Decentralized Cooperation between a Terrain Aided Mobile Robot and Rotary-Wing Aerial Robot for Exploration: An Approach

S. Datta, D.N. Ray, U.S. Patkar, S. Majumder, M. Majumder

Abstract

This paper presents an approach towards developing decentralized cooperation among different classes of robots for efficient exploration where each class is uniquely equipped with a sensory suite with a set perception range thereby building a system where each class merges the acquired information in a global map of the environment increasing final accuracy, quality of localization and reducing the occurrence of spatial conflicts. The present work attempts at decentralized cooperation between a Terrain Aided Mobile Robot (TAMR) and a Rotary Wing Aerial Robot (RWAR) to provide enhanced capability for security and surveillance in various areas such as border patrolling and mine detection. TAMR is used for terrain exploration and surveillance whereas RWAR encompasses the area which cannot be covered by TAMR on the ground. Each robot's activity encompasses a certain domain of operation which complements other robot's activities. The sensory system for TAMR and RWAR differ in nature thus cooperation between TAMR and RWAR merges the acquired information to generate composite information thus increasing final map accuracy, quality of localization and reducing the occurrence of spatial conflicts for providing with enhanced capability for navigating through difficult, hazardous and remote environment with suitable domain based robot.

Keywords: Terrain Aided Mobile Robot, Rotary Wing Aerial Robot, Decentralized Cooperation

1 Introduction

Decentralized cooperation and coordination mechanism is required to ensure exploration efficiency and to avoid spatial conflicts. In exploration, classes of robots, devised for different terrains, merge the information in a global gridmap of the environment, thus reducing the time required to complete the task. The redundant

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information provided by multiple robots is fused to increase the final map accuracy and the quality of the localization. Task decomposition and allocation are required i.e. strategies to conveniently distribute robots over the environment, is accurately devised to reduce the occurrence of spatial conflicts and reap the benefits of a multi-robot architecture.

In our present project on “Mobile Robot Technology for Security, Surveillance, Mining, Planetary Exploration and Building Inspection (SERBOT)” we focus on decentralized cooperation between Terrain Aided Mobile Robot (TAMR) and Rotary-Wing Aerial Robot (RWAR) through information sharing working in the same network to generate composite information to be used by the central command station. To achieve this, task decomposition and allocation are done i.e. strategies to conveniently distribute robots over the environment is accurately devised to reduce the occurrence of spatial conflicts. The area which cannot be covered by the TAMR (such as stiff slope, high rise building) on the ground, can be explored by RWAR.

2 TAMR Configuration

TAMR is an experimental mobile robot prototype for studying various navigational techniques associated with deliberative as well as reactive domain implementation of kinematically different mobile robotic systems for diverse applications[1]. Necessary algorithms are developed for navigation in unknown environment, fusing deliberate model and behaviour model with reinforcement learning. One unique feature of TAMR is hybridization such that if need arises track-belt configuration can be modified to wheeled one within a few minutes. Fig. (2) shows the transformation from a tracked system to a wheeled system.

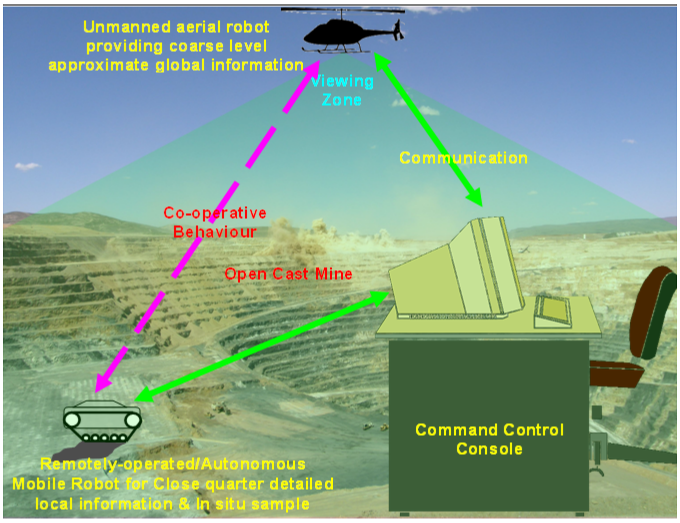


Figure 1: Schematic diagram of cooperation between Terrain Aided Mobile Robot and Rotary-Wing Flying Robot through information sharing to generate composite information for central command station

(a) (b)

