Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-15 (2016) 032–037

# Energy Efficient Dynamic Window Approach for Local Path Planning in Mobile Service Robotics ⋆

**Christian Henkel** * **Alexander Bubeck** ** **Weiliang Xu** ***

* *Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart, Germany, (e-mail: christian.henkel@ipa.fraunhofer.de).*

** *Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart, Germany, (e-mail: alexander.bubeck@ipa.fraunhofer.de)*

*** *Department of Mechanical Engineering, University of Auckland, Auckland, New Zealand, (e-mail: p.xu@auckland.ac.nz)*

**Abstract:** An energy efficient local path planner for navigation of omnidirectional battery-powered mobile robots in dynamic environments is presented in this paper. The proposed algorithm extends the Dynamic Window Approach (DWA) to incorporate a cost function based on energy consumption. The estimated energy consumption during planning is predicted using a linear regression model that is learned on the fly. Empirical results are presented on a mobile robot platform that show a 9.79% decrease in energy consumption in comparison to the DWA approach.



*Keywords:* Navigation, Path Planning, Resource Efficiency, Energy Efficiency, Machine Learning, Linear Regression

## 1. INTRODUCTION

Energy efficiency is a major goal for any technical system. Challenges like global warming and sparsity of fuel sources increase the importance of this topic. In the context of a mobile robot as a product, this goal has to be transformed into the economic system as described by Luhmann (1994). It is possible to transfer this into a more product focused interest: Energy efficiency leads to battery power saving. A system that drains less current from its battery can potentially run longer. The aspect of an increased battery life is a competitive advantage.

This paper focuses on energy efficiency in robot navigation. The topic of path planning is well studied from a theoretical point of view. This led for example to the popular graph search algorithms like A* Hart et al. (1968) and Dijkstra Dijkstra (1959). The practical use of path planning for omni-directional mobile robots demands the additional consideration of energy efficiency as an optimization criterion. A short path length is necessary for an energy efficient route but it is not sufficient because the energy consumption also depends on the velocity profile.

A practical approach is the analysis of motor control in terms of energy efficiency by Trzynadlowski (1988); Barili et al. (1995); Sheta et al. (2009); Zhao et al. (2013). Similar studies on non mobile robotic arms are: Katoh et al. (1994); Shiller (1996); Verscheure et al. (2008). In contrast, this approach considers energy efficiency on a higher level of robot motion as mobile robot navigation has a higher dimensional search space which needs to be considered. The additional dimensions are based on the mobility of the robot.

Kim and Kim (2005, 2008, 2014) did research on purely transitory trajectories achieving energy efficiency for three omniwheeled robots using an analytically optimized algorithm. As energy consumption, especially for heavier robots, depends on the execution of rotations and curved trajectories, this research also considers those.

Mei et al. (2004, 2005, 2006) used similar robots to research energy efficiency in terms of exploration, search and deployment. In contrast, this paper focuses on point to point navigation which is considered a sub problem of exploration and other top level robot actions.

Liu and Sun (2011, 2012, 2014) used an energy model similar to the one discussed in this paper, but consider energy efficiency as a global planning problem and extend the A* algorithm towards energy efficiency. In contrast, this approach treats it as a local planner problem, since the robot should also be able to react to dynamic changes in environment efficiently. These changes would require the robot to leave the global plan which would make global considerations obsolete.

The next section of this paper explains which general considerations have been made. It describes basic factors which influence the energy consumption of a mobile robot. In Section 3 the main contribution of this paper, the developed Energy Efficient Dynamic Window Approach (EDWA) algorithm which is an extension of the Dynamic

⋆ This work was conducted at the University of Auckland, Auckland, New Zealand


10.1016/j.ifacol.2016.07.610

Window Approach (DWA) planner is introduced. It also covers the linear model that is used and discribes the use of linear regression to fit the model. Empirical results with the Mecanum wheel based AuckBot are presented in Section 4.

## 2. ENERGY CONSIDERATIONS

This is a general consideration of the factors which influence the energy consumption of a mobile robot. The aspects are defined platform independent. They are generally applicable to any holonomic mobile robotic platform. All the mentioned aspects are explained with a quantified route in mind.

