Multi-Agent Robotics: Towards Energy Autonomy

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Abstract

In this paper, we aim to propose a novel trend in multi-agent robotics: energy autonomy. A definition of energy autonomy is developed from an original concept "potential energy" that is under constraints of remaining energy capacity and related distance among robotic agents. Towards energy autonomy, we initially present a simulation of multi-agent robotic system in which each robot is capable of exchanging energy cells to other robots. Our simulation points out that: (1) each robot is able to not only act as an autonomous agent but also interact with the others to be beyond the individual capabilities; (2) To adapt change of the environment, each robot is situated as an adaptive agent in a network or a cluster of the neighboring robots to lead to a state of energy autonomy. Finally, based on discovery of the simulation we adjust rules for our real multirobot system.

1. Introduction

A multi-agent system (MAS) is a system composed of a number of agents that are collectively capable of reaching goals that are difficult to achieve by an individual agent or monolithic system [6]. In a MAS there is no centralized control, information is distributed, computation is asynchronous, therefore each agent is incompletely capable of solving a problem [8], it needs assistant from other agents to solve its own problem or helps other agents with their problem appropriately. Adaptiveness of an agent is depending on the characteristic of such an agent, its surrounding environment, its capabilities of interaction with other agents or environment and capabilities of organization in a network or a cluster. Therefore, mapping MAS to multirobot system, an autonomous robot is able to exhibit as an autonomous agent in the MAS - robotic agent. However, a robotic agent is aware of as a physical robot in fact, thus the robot exists if it is capable of solving energy resource.

In the paper, we propose a multi-agent robotic system in which each robotic agent is a mobile agent and is equipped with a special mechanism of energy exchange, so that it is capable of fairly collecting and carrying energy cells, rechargeable batteries to share with others. The paper is organized as: we briefly describe our models of single robotic agent and their cooperation in section 2. In section 3 we perform our simulation of robotic agent behaviors under constraints of remaining energy and related distances. We implement the simulation in accordance with agent characteristics, interaction, organization and change of environment in order to suggest course of our real multirobot implementation. Finally, the paper is concluded in section 4.

2. Model of Multi-Agent Robotic System

Because Matlab software supports a lot of graphical libraries to easily execute mathematical computation, or generate graphs and charts, we are using the tool to implement our multirobot system.

2.1 Model of Single Robotic Agent Robot

We focus on the energetic autonomy of a multi-agent robotic system so we are going to simplify robotic agent as points moving on scanlines in the Euclidean space. Therefore, distance relation among robotic agents is based on Manhattan space. Because of difficulty of modeling a general equation of power consumption in robotics we are temporally using the Peurket's discharging function $C = I^k t$ where k is supported by the battery manufacturer.

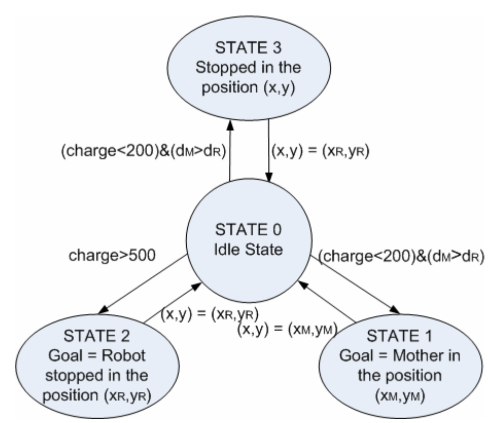

Fig1: Model of single robot

In the simulation, a robotic agent is initialized with 800 energy unit (**eu**) and it consumes a specific amount of energy using Peukert's equation for each step so we propose 4 states of a robotic agent: (State 1): a robotic agent has to go to mother to take full energy if its energy is less than 200 **eu** and by default, it has higher priority to go to the mother station;

(State 2): a robotic agent is able to exchange 100 **eu** to other robotic agent if its energy amount is more than 500 **eu**; (State 3): a robotic agent will stop to wait for other robot coming to charge 100 **eu** if its energy is less than 100 **eu** and it is impossible to go to the mother charging station; and (State 0): otherwise, a robotic agent is autonomously free to go anywhere to consume energy.