Figure 2: TAMR suitably geared for outdoor and indoor application. Transformed from track-belt configuration to wheeled configuration

Table1: Notable features of TAMR

Robot Type	Terrain Aided Mobile Robot (TAMR)
Category	Primarily Caterpillar type, Interchangeable to Wheeled configuration
Dimension	583 x 680 x 260 mm (approx.)
Weight	<50kg (approx)
Drive	Four Wheel drive using four separate motors Power: 150 W Volt: 24 V Continuous Torque: 0.3531 Nm Transmission: Tracked Belt
Power Supply	On-Board Li-ion battery bank with 4 Nos. of 25.9V, 22 Ah packs
Vehicle speed	0.5 m/s (min), 1 m/sec (Max)
Endurance	1.3 hrs
Power consumption	662 Watt @ 24 V (With all major instruments operating)
Communication	RF Modem based network
Architecture	Multi Agent based Client-Server using TCP/IP
Standard Sensors	Encoder, Compass, Inertial Sensors, Laser, Camera
Processor	Multiple PC 104+ Single Board Computers

2.1 TAMR system architecture

Single board computer forms the heart of the system and acts as the control computer. Multiple devices are connected to the computer as shown in Fig. (3). Computer peripherals are connected via the I/O bus whereas add-on cards comprising RTD’s DM6425 analog DAC module, DM6914 encoder module are connected over the PCI bus. 3-axis joystick is interfaced to the system through DM6425 ADC card. Four IR sensors, developed at CSIR-CMERI for obstacle detection, are integrated through the digital input ports of DM6425. In a similar manner, the analog voltage output to control the PMDC motors, are fed to the Maxon servo amplifiers. The encoder output feedback from the motors is through DM6924

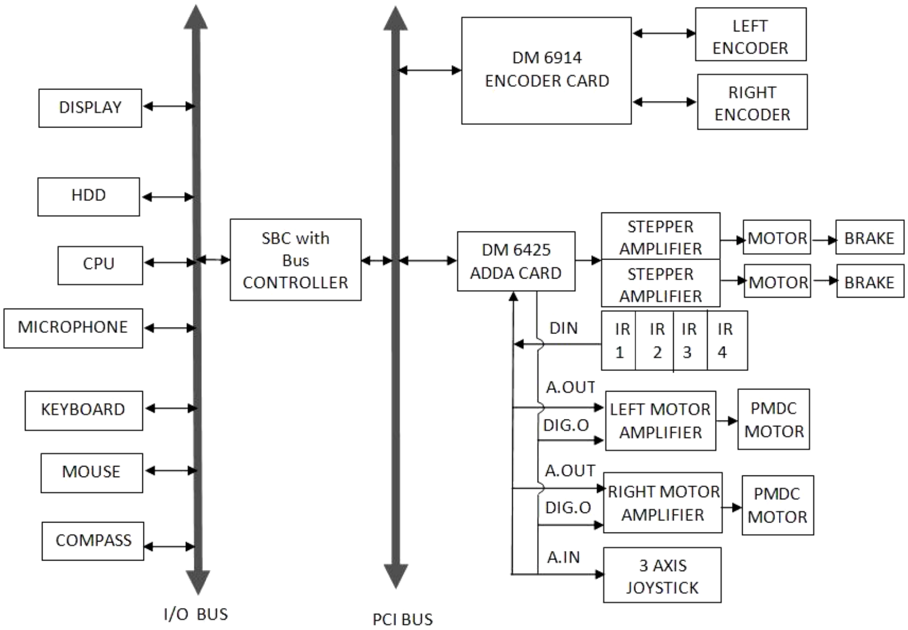


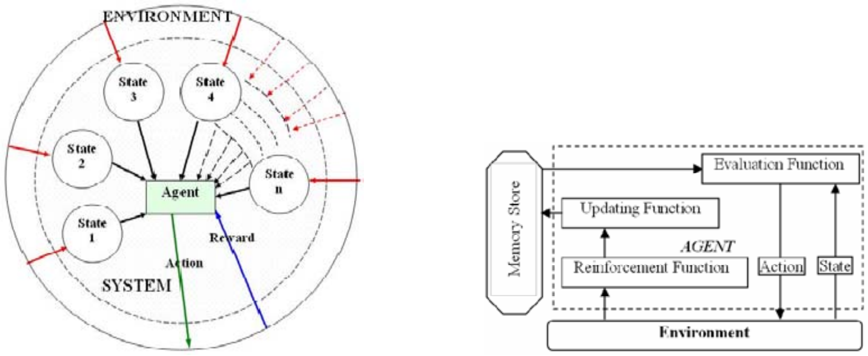
Figure 3: Block diagram of TAMR system architecture

encoder module for precise speed control. Other auxiliary I/Os such as direction reversal through stepper motor for braking purpose is activated through DM6425 module. This module is also used for monitoring battery health at TTL level. The voice command is through standard microphone.

