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ROBUST METHOD FOR CAMERA CALIBRATION WITH VARYING PARAMETERS USING HYBRID MODIFIED GENETIC SIMPLEX ALGORITHM

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ABSTRACT

In this paper, we present a new method of camera calibration with varying parameters by a hybrid optimization algorithm that combines simplex algorithm and the modified genetic algorithm. Comparing to traditional optimization methods, the cameras calibration with varying parameters by this approach can avoid being trapped in a local minimum and converge quickly to the optimal solution without initial estimation of the cameras parameters. Several experiments are implemented using a 3D grid characterized by these coordinates which are known, to demonstrate the validity and performance of the proposed technique. The results show that this approach is accurate and robust to single optimization methods.

Keywords: *Camera Calibration; Computer Vision; Genetic Algorithm; Simplex Method; Non-Linear Optimization.*

1. INTRODUCTION

The camera calibration is a crucial step in vision stereo and 3D reconstruction [1], it is to estimate intrinsic and extrinsic parameters of the cameras. Different calibration techniques exist in [2, 3, 12] they are generally based on the pinhole camera model and using the images of a reference object with known dimensions (cube, 2D grid of calibration).

The Genetic Algorithm (GA) is a stochastic and parallel search technique based on mechanism of natural selection and the evolution, which was developed by Holland in 1970 [6, 28]. In recent years, GA has been widely applied in various fields such as the calibration and self-calibration of cameras, computer vision, fuzzy systems, neural networks [4, 5, 11, 13, 15, 31, 32]. The GA has become one of the popular methods for solving the global optimization problems, the main problem of the GA is that it can be fallen into the local optimum of the objective function when the dimension of the problem is high and the very high convergence time [7, 9]. In order to correct these defects and to improve the efficiency of the GA optimization, the recent researches works have summer usually worn on two aspects. One is improvement on the algorithm mechanisms, such as the modification of genetic operators, or the use of the Niche technique [33]. The other is the combination of GA with others algorithms, such as the Levenberg-Marquardt (LM), Particle Swarm Optimization (PSO) [10, 14, 15].

In this paper, we are interested an exploitation of the Hybridization of the Modified Genetic Algorithm and Simplex Algorithm (HMGSA) to solve the problem of camera calibration with varying parameters. As a first step, we will run the Simple Genetic Algorithm (SGA). To improve the performances of the SGA, some genetic mechanisms are modified to form a Modified Genetic Algorithm (MGA). For the improving still of performances, we combine the MGA with the Simplex Algorithm (SA) to minimize the evaluation function to estimate the cameras parameters.

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Our approach solves the problem of camera calibration in three steps: First, the detecting and matching of interest points in the pair of image (left and right) is performed. Secondly, formulating the non-linear cost function, and finally the minimal value of the optimized cost function is calculated by the algorithm HMGSA.

The proposed approach is distinguished from other genetic approaches by the following points:

- We used a three-dimensional grid for calibration, this will provide more learning points in a shooting and can avoid the photographic capture of various orientations of a planar grid the chessboard type, and the calibration process is thus simplified and faster.
- The cameras used are characterized by varying parameters which render the calibration procedure most robust with any constraint on the cameras used.
- The classical methods of cameras calibration are classified into two categories, the first uses local search algorithms for the minimization of the non linear cost function, in this case an important initialization step to find the optimum, these algorithms may have some problems, the initial point of optimization (if the initialization is very far from the real configuration of the camera and of the optimum, then it is hard of converge to the optimal solution), they also have more chance of beings entrapped in a local minimum, because the minimization of the non-linear cost function isn't an easy task, since this function isn't convex and contains lots of complex local minimas, but they have some advantages: simplicity and computational efficiency. The second category uses global search algorithms (GA, EA), they are less likely to be entrapped in local optimum, but the convergence rate is increased, and the computational cost is high. The hybridization of these two categories allows accelerate the speed of convergence and avoid local minima to obtain a good estimation of the cameras parameters.

The rest of what paper is organized as follows: In section 2, we will present the survey of related work. Section 3 describes the background. In section 4 we present the camera calibration procedure by HMGSA. The experiments results and analysis are explained in section 5 and the conclusion is presented in section 6.

2. SURVEY OF RELATED WORK

The GA showed that they were promising in various applications of the computer vision, and recently in the calibration and self-calibration of the cameras. We describe below the various applications of evolutionary algorithms used for calibration and self-calibration of camera. Two genetic algorithms methods used to estimate the camera parameters, one lets find the intrinsic and extrinsic parameters of the camera directly by genetic algorithms, the other serves to find the camera parameters by compounds algorithms between the genetic algorithm and other non-linear optimization algorithms namely Levenberg-Marquardt, Particle Swarm optimization, Nelder-Mead simplex.

