Indian Journal of Science and Technology, *Vol 10(15), DOI: 10.17485/ijst/2017/v10i15/106335, April 2017*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Organization of a Unified Coordinate-Information Space to Provide for the Operation of the Multi-Agent Robotic System

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Abstract

Background/Objectives: The article outlines aspects of effective application of multiagent robotic systems and development of a unified coordinate-information space for such systems **Methods:** Authors review aspects of efficacy of application of multiagent robotic systems and questions of development and maintaining the unified coordinate-information space of these systems. Aspects of devices required to solve the identified problem are also considered in the article. **Findings:** The circle of the problems arising at creation of multiagent robotic systems has been outlined in the review and possible ways to solve these problems have been shown. **Applications/Improvements:** The article formulates a list of equipment and systems necessary to maintain a single coordinate-information space for the operation of multiagent robotic systems.

Keywords: Coordinate Measuring, Hybrid Lidar, Multi-Agent Robotic System, Supervisory Network-Centric Management, Technical Vision

1. Introduction

The area for practical applications of robots is getting bigger every year. Robots are being used in many manufacturing process, in areas of radio- and chemical pollution, to fight terrorists, in hostilities and in space. While studying space it was found that a single robot can solve simple tasks only or it can perform simple procedures. Therefore difficult tasks should be effectively solved by a group of robots. In that case radius of action increases greatly due to dispersal of robots across the entire working area, the functionality set expands which is provided by the installation of various actuators on individual robots of the group. That way higher probability of achieving preset goals is achieved due redistribution of tasks between robots within the group in case of one of them fails.

However use of group of robots is associated with several difficulties mainly due to the control problems and problem of organization of collective interaction of separate robots for more effective goal achievement. This second problem is especially important for intellectual robots with autonomous movement system and navigation or for mobile robots.

In general there are two ways to solve difficult tasks:

- Use of single robots which represent complicated multifunctional objects;
- Use of group of robots where every single robot is a simple object.

The first approach presumes robot functional expansion and complexity of its individual functional components, such as computing, information and control devices, sensors, actuators, power supplies. In that case system reliability is determined by reliability of the least fault-tolerant component of the robot. But that leaves the

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question about limited resources of a single robot with increasing task difficulty open.

The second approach presumes separation of functions between several robots. Each separate robot of the group is not able to solve a task completely but it can be done in case of collaborative work of the whole group of robots. That way every robot remains relatively simple which increases reliability of the system[1].

The most promising direction in group control of robots is the development of Multi-Agent Robotic Systems (MRS) consisting of active intellectual objects called agents[2].

Fundamental basics of the building of MRS are the following principles:

- unity of agents functioning purposes;
- the adequacy of intelligent and functional capabilities of the agents to the complexity of the solved tasks;
- unity of information space of the system;
- flexible tunability, determination of the network architecture that supports a unified information space of the system while implementing various strategies of group control;
- mutual information and logical compatibility of the agents[3].

This article focuses on technical means for ensuring a unified information space of the MRS.

2. Organization of MRS

Organization of MRS is determined by the chosen Group Control Strategy (GCS). There are three main types of GCS:

Centralized GCS

Centralized GCS presumes the concentration of the entire set of command and control functions in the authority of some unified organ providing planning and coordination of appropriate actions of group members solving general applied problems.

Structure of centralized GCS provides communication channels between commanding control organ and each member of the group. This feature creates main disadvantage of this GCS: failure of the commanding organ leads to complete failure of the system as a whole. Advantage of a centralized GCS is a significant decrease in functional load on group members as long as commanding control organ is responsible for analysis of the applied problem, collection, complexing and interpretation of the data and for planning of reasonable actions.

The following systems can be examples of centralized GCS: MARTHA project[4], "Scout" system for miniature robot group control[5-7], DARS system[8], "Tactical Mobile Robot Systems" project and some other projects[10,11].

