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Genetic algorithm-based optimal computed torque control of a vision-based tracker robot: Simulation and experiment

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ABSTRACT

In this paper, an optimal control scheme based on the application of genetic algorithm (GA) is applied to a tracker robot with machine vision capability. First, dynamic equations governing the robot system are extracted and then, kinematic relationships are acquired according to camera specifications. Then, the obtained open-loop model of the robot is simulated and its validity is evaluated through an experimental work. The computed torque control algorithm with conventional tuning technique is initially used to control the robotic system. However, it is found that tuning the mentioned robot controller via the conventional technique is not so effective due to the unseen hard non-linearity presented in the robot controller such as saturation of the actuators. Consequently, a more advanced GA-based optimal control scheme is proposed in this investigation. Thus, GA is used to obtain the optimum values of control constants based on a suitable cost function. Accordingly, a simulation study is conducted to highlight the superiority of the GA-based controller compared to the former algorithm. Besides, the linking approach of the vision subsystem to the robot controller is further described from both mathematical and experimental standpoints. Finally, the proposed visual tracker robot is developed and its performance to track a moving object on a circular as well as a butterfly-shape trajectory in the camera coordinates is investigated. The experimental results clearly reveal the effectiveness of the visual robot incorporating the optimal controller to follow the target trajectories and confirm the stability of the control system.

1. Introduction

If there is one technological advancement that makes human living easier, robot would be the answer. Robots are human-like machines capable of doing tasks they are designed to do. They have shown significant decrease in human work load, especially in industries. Robots are mostly utilized in the manufacturing industry in which the type of job is usually repetitive and monotonous. Vision is known as the most important human sense and thus, the human-like robots must have the vision capability for some specific tasks in order to achieve an acceptable performance. The robots can get much useful information about the world through their eyes that can be a camera for example. Using the captured images by a camera, an intelligent robot obtains clues to plan its motion for various goals; e.g., flexible object handling, autonomous navigation, etc.

Although machine vision is known as a complex technology and is usually computer-intensive, the costs of system arrangement and data computation have become lower than before as computer technologies have advanced rapidly in recent years. Many different applications of machine vision can be found in literature i.e. in recognition of brain tumor (Aslam et al., 2015; Fazel Zarandi et al., 2011). Mehta et al. (2015) applied a vision-based guidance system to the navigation problem of a sensorless missile. They thus proposed a robust control method to follow a ground target with unknown time-varying velocity based on an image feedback. Husmann and Meier (2014) employed the machine vision and image processing technologies to measure dimensions of radial–axial rolled rings in high temperature and harsh manufacturing conditions. Mironov et al. (2015) designed a system to predict the motion direction of a projectile by image processing. Recently, large amount of research has been conducted on the applications of machine vision and image processing in robotics. Oh et al. (2009) presented a robotic system with vision capability to inspect a bridge and to detect cracks. In Yu and Moreno-Armendariz (2005), the problem of visual servoing of planar robot manipulators was investigated in the presence of uncertainty associated with robot dynamics, camera system, and Jacobian matrix. They proposed radial basis function neural networks to compensate the uncertainties. Finally, a real-time experiment was presented to show

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Nomenclature

b_θ	Damping coefficient of the base (kg s^{-1})
b_α	Damping coefficient of the barrel (kg s^{-1})
d	Focal length of camera (pixel)
D	Dissipation function
e_θ	Error of base angle (radian)
e_α	Error of barrel angle (radian)
E_k	Kinetic energy (J)
E_p	Potential energy (J)
g	Gravitational acceleration (m s^{-2})
I	Inertia matrix (kg m^{-2})
J_θ	Base inertia (kg m^{-2})
J_α	Barrel inertia (kg m^{-2})
K_d	Derivative gain
K_p	Proportional gain
l	Length of barrel (m)
m	Weight of barrel (kg)
$\acute{m}$	Weight of camera (kg)
r	Distance between mass element of barrel and barrel joint (m)
R	Distance between center of the robot base and the barrel joint (m)
T	Torque (N m)
u	Distance between camera and barrel joint (m)
V_{base}	Control voltage of the base DC motor (V)
V_{barrel}	Control voltage to the barrel DC motor (V)
x	Target coordinate in horizontal direction (pixel)
y	Target coordinate in vertical direction (pixel)