2.1. Cameras Calibration By Genetic Algorithms

This method is the basis of numerous works [8, 9, 17, 18, 19, 20, 21, 23, 25, 26] which have developed of genetic algorithms for estimating the camera parameters per minimizing a non-linear cost function. They use 2D grid and objects geometrically known (cube) to calibrate the camera with very reliable results.

2.2. Camera Calibration With Compound Algorithms

In several papers [10, 24] the authors have proposed a procedure of camera calibration into two stages. First, a GA is used for finding a good approximation of the solution. Then a non-linear minimization algorithm (Nelder-Mead simplex, Levenberg-Marquardt) is applied to refine the results.

At the end of the execution of the GA, the best individual will make office as input to the non-linear minimization algorithm, a refined solution is obtained. If the error obtained after the latter execution is acceptable, the results will be final if not the calibration process will restart from the GA which will include the last best individual for initialization of the new population.

3. BACKGROUND

Order to understand the operating principle of our approach, we propose below the camera model and the vision system utilized for the calibration well as a brief introduction to the simplex algorithm and to genetic algorithms.

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3.1. Camera Model

In our approach, we consider the pinhole model of the camera by which a point M of the scene projects itself onto the image plane in a point m (Figure 1) by the following formula:

$$m \sim A(R/t)M \quad (1)$$

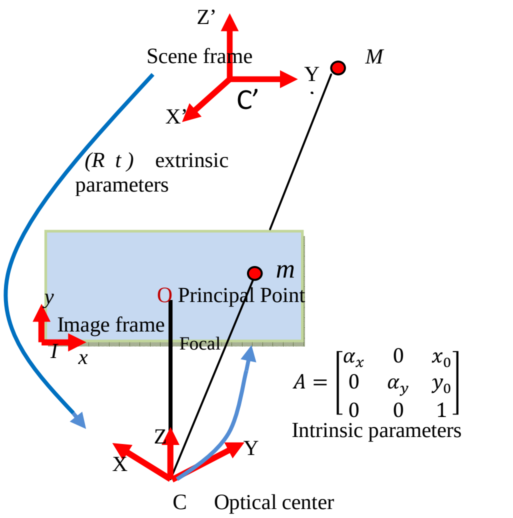

Figure 1. Pinhole Camera Model

The elements of the matrix A are the intrinsic parameters of the camera which will be determined by the calibration procedure. $\alpha_x = k_x f$, $\alpha_y = k_y f$ with f is the focal length and $(k_x,\ k_y)$ are scale factors vertical and horizontal, (x_0, y_0) are the coordinates of the principal point (the image center).

The translation vector $t = \left[t_x\, t_y\, t_z\right]^T$ and the elements of the rotation matrix R, which determines the three Euler angles $(\omega, \emptyset, \theta)$ on the three respective axes (X', Y', Z'), are the extrinsic parameters of the camera which will be determined also by the procedure of calibration.

$$R = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & -\sin\omega \\ 0 & \sin\omega & \cos\omega \end{bmatrix} \begin{bmatrix} \cos\emptyset & 0 & \sin\emptyset \\ 0 & 1 & 0 \\ -\sin\emptyset & 0 & \cos\emptyset \end{bmatrix} \begin{bmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (2)$$

3.2. Vision System

The projection the a three-dimensional grid provided with its global reference (O, X', Y', Z'), in the image plane left and right by two different cameras (Figure 2) is given by the projection matrices associated to each left and right cameras respectively according to the following expression:

$$\begin{cases} D_1 = A_1(R_1 \;\; t_1) \\ D_2 = A_2(R_2 \;\; t_2) \end{cases} \quad (3)$$

With A_1 and A_2 respectively matrices of intrinsic parameters of left and right cameras, and $(R_1\, t_1)$ and $(R_2\, t_2)$ are the matrices of the extrinsic parameters of left and right cameras.