KVH’s C100 compass is connected through the serial port for absolute heading measurement and SICK laser is connected over standard Ethernet port with RJ45 connection, using TCP/IP protocol for range detection.

2.2 TAMR navigation

Deliberative model based navigation assumes the kinematic and/or dynamic model of the system is precisely known and the sensor model detects the environmental changes so as to perform navigational and exploration task whereas behaviour based navigation does not require model for the system or environment. It is essentially a direct sensor to actuator mapping, which does not rely on the explicit world model and path planning used in the other approach. Behaviour-based robotics also referred as reactive due to its dependence on modeless approach using direct action for sensory stimulus. Obviously such approach on navigation cannot be considered as optimal one, yet it is perhaps the best possible action, given a set of sensory stimulus from its spatial neighbourhood. Even though such action is sub-optimal, yet this is arguably more rational for navigational task for the simple reason that in case of obstacle free path planning nearby objects has more influence than any obstacle or objects located far from the robots. Reinforcement Learning (RL) is a system-environment interaction with the help of reward/ punishment methodology against a previous action executed depending on the previous state of the system. This helps



(a) (b)

Figure 4: (a) System-environment interaction model of single agent Q-learning; (b) Detailed sub-parts of single agent Q-learning

the robot to act more rationally and subjective way even when the environment changes to a completely unknown/ unpredictable manner [2].

The Q-learning as application framework of RL is currently in use for many robotic applications is based on the concept of state-action table (Q-table) with delayed reward[3][4]. Here a single agent is used to look after all the necessary tasks; starting from gathering the states, selecting the action, obtaining the reward/punishment and updating it in the algorithm as depicted in Fig. (4a). The main feature of the work is the use of example trajectories to bootstrap the value function approximation and splitting learning into two different phases. The first phase uses human or an example for the task and reinforcement learning system observes the states, actions and rewards by the robot, Fig. (4b). When the approximation of the value-function is done properly, the reinforcement learning in the second phase is in the control of the robot as in the standard Q-learning framework.

3 RWAR Configuration

CSIR-CMERI has developed a Rotary-Wing Aerial Robot (RWAR) shown in Fig. (4) that is capable of controlling the dynamic behaviour while hovering, which is complex in shape and motion as nonlinear aerodynamic forces and gravity acts on the system. A controller for both roll and pitch dynamics is developed adopting cascade control loop feedback architecture where INS system feedback is used for outer control loop while the gyro feedback is adopted for the inner control loop to attain a high bandwidth, ensuring attitude stability with accelerated response required for a steady hover [5].

Table2: Notable features of RWAR

Robot Type	Rotary Wing Aerial Robot (RWAR)
Dimension	Length: 1.4m, Height:0.5 m (approx.)
Payload Capacity	3-5 kg
Operational Height/Range	1-1.5 km (approx)
Endurance	<30 min
Communication	2.4 GHz Transceiver, RFD 900 Radio Modem
Flight Computer	PC104+ based SBC with FPGA based Servo Control Unit

Field Computer	Industrial Touch Screen computer
Navigational Sensors	INS, GPS/DGPS, Compass
Payload Sensors	Camera, thermal camera for surveillance

