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COLLABORATIVE AGENT-BASED SYSTEM FOR MULTIPLE CRANE OPERATION

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ABSTRACT

Operating cranes in a construction project should meet several requirements of capacity, safety and spatial constraints. Much research has been done about selecting cranes, simulating the work processes, training operators and optimizing working paths to improve the efficiency and reduce conflicts in real construction operations. However, most of the research focused on equipment working individually rather than coordinating multiple works, such as the case of two cranes working together to lift a heavy or large object. The complexity of coordinating equipment requires more detailed planning and better real-time control of the work. The present paper proposes a new approach using artificial intelligent agents to enhance communication between two cranes and resolve distributed problems in the construction industry. A framework is developed to simulate the working environment of two cranes on site. A simulation model is under development using a case study to investigate the feasibility of the proposed approach.

KEYWORDS

Collaborative Agents, Crane Operation, Simulation

1. INTRODUCTION

Most of the materials and components in a construction project are lifted by cranes. It is estimated that one crane upset occurs during every 10,000 hours of crane use. Nearly 80% of these upsets can be attributed to predictable human error when the operator inadvertently exceeds the crane's lifting capacity [1].

Much research has been done about selecting cranes, simulating the work processes, training operators and optimizing working paths to improve the efficiency and reduce conflicts in real construction operations. Commercial software is available for crane selection and path planning [2, 3]. The advantage of visualizing the work is that the user can simulate and check the functional constraints and interferences that may happen in reality between the 3D physical elements and virtual workspaces. However, these simulation tools focus on equipment working individually rather than coordinating the work of several cranes, such as the case of two cranes working together to lift a heavy or large object. The complexity of coordinating equipment requires more detailed planning and better real-time control of the work. Ali et al. [4] have proposed a path planning approach using a Genetic Algorithm (GA) for automating the path planning of two cooperative construction manipulators. Artificial intelligence (AI) research aiming at the creation of unmanned construction systems, capable of performing complex tasks as well as human operators, has been carried out to control construction work on hazardous sites or for space and underwater constructions. These systems have been applied to perform emergency countermeasure and restoration work at disaster sites [5]. It is mentioned that the efficiency of unmanned construction is roughly 60-70% of that of manned construction, but sharply decreases in cases where the machinery moves or high precision work is necessary [5]. For example, collaborative equipment work is a common case in construction where communication and negotiation are essential to properly accomplish the work. Some research involving AI has been done to enhance communication between team workers and resolve problems in the construction industry. The concept of agents in AI refers to relatively independent and autonomous entities, which operate within communities in accordance with complex modes of cooperation, conflict and competition in order to survive and perpetuate themselves [6]. Using agents to plan and coordinate construction activities can simulate the manoeuvring of the equipment and enhance communication to reduce conflicts and improve efficiency. Agent systems have been used for construction claims negotiation [7] and dynamic rescheduling negotiation between subcontractors [8]. However, little research has focused on real-time control for construction equipment operation using agents. Furthermore, activities may need to be carried out in a multi-equipment environment to achieve a specific goal, such as two cranes working together to lift heavy or big objects. Multiple agents can be used to simulate such type of collaborative work. The distributed organization is able to adapt more easily to unforeseen modifications in the environment and, in particular, to possible malfunctions of certain agents [9]. In some cases, re-planning is needed to avoid obstacles that were not considered in the original plan. Once this happens, communication between operators is essential to exchange information and generate new actions based on the individual's knowledge. Multi-agents are able to interactively simulate such kind of re-planning based on negotiation.

In the present paper, a new approach based on collaborative agents is proposed to coordinate construction equipment operation. A multi-agent framework is developed to simulate the working environment of two cranes on site. A simulation model is under development using a case study to investigate the feasibility of the proposed approach. Compared with the previous research for cranes path planning, this method enhances the real-time control based on the perception of the environment.

2. FRAMEWORK

2.1 Framework Structure

Figure 1 shows the framework of an agent-based system for collaborative cranes. Many agents are involved to plan the path and guide the two cranes to finish the task on the worksite. Agents have separate but interdependent tasks to meet their final objective and to carry their work. Every agent has basic functionalities of sending and receiving messages, and decision making. Three major agents are involved: *Crane Agent A*, *Crane Agent B*, and *Site State Agent*.

