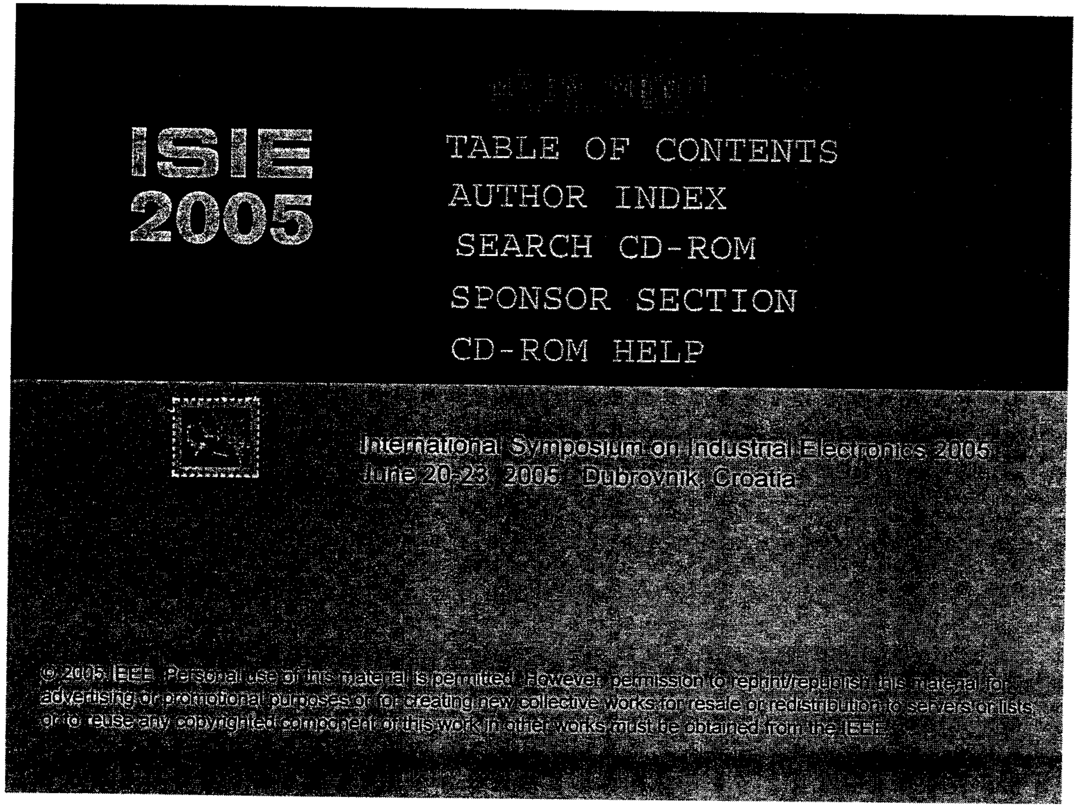
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The Efficiency of Supplement Schema for IBVS Algorithms

Mirjana Bonković*, Darko Stipaničev*, Maja Štula*

* LaRIS-Laboratory for Robotics and Intelligent Systems

Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture

University of Split

mirjana.bonkovic@fesb.hr;dstip@fesb.hr;kiki@fesb.hr

Abstract— **In this paper we propose a special geometric feature parameter supplement schema for IBVS systems in which, the servoing is based on the point to point correspondences. The proposed algorithm with special feature parameters is compared with the "classic" feature parameters algorithm. Simulation results show that supplement schema improves the convergence rate and the stability of the visual servoing system.**

I. INTRODUCTION

One of the most important considerations of all vision based systems is the process of extracting and using the image data efficiently. The typical field in which vision is introduced to increase accuracy and flexibility is robotics. A formal classification [1] differentiates such systems based on the error signal domain. If the error is defined in 3D (task space) coordinates, the position based system is considered (PBVS). Otherwise, if it is defined directly in terms of image features, the system is said to be an image based (IBVS). The specification of an image-based visual servo task involves determining an appropriate error function e, such that when the task is achieved, e=0 [2].