Greek symbols

£	Lagrangian
θ	Base rotational angle of the base (radian)
α	Barrel rotational angle (radian)
ρ	Mass of unit length (kg m^{-1})

the effectiveness of the proposed control approach. Ji et al. (2012) developed a visual robot with image processing capability for picking the ripe apples. In Shirzadeh et al. (2017), a vision-based control method was applied to a quad-rotor helicopter to track a moving target. Yang and Noguchi (2012) presented a detection system for an agricultural tractor using machine vision with which obstacles i.e. workers and farmers were recognized to prevent accident. In Hamed and El-Moghany (2012), a vision-based system was applied to a sun-tracking robotic system incorporating a fuzzy controller. Obviously, the output powers of the concentrating solar collector or other photovoltaic systems pertain directly to the amount of solar energy absorbed by the system, and it is therefore necessary to track the sun position with a high degree of accuracy. Fuzzy control of a non-linear rotary chain pendulum was reported by Aranda-Escolástico et al. (2016). The main objective of this paper was to design an intelligent control strategy that maximized the region of attraction of the stabilization control of a rotary chain pendulum by means of a Takagi–Sugeno fuzzy model. Indeed, selection of controller parameters is a challenge affecting the performance of control systems. Garcia-Aunon et al. (2017) proposed a method based on fuzzy logic which dynamically set the control parameters depending on the characteristics of the path to be followed. Abu-Malouh et al. (2011) developed a solar oven equipped with a sun tracking system. A dish was thus used to concentrate solar radiation on a pan fixed at the focus of the dish and the dish tracked the sun using a two-axis sun-tracking robotic system. Visual robots have also been employed in welding process or other hazardous environments (Wu et al., 1994; Xu et al., 2015).

Another important issue that significantly affects the performance of visual robotic systems is the control algorithm. Among robot control techniques, computed torque control is known as the most fundamental control algorithm for linearizing the nonlinear dynamics of the robotic systems and it has been considered in many papers. Kelly (1990) presented an adaptive motion controller for a rigid robot manipulator. The proposed adaptive controller consisted of a computed torque control incorporating a compensation control law and an integral adaptive law. Middleton and Goodwin (1988) proposed an adaptive control scheme for a manipulator system with rigid links. Linear estimation techniques together with the computed torque control law were thus used to provide a globally convergent adaptive system without the necessity of acceleration measurement. Qu et al. (1991) showed the standard computed torque control law applied to the robot manipulators could be robust with respect to unknown dynamics by judiciously choosing the feedback gains and estimating the nonlinear dynamics. Zelei et al. (2011) investigated the motion planning of a suspended robotic platform equipped with ducted fan actuators. The platform consisted of an RRT robot, and a cable suspended swinging actuator that formed a subsequent parallel kinematic chain and it was equipped with the ducted fan actuators as well. In spite of the employed complementary ducted fan actuators, the proposed system was under-actuated. The method of computed torque control was thus applied to the motion control problem of the presented robot.

Optimal control is known as a famous well-defined control strategy with extensive applications i.e. controlling the robot manipulators. In Ozkan Aydin et al. (2014), an optimal control strategy was proposed for dynamic locomotion of a simplified planar compliant half-circular legged monopod model. In Hemami et al. (1992), an optimal control law was obtained for path tracking control of a class of wheeled mobile robots (WMR). The considered optimality was based on minimizing a quadratic performance index in the position and orientation errors and the steering angle. Yedeg and Wadbro (2013) presented a technique for offline optimal control of a two-link ball-pitching robot aiming at throwing a ball as far as possible. Besides, finding an optimal piecewise constant motor torque profile and the impact position were the main objectives of the optimal controller design.

Nowadays, genetic algorithms are extensively used in designing the optimal controllers for complex dynamic systems. Michalewicz et al. (1992) applied a GA to design a discrete-time optimal controller. In Roy and Chakraborty (2009), a modified GA was proposed for optimal vibration control of smart fiber reinforced polymer (FRP) composite shell structures. Ustun and Demirtas (2008) proposed a novel speed control for an induction motor based on a genetic-fuzzy system. They thus improved the coefficients of a conventional proportional integral (PI) controller via an off-line optimal control scheme. Alam and Tokhi (2008) developed a GA-based hybrid fuzzy logic control strategy for input tracking and vibration reduction of a single-link flexible manipulator. Then, a GA was used to extract and optimize the rule base of the fuzzy logic controller. Tavakolpour et al. (2010) applied a modified genetic algorithm to identify a flexible system for the purpose of active vibration control. The presented results clearly demonstrated the effectiveness of modified GA in the vibration control application. A general method to learn the inverse kinematic of multi-link robots by means of neuro-controllers was presented by Martin et al. (2009). The main advantage of the proposed method over traditional ones was the simplicity of the training process as it was not necessary to provide a set of valid input-target pairs in the training set. Instead, a set of inputs without the need to know in advance a representative set of input-target pairs was used.

Based on the outlined literature, there was no published paper in which a visual target tracker robot is modeled, simulated, and experimented in spite of its extensive applications i.e. military, solar and telecommunication applications. In addition, a GA-based optimal computed torque control with a suitable cost function is proposed in this article for effective target tracking purpose taking into account the unavoidable hard-nonlinearity of the control system i.e. saturation of the actuators. Furthermore, the linking approach of the machine vision subsystem and the robot controller is described from both analytical