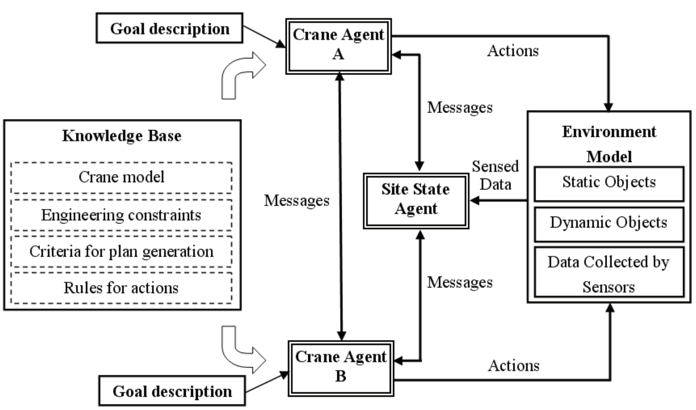

Figure 1 Framework of an Agent-based System

2.1.1 Crane agent

A *Crane Agent* has several low-level agents working together to communicate, detect the position of the crane and plan the path. As shown in Figure 2, the *State Receiver* gets information from sensors about the components' position, such as the boom length, boom swing angle, and other parameters necessary to describe the states of the crane; then, it extracts and transfers data to the *Path Planner*, which is responsible for path planning based on searching possible movement of the crane. The *Controller* is responsible for getting information from the knowledge base and other agents and extracting and transferring data to the *Path Planner*. The information obtained from other agents shows the states of the other crane and the worksite environment, such as whether there is an obstacle on the moving path of the cranes. The *Path Planner* will read the goal descriptions and search the possible path according to predefined rules to avoid the obstacles and meet the constraints imposed either from the engineering or safety aspects. The path decided by the *Path Planner* is sent to the *Controller* to check with the other *Crane Agent* and revise the plan if necessary. After a final path is decided, the *Path Planner* sends the actions to the *Operator*, which translates the actions to lower level actions that can be understood by the crane operator on the site or to automatically operate the crane.

2.1.2 Site state agent

The *Site State Agent* is responsible for collecting states from the crane agents and the work site environment model, including both static and dynamic information. Static information includes geometric, kinematic, and static information of all system components. Most of the previous research has been focusing on path planning with assumptions of the site containing static obstructions [10]. The present work tries to enhance the communication by collecting information from the dynamic world. Therefore, knowing the position of each part of the boom and detecting any obstacle on the moving path is essential to ensure that the work is done properly while meeting the kinematics and engineering requirements. Different sensors can be used to either report the position of the crane [11] or to detect the collisions in real time [12].

