A Bio-Inspired, Distributed Control Approach to the Design of Autonomous Cooperative Behaviors in Multiple Mobile Robot Systems

Gen'ichi Yasuda
Nagasaki Institute of Applied Science, Japan

INTRODUCTION

This chapter concerns the design and implementation of bio-inspired control architectures for intelligent multiple mobile robot systems. In a multi-robot system, robots work together efficiently to accomplish tasks intrinsically distributed in space, time, or functionally. Due to the cost of increasing system complexity especially in control and communication, it is difficult to implement a centralized controller for multi-robot systems under unknown dynamic environments (Khoshnevis & Bekey, 1998; Klavins, 2003). Focusing on building control systems for intelligent mobile robots, this chapter presents a non-centralized, behavior-based methodology for autonomous cooperative control, inspired by the adaptive and self-organizing capabilities of biological systems, such as turning over behavior of starfishes (Suzuki, et al., 1971), which can generate robust and complex behaviors through limited local interactions in the presence of large amount of uncertainties (Pfeifer et al., 2007; Salazar-Ciudad et al., 2000; Shen et al., 2004).

Traditionally, the fundamental feature of asynchronous concurrent processes in robot control systems was already employed in the control system design as a centralized control, where a single multitask operating system controls different programs, or processes, to be performed concurrently, such as locomotion control, environment recognition, path planning, decision making in uncertain environments, etc. under a set of timing requirements. From the view of asynchronous concurrent processes, modularity and localization of control are critical issues in control system design. Thus, in this chapter, the distributed control architecture, based on discrete event systems as a formal approach, is configured as a collection of asynchronous, concurrent processes in a hierarchical but non-centralized way, and consequently it can be developed in such a way to reduce the programming requirements. While actuator and sensor controls, such as vehicle control and image processing, are prerequisite at the lowest control level, a unified and systematic methodology has been developed to combine given techniques for controlling the robot motion and for integrating sensory information at some higher control levels, into one complete robot control system for real-world robotic applications.

Asynchronous concurrent processing on parallel distributed architecture can support the coordination between the global intelligence or control center and the set of local centers as well as among local centers (Alon, 2006; Kondacs, 2003; Taylor, 2014), where each local center supports at least one robotic module and each module is governed by only one local center. The channel between two local centers is also open for emergent responsive motions. The object-oriented concept can be employed to support the system requirements for modularization of robot intelligence including the reconfiguration of global-local interaction through parallel distributed processing, utilizing the traditional technique in spatial and kinematic

DOI: 10.4018/978-1-5225-2255-3.ch592

planning, and dynamic control as building blocks (Werfel, 2004). Thus, the distributed autonomous control system design based on asynchronous concurrent processing would provide the necessary flexibility to overcome some of limitations of current intelligent mechatronic system design. Furthermore, the flexibility for different tasks and control environments can be increased, by integrating various robots and components into systems in a heterogeneous robot environment where each robot has its own kinematic structure and programming language.

This chapter describes the hierarchical task specification in terms of event driven state based Petri net modeling (Yasuda, 2014), where the robotic task model is hierarchically decomposed into subtasks in such a manner that every subtask, represented as a subnet of the task specification net model, is assigned to a local module, based on the geographical distribution of the local centers.

BACKGROUND

The control of autonomous robots evolves from the control of an individual robot to the self-coordination of a group of robots that interact and function together to form a social group, where the interactions among robots can produce behaviors that no single robot can accomplish without the other individual robots. In recent studies focusing on cooperation of distributed autonomous multiple robot systems, the cooperation strategy is mostly based on distributed problem solving and distributed decision (Shi et al., 2012), like a human individual, considering each of these robots as an agent in the social interaction. The behavior of a robot can extend beyond itself to include other individual robots. However, a robotic task is considered as a succession of many primitive reactive behaviors or actions, each activated with some events or external sensing information. For example, in collision avoidance among mobile robots and transporting many discrete litters by multiple robots, each robot gets some information about other robots by communication, and then uses the information for making a distributed decision. Collective execution of cooperative tasks with dynamic constraints, such as large object manipulation, may have more dynamic factors. Because the robots which are working on manipulation, interfere each other dynamically through the manipulated object, the increase in communication required for achieving harmonious cooperation between moving motion and manipulating motion in a robot makes the control system difficult to realize in a pure distributed system. So, some global information about the object and robots should be collectively reflected from sensors on each robot, so that all the robots can react synchronously to environmental change or upper level mastering event in real time.