3.1 RWAR Architecture

CSIR-CMERI’s RWAR represents an excellent platform for monitoring, surveillance and inspection because of its state-of-the-art instrumentation. It has dual mode of control. In tele-operated mode, RWAR is remotely controlled through a 2.4 GHz radio system consisting of a transmitter and a 10-channel receiver. Out of 10-channels, 8-channels are used. Four channels are used for controlling aileron, elevator, rudder and throttle/pitch and three are used as aileron, elevator and rudder gyro sensitivity channels. The final channel acts as a system mode selector that switches between the control signals from transmitter and RWAR computer system and route them to respective servos. This gives the user the ability to activate and deactivate the auto controller as and when necessary. For flight computer system, RWAR is equipped with Pentium-M 1.6GHz based SBC with 1 MB cache and PC/104+ expansion site running on Windows operating system. A PC/104+ based RTD’s DM7820 high-speed digital FPGA card is mounted on the SBC to allow for high-speed data throughput. This includes generating PWM outputs using programmable clocks for controlling the servos as well as for measuring the pulse width of incoming PWM signals from the receiver. For sensor feedback, Microstrain’s high performance MEMS based miniature Attitude Heading Reference System (AHRS) with GPS 3DM-GX3-35 is interfaced to the RWAR system. It provides direct measurement of acceleration, angular velocity and air pressure. It can handle sampling rates of up to 30 kHz with data output up to 1 KHz. The sensitivity of accelerometer is +/- 5g which makes it suitable for controlling nonlinear aerodynamic forces and gravity of RWAR. 3DM-GX3-35 is mounted underneath the chassis as close to the system centre of gravity (CG) as possible. This minimizes any lever effect that can contribute to direct errors in measured rotation relative to the system axis. The field computer communicates with RWAR through RFD 900

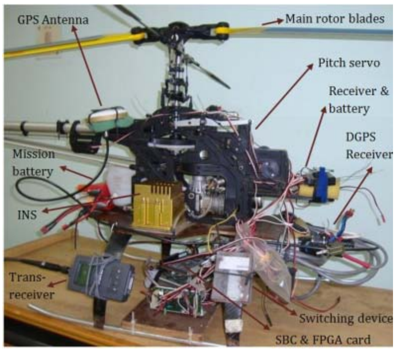


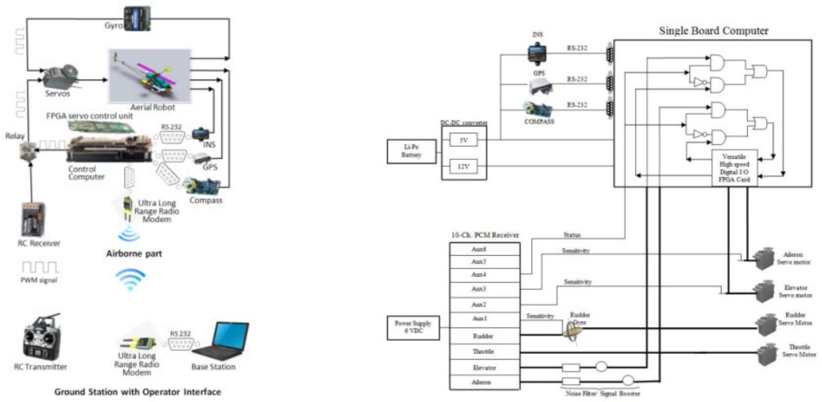
Figure 5: CSIR-CMERI RWAR equipped with INS and GPS interfaced to SBC with FPGA card for hovering

Radio Modem using serial protocol. It monitors all mission data from navigational sensors mounted on RWAR as stated above and displays the series of images grabbed by the onboard camera. In case of any aberration in the sensor data as monitored on the field computer, the mission may be re-planned or aborted. Suitable system architecture is devised with mission specific sensors as shown in Fig. (6a). RWAR system for terrain aided navigation includes:

1. A basic air frame with an overall length of 1.4 m, height of 0.5m, approximate weight of 15 kg with the capability to handle 3-5 kg payload and operational height & range of 1-1.5 km.
2. Battery bank for enduring a flying time of greater than 40 minutes in ideal weather condition
3. 2.4 GHz RC receiver and ultra long range radio modem for communicating with the ground station
4. Flight computer system with FPGA servo control unit for navigation
5. Sensors include INS, GPS and compass for navigation
6. Payload sensors such as camera, thermal camera for general surveillance

3.1.1 RWAR configuration for in-flight switching for hovering

RWAR's configuration accommodates for smooth switching while in flight from tele-operated mode to auto mode for steady hovering. This include reading incoming PWM signals from transceiver using high-speed digital FPGA card mounted on the control computer to allow for high-speed data throughput required for switching and ensuring attitude stability with accelerated response required for a steady hover. Schematic layout for switching to hovering mode is shown in Fig. (6b).



