International Conference on Information Engineering, Management and Security
2015 [ICIEMS 2015]

ISBN	978-81-929742-7-9		**VOL**	01
Website	www.iciems.in		**eMail**	iciems@asdf.res.in
Received	10 - July - 2015		**Accepted**	31- July - 2015
Article ID	ICIEMS023		**eAID**	ICIEMS.2015.023

Study of an Orchestrator for Centralized and Distributed Networked Robotic Systems

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Abstract: *This paper presents an Orchestrator, developed for execution of given tasks on robotic nodes. The tasks execute in two modes, parallel and sequential. The orchestrator assigns task to multiple sets of robotic nodes. The nodes of a set perform the assigned tasks either synchronously or in parallel. Each set divides the given task in subtasks and each subtask further performs on different robotic nodes sequentially. Each robot has unique address. Robots possess capability to interact with each other using RF radio. Networked controlled robots (NCRs) imbibe two addition properties—fault tolerance and greater system efficiency. The experimental results of study of orchestration are also presented using the Orchestrator.*

Keywords: Robotics, Orchestration, Networks and Distributed Tasks.

I. INTRODUCTION

Networked controlled robots are subject to research in recent years. They find uses in civil, military and space applications. This research focuses on two types of NCRs, centralised and decentralised. A Robotic Systems' Network is a group of artificial autonomous systems which are mobile. The systems communicate among themselves either directly as in case of distributed network robotic systems [1] or through a central controller in case of centralised network robotic systems. Distributed autonomous robots are designed to perform collaborated mission [2], whose success depends on communication between individuals. Therefore, robots count sufficient knowledge of the network connectivity, and exploit this knowledge in order to best maintain the network connectivity while performing other tasks [3-5]. A broad challenge is to develop a model architecture that couples communication with control to enable such new capabilities, like Cloud Robotics, Global localization in Mobile Robot, Fleet management, Assert tracking and Covert surveillance [6, 7]. Orchestration deploys elements of control theory [8]. The usage of orchestration has been studied earlier in context of the service oriented architecture, virtualization, provisioning, converged infrastructure and dynamic data centre [9]. One service may be realized using orchestration through the cooperation of several services. Orchestration can also be defined as a type of cooperation in which the one service directly invokes other services. A new approach "Robotic Orchestration" is introduced, in this paper, which has advantages and minimum disadvantages of both approaches. An Orchestrator controlled robotic network performs Robotic Orchestration. It describes the automated arrangement, coordination, the management of complex robotic systems, and the services. The work focuses on developing a Robotic Orchestrator (Coordinator). This Orchestrator is able to invoke and coordinate other services by exploiting typical workflow patterns such as parallel composition, sequencing and choices or a manager which

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controls and coordinates the functions and roles of the nodes (Slave robots). Orchestrator organizes and manages a set of activities in a network. Orchestrator assigns service to a robotic node. A robotic node performs the given service and after completing the service messages to the Orchestrator about the service completion. The paper is organised as follows. Section II presents the basic problem statement. Section III describes the hardware developed. Section IV gives the experimental results. Conclusions derived from the present study are given in Section V.

II. PROBLEM FORMUATION

This section describes the task flow pattern in network robotic system. Figure 1 shows the task flow pattern. The results of three coordinating ways are compared, after introduction of the task flow pattern and defining the experimental procedure.

Let *H* denote a set of *k* heterogeneous robots, and *T* denote a set of *n* tasks, that is,

$$H = \{h_1, h_2, \ldots, h_k\}, \quad (1)$$
$$T = \{t_1, t_2, \ldots, t_n\}. \quad (2)$$

The tasks are assigned to robotic node on fixed time interval like $(t_{s1}, t_{s2}, \ldots.)$ and Ts_i define the set of time interval,

$$Ts = \{t_{s1}, t_{s2}, \ldots, t_{sn}\}. \quad (3)$$

Each time slots are equal $t_{s1} = t_{s2} = \ldots, = t_{sn}$.

Also, let *A* denote the allocation

$$A = \{a_1, a_2, \ldots, a_k\}, \quad (4)$$

where a_s is a cluster of tasks,

$$\bigcup_{s=1}^{k}(a_s) = T, \quad (5)$$

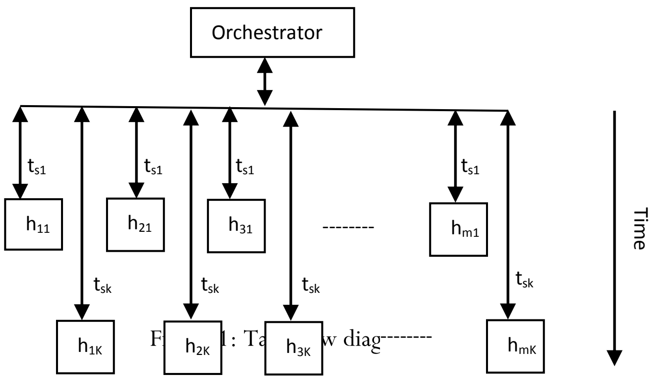
$$a_s \cap a_t = \emptyset, (s \neq t), \quad (6)$$

and the cluster a_s is assigned to robot h_s.

