Expert Systems with Applications 42 (2015) 2624–2637

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

# Bio-inspired approach to learning robot motion trajectories and visual control commands

Marko Mitić *, Zoran Miljković [1]

*University of Belgrade, Faculty of Mechanical Engineering, Production Engineering Department, Kraljice Marije 16, 11120 Belgrade 35, Serbia*

ARTICLE INFO

*Article history:*
Available online 13 November 2014

*Keywords:*
Firefly Algorithm
Mobile robot
Learning from Demonstration
Visual control
Homography
Particle Swarm Optimization
Bat Algorithm

ABSTRACT

In this paper, a novel bio-inspired learning control approach (BILCA) for mobile robots based on Learning from Demonstration (LfD), Firefly Algorithm (FA), and homography between current and target camera view is developed. BILCA consists of two steps: (i) first step in which the actuator commands are learned using FA and demonstrations of desired behavior, and (ii) second step in which the obtained wheel commands are evaluated through the real world experiment. Two different problems are considered in this study: trajectory reproduction, and generation of visual control commands for correction of robot orientation. Developed simulations are used to evaluate BILCA in the domain of learning actuator commands for reproduction of different complex trajectories. Results show that the bigger firefly swarms produce better results in terms of accuracy in the final mobile robot pose, and that the desired trajectory is reproduced with minimal error in final control iteration. Likewise, simulations prove that the FA outperforms other metaheuristic techniques. Experiment conducted on a real mobile robot in indoor environment unifies two considered problems within a single transportation task. Depending of the feature position in the image plane, the homography controller for forward motion or the BILCA based controller for robot orientation correction is employed. Experimental results show the applicability and effectiveness of the developed intelligent approach in real world conditions.

## 1. Introduction

Today robotic systems are able to behave autonomously and to improve the system performance by interacting with the environment. Similarly to systems found in nature, new generations robots are able to adapt to the changing and undesirable conditions in real time. Learning complex robotic behaviors, however, is still a challenging task for the researchers worldwide. Various approaches that include evolutionary techniques (Berman, Lindsey, Sakar, Kumar, & Pratt, 2011; Kala, 2012; Kim, Kim, Choi, & Park, 2009; Lee & Kim, 2013; Neri & Mininno, 2010; Wei, Wang, Wang, Shao, & Chan, 2012), soft computing algorithms (Lian, 2014; Wai & Muthusamy, 2013), and combined methods (Das Sharma, Chatterjee, & Rakshit, 2012; Hsu & Juang, 2013; Juang & Chang, 2011; Melin, Astudillo, Castillo, Valdez, & Garcia, 2013) have been proposed in previous years. The diversity and robustness of these intelligent control schemes conditioned the learning of the complex skills and behaviors that are hard to mathematically describe and/or to program explicitly. Furthermore, nowadays robots have the capability to learn from humans through demonstrations and observations. This can be accomplished using the Learning from Demonstrations (LfD) methodology which enables the transfer of knowledge from human teacher to robotic learner. This paper proposes a novel robust bio-inspired learning control approach (BILCA) for mobile robots within the LfD framework, which is applied for assessment of robot motion trajectories and visual control commands.

LfD represents a subset of supervised learning in which the behavior is represented as pairs of states and actions (Argall, Chernova, Veloso, & Browning, 2009). The teacher (human or another robot) demonstrates the correct actions in accordance with the determined states, with an aim to develop a successful mapping from world observations to the robot actions (Argall et al., 2009; Mitić & Miljković, 2014). This methodology is successfully applied for object grasping (Sweeney & Grupen, 2007), mobile robot motion control (Argall, Browning, & Veloso, 2008), or for a trajectory learning (Vakanski, Mantegh, Irish, & Janabi-Sharifi, 2012). Learning a skill at a trajectory level involves modeling the demonstrated set of trajectories and retrieving a generalized representation of the set suitable for reproduction by a robot learner

---

* Corresponding author. Tel.: +381 642835 287.
*E-mail addresses:* mmitic@mas.bg.ac.rs, miticm@gmail.com (M. Mitić), zmiljkovic@mas.bg.ac.rs (Z. Miljković).
*URL:* http://cent.mas.bg.ac.rs/english/staff/zmiljkovic.htm (Z. Miljković).
[1] Tel.: +381 11 3302 468.

http://dx.doi.org/10.1016/j.eswa.2014.10.053

(Vakanski et al., 2012). Many of the reported works in this field include the use of hidden Markov Models, Gaussian mixture models, or conditional random fields (Billard, Calinon, Dillmann, & Schaal, 2008; Calinon, 2009; Lopes & Santos-Victor, 2007; Pardowitz, Knoop, Dillmann, & Zollner, 2007; Vakanski, Janabi-Sharifi, Mantegh, & Irish, 2010). Researches has also interpreted LfD in terms of Behavior Based Robotics (BBR) (Arkin, 1998). Nicolescu et al. superpose existing behavior primitives in order to learn different sequential activities (Nicolescu, Chadwicke Jenkins, Olenderski, & Fritzinger, 2008). Special kind of BBR architecture is introduced in (Kasper, Fricke, Steuernagel, & von Puttkamer, 2001), in which the history-dependent mobile robot behaviors are learned within LfD scheme. In (Hartland & Bredeche, 2007), navigation of mobile robot is based on LfD framework and recurrent neural networks. Likewise, vision systems are often integrated in the LfD framework: for example, learning of grasping movement (Lopes & Santos-Victor, 2005), manipulation task (Dillmann, Kaiser, & Ude, 1995), and mobile robot navigation (Narayanan, Posada, Hoffmann, & Bertram, 2011, 2013) is conducted via visual observations. Recently, a novel neural network LfD based mobile robot visual control scheme is verified through the real world experiments in indoor environment (Mitić & Miljković, 2014). However, none of existing literature sources propose the integration of bio-inspired metaheuristic optimization algorithm and LfD framework in robotic applications. To the authors' best knowledge, BILCA is the first method that utilizes firefly-inspired optimization algorithm and LfD to generate motion trajectories and mobile robot visual control commands.

