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Wireless hybrid visual servoing of omnidirectional wheeled mobile robots

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HIGHLIGHTS

- A new hybrid control algorithm for visual servoing of mobile robots is proposed.
- The algorithm includes Position-based visual and image-based visual servoing.
- The algorithm requires only the desired and actual poses of the mobile robot.
- To have linear signals output, neural network extended Kalman filter is used.

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ABSTRACT

In this paper, we propose a new wireless hybrid control algorithm for visual servoing of mobile robots. In particular, the hybrid system is developed using the two autonomous control algorithms, i.e., position-based visual servoing (PBVS) and image-based visual servoing (IBVS). The PBVS algorithm is used for global routing, whereas the IBVS algorithm is used for the fine navigation. It helps in the specific steering towards the desired point for approaching the searched object. The proposed algorithm requires only the desired and actual poses of the mobile robot, and does not need any additional requirements such as the map of the environment or artificial landmarks. For the linearization of output signals, neural network extended Kalman filter is used. Several experimental as well as simulation results are presented in order to show the applicability of the proposed algorithm in the hybrid vision based control of mobile robots.

1. Introduction

In a given environment, navigation of a mobile robot depends on certain landmarks for providing a properly constructed guided structure to maneuver. The latest advancement of the technology enforces the improvement of automated guided vehicles to be autonomously functional in the existing working environment. For fulfilling the necessities of a well operational transport system, the automated vehicles should avoid their reliance on extra infrastructure by implementing on-board sensing devices in the vehicle systems.

Automated guided vehicle-based transport systems seldom utilize cameras for acquisition of appropriate information. Some of the methods [1–3], utilized laser range-based sensors for grabbing the information about the environment. Modern progresses in robotic-vision offer a good quality preliminary model for integration of the camera with modern automated guided vehicles. In automated guided vehicles, visual cameras become a popular choice due to their cheaper cost, extra reliability, and capability to offer great amount of spatial information. Additionally, the information gained from the camera have value for vision-based control, estimation of state, path planning, and avoidance of obstacle. Consequently, the future generations of transport systems based on autonomous guided vehicles should incorporate the camera in addition to other sensors for autonomous maneuver in the working environments.

A mobile robot can move from its initial configuration to the desired one, using the information (image features) which is acquired by a camera. This is done based on the feedback of visual servoing. Mobile robots are mainly liable for non-holonomic constraints which include more challenges for the visual servoing based asymptotic stabilization. To minimize the visual servoing duty to a control problem the method position-based visual servoing (PBVS) of mobile robots has been considered in the

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Nomenclature

Symbol	Representation
D	Mass diagonal matrix of the robot
f	Focal length of the camera
G	Vehicle center of gravity
d	Distance between each wheel from center of gravity
F_i	Deriving force of ith wheel
K	Intrinsic parameter matrix of a camera
K_f	Control gain matrix
$R(\theta)$	Rotation matrix
V	Wheel motor applied voltage vector
m	Homogeneous coordinate of a 3D point
M	2D projection of a point
C_a	Actual pose of the camera
C_d	Desired pose of the camera
F	Fundamental matrix
e_a	Actual view of the epipole
e_d	Desired view of the epipole
e_{ax}^d	Desired trajectory of the actual epipole along x axis
e_{ax}^d	Desired trajectory of the desired epipole along x axis
S_j	Joint state vector
s_u	Pose joint state vector of the robot relative to the world frame
s_f	Feature coordinates in the environment
s_w	Entire connecting weights vector
f_{true}	Matrix valued function that estimates the target dynamics
ϵ	Model insignificant errors
θ	Orientation of the mobile robot

Cartesian space [4,5]. A hybrid control algorithm based on polar coordinates has been proposed in [5]. Lyapunov theory [6] has been used to tackle a non-holonomic mobile robot parking problem where the features of the camera field-of-view (FOV) can be used throughout the visual servoing process. However, there is a disadvantage of this approach which is the need of some 3-D metric information (depth) of the features identified as a priori.