The cost associated with *A* is given by [10]

$$C(A) = \sum_{s=1}^{k} c_s(a_s) \quad (7)$$

where $c_s(a_s)$ is the minimum cost for robot h_s to complete the set of tasks a_s. In practice the cost function in (7) might be used to represent the total distance traveled or the total energy expended by the robots.



Robotic Orchestration in a networked robotic system is performed by defining a task of Robotic Relay Racing (RRR). RRR is similar to human relay racing in Olympics games. The two standard relays are the 4x100 meter relay and the 4x400 meter relay. A 4x400 relay race is a race in which four runners of each teams completes race between starting point to end point. Generally 4x400 relay starts in lanes for the first runner and first runner handoff the baton to second runner after first 100 meter. The second runner handoff the baton to third runner after second 100 meter and so on. The last runner completes the race to the finish line.

The Robotic relay race uses similar rules but some variation. The master (Robotic Orchestrator) controls the race. Each slave (Robotic node) takes command from orchestrator and after performing task give reply to orchestrator. The nodes are unable to communicate with each other.

The Robotic Relay Racing (RRR) is demonstrated by Figure 2. Here one Orchestrator (master) and four Robotic nodes (RN) are used to perform the experiments. The RN is divided in two groups '1' and '2' and each group has two members. The group '1' members are 1a and 1b, group '2' members are 2a and 2a. When Orchestrator starts the race 1a and 2a starts moving on and after reaching their finishing line both RN passing baton to their team members. Now RN 1b and 2b continue the race up to finishing line.

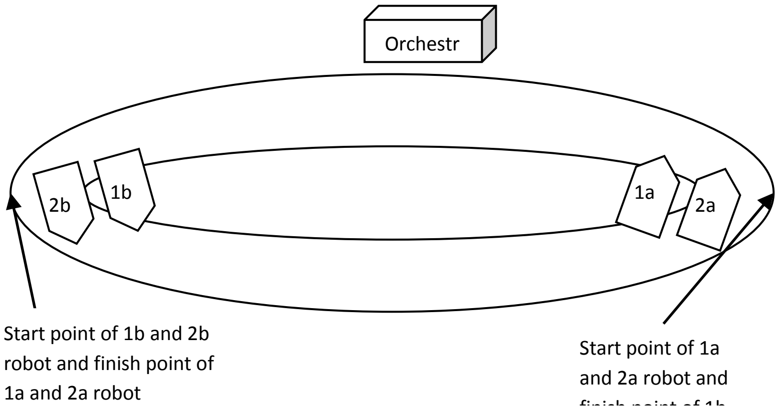


Figure 2: Robotics Relay Racing for Orchestrator control Robotic node.

The RRR experiment is performed by all three approaches discussed in this paper. The parameters used in experiments are shown by Table 1. The comparison is made by measuring the following three parameters.

1. Number of message passing in robotic network to perform given task.
2. Execution time of task.
3. Bandwidth for communication.

The approaches below have also been followed by other researchers [10-13] but not for Robotic Orchestration.

Experiment 1: Centralized RRR is performed under the following points.

1. The RN cannot communicate to each other directly. They can communicate to each other only through master.
2. All RN are using a single communication channel.
3. The master have task plan for each RN.
4. Each RN performing given task under monitoring of master.

TABLE I.
PARAMETERS USED FOR EXPERIMENTS.

S. No.	Parameters	Units
1	Number of robots	4 slave and 1 Master
2	Track Length	10m
3	Communication Range of Robots	12m
4	Max. Achievable speed of robots	$0.5ms^{-1}$
5	Normal speed of robots	$0.2\ ms^{-1}$
6	Min. Distance between robots to avoid collision	0.3m
7	Max. distance between robots to keep on track	1.1m

Experiment 2: Decentralized RRR is performed under the following points.

1. All RN communicate to each other through separate channel.
2. Each RN must know status of each of other RN in network to perform the collaborate mission.
3. The master only initiates the task. After that, the RN collaboratively performs the given task.

Experiment 3: Orchestrator RRR is performed under the following points.

1. The orchestrator only assigns the tasks and monitors the status of task.
2. The task plan is preloaded in RN similar to a musical orchestra member.
3. The RN has limited communication capability to each other.
4. Each RN has two communications channel, one for Orchestrator and other for group member.

