An Efficient Ant Colony System for Multi-Robot Task Allocation with Large-scale Cooperative Tasks and Precedence Constraints

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南開大學 Nankai University

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College of ArtificialIntelligence

Multi-Robot

Environment Monitoring

Logistics

Multi-Robot

Disaster Rescue

Support in Healthcare Facilities

Extraterrestrial Exploration

compared to single-operating robots

Multi-Robot

Decrease task complexity
Enhance system reliability

Multi-Robot

Multi-Robot Task Allocation

Multi-Robot Task Allocation

Market-Based
Optimization-Based

Multi-Robot Task Allocation

Market-Based

Optimization-Based

Small-Scale

without Precedence Constraints

Multi-Robot Task Allocation

Large-Scale
Complex Precedence Constraints

Multi-Robot Task Allocation

Large-Scale
Complex Precedence Constraints

Ant Colony System

Multi-Robot Task Allocation

Ant Colony System

Up to **50%**

better than the state-of-the-art Neighboring Heuristic methods

Tasks

$t_1, \ldots, t_m$

Tasks $t_1, \ldots, t_m$

Robots $r_1, \ldots, r_n$

Tasks $t_1, \ldots, t_m$

Robots $r_1, \ldots, r_n$

Alliances

$\{r_1\}, \{r_2\}, \{r_3\}, \{r_1, r_2\}, \{r_1, r_3\}, \{r_2, r_3\}, \{r_1, r_2, r_3\}$

Tasks $t_1, \ldots, t_m$

Cost *robot alliance* a_j *to execute task* t_i

Alliances

Robots $r_1, \ldots, r_n$

$\{r_1\}, \{r_2\}, \{r_3\}, \{r_1, r_2\}, \{r_1, r_3\}, \{r_2, r_3\}, \{r_1, r_2, r_3\}$

$$\begin{bmatrix} c & \cdots & c \\ \vdots & \ddots & \vdots \\ c & \cdots & \infty \end{bmatrix}$$

precedence constraint

Neighboring Heuristic method

Neighboring Heuristic method

$$\textit{minimize}\ f(S) = FT(S) + w \times (TR(S) + FR(S))$$

Scheduling Solution

$$f(S) = FT(S) + w \times (TR(S) + FR(S))$$

latest Finishing Time

$$f(S) = FT(S) + w \times (TR(S) + FR(S))$$

average Traveling Time

$$f(S) = FT(S) + w \times (TR(S) + FR(S))$$

average Finishing Time

$$f(S) = FT(S) + w \times (TR(S) + FR_{(S)})$$

$$0.001$$

$$f(S) = FT(S) + W \times (TR(S) + FR(S))$$

Proposed method

Ant Colony System

Ant Colony System

Solution Encoding

dim	1	2	3	4	5	6	7	8	9	10
value	(1, 1)	(2, 4)	(3,5)	(4,6)	(5,2)	(6,3)	(7,7)	(8,4)	(9,5)	(10,5)

Ant Colony System

Hierarchical Greedy Strategy

$$\tau_0 = (m \times f(S_{greedy}))^{-1}$$

Ant Colony System

Hierarchical Greedy Strategy

State Transition Rule

$$a_j = \begin{cases} \arg\max_{a_h \in A_{t_i}} \tau_{ih} \eta_{ih}^{\beta}, & \text{if } q \le q_0 \\ J, & \text{otherwise} \end{cases}$$

Ant Colony System

Hierarchical Greedy Strategy

State Transition Rule

Local Updating Rule

$$\tau_{ij} = (1-\rho)\times\tau_{ij} + \rho\times\tau_0$$

Ant Colony System

Hierarchical Greedy Strategy

State Transition Rule

Local Updating Rule

Global Updating Rule

$$\tau_{ij} = (1-\alpha) \times \tau_{ij} + \alpha \times \Delta\tau$$

$$\Delta\tau = (f(S_b))^{-1}$$

Ant Colony System

Hierarchical Greedy Strategy

State Transition Rule

Local Updating Rule

Global Updating Rule

Heuristic Information

$$\eta_{ij} = \left(\max_{r_l \in a_j}(st(r_l) + tt(r_l)) + c(t_i, a_j)\right)^{-1}$$

$$tt(r_l) = dist(p_{t^l_{o-1}}, p_{t_i}) / v_{r_l}, \quad t^l_{o-1} \in L_l \wedge t^l_o \in L_l \wedge t^l_o = t_i$$