Decentralized GCS

Use of decentralized GCS presumes that each of the group member plans collective actions within the group separately in order to achieve group goals. AMADEUS project is an example of implementation of decentralized GCS. In this project transport robot action control is executed by several stationary loading robots which are connected to each other and to transport robots by information channels[12]. There are several options of organization of a decentralized GCS that can be divided into collective and gregarious. In a collective decentralized GCS there is a direct information exchange between group members when in a gregarious GCS this exchange is performed indirectly based on the analysis of environmental changes in the absence of mutual data transfer. Therefore structure of a decentralized GCS has to provide channels of two-way communication between all members of the group to coordinate of the actions they perform and for exchange of information about current environment state. The main advantage of this option of system building is keeping its operability in case of failure of one or several elements. The main disadvantage of decentralized GCS is associated with a significant amount of functions loaded on each group member.

It should be noted that in case of gregarious control provision of group interaction is limited to describing of formulation of a general applied problem and its further transfer to separate executors which should have intellectual and functional capabilities high enough to decide and implement these decisions about form and proportion of their participation in achieving the set goal[3]. In the field of technical applications problems of gregarious control provision is actually reduced to the formation of appropriate task-oriented behavior of intelligent agents operating autonomously under uncertainty[13,14].

Large Scale Robot Societies project is an illustration of gregarious control of group of robots. This project aims to study group management principles typical for flocks of living organisms[15].

Mixed GCS

In general case GCS can be built not only in correspondence with centralized or decentralized structure but also in correspondence with combined or mixed structure formed hierarchically. Such systems are supposed to control large groups where all members are considered a priori divided into several smaller formations[16]. To control these formations as well as separate agents various strategies (and organizing structures) of group control can be used.

2.1 MRS Composition

MRS can be used for a wide range of tasks. This requires informational interaction between the objects of MRS i.e. information network with a high bandwidth. In order to organize information network all agents of the group should act in a unified coordinate system which can be formed by means of stationary but transportable station. The apparent contradiction is resolved by the fact that the station is stationary only when MRS is operating, while before the deployment of the group it can be relocated to a pre-set space point providing maximum area of a straight sight line in the zone of interest for the user or in the border zone or hazardous area.

Along with a Stationary Communication Point (SCP) MRS includes several mobile complexes (MC). Optimal number of MC in MRS depends on the specific task which MRS has to solve. It should be noted that in especially rough terrain several SCP can be used, or MC can be used as communication centers if it is impossible to place SCP in the required spots (for example, in hazardous areas).

2.2 Dynamic Reconfiguration Algorithm

High network bandwidth required for MRS determines a choice of optical transceivers for the implementation of the physical level of the network. Optical Information Network (OIN) from communicational point of view (at a logical level) is similar to mesh-networks in configuration arbitrariness. At the same time it has some specific features determining highly specific character of its functioning algorithms such as:

- unlike mesh-networks where all centers are equal OIN has a center controlling the network which determines current network configuration at a physical level;
- within the current network configuration OIN works as a mesh-network at a logical level;
- in order to establish communication channel a long time is required for mutual prompting of communication terminals, capture and establishing communication;
- because of the dynamic character of MRS and variability of atmospheric tracks reliability of optical communication channels is low which periodically creates needs for reconfiguration of an optical network;
- as long as disappearance and the emergence of the possibility of establishing and maintaining communication are partially predictable a reserve communication line can be organized which is included into current network configuration and is becoming active after predicted disappearance of communication in previously operating line;
- because of a low reliability of optical channels active use of auxiliary radio frequency lines is supposed to transmit control commands (narrowband channels) and to transmit information through optically opaque medium (broadband channels);
- the main information flow is one-side directed (to SCP).

