Constrained Path Planning for Energy Efficiency in Mobile Robots

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Abstract

The area of embedded robots received a boon with the advent of System-on-Chip processors, which continuously shrink in size and grow in computing power. However, as they become increasingly powerful, their energy requirements increase as well, clashing with the restricted energy supply of battery-powered robots. In this paper, an energy-efficient path planning solution for mobile robots is proposed, where constrained heuristic planning is used to determine a robot's optimal route when considering travel distance and power draw. The expected contribution is the development of a path planning solution for mobile robots which accounts for power restrictions, and thus increases a robot's battery life.

Introduction

Embedded processors and Systems-on-Chip (SoCs) have gained attention in mobile robotics, as they are attractive substitutes for conventional computers due to their reduced size and weight, and high performance-per-watt[1]. However, many state-of-the-art solutions in mobile robotics require significant computing power. As SoCs become increasingly more powerful to meet this computing power requirement, so too increases their energy consumption, and the unconstrained use of these state-of-the-art solutions reduces a battery-powered robot's potential operating time.

This paper proposes the use of constrained optimal planning to implement energy-efficient path planning in an embedded mobile ground robot. Specifically, the mapping between CPU frequency and energy consumption of an embedded processor is considered alongside the robot's travel distance to a goal, effectively constraining the path planning task to choose the path which simultaneously minimizes power draw and travel distance. This solution will be tested in a Turtlebot 2 ground mobile robot, and compared to a conventional D* (Stentz 1994) path planner in terms of reliability (i.e., how often it reaches the goal position) and battery power consumption. The expected contribution is a solution which simultaneously minimizes the robot's travel distance and increases battery life.

[1]https://www.insight.tech/health/88-more-performance-per-watt-for-embedded-and-iot

Regarding related works, energy-efficiency is often a bonus of optimal path planning (Stentz 1994)(Kruger et al. 2007), and few works consider energy draw as a key aspect in their planning domains (Mei et al. 2006)(Ooi and Schindelhauer 2009)(Plonski, Tokekar, and Isler 2013)(Franco and Buttazzo 2015)(Cabreira et al. 2018). An example is (Ooi and Schindelhauer 2009), where the authors propose a path planner which minimizes energy consumption for both mobility and communication, considering a robot's total distance to a goal and the transmission power required for communication from the robot's position to a fixed base station.

Technical Approach

Constrained heuristic search, applied to the domain of automated planning (Fox, Sadeh, and Baykan 1989), is the method chosen to implement the energy-efficient path planning discussed here. This method consists in combining constraint satisfaction (i.e., ensuring that a given restriction will be met) with heuristic search. It was chosen because considering energy restrictions on top of the distance-based heuristics naturally fits the definition of constrained heuristic search.

In mobile robotics, the A* algorithm (or variations, such as D*) is commonly used for finding the optimal route between points A and B in a robot's known environment[2]. Assuming a mostly static environment, the distance cost can be computed offline for each map position, generating a *costmap*. Thus, an optimal route is found considering the robot's initial position, its goal and the costmap.

Here, we aim to add an additional energy constraint to this planning solution. We assume that the robot can adopt different levels of responsiveness, given it's position in a known environment: When nearing an obstacle, it must be increasingly responsive in order to avoid a collision. The responsiveness levels can be attained by changing the embedded CPU's frequency. Since CPU frequency and power draw are directly proportional, as seen in Figure 1, we can compute an "energy map" offline, which will be considered alongside the costmap to find an optimal route. In other words, the clock frequency increases as the robot nears an obstacle, and vice-versa.

[2]http://wiki.ros.org/global_planner

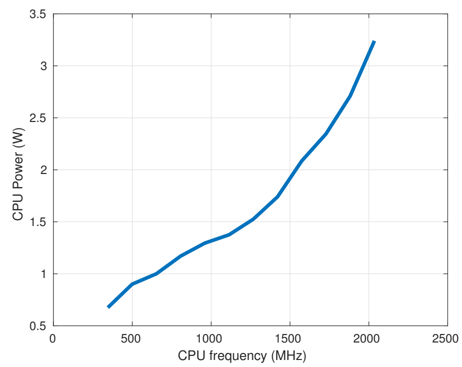

Figure 1: Relationship between CPU frequency and power draw in a Jetson TX2 embedded computer

To evaluate the solution discussed above, it will be implemented and tested in a mobile ground robot, the Turtlebot 2[3]. A Jetson TX2[4] embedded computer will be used to control the Turtlebot, powered by a standalone 12 Volts Lithium Polymer (LiPo) battery. The Jetson TX2 was chosen for two reasons: (i) It has internal power sensors, allowing us to effortlessly obtain power measurements; (ii) Its power draw due to computation was the largest when compared with other embedded processors for the same application, as seen in Table 1. This means that changes in power due to CPU frequency are more expressive in the Jetson TX2.

Table 1: Comparison between power draw due to computation in different embedded computers

	Max. overall power (W)	Max. power due to computation (W)	Percent of power due to computation
Jetson TX2	9.50	6.96	**73.32 %**
ODroid xu4	**11.52**	**7.15**	62.07 %
Jetson TK1	4.19	2.04	48.69 %
Raspberry Pi 3	4.79	2.20	46.41 %

The Jetson's battery level will be monitored as autonomous navigation is performed with the Turtlebot 2. The battery discharge curve obtained when using the proposed solution will be compared to the curve obtained when using a conventional path planner. The expected result is an increase in Jetson's battery life with the proposed solution.

Project Management

The main tasks in this project are as follow:

1. Define the constrained planning problem for the domain of energy-efficient path planning;
2. Implement and validate the proposed solution;
3. Integrate the implemented solution with the Turtlebot 2 platform;
4. Measure the battery discharge curves for the proposed solution and for a conventional path planner;
5. Compare the results and write a report;

A tentative time schedule for this project follows below, divided in weeks. Week 1 starts on October 11, 2018, and week 5 ends on November 15.

Table 2: Tentative time schedule for completing the project's tasks

Task \ Week	1	2	3	4	5
1					
2					
3					
4					
5					

[3]https://www.turtlebot.com/turtlebot2/

[4]https://developer.nvidia.com/embedded/buy/jetson-tx2

Conclusion

This paper proposes the implementation of an energy-efficient path planning solution to mobile robots, through constrained heuristic search. It considers the relationship between power draw and CPU frequency when performing heuristic search, to obtain the path which is simultaneously optimal in distance and energy consumption. The expected result is an increase in battery life when using our energy-aware path planning method, when compared to common heuristic search algorithms (e.g., D*).

References

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