The behavior-based approach emphasizes the decomposition from a task to a set of pure reactive behaviors for real-time control, which implies fully parallel control architecture composed of multiple behavior modules. The important problem is that, in cases where control should be shared between multiple modules, the output would result from the arbitration of multiple conflicting module outputs. The activation and inhibition mechanism of conflicting modules composes the intelligence center of the distributed control system. The behavior network is another example where a behavior is chosen by comparing and updating activation levels for each behavior. Each enabled behavior selects the required actions, computes run-time parameters, and generates a bid describing the appropriateness of the behavior. The most appropriate behavior is determined in a distributed manner through inter-behavior bidding without any centralized mechanism. Although the problem of arbitration between behaviors is better solved in a centralized system with some knowledge, the arbitration occurs only for specific cases in a system where tasks are partially ordered with a planner. Because, in dynamic environment, a robot needs to quickly decide what to do and how to do it, the deliberative components must keep pace with changes in the environment to reactively

9 more pages are available in the full version of this document, which may be purchased using the "Add to Cart" button on the publisher's webpage:
www.igi-global.com/chapter/a-bio-inspired-distributed-control-approach-to-the-design-of-autonomous-cooperative-behaviors-in-multiple-mobile-robot-systems/184380

Related Content

Facilitating Interaction Between Virtual Agents Through Negotiation Over Ontological Representation
Fiona McNeill (2018). *Encyclopedia of Information Science and Technology, Fourth Edition (pp. 2697-2706).*
www.irma-international.org/chapter/facilitating-interaction-between-virtual-agents-through-negotiation-over-ontological-representation/183981

Fuzzy Rough Set Based Technique for User Specific Information Retrieval: A Case Study on Wikipedia Data
Nidhika Yadav and Niladri Chatterjee (2018). *International Journal of Rough Sets and Data Analysis (pp. 32-47).*
www.irma-international.org/article/fuzzy-rough-set-based-technique-for-user-specific-information-retrieval/214967

A New Heuristic Function of Ant Colony System for Retinal Vessel Segmentation
Ahmed Hamza Asad, Ahmad Taher Azar and Aboul Ella Hassanien (2014). *International Journal of Rough Sets and Data Analysis (pp. 15-30).*
www.irma-international.org/article/a-new-heuristic-function-of-ant-colony-system-for-retinal-vessel-segmentation/116044

Virtual Tours and Serious Game for Promoting Educational Tourism Using Non-Intrusive Human-Computer Interfaces
Mario Martínez-Zarzuela, Francisco Javier Díaz-Pernas, Míriam Antón-Rodríguez, Sergio Martín-Calzón and David González-Ortega (2015). *Encyclopedia of Information Science and Technology, Third Edition (pp. 3676-3683).*
www.irma-international.org/chapter/virtual-tours-and-serious-game-for-promoting-educational-tourism-using-non-intrusive-human-computer-interfaces/112801

Mobile Commerce Use among UK Mobile Users Based on a Proposed Mobile Network Utilization Framework: An Experimental Approach – Part 2
Asem Moqbel, Mirella Yani-Di-Soriano and Shumaila Yousafzai (2012). *Knowledge and Technology Adoption, Diffusion, and Transfer: International Perspectives (pp. 166-199).*
www.irma-international.org/chapter/mobile-commerce-use-among-mobile/66943