2.2 Model of Robot Coordination

To facilitate our approaching to battery exchange, we implement a coordination algorithm for the multi-agent robotic system based on two phases: path planning and battery exchange. Briefly, each robotic agent has a own battery exchange supervisor. The supervisor collects input data of the robots: current coordinate (X,Y) and current state of energy STATE; deals with such updating data; issue output commands: NEXT STATE of energy, goal coordinate (Xgoal, Ygoal). To be more detailed, algorithm of the battery exchange executes infinite loops of comparison of energy states and current positions among the robotic agents as well as the robotic agent with the mother to issue commands what the robotic agent should do (goal of the robot). Meanwhile path planner is to guide the robotic agent to reach the directed goal and updating the next position of the robotic agents, which is used as a feedback for the battery exchange algorithm to compute the next states of the robotic agents.

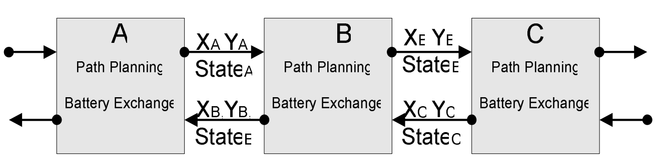

Fig 2: Model of multi-agent robotic system

3. Simulation

We present early simulation results of our objectives. First, we emphasize potential energy and its constraints among robotic agents, and the robotic agent with the mother agent. Second, we examine how interaction and environment can effect to behavior of robotic agents in the entire network. Third, we demonstrate that an robotic agent is able to be energetically autonomous if it is able to exchange energy with other robotic agents or the mother agent.

In the simulation setup shown in figure 3, we present significant information of the system. It shows four graphical windows (left to right): animation of robotic motion, potential energy of the mother agent and the robotic agent, the energy state of the robotic agents, and the task of the robotic agents. That is, the animation window shows us the motion planning of the robotic agents; the potential energy window presents the remaining energy of the robotic agents (height of the pyramids) and their capability to share energy with the others (projected contour of the pyramids); the window of the state of energy realizes the energy chart of the robotic agents according to the instant; and the task window reports operating tasks of the robotic agents. We also generate a register of the states of the robotic agents in every experiment:

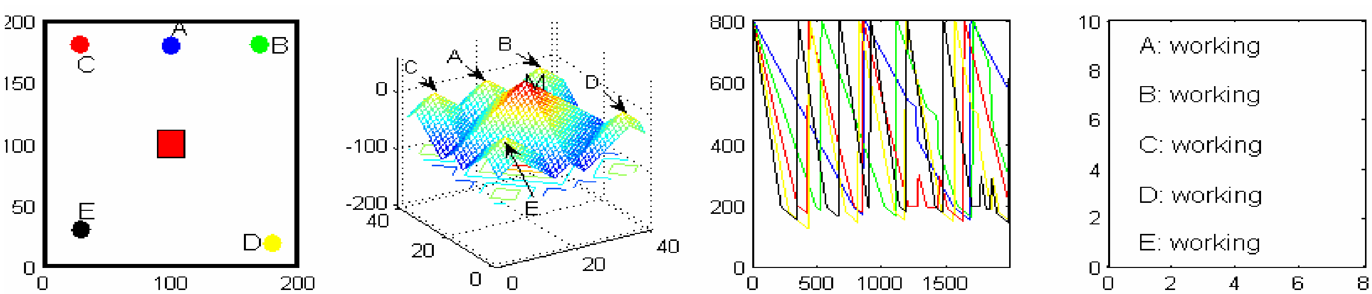

Fig 3: Graphical simulation setup

Time	A	B	C	D	E
221	A: working'	'B: working'	'C: working'	'D: working'	E -> Mother'
281	'A: working'	'B: working'	'C: working'	D -> Mother'	'E: working'
351	'A: working'	'B: working'	C -> Mother'	'D: working'	'E: working'
491	'A: working'	B -> Mother'	'C: working'	'D: working'	'E: working'
571	'A: working'	'B: working'	'C: working'	'D: working'	E -> Mother'
721	'A: working'	'B: working'	'C: working'	D -> Mother'	'E: working'
781	A -> Mother'	'B: working'	'C: working'	'D: working'	'E: working'
781	'A: working'	'B: working'	C -> Mother'	'D: working'	'E: working'
891	'A: working'	'B: working'	'C: working'	'D: working'	E -> Mother'
1021	'A: working'	B -> Mother'	'C: working'	'D: working'	'E: working'
1101	'A: working'	'B: working'	'C: working'	D -> Mother'	'E: working'
1131	'A: working'	'B: working'	'C: working'	'D: working'	E -> Mother'
1201	A -> C'	'B: working'	C <~ A'	'D: working'	'E: working'
1341	'A: working'	B -> C'	C <~ B'	'D: working'	'E: working'
1411	'A: working'	'B: working'	'C: working'	'D: working'	E -> Mother'
1461	'A: working'	'B: working'	'C: working'	D -> Mother'	'E: working'
1501	'A: working'	'B: working'	C -> Mother'	'D: working'	'E: working'
1551	A -> Mother'	'B: working'	'C: working'	'D: working'	'E: working'
1581	'A: working'	B -> Mother'	'C: working'	'D: working'	'E: working'
1691	'A: working'	'B: working'	'C: working'	D -> E'	E <~ D'
1801	'A: working'	B -> E'	'C: working'	'D: working'	E <~ B'
1841	'A: working'	B -> D'	'C: working'	D <~ B'	'E: working'
1881	'A: working'	'B: working'	'C: working'	'D: working'	E -> Mother'
1901	'A: working'	'B: working'	'C: working'	D -> Mother'	'E: working'
1981	'A: working'	'B: working'	C -> Mother'	'D: working'	'E: working'

Fig 4: An example of a register of 5 robotic agents in 2000 running steps

3.1 Potential Energy

In this section we emphasize the potential energy of robotic agents under constraints of remaining energy and related distance. As described in figure 5, the potential energy can be divided into two meanings: **H**eight of the pyramids (**H**) is to imply the remaining capacity of an agent while **C**ontour of the pyramids (**C**) is to determine how wide the robotic agent is capable of distributing energy to the others. Actually, considering a robotic agent in state of low energy, if its pyramid peak, **H** is fully covered by the another pyramid, it means it is now in the space where the other robotic agent is able to share energy, also we can say *the agent is inside the potential energy of other agents*, and it will be in rechargeable state. Otherwise, the robotic agent must be waiting until the other robotic agents are moving close to it. Further, interfering wave of **C**ontour of the pyramids also tells us more about the distance and the energy relationship among the robotic agent, and these with the mother agent.

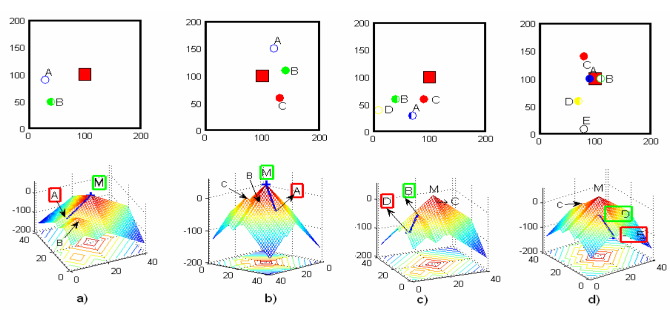

Fig 5: Potential Energy of robotic agents

The blue lines in figure 6 show the energy and related distance constraints between the robotic agents, or between the robotic agents and the mother agent. Moreover, creating the blue line is based on the gradient of the potential energy between the robotic agents, or the mother agent. The slope of the blue lines shows us the reciprocal energy effects and the length of the projected blue lines to the corresponding distance.