Ant Colony System

Hierarchical Greedy Strategy

State Transition Rule

Local Updating Rule

Global Updating Rule

Heuristic Information

Iterations

Experiment

16

Instances

16 Instances

100 or 200 Tasks

4 or 10 Task Types

3 or 5 Robot Types

7 or 31 Robot Alliances

Ant Colony System

Parameters

Parameters

20 *Size* 0.7 q_0 0.4 α 0.4 ρ 2.0 β

500 *Iterations* 20 *Runs*

10000 *Evaluation Times*

Experiment Results

Problem	*m*	NHM	ACS			
			average	std	min	max
P1	100	30495.6	29008.5	217.209	28601.7	29363.7
P2	100	40719.0	39403.4	348.049	38868.5	40152.5
P3	100	42812.8	31944.2	103.964	31722.4	32156.8
P4	100	9931.5	8625.5	76.634	8443.6	8740.6
P5	100	7901.1	7764.4	43.219	7680.2	7821.6
P6	100	8260.1	8141.4	28.856	8095.3	8194.9
P7	100	9465.3	7807.8	47.767	7716.0	7895.1
P8	100	20705.7	14019.1	18.276	13983.7	14052.9
P9	200	33949.4	27919.4	430.782	27066.1	28345.4
P10	200	16393.4	15007.5	84.133	14828.5	15140.3
P11	200	16907.1	16379.7	90.799	16191.8	16551.0
P12	200	26284.5	16969.2	93.909	16774	17145.6
P13	200	32085.9	16275.5	84.001	16044.7	16373.7
P14	200	16607.6	16534.4	80.244	16379.3	16671.4
P15	200	21732.2	16160.3	79.771	15924.8	16268.5
P16	200	16862.7	15288.9	60.826	15176.7	15388.7