In image based visual servoing, the control error in the feedback loop is expressed directly in image coordinates. As the robot control input is usually defined in joint or in task space coordinates θ_t, it is necessary to relate the changes in visual appearance y_t with the changes in task space through the image Jacobian matrix (J).

$$\dot{y}_t = J\dot{\theta}_t \qquad (1)$$

Identifying the Jacobian is the process which can be generated either analytically, assuming a projective camera projection [2], or by doing linear-independent test movements in the actuator space [3]. In visual servoing we are interested in determining the manipulator velocity $\dot{\theta}_t$, required to achieve some desired value of $\dot{y}_t$. This requires solving the system given by (1). If the number of image features (visual appearance elements - feature vector elements) differs from the number of tasks degrees of freedom, we can compute a least squares solution for a Jacobian parameter estimation [4], [3]. One of the main drawbacks of under constrained IBVS systems (systems in which the number of feature parameters is smaller than the number of tasks degrees of freedom) lie in the fact that some components of the object velocity are unobservable (for example those belongs to the pure rotation around optical axes) [5]. That physically means that sometimes it is simply not possible, in a real situation, to fulfill the task using the minimum energy condition or using the shortest path in image space, which is a straight line.

The numerous hybrid methods are described in [5], [6], which with varying degrees of successfulness eliminate the mentioned drawback.

If the target is moving, the system model has encountered the error not only as a function of robot pose but also as a function of the pose of a moving object [7].

In this paper we propose a special geometric feature parameter supplement schema for IBVS systems in which, the servoing is based on the point to point correspondences. The proposed algorithm with special feature parameters is compared with the "classic" feature parameters algorithms. Simulation results show that supplement schema improves the convergence rate and the stability of the visual servoing system. Coupled with fuzzy [8], the proposed schema makes the servoing possible even for moving object tracking.

II. THE ALGORITHMS

In this section we shortly present the tested algorithms. We start our study with the "classic", well known and often cited IBVS algorithm defined by Jagersand [3] for over constrained (number of feature parameters is greater than number of system degrees of freedom) case. He proposed a Broyden hierarchy for Jacobian updating schema and used trust region methods to increase covergency. The algorithm is experimentally verified for 12 degrees of freedom robot for pick and place tasks. In the beginning it is necessary to perform linearly independent test movements, while updating schema is performed on-line during the target approach phase. Jacobian is updating according to the (2):

$$J_{k+1} = J_k + \frac{(\Delta y_{measured} - J_k \Delta\theta_k)\Delta\theta_k^T}{\Delta\theta_k^T \Delta\theta_k} \qquad (2)$$

The control vector is generated from (3) finding appropriate pseudoinverse of the Jacobian matrix (J_{k+1}):

$$f = \Delta y_{to\_goal} = J_{k+1}\Delta\theta_{k+1} \quad (3)$$

where f is a feature vector parameters, J_{k+1} is an estimated Jacobian matrix and $\Delta\theta_{k+1}$ is a join angle changes needed for zeroing a feature vector parameters, which is a goal of the IBVS control.

The algorithm performs well for over constrained system if the initial Jacobian is well estimated. Consequently, for randomly moving target the algorithm performs poorly since it is necessary to estimate the initial Jacobian frequently which interferes with target approach movements.

On the other side, we have experience with the fuzzy visual servoing algorithm [8], which estimates the minimum distance to target point by moving the joints sequentially. For algorithm implementation we introduce special geometric image plane considerations which, we suppose, could improve the "classic" approach, in a way to accelerate the target approach convergence rate and could be suitable especially for under determined systems. The key point of the fuzzy algorithm is to overlap the images from the cameras through the target point (Fig. 1).

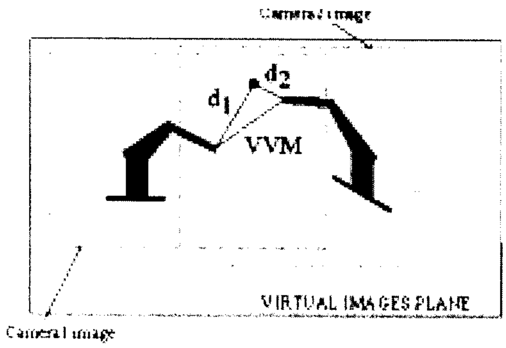

Figure 1. The process of the supplement parameters extraction.

The feature vector parameters for one point to point correspondences consists of up to seven parameters, instead of four ordinary parameters (four differences along the x and y axes between the interesting point and its goal position in each image). The three new feature vector parameters, which we have used for fuzzy control, are: the distance from robot end-effector on the first image to the target point (d1), the distance from robot end-effector to the target point on the second image (d2), and the distance between end-effectors measured on the common plane which is formed by "gluing" the images from the cameras by overlapping the target point (VVM-Fig. 1). If we need to control more than 3 degrees of freedom, additional point correspondences would introduce up to seven additional feature vector parameters. Under such circumstances, it would be necessary to perform additional overlapping through the new point and to stack the appropriate matrix elements with the new parameters.

