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Localization, obstacle avoidance planning and control of a cooperative cable parallel robot for multiple mobile cranes

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ABSTRACT

This paper addresses the cooperative problems in terms of localization, obstacle avoidance planning and automatic leveling control for a cable parallel robot for multiple mobile cranes (CPRMCs). The design model of the CPRMCs is elaborated on. The three-dimensional grid map method is utilized to plot the environment map based on the operation environment model. By combining the relative localization method with the absolute localization method, a cooperative localization scheme of the CPRMCs is developed, and an improved localization algorithm is designed on the basis of multilateration method. Then, according to the grid-based artificial potential field method, a global path planning of the CPRMCs is performed. Considering the possible collision of the single mobile crane, the sensor technology is applied to the cooperative obstacle avoidance. In addition, a four-point collaborative leveling method is adopted for automatic leveling control of the platform of the CPRMCs. Finally, the effectiveness of the CPRMCs system is verified through simulations.

1. Introduction

During the last few decades, mobile cranes have become an essential part of modern construction and manufacturing, such as loading, mounting, carrying large heavy-duty loads for the construction of the factory, railway, port, mine, power equipment, etc. Compared to other types of cranes, mobile cranes are of better mobility performance and load carrying capacity. The fast developing construction and manufacturing bring new challenges for the comprehensive performance and lifting strategy of mobile cranes, including the increasing requirements for construction quality, safety and efficiency. In recent years, cooperative multiple robotics are an active research domain, in which the problem of the implementation of cooperative manipulation on conventional set-ups has attracted an increasing interest of the researchers [1].

Actually, cooperative operation of multiple mobile cranes has been applied in a number of modern construction projects, such as the one shown in Fig. 1, which can be treated as the CPRMCs. Therefore, the CPRMCs can take the advantages of the characteristics of both mobile cranes and cable parallel robots (CPRs).

Manipulating objects with cables instead of rigid links, the CPRs are a promising alternative to traditional rigid-link parallel mechanisms. The CPRs are of simple and light-weight structure, large reachable workspace, high acceleration capability and good reconfigurability [2,3]. Different aspects like time optimal trajectory tracking [4], workspace [5,6], integrated mechanism design and control [7], and design of a new CPMs for large-scale manipulation [8] were investigated extensively. In addition, due to their extended capabilities, multiple robot manipulators have attracted a lot of attention.

For instance, Jiang and Kumar [9] addressed the kinematics of cooperative transport of payloads suspended by multiple aerial robots with cables, and study the stability of all equilibrium configurations of the robots. Sladek et al. [10] proposed a description of coordinate measuring arms with the use of kinematic parameters. Bozma and Kalalioglu [11] considered the problem of multirobot coordination in pick-and-place tasks on a conveyor. Renzaglia et al. [12] proposed a new method for dealing with the problem of the surveillance coverage in unknown terrain of complex and non-convex morphology. Wang et al. [13] presented a machine learning approach for object transportation by utilizing multiple cooperative and autonomous mobile cranes. Zi et al. [14] developed and analyzed a cooperative cable parallel manipulator for multiple mobile cranes with 6 degrees of freedom. Senthilkumar and Bharadwaj [15] investigated multi-robot exploration and terrain coverage in an unknown environment.

A cost-effective, safe, and compliant solution for the operation of the CPRMCs is the urgent need to reach potential advantages of both mobile cranes and the CPRs. And there are still some important unresolved problems. In particular, cooperative localization technology is fundamental to cooperative robotics within the unknown