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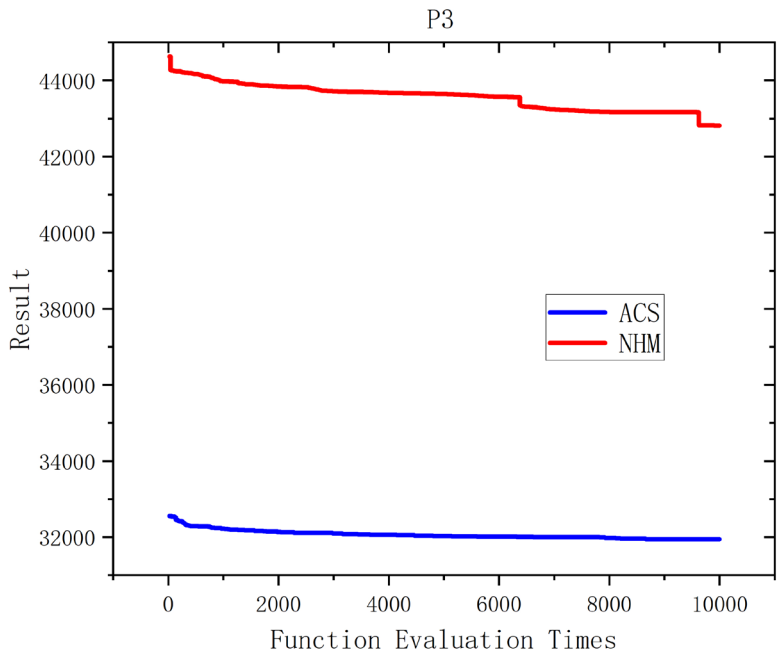
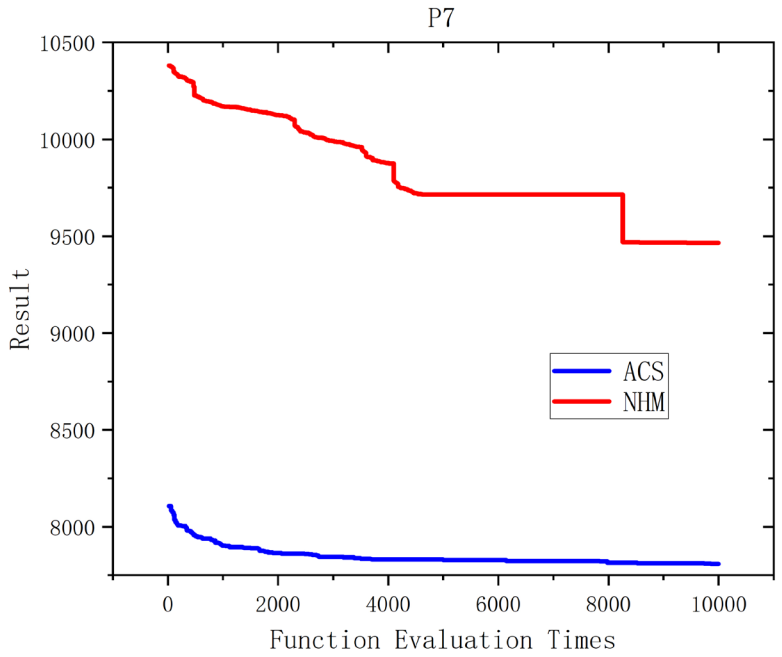
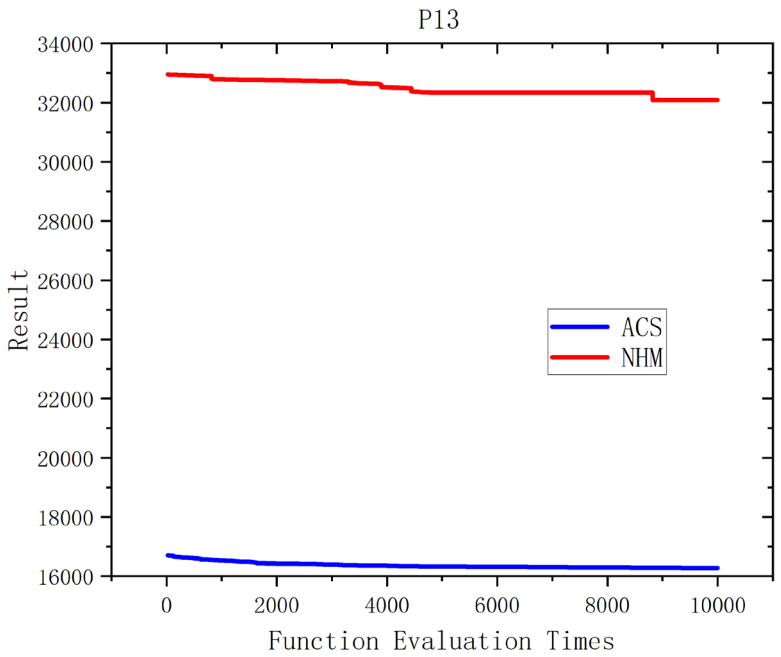
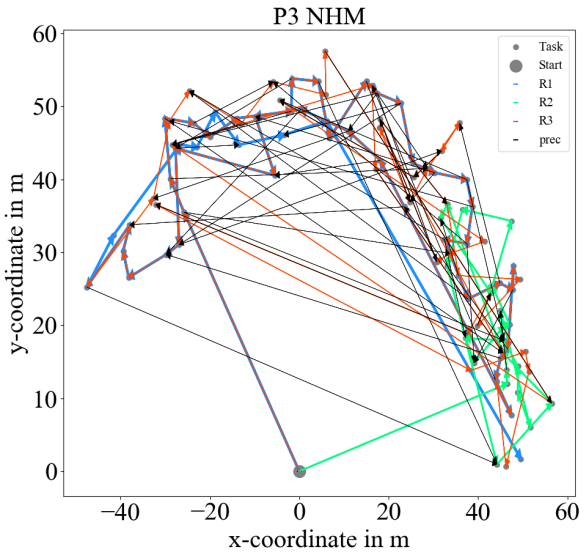
Convergence Curves

