply chain trading", *Procedia CIRP*, Vol. 25, pp. 329-336.

Cheng, S.T., Wang, C.H. and Horng, G.J. (2012), "OSGi-based smart home architecture for heterogeneous network", *Expert Systems with Applications*, Vol. 39 No. 16, pp. 12418-12429.

De Koster, R. and Yu, M. (2008), "Minimizing makespan and throughput times at aalsmeer flower auction", *Journal of the Operational Research Society*, Vol. 59 No. 9, pp. 1182-1190.

Dev Bahadur Poudel (2013), "Coordinating hundreds of cooperative, autonomous robots in a warehouse", working paper, Jacobs University Bremen, Bremen.

Faber, N., de Koster, R.M.B. and van de Velde, S.L. (2002), "Linking warehouse complexity to warehouse planning and control structure: an exploratory study of the use of warehouse management information systems", *International Journal of Physical Distribution & Logistics Management*, Vol. 32 No. 5, pp. 381-395.

Fang, J., Qu, T., Li, Z., Xu, G. and Huang, G.Q. (2013), "Agent-based gateway operating system for RFID-enabled ubiquitous manufacturing enterprise", *Robotics and Computer-Integrated Manufacturing*, Vol. 29 No. 4, pp. 222-231.

Furmans, K., Nobbe, C. and Schwab, M. (2011), "Future of material handling-modular, flexible and efficient", *IEEE/RSJ International Conference on Intelligent Robots and Systems, San Francisco, CA, September 25-30*.

Garbade, K.D. (1982), *Securities Markets*, McGraw-Hill, New York, NY.

Gue, K.R., Furmans, K., Seibold, Z. and Uludag, O. (2014), "GridStore: a puzzle-based storage system with decentralized control", *IEEE Transactions on Automation Science and Engineering*, Vol. 11 No. 2, pp. 429-438.

Huang, G.Q. and Kong, X.T.R. (2013), "Cloud-enabled real time platform for auction logistics in perishable supply chain trading", in Blecker, T., Kersten, W. and Ringle, C.M. (Eds), *Pioneering Solutions in Supply Chain Performance Management: Concepts, Technologies and Applications*, Books on Demand GmbH, Hamburg, pp. 199-217.

Huang, G.Q., Chen, M.Z. and Pan, J. (2015), "Robotics in ecommerce logistics", *HKIE Transactions*, Vol. 22 No. 2, pp. 68-77.

Huang, G.Q., Wright, P.K. and Newman, S.T. (2009), "Wireless manufacturing: a literature review, recent developments, and case studies", *International Journal of Computer Integrated Manufacturing*, Vol. 22 No. 7, pp. 579-594.

Kambil, A. and Van Heck, E. (1998), "Reengineering the Dutch flower auctions: a framework for analyzing exchange organizations", *Information Systems Research*, Vol. 9 No. 1, pp. 1-19.

Kong, X.T.R., Chen, J., Luo, H. and Huang, G.Q. (2015a), "Scheduling at an auction logistics centre with physical internet", *International Journal of Production Research*, Vol. 54 No. 9, pp. 2670-2690.

Kong, X.T.R., Fang, J., Luo, H. and Huang, G.Q. (2015b), "Cloud-enabled real-time platform for adaptive planning and control in auction logistics center", *Computers & Industrial Engineering*, Vol. 84, pp. 79-90.

Kuffner, J.J. (2010), "Cloud-enabled robots", *10th IEEE-RAS International Conference on Humanoid Robots (Humanoids 2010), Nashville Marriott at Vanderbilt University, Nashville, TN, December 6-8*.

Martínez-Sala, A.S., Egea-López, E., García-Sánchez, F. and García-Haro, J. (2009), "Tracking of returnable packaging and transport units with active RFID in the grocery supply chain", *Computers in Industry*, Vol. 60 No. 3, pp. 161-171.

Mendelson, H. and Tunca, T.I. (2007), "Strategic spot trading in supply chains", *Management Science*, Vol. 53 No. 5, pp. 742-759.

Nakandala, D., Lau, H., Zhang, J. and Chan, H.K. (2016), "Cost-optimization modelling for fresh food quality and transportation", *Industrial Management & Data Systems*, Vol. 116 No. 3, pp. 564-583.

Opara, L.U. (2003), "Traceability in agriculture and food supply chain: a review of basic concepts, technological implications, and future prospects", *Journal of Food Agriculture and Environment*, Vol. 1, pp. 101-106.

Pieter van Donk, D., Akkerman, R. and Van der Vaart, T. (2008), "Opportunities and realities of supply chain integration: the case of food manufacturers", *British Food Journal*, Vol. 110 No. 2, pp. 218-235.

Qin, K., Chen, F.Y. and Ma, L. (2014), "Cutting down the travel distance of put systems at Kunming international flower auction market", *International Journal of Production Research*, Vol. 53 No. 12, pp. 3573-3585.

Qiu, X., Luo, H., Xu, G.Y., Zhong, R.Y. and Huang, G.Q. (2014), "Physical assets and service sharing for IoT-enabled supply hub in industrial park (SHIP)", *International Journal of Production Economics*, Vol. 159, pp. 4-15.

Riazuelo, L., Civera, J. and Montiel, J.M.M. (2014), "C 2 TAM: a cloud framework for cooperative tracking and mapping", *Robotics and Autonomous Systems*, Vol. 62 No. 4, pp. 401-413.

Taylor, D.H. and Fearne, A. (2006), "Towards a framework for improvement in the management of demand in agri-food supply chains", *Supply Chain Management: An International Journal*, Vol. 11 No. 5, pp. 379-384.

The New York Times (2014), "Dutch flower auction, long industry's heart, is facing competition", available at: www.nytimes.com/2014/12/17/world/europe/dutch-flower-auction-long-industrys-heart-is-facing-competition-.html?_r=0 (accessed December 16, 2014).

Wang, J., Wang, H., He, J., Li, L., Shen, M., Tan, X., Min, H. and Zheng, L. (2015), "Wireless sensor network for real-time perishable food supply chain management", *Computers and Electronics in Agriculture*, Vol. 110, pp. 196-207.

Wurman, P.R., D'Andrea, R. and Mountz, M. (2008), "Coordinating hundreds of cooperative, autonomous vehicles in warehouses", *AI Magazine*, Vol. 29 No. 1, pp. 9-19.

Xu, G.Y., Huang, G.Q. and Fang, J. (2015), "Cloud asset for urban flood control", *Advanced Engineering Informatics*, Vol. 29 No. 3, pp. 355-365.

Zhang, Y.F., Huang, G.Q., Qu, T. and Ho, O. (2010), "Agent-based workflow management for RFID-enabled real-time reconfigurable manufacturing", *International Journal of Computer Integrated Manufacturing*, Vol. 23 No. 2, pp. 101-112.

Zhang, Y.F., Zhang, G., Du, W., Wang, J., Ali, E. and Sun, S. (2015), "An optimization method for shopfloor material handling based on real-time and multi-source manufacturing data", *International Journal of Production Economics*, Vol. 165, pp. 282-292.

Zhong, R.Y., Dai, Q.Y., Qu, T., Hu, G.J. and Huang, G.Q. (2013), "RFID-enabled real-time manufacturing execution system for mass-customization production", *Robotics and Computer-Integrated Manufacturing*, Vol. 29 No. 2, pp. 283-292.

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