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Nomenclature

p	position and orientation of the CPRMCs
v	velocity of the CPRMCs
θ	posture direction of the CPRMCs
θ'_n	orientation of the mobile crane
C	propagation velocity of the ultrasound in air
Δt_i	time interval of the ith ultrasonic receiver and transmitter
T	the ambient temperature
Δl_i	difference between the measured and calculated distance
D_i	distance between the estimate coordinate and the ith ultrasonic receivers
D'_i	distance between the exact coordinate and the ith ultrasonic receiver
F_1	offset between the exact position and estimated position
L	distance between the CPRMCs and the obstacle
P	workspace
$B_{obstacle}$	obstacle space
B_{free}	free space
$B_{obstacle}(i)$	each individual grid obstacle
F_{att}	gravitation of potential field
F_{rep}	repulsion of potential field
F_R	resultant force of potential field
W	position of mobile crane
Q_W	position and direction of mobile crane
$U(Q_W)$	virtual potential energy
$U_{att}(Q_W)$	attracted potential energy
$U_{rep}(Q_W)$	exclusion potential energy
$\nabla \boldsymbol{U}(Q_W)$	gradient vector of Q_W
$\overline{\boldsymbol{F}}_{att}(Q_W)$	gradient of F_{att}
$\overline{\boldsymbol{F}}_{rep}(Q_W)$	gradient of F_{rep}
$\overline{\boldsymbol{F}}_R(Q_W)$	gradient of F_R
ζ	gravitational potential field constant in the electrostatic field
Δl_{W-G}	distance between $W(x, y)$ and $Goal\ (x_{goal}, y_{goal})$
ξ	repulsion potential field constant in the electrostatic field
Δl_{W-B}	distance between $W(x, y)$ and $B_{obstacle}(i)$
Δl_k	the farthest influencing distance of individual grid obstacle
$\hat{U}_{rep}(Q_W)$	resultant exclusion potential energy of all grid obstacles in potential field
$\hat{F}_{rep}(Q_W)$	resultant repulsion force of all grid obstacles in potential field
ϕ	orientation of the platform
$\boldsymbol{R}(\phi)$	transformational matrix
α	roll angle of the platform
β	pitch angle of the platform
γ	deflection angle of the platform
l_i	distance between the four top points and the ground
$\bar{l}$	height of the mid-point datum
Δl_i	difference between the measured and calculated distance
l_a	length of the platform
l_b	width of the platform
l_c	height of the platform
h	distance of the points B_1, B_2, B_3, B_4 to the ground
Δd_i	error of the actual length before and after leveling
K_p	proportional gain
K_i	integral gain
K_d	differential gain
T_k	the kth sampling period

environment [16], which has been widely used in different applications including but not limited to tracking automated guided vehicle, robot navigating and large scale metrology [17–19]. Considering the positioning control problem in robot applications, localization is meaningful for data aggregation, velocity estimation, and geographic-aware routing, so robots cannot effectively carry out a task without the location information [20,21]. Then, based on cooperative localization, the CPRMCs is expected to traverse the path to desired goals within an obstacle-ridden environment [22]. Taking the safety factors for the CPRMCs into consideration, there are two crucial requirements in terms of obstacle avoidance planning and automatic leveling control. Thus, the robots can avoid collision with obstacles that exist in its environment [23–25]. In addition, automatic leveling control can help the CPRMCs to prevent the overturning of cargo platform caused by the asynchronous of each single mobile crane, and keep the stability and improve the accuracy of the whole system [26].

The major contribution of this paper includes three aspects: (1) design model and cooperative localization scheme of the CPRMCs are presented, and an improved localization algorithm is designed based on multilateration method; (2) the global path planning of the CPRMCs is performed with the grid-based artificial potential field method, and the sensor technology is applied in the cooperative obstacle avoidance, and a co-simulation of Matlab and LabVIEW is carried out for cooperative obstacle avoidance analysis; and (3) a four-point collaborative leveling method is adopted for automatic leveling control of the platform for the CPRMCs.

Fig. 1. Multiple mobile cranes.

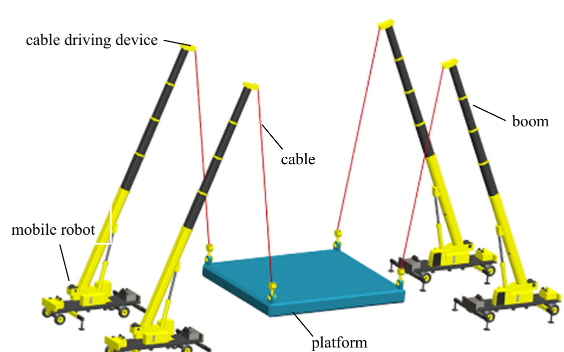

Fig. 2. Three-dimensional model of hoisting multi-mobile robots system.