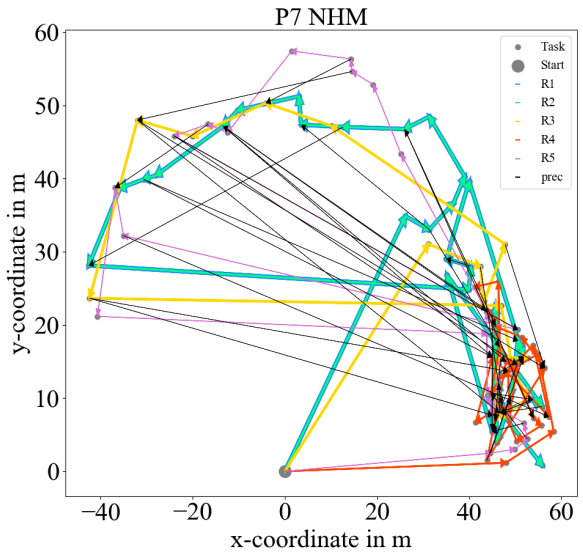


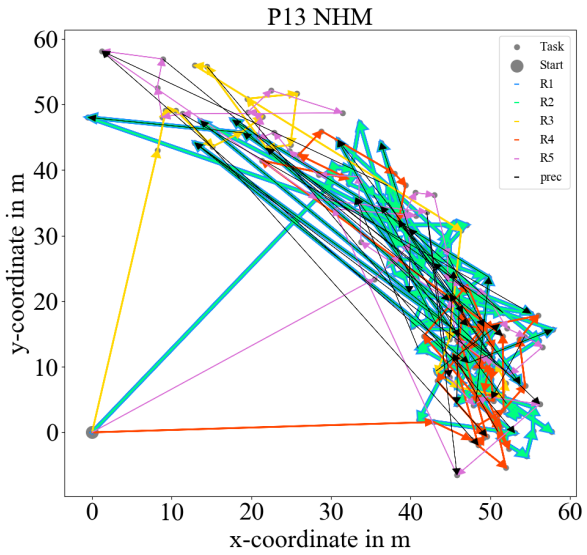


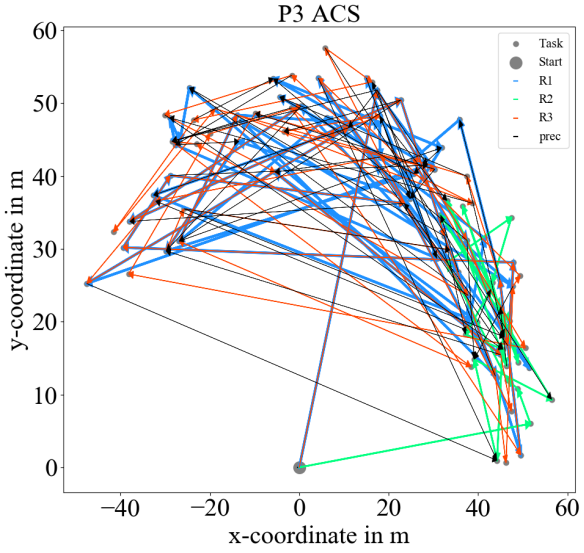


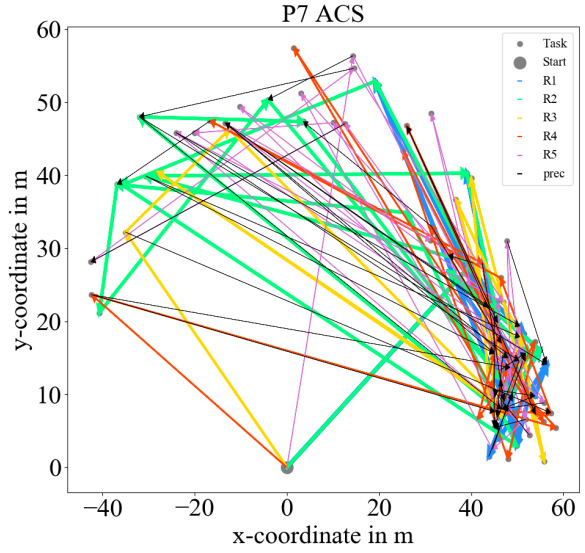
Task Paths

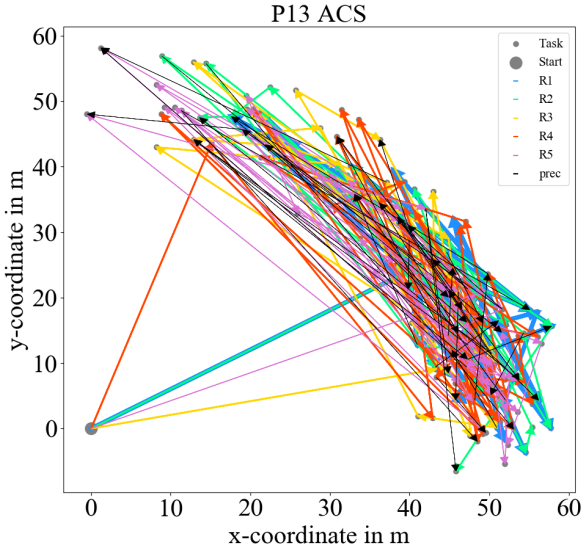

P3 NHM
Task
Start
R1
R2
R3
prec
y-coordinate in m
x-coordinate in m


P7 NHM
Task
Start
R1
R2
R3
R4
R5
prec
y-coordinate in m
x-coordinate in m

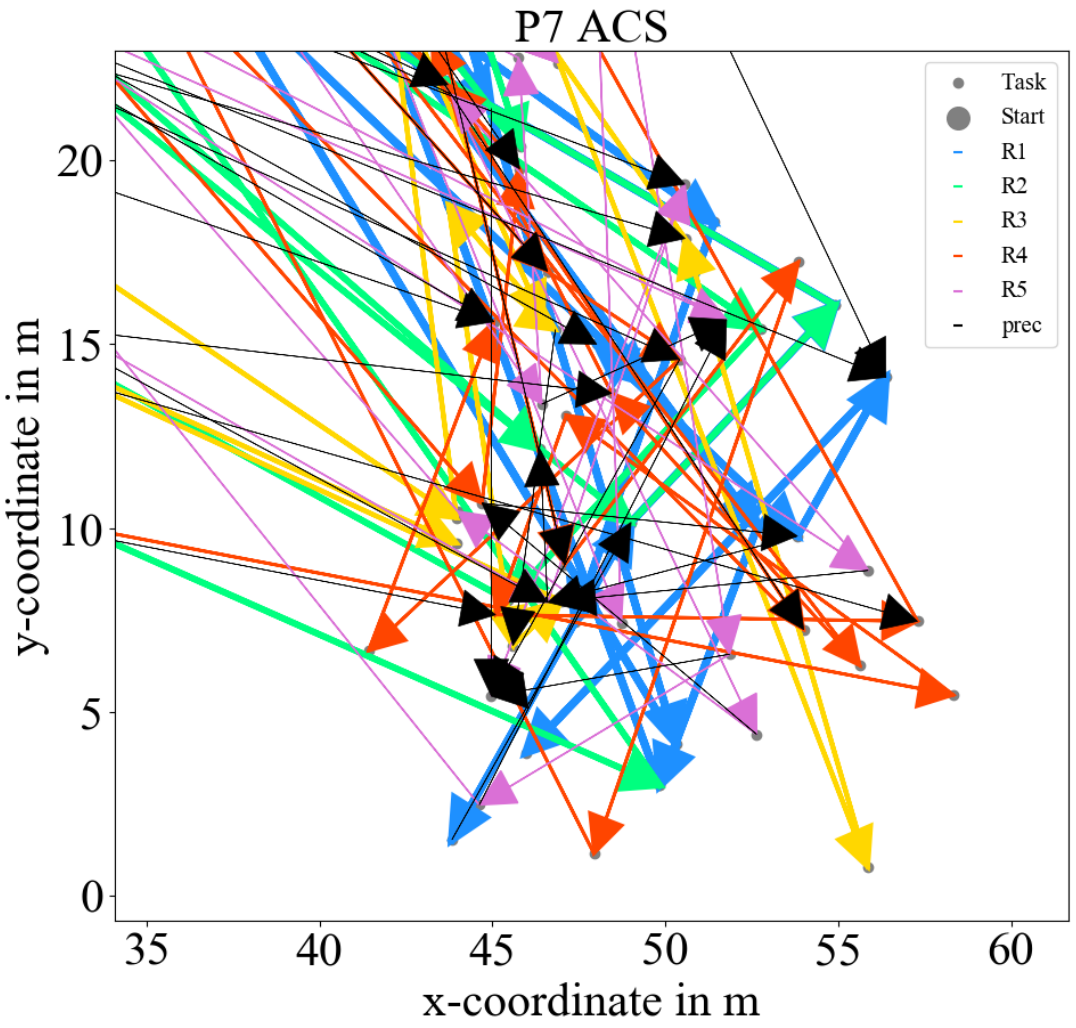

P13 NHM
Task
Start
R1
R2
R3
R4
R5
prec
y-coordinate in m
