

# Image-based Mobile Robot localization using Interval Methods

Ide-Flore Kenmogne<sup>1</sup> and Vincent Drevelle<sup>1,2</sup>

<sup>1</sup> IRISA - INRIA Rennes-Bretagne Atlantique, LAGADIC Project

Campus de Beaulieu, 35042, Rennes, France

`ide-flore.kenmogne@inria.fr`

<sup>2</sup> Université de Rennes I,

Campus de Beaulieu, 35042, Rennes, France

`vincent.drevelle@irisa.fr`

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## Introduction

To navigate, robots need to locate themselves. In the case of unmanned aerial vehicles (UAVs), the standard solution consists in using GPS, INS and Compass measurements. Yet, this solution is not appropriate in difficult environment like indoors or close to large buildings; where GPS signals losses and erroneous orientation measurements from the compass are observed.

Our aim here is to provide a reliable pose confidence domain; a box in which we are sure the robot is situated. In other words, we wish to compute a “safety area” around the robot that should be considered by the controller in order to avoid collisions with eventual robots or objects present in the navigation environment.

GPS and compass unavailability can be overcome by using a camera in order to enhance robot localization. In computer vision, many solutions to pose estimation from a set of known landmarks (such as POSIT, PnP, etc. see [1] for a survey) exist but classically provide a punctual estimate of the robot location. Interval analysis is a powerful tool for rigorous uncertainty propagation (see [2] for a 3D vision application, and [3] for GPS position uncertainty domain computation). To quantify the robot pose uncertainty, we propose an interval-based set-membership approach, which computes over time a bounding box of the pose of the robot, taking image measurements and landmark positions uncertainties into account.

## Method

We propose here an algorithm that tracks the robot trajectory using uncertain image measurements of landmarks that are in the UAV’s camera field of view. Starting from an initial box (representing the initial search space), at each image acquisition epoch, we contract the robot pose box by using the camera projection equations (expressed as constraints) that give the correspondence between a point from the world to the image plane. This step can be seen as a correction step.

Between two image acquisitions, the robot evolution is predicted using velocities measurements acquired by embedded proprioceptive sensors.

## Image-based pose estimation

Let  $x^c$  and  $X^w$  be the vectors containing respectively the measurements in the image plane and the landmarks positions in the world frame (represented with homogeneous coordinates). Then, the

observation model is in the form of:

$$x^c = K \Pi {}^cT_w X^w \quad (1)$$

where,

- $K$  is the camera intrinsic parameters matrix,
- $\Pi$  is the perspective projection matrix (from meters to pixels),
- and  ${}^cT_w$  an homogeneous matrix that permits to compute the frame transformation (projection from world to image). This matrix is a function of the robot pose (rotations using Euler angles representation  ${}^cR_w$  and position  ${}^ct_w$ ) in the world frame and is expressed as follow :

$${}^cT_w = \begin{pmatrix} {}^cR_w & {}^ct_w \\ 0_{3 \times 1} & 1 \end{pmatrix} \quad (2)$$

The classical pose estimation methods (e.g. the POSIT algorithm) relies on finding the pose (best matrix) that minimizes the re-projection error.

In the proposed interval-based method, since the measurements have some bounded uncertainty, each  $x_i^c$  and  $X_i^w$  is an *interval vector*, such that  $x_i^c \in [x_i^c]$  and  $X_i^w \in [X_i^w]$ . We then define a constraint satisfaction problem (CSP) using  ${}^cR_w(\phi, \theta, \psi)$  and  ${}^ct_w(X, Y, Z)$  as *variables* and we define its *constraints* by applying Eq.(1) on each pair  $i = 1 : N$  ( $N$  number of observed landmarks) of image-world points. We also add geometric constraints in our CSP considering the limitations and characteristics of some UAV parameters and movements feasibility. Afterwards, we build a contractor that contracts the initial box with respect to the whole system's constraints.

A test case will be presented to illustrate the method and quantify the pose uncertainty. As classical control strategies rely on a point position estimate, our method which provides rigorous bounds (but no point estimate) is later combined with POSIT (which gives a precise point estimate).

## References

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