An image-based visual servoing approach is used in [7–9] by computing the epipolar geometry, to drive the mobile robot up to the desired configuration. One of the limitations of IBVS in the visual servoing is that there is no direct controlling of the distance between the current and desired positions, particularly when the initial state configuration is near to the desired one. However, in such cases, many feature points (commonly, eight or more) are required to compute the fundamental matrix [10]. But, the visual servoing applied in IBVS study specifies teach-by-showing control approach in which the information from the desired and current images are taken to compute the epipolar geometry. It results in vehicle linear and angular velocities which become known from the control law. The kinematics and dynamics control model of the omnidirectional wheeled mobile robot is presented in [11,12] respectively.

In [13], an asymptotically stable predictive algorithm with a pair of controllers was proposed. The main advantage of the algorithm was the least computation time. The first controller was used for hybrid visual servoing, while the second one was used to reduce the error that occurred in both image features and Cartesian space with preferred ratios simultaneously. In [14], a hybrid controller was proposed that combines the position-based method for global stability along with image-based robust approach. This was accomplished by applying a switching approach, which favors the average error of servoing as an advantage. In [15], a hybrid method was introduced which uses a teach-and-replay based technique by combining path following and navigation based on features algorithms. In [16], an adaptive neural network controller was considered for vision based control of a camera-in-hand robot manipulator.

Autonomous navigation of a mobile robot is a circumstance in which a vehicle is capable to identify its pose in a working environment by means of sensor information. In problems where a vehicle is situated in an unknown environment, this approach can be extended to simultaneous localization and mapping (SLAM). A number of approaches have been listed in the literature on SLAM, and still it is a popular area of research in robotic vision [17–20]. At the present time, the visual SLAM (or VSLAM) is also becoming part of controlling method for the system which refers SLAM based on the information obtained from the camera. The spatial information extracted for estimation of the lane of mobile robots, a monocular camera and encoders of the wheels were used in [21]. The assumptions considered in our study are applying neural network Kalman filter (NEKF) as estimator for tackling the uncertainties that existed in the hybrid visual servoing algorithm. We did not consider any wheel slippage parameter in this study.

In order to make clear that the contribution of the proposed work is different from all of the above discussed algorithms, the following points are explained:

- In the proposed study, hybrid control algorithm estimates the robot pose with the information obtained by the integration of odometry of wheel encoders and a monocular camera. Here, linear and angular velocities of mobile robot become known from the control law which results a teach-by-showing approach. Our algorithm does not require any synthetic landmarks for guiding and localizing the mobile robot (i.e., unlike the algorithms [22,1,2], where a number of artificial landmarks are required). In our approach, from the projections of the points and lines of a 3D world object in the image plane, 2D image features are obtained. This approach is flexible since arbitrary 3D object (possibly anonymous) with unidentified position can produce image features, which can be appropriate for vision based control. Additional methods [23,24] are not so flexible and depend on the various types of synthetic landmarks that the mobile robot identifies and utilizes for localizations and visual servoing towards a target point. Also, the proposed algorithm needs the desired pose and the target image, and hence eliminates the requirement of the correct map of the environment. Unlike existing algorithms, the proposed algorithm is effective in a case where the working environment is altered any time.
- The proposed algorithm is used for searching and approaching towards the required object. PBVS is applied in order to recognize how far the object from the mobile robot is placed, meanwhile the IBVS is used for identifying the exact image features of the object. This approach is better as compared to other methods, where the goal image should be in the field of view of the camera from the initial state.
- Neural network extended Kalman filter (NEKF) is applied for linearization of the nonlinearities which existed in the system in the execution of the IBVS and PBVS algorithms. An access point is placed on the autonomous vehicle, which produces communication through the commands from laptop computer given by the user and the information received from the sensors fixed on the mobile robot.

2. The hybrid visual Servoing algorithm

The hybrid method consists of PBVS and IBVS controlling systems and a discontinuous system for switching purposes between these two subsystems. When a robot is placed at a

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