Modern robots often use computer vision techniques to obtain rich information from the environment (DeSouza & Kak, 2002). It is known that the feedback information from monocular and/or stereo vision system can significantly improve the navigation capabilities of the mobile robots. In the image based visual scheme, control values are computed on the basis of the image features directly, while the position based visual servoing represents the technique in which the features from the image are used for the estimation of target pose with respect to the camera (Chaumette & Hutchinson, 2006; Hutchinson, Hager, & Corke, 1996). In recent years, mobile robot control approaches based on homography have become very popular in the research community (Fang, Dixon, Dawson, & Chawda, 2005; López-Nicolás, Aranda, Mezouar, & Sagues, 2012; López-Nicolás, Guerrero, & Sagüés, 2010; López-Nicolás, Sagüés, & Guerrero, 2007a; López-Nicolás, Sagüés, & Guerrero, 2007b; López-Nicolás and Gans, et al., 2010). One of the first papers addresses the asymptotic regulation of the mobile robot pose using the decomposed homography (Fang et al., 2005). This decomposition is bypassed in López-Nicolás and Gans, et al. (2010), where the robot control is based on the input–output linearization of the system considering the nonholonomic constraints of the platform. The same authors next developed the shortest path homography based visual control algorithm for differential drive mobile robots (López-Nicolás et al., 2007b). The significant improvement was reported in this study, since the three novel methods for calculating the robot velocities are introduced. By invoking the homography based control law in the hybrid scheme in López-Nicolás and Guerrero, et al. (2010), the drawback of homography approach for planar scenes is eliminated. Likewise, the field of view constrain is treated in López-Nicolás and Gans, et al. (2010), which gives the individual control laws for the three path classes that define the language of optimal paths: rotations, straight-line segments and logarithmic spirals. In López-Nicolás et al. (2012) multi robot systems are controlled in indoor environment using homography. However, the major drawback in all of these methods is that none of them employs learning algorithms capable to cope with unpredictable and undesirable real world conditions. In this paper, BILCA is applied for obtaining visual control commands for correcting the robot pose in cases of changing scene illumination, image noise, and/or image feature mismatch.

Behavior of fireflies serves as an inspiration to solving various problems such as flowshop scheduling (Christensen, O'Grady, & Dorigo, 2009) or decentralized robot control (Marichelvam, Prabaharan, & Yang, 2014). In this study, novel BILCA is founded on the recently developed metaheuristic Firefly Algorithm (FA) (Yang, 2009). The FA is based on a physical formula of light intensity that decreases with the increase in the square of the distance between fireflies (Fister, Fister, Yang, & Brest, 2013). In other words, the phenomena of change of light intensity which depends on the distance from the light source is associated with the objective function to be optimized. Robust BILCA consist of two independent steps: (i) phase 1 based on the FA within the LfD framework, which is used to generate robot motion trajectories and visual control commands, and (ii) an phase 2 with the trajectory based controller and a separate vision based control switching scheme. Using BILCA the mobile robot is enabled to reproduce the desired complex trajectory and, after that, to perform a visual homing task using homography and FA generated actuator commands.

Overall, the main contributions of this paper are threefold. Firstly, to the authors' best knowledge, this is the first paper that delivers integration of bio-inspired optimization algorithm and LfD and trajectory learning problem. Simulation results confirm the usefulness of this approach for different complex mobile robot trajectories. Secondly, this is thought to be the first paper to integrate bio-inspired optimization technique and visual homing strategy. Thirdly, the trajectory reproduction and visual servo control are combined in a single control task, which is verified on a real mobile robot in an indoor environment. Experimental results show robustness of BILCA for a mobile robotic system regarding real world changeable conditions.

One should also note that the developed hybrid vision method based on BILCA has the following advantages. Firstly, it is robust regarding the real time conditions. Feature outliers, changing scene illumination, image noise and low image acquisition frequency have no effect on the robot motion. Secondly, by implementing BILCA for vision based control the need for artificial markers or specific model of the static environment is bypassed. Thirdly, the known drawback of homography, problem of non-existence of the homography plane (Hartley & Zisserman, 2004), is solved using proposed intelligent control approach. In case when homography based controls cannot be computed, the mobile robot adjust its pose using the bio-inspired correction controller which leads to a new robot pose for the plane detection.

It is important to note the applicability of the developed intelligent system with the aforementioned advantages. Similarly to work presented in (Miljković and Vuković, et al., 2013; Nygårds, Hogstrom, & Wernersson, 2000; Pradalier, Tews, & Roberts, 2008), robust BILCA could be implemented for robot-based material handling in a manufacturing environment, as a replacement to the conventional automated guided vehicles (AGVs). Hybrid learning scheme in BILCA can achieve learning and reproduction of various complex AGV trajectories, thus eliminating the need for different artificial landmarks or wires mounted in the floor necessary for accurate navigation in the working space. Likewise, LfD based visual servoing proved to be very efficient (Mitić & Miljković, 2014), which indicates that BILCA is the right choice for accurate positioning of the working piece in the desired location. Similarly to Miljković and Vuković, et al. (2013), the usefulness of this approach is noticeable when the layout of the working environment is changed; new robot trajectory to reproduce, as well as the desired image for visual servoing task, could be obtained and stored in a quick and efficient manner.