### 2.1 Duration

Often navigation is defined to be time optimal (see Shiller (1996)). In contrast, this paper solely speaks about energy optimization because time optimality is for all practical robots considered to be a necessary condition of energy efficiency. This is mostly due to idle currents which are consumed by a robot even without motion. That idle current consumption means a robot spending less time to reach its goal potentially needs less energy than one taking more time.

### 2.2 Route Length

A basic requirement for a planned route regards the length. The path from the current position ($s$) to the goal ($e$) over all length segments $dL_i$ should be as short as possible. Any additional length would require more energy.

$$\min \sum_{i=s}^{e} dL_i \tag{1}$$

In the presented architecture (see Figure 1) this requirement is met by the global planner which uses the previously mentioned Dijkstra (1959) algorithm. Also the local planner which is proposed here, prefers short trajectories as described later.

### 2.3 Pose Efficiency

A robot has a set of possible movement poses $\mathbb{C}$, which have different energy consumptions $E$. It is a goal to move for as many route sections $dL_i$ as possible in an efficient pose $p$.

$$\min_{p \in \mathbb{C}} \sum_{i=s}^{e} E(dL_i, p) \tag{2}$$

For most configurations this is mainly influenced by the robots heading angle. For example, in the case of a Mecanum wheeled robot the amount of wheel slippage varies for different directions of movement. In this approach this aspect is taken into account by the splitting of the motion into the two planar Cartesian components. This way the model can include information about the advantage of one direction of movement over another.

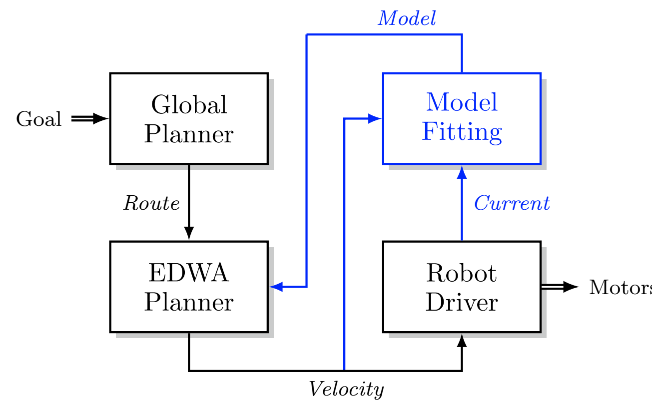


Fig. 1. Navigation Architecture consisting of global planner, local planner, robot driver and model fitting components.

### 2.4 Smoothness of Motion

The mathematical notion of smoothness is defined as the existence of derivatives in a possibly high order. This should be a goal for a robots trajectory, since jerky motion can create vibrations which result in energy loss (see Rao (2007)). This is taken into account by the inclusion of the acceleration into the cost function. Which is described in Subsection 3.5. Higher order derivatives are currently not considered because data for those are expected to have high noise and it is therefore unlikely to create any benefit.

## 3. ENERGY EFFICIENT DYNAMIC WINDOW APPROACH

The creation of a energy efficient local planner is studied by the creation of a model based cost function that evaluates potential trajectories in terms of their expected energy consumption. The model on which this cost function is based is fitted dynamically using online data. The architecture necessary for this setup is described in the following Subsection.

### 3.1 Architecture

To be able to include the neccesary moduls a specific architecture is designed. Figure 1 shows the general structure of the used architecture. The left boxes symbolize the basic planner infrastructure, consisting of a *Global Planner* which receives the current goal as input and produces a route from the robots current position to this goal. This route is input for the *EDWA Planner* as local planner which is intended to make the robot follow this route. This is where the cost function described in Subsection 3.5 is implemented. The velocity commands are sent to the robot using the *Robot Driver* module which is where the electrical current consumed by the robots motors is measured as well. This data is used by the *Model Fitting* component together with the velocity commanded to the robot to fit a model to this data, which is described in Subsection 3.6. This model is fed back to the *Local Planner* to be used for planning.

The setup consisting of global planner, local planner and robot driver is popular in robot navigation. This approach