Indeed, figure 5 is to perform that density of the potential energy is stronger when the number of agents is increasing (a): 2 agents, b): 3 agents, c): 4 agents, d) 5 agents) in the same field. We discuss that a robotic agent in need of energy has more opportunity to be recharged if the density of the potential energy in the field raises up, but it is more hard to reach other robotic agents since the number of physical interaction increases. Thereby, we have to estimate the balance of the number of robots and the mother location to deploy such a multi-agent robotic system.

3.2 Effective Elements in Multi-Agent Robotic System

The section is to present effectiveness to energy in a multi-agent robotic system. First we experiment with increasing the number of agents in the same field. Figure 6 shows that if the number of agents increases (left to right) from 2 to 5, the number of battery exchange between robots also raises from 0 to 4. It is indispensable that the battery exchange between agents is proportional to the number of agents and the robotic agent being far away from the mother agent need more assistance than the closer ones. Thereby, we have to take a number of robotic agents into account when we deploy them in a specific environment.

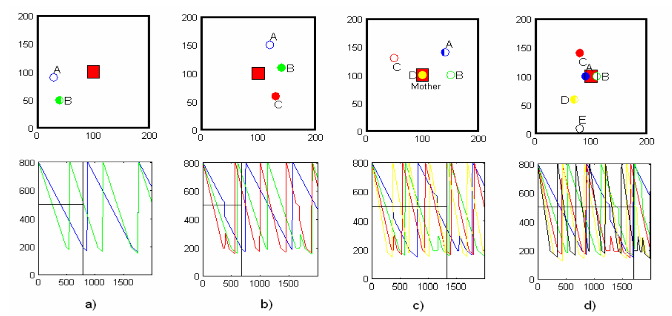

Fig 6: A comparison of the increasing number of robotic agents

Consequently, keeping a number of 5 robotic agents, we try to change the location of the mother agent in the same field. First, we locate the mother agent in the center of field. The result of 100 experiments shows that the total number of the battery exchange is almost the same. That is, the overall energy consumption is only depending on the size of the field. However, in the distribution seen in figure 7, since we move the mother to one corner of the field, robotic agents must come back at a more narrow area thereby, they are preferable to be charged by the other agents than the mother agent (red-line).

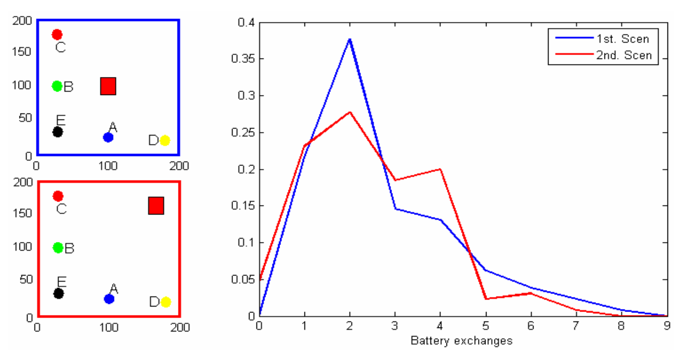

Fig 7: A comparison of the different location of the mother agent

3.3 Energy Autonomy

In fact, if a mobile agent wants to act, it will face the problem of providing food as animals. Most of mobile robots are using rechargeable batteries as a power source. Thereby, it has only autonomous behavior in the duration of the battery-life, e.g. free moving around to explore, free searching a way to carry heavy objects, or searching to rescue humans after earthquake. A robot is able to be absolutely autonomous if it achieves state of energy autonomy.

The section shows that the robotic agents are able to self-organize in order to achieve complete autonomy, without human intervention if they are able to coordinate energy sharing with the other robotic agents. The objective also means that each robotic agent is able to be energetically autonomous or assist others to be completely autonomous.