(a) (b)

Figure 6: (a) RWAR architecture (b) Schematic layout for in-flight switching

4 Decentralized cooperation between TAMR and RWAR

Amongst the current trends on unmanned autonomous vehicle navigation is application of decentralised data fusion [6][7]. The motivation is that of multiple autonomous flight and ground vehicles cooperatively building a map of the terrain over which they are flying and moving, each using one or more terrain sensors. Ultimately, the algorithms should scale such that any number of vehicles, with any number of payloads, in any configuration can be used. A group of robot units with different functions can be configured dynamically and autonomously to operate cooperatively according to the variation of environment and task.

Generally, the cooperation among multiple robots for task does not rely on centralized control mechanism but on autonomous actions of the robot unit, action decision and related efficiency of robot unit for cooperation with other robot units. Thus decision of effective actions strongly relies on reasoning and planning which comes from knowledge of that domain. Here this knowledge is gained from states of the robot and states of the environment. Sensing set from TAMR and RWAR provide descriptions of environment from different space-time point of view because sensing of each robot is different from the other in space, time and functionality owing to different states of robots such as position, moving speed etc. from domain sensors. So through sharing of sensing information of the environment between TAMR and RWAR the efficiency of environment sensing and description for individual robot can be enhanced.

The full state vector $\mathbf{x}_s(t)$ with full state space representation for decentralized cooperation between TAMR and RWAR is as follows:

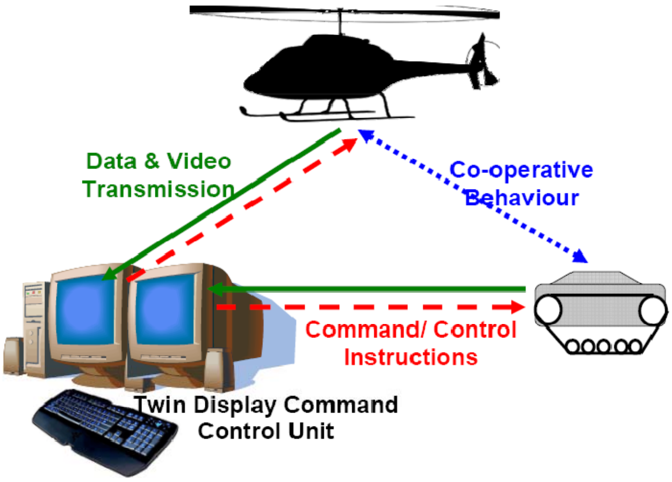


Figure 7: Information sharing between TAMR and RWAR working in the same network to generate composite information to be used by central command station

$$\mathbf{x}_s(t) = \begin{bmatrix} p_{\mathrm{T}}(t) \\ \mathrm{v}_{\mathrm{T}}(t) \\ a_{\mathrm{T}}(t) \\ \omega_{\mathrm{T}}(t) \\ \theta_{\mathrm{T}}(t) \\ p_{\mathrm{R}}(t) \\ \mathrm{v}_{\mathrm{R}}(t) \\ a_{\mathrm{R}}(t) \\ \omega_{\mathrm{R}}(t) \\ \theta_{\mathrm{R}}(t) \end{bmatrix}$$

where $p_{\mathrm{T}}(t), \mathrm{v}_{\mathrm{T}}(t),\ a_{\mathrm{T}}(t)$ are respectively the position, velocity, acceleration of TAMR and $\omega_{\mathrm{T}}(t), \theta_{\mathrm{T}}(t)$ are angular velocity and heading angle of TAMR. Similarly, $p_{\mathrm{R}}(t)$, $\mathrm{v}_{\mathrm{R}}(t)$, $a_{\mathrm{R}}(t)$ respectively the position, velocity, acceleration of RWAR and $\omega_{\mathrm{R}}(t), \theta_{\mathrm{R}}(t)$are angular velocity and orientation of RWAR at a particular instant.

5 Conclusion

Approach to decentralized cooperation through distributed sensing depends on the characteristics of sensing information of robots. Due to errors from sensor measurements and sensing system modelling, the information describing environment states inferred from sensor data is uncertain and may be inconsistent. However, approaches like Simultaneous Localization and Map Building attempt to estimate correctly the current state of the robot to compensate such sensor errors [8]. With distributed sensing by different domains of robot and fusing this information compensates for such sensor errors and gives an accurate map of the environment of the robot system for navigating through difficult, hazardous and remote environment with suitable domain based robot. The mathematics of localization of robot with respect to the environment and enhancing environment sensing by fusing sensor information from TAMR and RWAR will be presented in a full paper.

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