The fuzzy algorithm is described minutely in [8]. Based on the production rules in which the antecedent part of the clause includes the specific distance from end-effector to the target, measured in the images, and the "visual approach speed", it is possible to estimate the appropriate joint angle speed change for positioning the joint into the minimum to target distance. As the algorithm is designed for one dimensional case, the main drawback is related with its estimation "range". For example, if the joint angle is in its right position, the time would be spent to check if the position could be corrected, which is costly for static target but helpful for moving target tracking, especially if the object moves randomly in a robot workspace.

III. THE SIMULATIONS

The simulations have been performed using robot of a RRR structure for a point positioning task. The algorithms have been tested using simulator (Fig. 2) for different robot end-effector start and target positions [9].

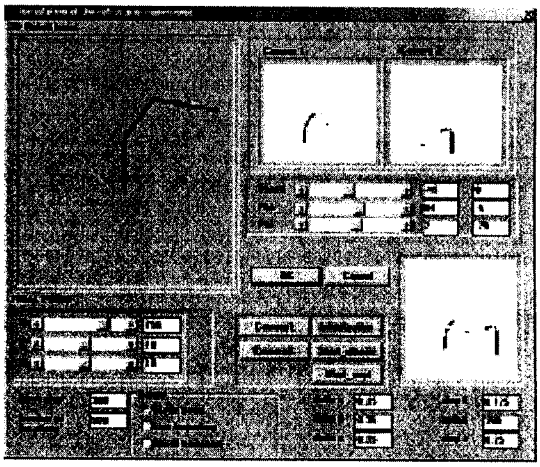

Figure 2. The simulator graphical user interface

We were interested how the "classic" approach would behave if we exchanged the "classic" – four feature parameters which consist of an appropriate distances along the x and y axis from the interesting point to its goal position on the images of two cameras (needed for 3D positioning)., with the three feature parameters described in section 2. The curve of the robot joint angles has been shown in the Fig. 3. The first group of results is presented in a the first row of the Fig. 3. The "classic" – four feature vector parameters are presented in a second row, while "supplement schema" results, which use feature vector parameters consisted of four "classic" and one additional parameter marked as VVM distance in Fig. 2, are presented in the third row of the Fig. 3. In the fourth row we have presented the fuzzy control achievements for the comparison purposes. We have tested the different algorithms using three different robot end effector start and goal position, presented in columns of Fig. 3, and titled as POSITION 1, 2, 3. The first start position for the robot end-effector has had a coordinate (917,10,10), the second (16, 499,1110), while the third start end-effector position is the same as second, but has different robot joint angles start configuration. The same schedule of the various parameters results has been presented in Fig. 4 for 3D robot end-effector trajectory curves.