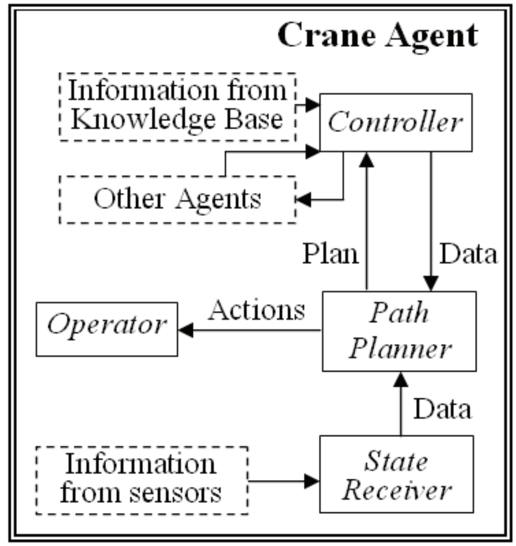

Figure 2 Crane Agent Hierarchy

2.1.3 Knowledge Base

The *Knowledge Base* includes four parts: crane model, engineering constraints, criteria for plan generation, and rules for actions. The crane model has the kinematic constraints for the selected cranes. A loaded crane has a maximum of eight degrees of freedom (DoFs), and path planning for manipulators having more than four DoFs is considered to be complex [13]. The scope of the present work is limited to four DoFs, as shown in Figure 3. The engineering constraints of cranes are mainly from the working range and the load charts. The working range shows the minimum and maximum boom angle according to the length of the boom and the counterweight. Load charts give the lifting capacity based on the boom length, boom angel to the ground and the counterweight. Three major criteria should be taken into account: Lift path clearances, capacity during lift, and ground support during lift. Rules should be developed to represent these constraints which are stored in a database. One important rule is that the distance between two hooks should be equal to the length of the lifted object, and crane load lines must be kept plumb at all times for multiple crane lift [14]. Other rules include avoiding combinations of hoisting and swinging or hoisting and luffing at the same time; and avoiding boom's motion when a crane is traveling.

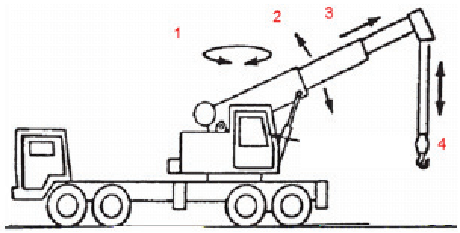

Figure 3 DoFs of a Crane

2.2 Communication between Agents

When several agents are working together, it is necessary to define the relationships between their actions to improve the coordination of these actions and reduce conflicts. Communication between agents is essential for arranging the behaviors of the agents in time and space, which basically requires exchanging messages between agents. KQML (Knowledge Query and Manipulation Language) [15] provides a framework for agents to exchange information and knowledge. It defines the operations that agents may attempt on each other's knowledge bases and provides a basic architecture for agents to share knowledge and information. The messages transferred between crane agents and the *Site State Agent* follow the KQML format (Figure 1). One agent can simply *accept* or *reject* the proposed action from other agents to achieve a shared plan through these messages.

2.3 Collaboration between Agents

Coordination-by-planning technique is the most traditional approach in AI, which is based on breaking the work down into two phases. In the first phase (planning), a set of plans are produced including a set of actions to be carried out by agents. The selection of a correct representation of actions becomes even more crucial than in the planning for a single agent [9]. In the second phase (executing), one plan is selected and then executed. Due to the dynamic environment, re-planning may be needed, which requires real-time information updating and searching a new path based on this information.

3. COMPUTING ASPECTS

Properly represented information is important to avoid complex computation and improve the knowledge acquisition. Parameters are defined to describe the goals, actions and the states. These facts can be used to fire specific rules defined in the Knowledge Base to generate new facts and guide further actions.

3.1 Representation of Goals

The goal of the crane operation can be simply represented by two points related to the load object: origin and destination. Origin (ob, P_o, Φ_o) represents the original position P_o and orientation Φ_o of the object ob. P_o (x_o, y_o, z_o) is given by the coordinates of the reference point of ob. Destination (ob, P_d, Φ_d) represents the destination position P_d and the orientation Φ_d of ob. Duration (t_1, t_2) represents the start time t_1 and the end time t_2 of the work.

3.2 Representation of Actions

Different movements of a crane can be decomposed into a series of actions. Taking a hydraulic crane as an example, the movement of the crane includes the following actions:

Base movement: BaseMove, BaseStop;

Boom movement: BoomRaise, BoomLower, BoomExtend, BoomRetract, BoomSwing;

Hook movement: HookHoist, HookLower, HookStop, HookGrip, HookRelease.

3.3 States Description

States representation is based on the actions taken before. For example, at State j:

ObjectLocation (ob_k, P_{kj}, Φ_{kj}): object ob_k is at position P_{kj} with orientation Φ_{kj};

CraneLocation ($crane_i$, P_{ij}, Φ_{ij}, θ_{ij}, α_{ij}, l_{ij}, P^h_{ij}): crane i is at location P_{ij}, with base orientation Φ_{ij}, boom swing angle θ_{ij}, boom angle to the ground α_{ij}, boom length l_{ij}, and hook position P^h_{ij};

HookGrip ($crane_i$, ob_k): the hook of $crane_i$ is gripping ob_k;

Distance ($hook_i$, $hook_{i+1}$, d_j): the distance between two hooks is d_j;