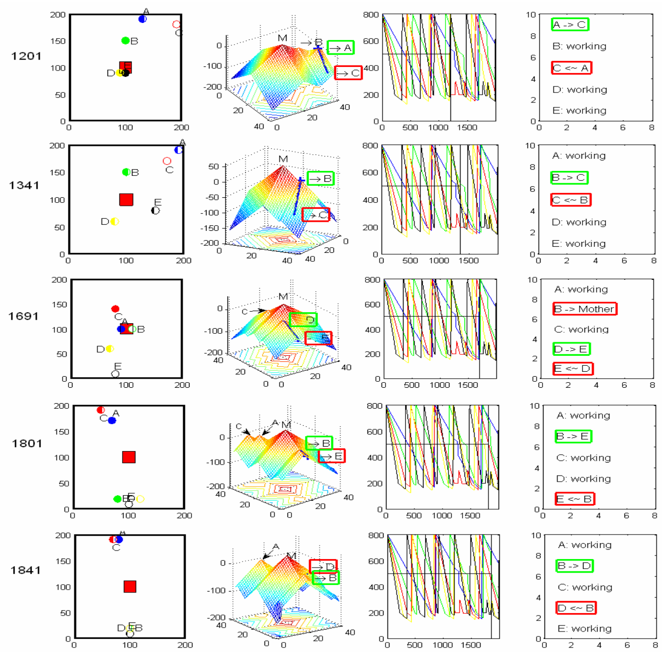

Fig 8: Energy autonomy of 5 robotic agent in time scale

Figure 8 shows an experiment of 5 robotic agents executing in 2000 steps. On the second column, we see that the potential energy of the mother agent can always cover the field. That is, every robotic agent can be globally covered by the mother agent (**M**) so it can be refilled if it is able to come to the mother agent. However, the potential energy of the robotic agents (**A, B, C, D, E**) is much lower so it is capable of covering a local vicinity. Because the robotic agent is a moving agent, it can be sub-mother agent for the other agents in its local vicinity. Therefore, every agent can be a first-aid unit in the case of emergency in which other agents have not enough energy to go back to **M**, or desire to finish their duty in a short time before coming back to **M**. Additionally, referring to the fourth column, we see that at the instant 1201, **A** is going to (**->**) share 100 **eu** with **C**, and **C** stops working to save energy and waiting (**<~**) for **A**. At the instant 1341, **C** still needs energy again since **C** has already consumed 100 **eu**, **B** is indicated to give battery for **C**. Therefore, at the instant 1691, we can easily be aware that C has already come back to **M** in order to be fully replenished and is now working with an amount of 700 **eu** approximately. Due to the assistance of **A** and **B**, **C** can survive to continue its duty, instead of being stuck on the field. As a result, robotic agents can have complete autonomy if they are able to achieve energy autonomy.

4. Conclusion & Future Works

This paper issues the concept of the potential energy in multi-agent robotic system and how to make the system to be complete autonomy. In a multi-agent robotic system, each robotic agent is a mobile agent, so it has own potential energy. This is the reason why it is able to be self-sustained with energy if it is capable of sharing energy. To deploy robotic agents in a specific environment, we have to solve the problem under constraint of effective elements as mentioned in section 2. However, to facilitate the process, we proposed the concept Potential Energy and its elements in order to analysis and setup a multi-agent robotic system in section 1.

Next, based on initial results of the simulation, we are going to experiment with our testbed of the real multirobot system. First, to simplify high requirements of localization and approaching, our mobile robots are also following the lines in a grid so the robot is able to know its current location. In this way it is rather easy to approach to contact to the mother station, or the other robot in order to exchange batteries. We will improve the techniques of sensor fusion for such robots to remove the grid, so our robots can be more sociable. They can be applied for home, office or manufacturer environments.

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