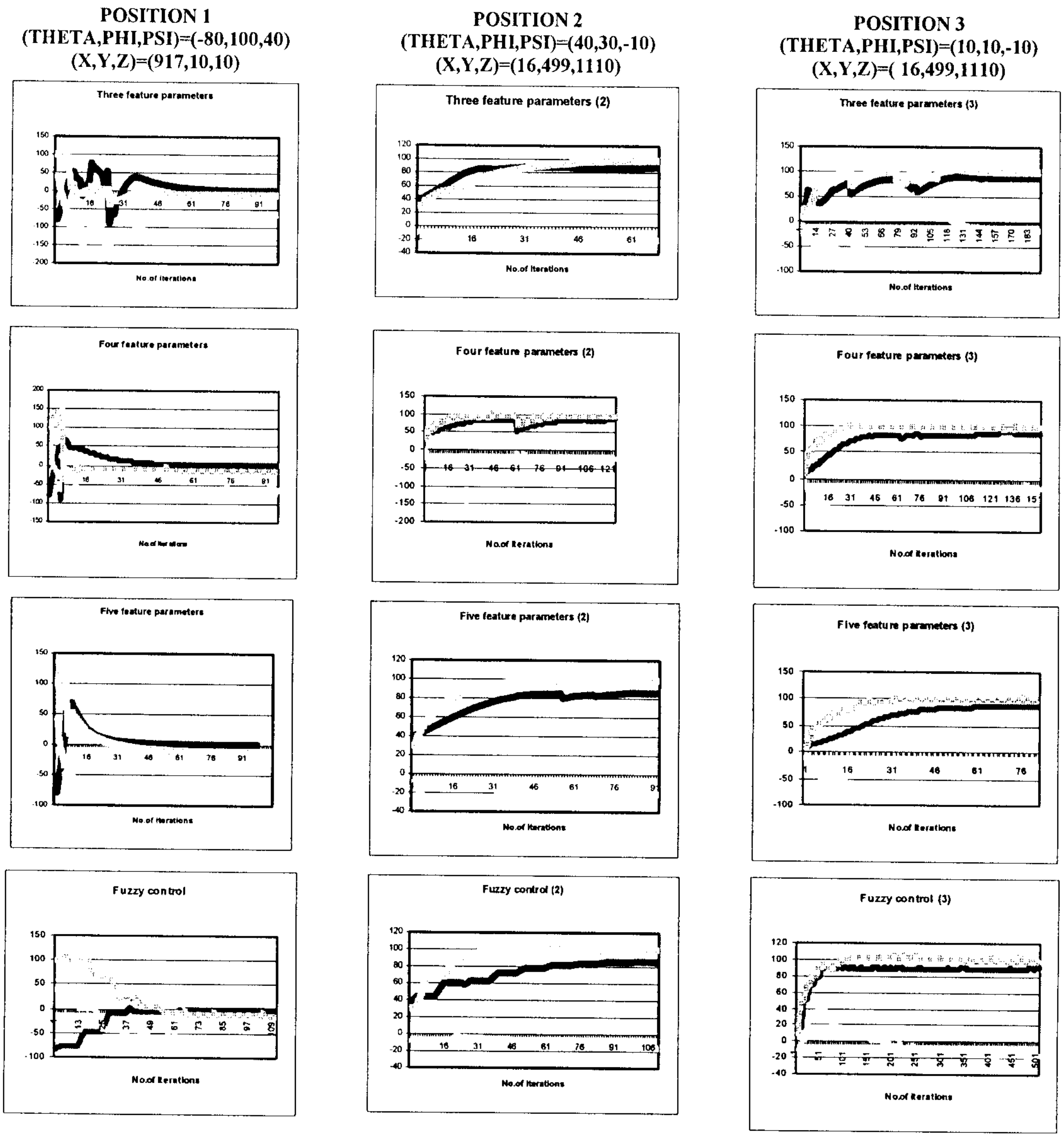

Figure 3. The shape of the angle joints curves for different control approaches

The simulation results (Fig. 3) have shown that the convergence rate and the stability have been improved by increasing the number of feature parameters. The 3D trajectory curves (Fig. 4) look more smoothly for feature vector with more parameters which means that robot passes shorter path on its way to the target point.

The algorithms have also been compared for the target tracking efficiency. According to (1) and (2) the algorithm performed well if the initial Jacobian is well estimated. For moving target tracking, the process of initialization has to be performed rather frequently interfering with the task. Our suspicions have been confirmed as simulations on Fig. 5 show. After the initialization, the end-effector has been positioned precisely into the target point. As the target has been moved, the algorithm results in instable control. Regardless the number of feature vecto parameters, the "classic" algorithms perform poorly and result in instable control. On the other side, fuzzy algorithms need no initialization and perform well for static and moving target tracking as well.