III. HARDWARE DISCRIPTION

Intel Galileo Gen 2 development board is shown in Figure 3(a) which is used for designing Orchestrator and RN. It is based on the Intel QuarkSoC X1000, a 32-bit Intel Pentium processor-class system on a chip (SoC), the genuine Intel processor and native I/O

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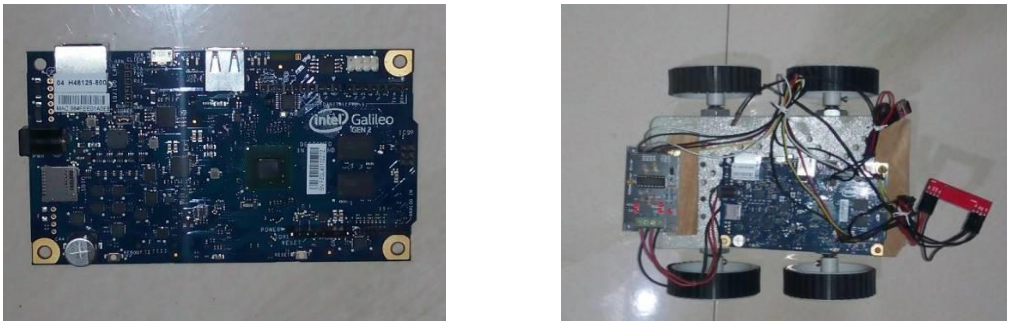
capabilities of the Intel Galileo board (Gen 2) provides a full-featured offering for a wide range of applications. The Intel Galileo Gen 2 board also provides a simpler and more cost-effective development environment compared to the Intel Atom processor- and Intel Core processor-based designs. The Intel Galileo board (Gen 2) is an open source hardware design [14].

The Orchestrator explained in Figure 2 is shown in Figure 3(b). RN ‘1a’ and ‘1b’ are shown in Figure 4(a) and RN ‘2a’ and ‘2b’ are shown in Figure 4(b). An Orchestrator is two wheel drive robot. Orchestrator uses two 60 rpm, 12V DC motors as a power train. The RF radio (TX/RX) is used for communication in robotic network. This radio frequency (RF) transmission system employs Amplitude Shift Keying (ASK) with transmitter/receiver (Tx/Rx) pair operating at 434 MHz. The transmitter module takes serial input and transmits these signals through RF. The transmitted signals are received by the receiver module placed away from the source of transmission.



(a) (b)

Figure 3: (a) Intel Galileo Gen 2 board. (b) Robotic Orchestrator for Robotic relay racing.

(a) (b)

Figure 4: Robotic nodes for Robotic relay racing. (a) Robotic node 1a and 1b. (b) Robotic node 2a and 2b.

IV. EXPERIMENTAL RESULTS

The experiments are performed for all three approaches according to the predefined points. Results are explained by three graphs. The graph in Figure 5(a) shows the task execution time for all three approaches. The centralized approach takes 90 second to complete the given task, distributed approach takes 55 second and orchestrator approach takes 56 second to complete the given task. The graph in Figure 5(b) shows number of message passing in network between RN and master for completing the task. The centralized approach passes 13 messages, distributed approach passes 8 messages and orchestrator approach passes 9 messages to complete the given task. Figure 5(c) shows number of communication channel required for completing the task according to predefine statement made.

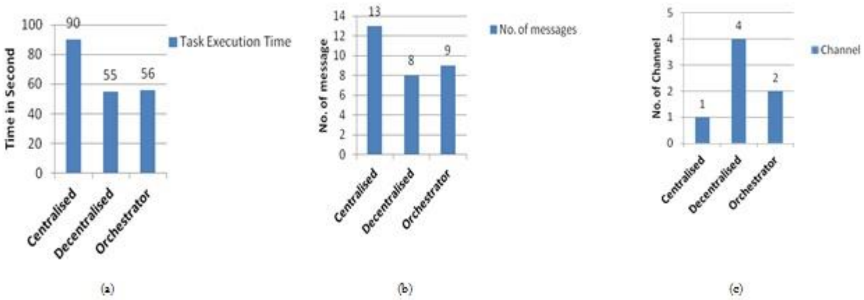


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Figure 5: (a)Task execution time of all three approaches in second,(b)Number of message during task execution in all three approaches, (c) Number of communication channels used in all three approaches.

V. CONCLUSION

Experimental results show that the centralised approach has advantage of communication bandwidth but takes more time to execute the given task. This is because of number of messages passed in network is large. The decentralised approach executes the given task fast due to lesser accesses to communication channels. This reduces the communication overhead. The Orchestration approach lies between these two approaches. Orchestration reduces the number of messages passing on network robotic system and also reduces the task execution time.

The centralised approach has strong dependency on master. If master fails due to some reason the robotic system network is unable to complete the task. While in orchestration approach, each RN knows its task, so replacing an Orchestrator is not a tedious job. The orchestration approach in robotic is good for military control operation, disaster management and other areas. These applications need a monitoring authority for completing task. The task can be modified during the execution, whereas, modification is not possible in decentralised approach.

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