3.4 Plan Generation

Generating a plan may be seen as a state space search. Most implementations of search algorithms should be assisted by appropriate domain heuristics to find a good/optimal path within a reasonable time [16]. As discussed in the previous section, the kinematic motion requirements and engineering constraints are integrated to generate reasonable plans for each crane. The whole plan can be divided into tasks which consist of sub-tasks or a set of crane actions. Three major tasks category can be defined as: pre-lift task, lifting task, and post-lift task. The pre-lift task includes the actions for positioning the cranes on site and attaching the load to the hook; the lifting task, which is the main body of the work; and the post-lift task, which includes detaching the load and moving to another place. The lifting task combines several sub-tasks, which indicates the milestones on the moving path. These milestones can be used as the target when re-planning is needed to reduce the search time. Each task is fulfilled by taking actions to change the states of the crane. The study of Varghese et al. [17] has shown that no industry-wide standard for heavy lift planning practices exists at present. The experts rely primarily on experience to develop the plans or to perform optimization. Furthermore, collaborative requirements also limit the possible movement of each crane, which reduces the actions that can be taken by agents. In one scenario, one crane agent is given the priority to generate the actions and the partial plans to move the object lifting half of its weight. The other crane agent can follow by taking reactive actions or reject the actions due to its own constraints. Rules are used to check the feasibility of each action. The priorities of an agent may change according to specific rules. Through negotiation, an effective plan can be generated based on possible combinations of movements of cranes from one step to another.

4. CASE STUDY

The re-decking project of Jacques Cartier Bridge in Montreal is used to demonstrate the proposed collaborative agent-based system. The deck of this bridge was replaced during 2001-2002. The existing deck was cut by saw into sections. Each section was removed by two telescopic cranes and a new panel was installed using the same cranes. Figure 4 shows two telescopic cranes lifting a panel.

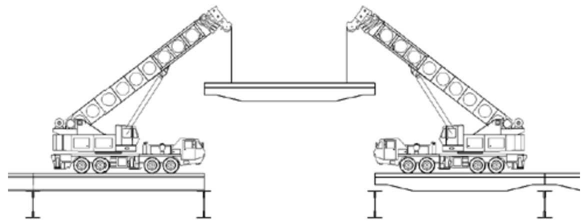

Figure 4 Two Cranes Lifting a Panel [18]

The contractor built a physical model of a part of the bridge and different types of cranes to check the feasibility and to plan the movement of each crane. In the real lifting situation, the operators were guided by a coordinator to ensure the safety and to guide the operations. By repeating the same tasks, the productivity was improved from 1 panel to 6 panels per night. Figure 5 shows the schematic representation of two cranes working together to lift an old section and load it on a trailer.

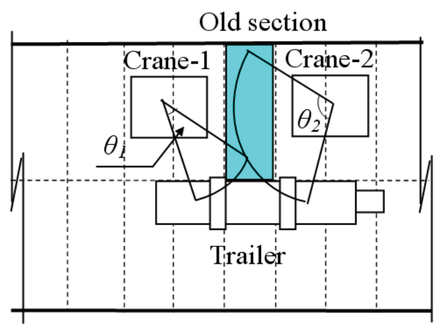

Figure 5 Swing Ranges for Two Cranes

The task shown here can be described by changing only the swing angles of the cranes (θ_1 and θ_2). One possible plan to synchronize the movement of the boom of the two cranes is to define the unit movement of the cranes as θ_1/T and θ_2/T, respectively (T is the duration of the task). A simulation model is under development using Java language to create a virtual environment including the work site, the bridge structure and two virtual cranes. Transformation matrices are used to specify the relative location of each component of the cranes with respect to its parent. Load charts and working ranges are retrieved from a database to control the cranes' movement. A preliminary test is under development to facilitate the communication between two agents representing the two cranes.

5. CONCLUSIONS

This paper described a framework of multi-agent system for collaborative cranes on construction site. Agents are used to plan and execute the work on site by communicating with each other and making decisions for actions based on negotiation. Computing aspects are discussed for representing the goal, actions, and states and for path planning. A simulation model is under development using a case study about a bridge rehabilitation project where two cranes were working together to lift a panel with a height constraint from the bridge structure. The preliminary test shows the feasibility of the proposed approach. Future work will focus on further developing and testing the system. -

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