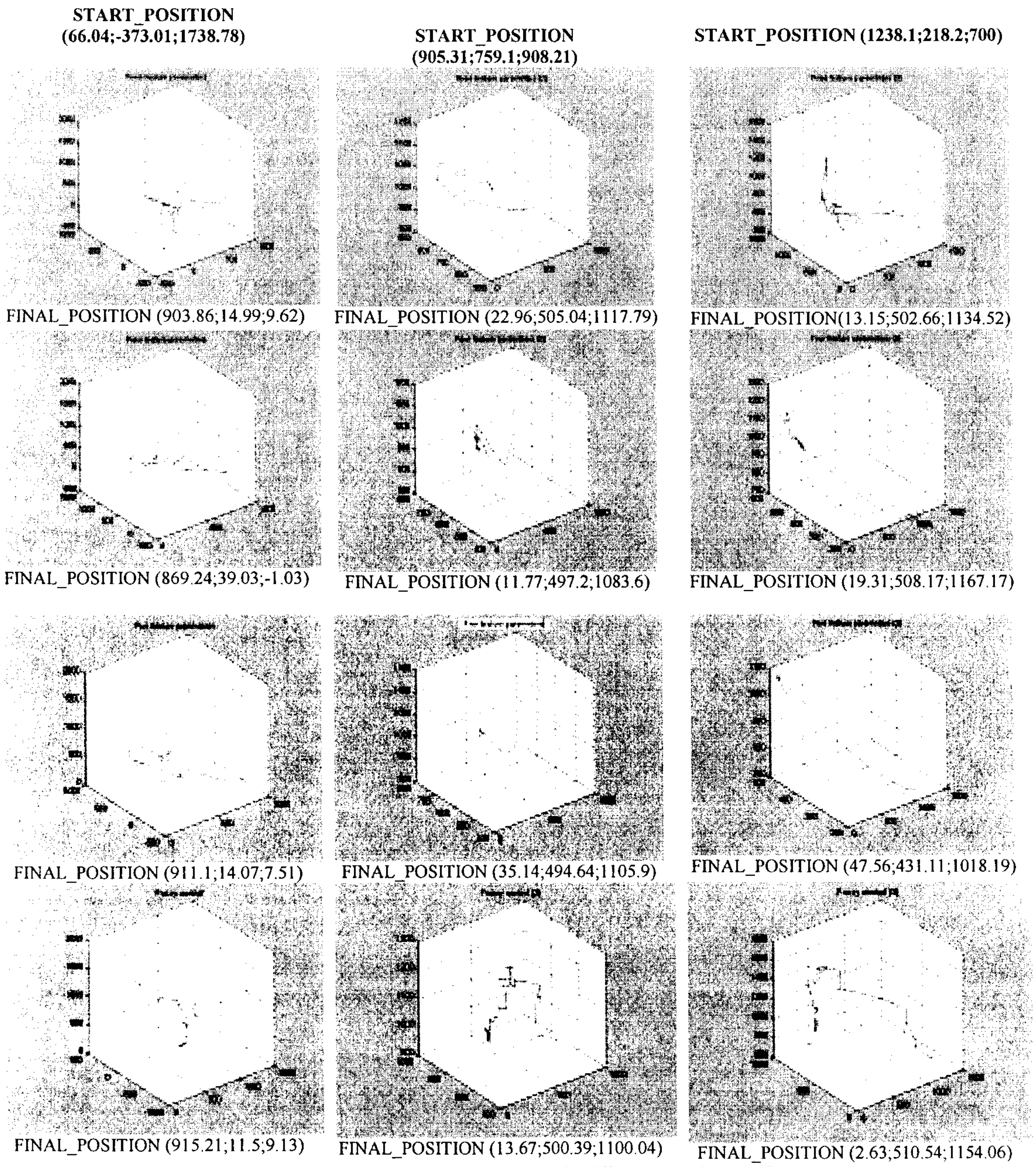

Figure 4. The shape of the 3D trajectories for different control approaches

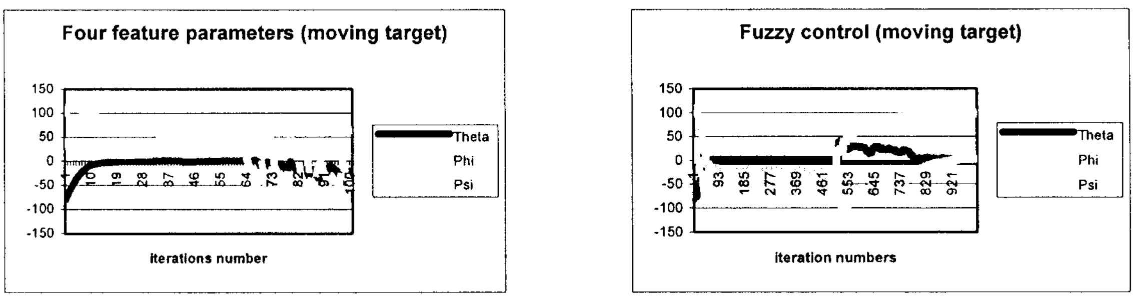

Figure 5. The shape of the joint angles curves for moving target tracking

It is also interesting to notice that the shape of all curves in an appropriate columns of the first, second and the third row in Fig. 4 look similar (with varying degree of smoothness), while "fuzzy" curves have their own "look". The possible reason lie in the fact that the fuzzy control has been achieved by sequential joints movement, while "classic" control assumes simultaneous control for all robot joints and it is a subject of our future consideration.

IV. Conclusion

The presented results have shown that the "supplement schema", which increases the number of feature parameters for the same feature elements selected from image, improve the convergence rate and the stability of a IBVS system. For that reason "supplement schema" can be useful for IBVS systems, especially for under determined cases where the number of feature elements are less than system degrees of freedom.

In our future considerations it would be interesting to compare the presented trajectory curves performed with end-effector of an articulated robot of a RRR structure (which reminds on a human hand) with the trajectory of a real human hand when performing similar task. It would be helpful for the process of understanding the simplest but fundamental task of an intelligent control: which parameters and how many of them are important for the visual-motor control, which humans apply intuitively and perfectly, as it always occur in infinite inspiration source of nature.

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