# Visual Servoing for Constrained Robots in an Unknown Environment: A New Complete Theoretical Framework and its Experimental Validation

E.C. Dean-León*, V. Parra-Vega*, A. Espinosa-Romero**

* Mechatronics Division
CINVESTAV-IPN
I PN 2508,Sn P. Zacatenco, México, D.F.,7300.
edean, vparra@cinvestav.mx

** Faculty of Mathematics
Universidad Autónoma de Yucatán
Mérida, Yucatán. México
eromero@tunku.uady.mx

Contact person: M.Sc Emmanuel Carlos Dean-León, IPN Av. 2508 Sn. Pedro Zacatenco, GAM, México City, +52-55-50613800 Ext. 6318. e-mail: edean@cinvestav.mx.
Speaker: M. Sc. Emmanuel Dean-León.

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**Abstract:**

The theoretical framework and experimental validation of a new image-based position-force control in an unknown environment is presented in this paper. This scheme produces simultaneous convergence of the constrained **visual position** and the **contact force** between the end-effector and the **unknown constraint surface**. Camera, robot, jacobian parameters and constrain surface are considered uncertain, neither direct nor inverse robot kinematics is needed. This approach is based on a new formulation of the orthogonalization principle used in force control, coined here *visual orthogonalization principle*. This allows, under the framework of passivity, to yield a synergetic scheme that fuses accordingly camera, encoder and force sensor signals. In order to prove the effectiveness of the theoretical scheme, a Linux-RTAI real-time OS experimental system is used to obtain a direct-drive robot manipulator equipped with six axis JR3 force sensor and a CCD commercial digital fixed camera. Results show an excellent performance.

**Motivation:**

Image-based visual servoing schemes of robot manipulators for free motion have been proposed recently, which guarantee tracking, including the dynamic model in the stability analysis. The task under study is that the robot end effector tracks a **visual** trajectory along the surface of an **unknown** object, and at the same time, control the applied force exerted by the end-effector in the **unknown surface**, see Figure 1. This task is very relevant in many robotics applications. However, for any practical impact, uncertainties in camera system and robot parameters must be considered. Nevertheless, for constrained robot, there remain important open problems, essentially because, from the theoretical viewpoint, it involves redundant sensors, thus it is not evident how to handle sensor fusion in a complex nonlinear dynamical system. From the experimental viewpoint, exhibits a multi-rate system due to the slow latency of the camera, in comparison to the latency of the encoder and force sensors, see Figure 1 Therefore, a theoretical constrained visual servoing scheme must be accompanied with its experimental validation. In this paper, a new scheme and its real time performance are proposed.

**Contribution:**

A second order sliding mode controller driven by **constrained image errors** is proposed to solve by first time the problem posed above. The underlying reason that allows obtaining this result is that a new image-based error manifold is introduced to produce a visual-based orthogonalized principle.

Thus, similar results to the case of nonvisual-based orthogonalized principle are obtained. The closed-loop system guarantees exponential tracking of position and force trajectories subject to **parametric uncertainties** and **unknown constraint environment**. This scheme delivers a smooth controller and presents formal stability proofs. Moreover, its experimental validation is presented.

Surprisingly, the control structure is quite simple, in contrast, the proof is rather involved, though straightforward. The simplicity of the controller enhances its practical applications since the desired task is designed in image space, i.e., the user defines the desired task right from the image that sees, provided that the fixed position of the camera is set to covers the reachable space of the robot, in this way a task free of singularities is ensured, see Figure 1, wherein the fixed camera supplies a perspective of the desired task.

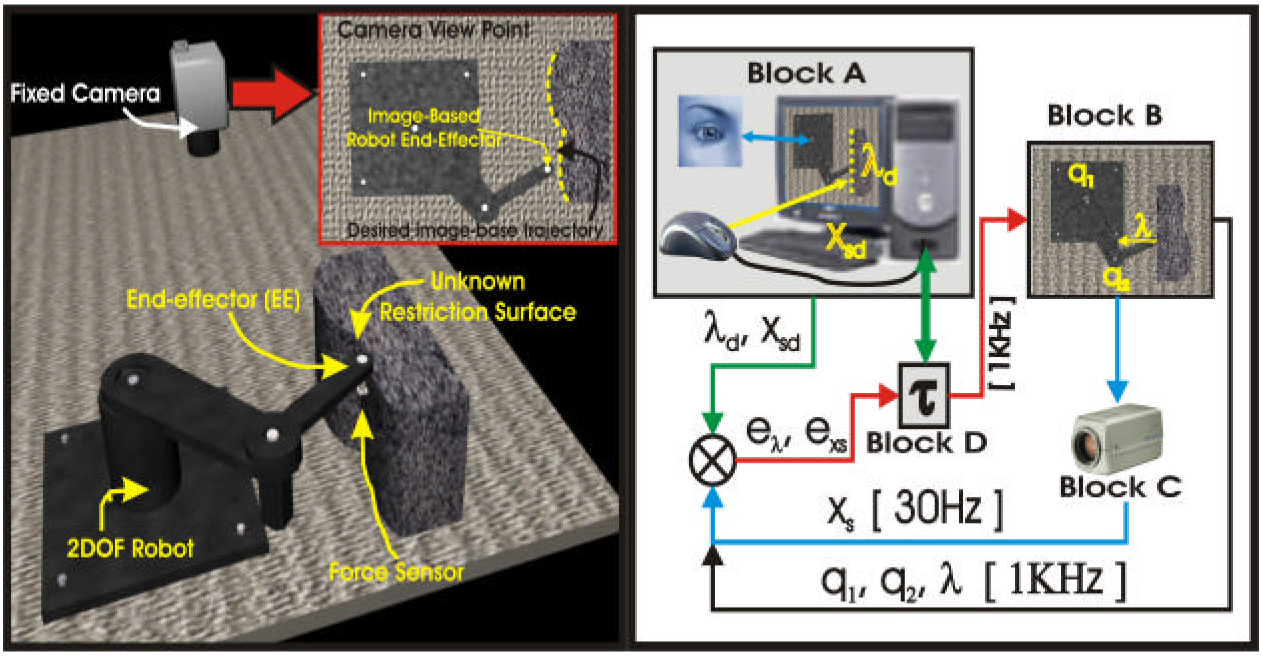


Figure 1. Robot Force-Vision Experimental System: Where, $e_l$, $e_{xs}$, stands for force errors and visual errors. $l_d$ is the desired force, $l$ is the applied end effector force, $x_s$ is the visual position of the robot end-effector and $q_i$, stands for generalized position. The Restriction Surface is unknown but with continuous gradient.