In the conditions of MRS functioning OIN has relative predictability of disappearance and recovery of optical communication between any two centers (both mobile and stationary). Relativity of predictability is determined by the fact that along with the calculated factors (topography, mobile objects with stationary forms, buildings) non-controlled or hardly controlled conditions (aerosols, swaying treetops, birds etc.) can influence on channel transmission. From a low reliability of optical communication channels comes the need in increased flexibility of OIN. Redundancy of information flows may be implemented, primarily, by duplicating and (or) reserving communication channels (information transmission paths). Such an approach is possible when MC has 3 or more optical transceivers. Considering the fact that one of the transceivers is used for transmitting information in the direction of SCP, the multiplication factor of lines in a center differs from the number on-board transceiver by one is shown in Figure 1.

Thus, the most complicated functioning algorithm of OIN is a Dynamic Reconfiguration Algorithm (DRA) considering topography, position and orientation of communication centers (stationary and mobile), evaluation of capacity of optical and radiofrequency (potentially generated) channels between the centers. Therefore, DRA makes demands to the navigation system of mobile centers (their position and orientation), to collection of coordinate information system (topography) and to collection of visual information system (evaluation of channels capacity)

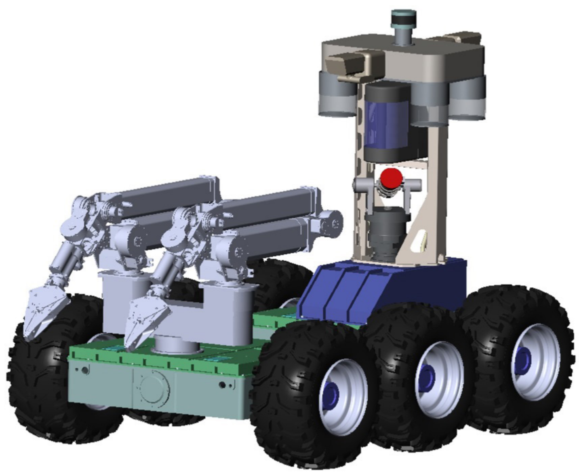

Figure 1. Mobile Complex of MRS.

Figure 2. Laser Locator of the Front View.

3. Technical Means Providing a Unified Coordinate-Information Space

MRS functioning presumes simultaneous existence of objects in informational and geometric space. Moreover, in the framework of a functioning MRS the bond between informational and geometric spaces is indivisible. The element of MRS disappearing in geometric space cannot be found to be included into the structure of MRS. At the same time disappearance of the element of MRS from information completely eliminates any knowledge about its coordinate position because this element can't be restored in MRS.

In order to provide unified coordinate-information space systems providing building of a 3D local map with precision reference to landmarks, optical and radio communications are placed in MRS centers. These systems are:

3.1 Laser Locator of the front view (LL) is shown in Figure 2.

LL is the main sensor center providing current control of MC and building of 3D local map. The principal of its work is based on hybrid system of laser location[17]. High definition along with the high frame frequency of this locator provide detailed look on the underlying surface along the MC movement in order to reveal obstacles and to locally correct the route.

3.2 Laser Locator of Circular View (LL CV):

LL CV serves for building 3D local map of low resolution aiming to reveal large (global) obstacles.

3.3 Optical Electronic System of Coordinate Measurements (OESCM) is shown in Figure 3.

For MRS functioning highly precise binding of MRS centers positions to the coordinates on the terrain is required. In order to implement this function mobile and stationary modules of OESCM are used. They allow determining the angular coordinates of objects with high accuracy, thus allowing determining the position of the carrier based on the previously known coordinates of reference objects (buildings, landmarks).

3.4 Television Cameras of Circular View (TC CV)

TC CV serves as the main visualization instrument of the environment around a MC for the operator. They translate video images to SCP allowing the operator to evaluate the environment and react to events operatively.