x-coordinate in m

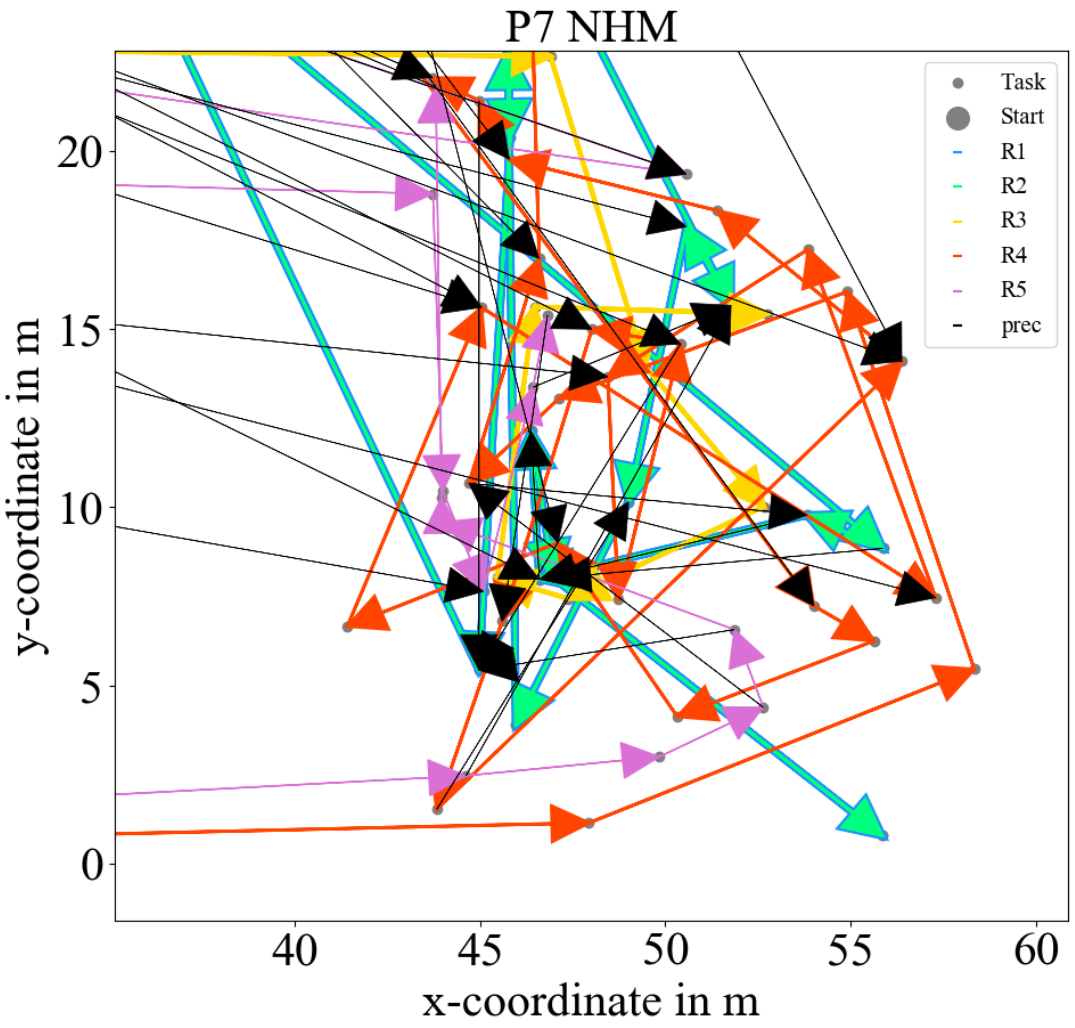

P3 ACS
Task
Start
R1
R2
R3
prec
y-coordinate in m
x-coordinate in m


P7 ACS
Task
Start
R1
R2
R3
R4
R5
prec
y-coordinate in m
x-coordinate in m


P13 ACS
Task
Start
R1
R2
R3
R4
R5
prec
y-coordinate in m
x-coordinate in m

Task Paths


P7 ACS
Task
Start
R1
R2
R3
R4
R5
prec
y-coordinate in m
x-coordinate in m
0
5
10
15
20
35
40
45
50
55
60


P7 NHM
Task
Start
R1
R2
R3
R4
R5
prec
y-coordinate in m
x-coordinate in m
0
5
10
15
20
40
45
50
55
60

Conclusion

Multi-Robot Task Allocation

Large-Scale
Complex Precedence Constraints

Multi-Robot Task Allocation

Proposed method

Ant Colony System

Up to **50%**

better than the state-of-the-art Neighboring Heuristic methods

Multi-Robot Task Allocation

Proposed method

Significantly Better

Up to **50%**

better than the state-of-the-art Neighboring Heuristic methods

THANKS

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