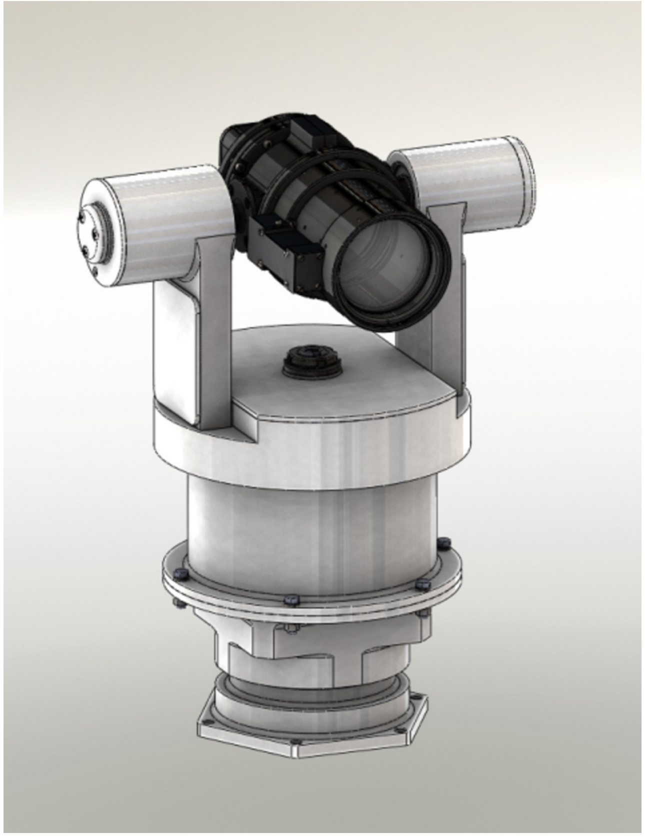

Figure 3. Optical Electronic System of Coordinate Measurements.

3.5 Strapdown Inertial Navigation System (SINS)

Formation of OIN and building of 3D local map requires current information about MC orientation in the unified coordinate system. This information can be obtained from OESCM but this process will take a large period of time. To obtain information about MC orientation in real scale of time the SINS set on the MC is used.

3.6 Global Navigation System (GNS)

GNS is also used to obtain information about MC orientation in real scale of time. Moreover placing high-precision GNS on SCP allows MC to obtain differential corrections, allowing determining the position in space with high accuracy.

3.7 Equipment forming OIN

This equipment is the key for forming unified information space. Optical transceivers provides wideband transmission channel between the centers of MRS. At the same time control system of MRS performs network reconfiguration to preserve from disconnection.

3.8 Equipment Forming Radio Channel

Radio channel is an auxiliary narrow-band communication channel. Basically it does not lose efficiency in all weather conditions and has the ability to pass through various obstacles. It is required for maintaining communication between MRS centers even when forming of OIN is impossible. It is difficult to transmit video information or any other high-volume data through this channel. However this channel is sufficient for real-time transmission of telemetry and supporting information about the state of MRS center.

4. Conclusions

Development of the unified coordinate-information space to provide functioning of Multiagent Robotic System requires several key elements:

- wideband information transmission channels;
- dynamic network reconfiguration algorithms;
- high-precision systems for coordinate binding;
- means for building 3D local map;
- auxiliary communication channels;
- Local and global navigation systems.

All together these systems and devices are able to solve tasks aimed at the high-accuracy determination of MRS centers coordinates in local coordinate system, transmission of large amount of information through the main broadband communication channels, telemetry transmission through auxiliary and main communication channels, building of 3D local map, dynamic network reconfiguration based on the static and dynamic environment.

Development and maintaining of a unified coordinate-information space is not limited by the tasks mentioned above but without solving these tasks MRS turns into simple group of robots or even into separate autonomous robotic complexes.

5. Acknowledgements

This article was prepared with financial support from the Ministry of Education and Science of Russian

Federation for the research under the Agreement of 09.11.2015, grant №14.581.21.0018 (unique identifier RFMEFI58115X0018) for the implementation of the federal target program "Research and development on priority directions of scientific-technological complex of Russia for 2014-2020 years".

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