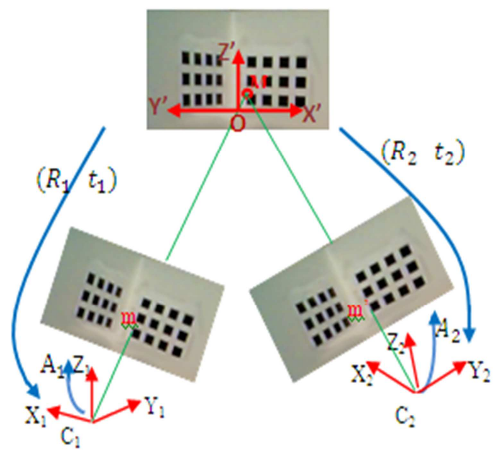

Figure 2. Vision System Used For Calibration

3.3. Genetic Algorithms

GA realizes a multi directional research in a population of potential solutions. A population of potential solutions is modified by the application of genetic operators from one generation to another. The main "genetic operators" are: the generation of the initial population, evaluation of each individual, selection and recombination (crossover/mutation). The evaluation of an individual aims to give a score for each following its relevance (fitness) the problem treated order to make evolve the population in the sense of acceptable solutions [16]. The execution of a genetic algorithm a general way can be unwound in the following manner:

- Generating random population of individuals
- Evaluation of each individual in the population
- Selection two individuals parent according to their fitness score
- Depending on the probability of crossover, cross the two individuals parent and generate two children
- Depending on the mutation probability, mutate the two children previously generated
- Place the new individuals in the population.

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- Use the new population for new execution of algorithm until an approximate solution is found satisfactory.

3.4. Simplex Algorithm

The SA is an algorithm for non-linear optimization that seeks to minimize a function in a multidimensional space. The algorithm uses the concept of simplex which is a polytope of $h+1$ summit in a space of h dimensions. Starting initially as a simplex, this one undergoes simple transformations during iterations: it deforms, moves and gradually reduces until its summits approach to a point where the function is locally minimal [28]. The method proceeds to a series of:

- Reflections (Simplex volume rest constant) for move the barycenter of the simplex towards the point of the lower criterion.
- Expansions (volume increases) that expand the Simplex in direction the point of the lower criterion.
- Contractions (volume decreases) that allow it to pass into the "goulet".

4. CAMERA CALIBRATION USING THE HYBRID MODIFIED GENETIC SIMPLEX ALGORITHM

In this part we will explain the necessary steps for determine the cameras parameters, passing through the matching of interest points between to the images couple to calculate the evaluation function which will optimized by a HMGSA to estimate the cameras parameters.

4.1. Input Data

The input data of our method is a set of coordinates of 3D points beforehand determined in the 3D grid. And the coordinates of 2D points detected and matched on each pair of images. These points are detected by the Harris detector and matched by a correlation measure ZNCC [2, 22, 30].

We also provide to algorithm the initial bounds to the parameters to be estimate which limiting the search space for the optimal solution. Parameters to be estimated are:

- The intrinsic parameters of the left camera are: $f_g, k_{xg}, k_{yg}, x_{0g}, y_{0g}$
- The extrinsic parameters of the left camera are: $\mathrm{\omega_g}, \mathrm{\emptyset_g}, \mathrm{\theta_g}, \mathrm{t_{xg}}, \mathrm{t_{yg}}, \mathrm{t_{zg}}$
- The intrinsic parameters of the right camera are: $\mathrm{f_d}, \mathrm{k_{xd}}, \mathrm{k_{yd}}, \mathrm{x_{0d}}, \mathrm{y_{0d}}$
- The extrinsic parameters of the right camera are: $\mathrm{\omega_d}, \mathrm{\emptyset_d}, \mathrm{\theta_d}, \mathrm{t_{xd}}, \mathrm{t_{yd}}, \mathrm{t_{zd}}$

Offering a total of 22 parameters for the two cameras, to estimate these parameters, we opted for a favoured generation of the initial population, for a desired initial population for example, a P individuals numbers will be randomly generated according the initial bounds of parameters. Each individual represents a potential solution to the calibration problem, and each individual is composed of genes representing the intrinsic and extrinsic parameters to estimate.

4.2. Genetic Representation Of Individuals

Knowing that all cameras parameters to be estimated are real numbers bounded by intervals provided as input, we propose in this paper, real coding to represent individuals in the population. So, we have represented the individuals in the population in a vector of 22 elements, these elements are the intrinsic and extrinsic parameters of the two cameras see equation (4).

$$v = [f_g, k_{xg}, k_{yg}, x_{0g}, y_{0g}, \omega_g, \emptyset_g, \theta_g, t_{xg}, t_{yg}, t_{zg},$$
$$f_d, k_{xd}, k_{yd}, x_{0d}, y_{0d}, \omega_d, \emptyset_d, \theta_d, t_{xd}, t_{yd}, t_{zd}]^{\mathrm{T}} \quad (4)$$

For reasons of notation the vector v is denoted by: $v = (v_1, v_2, \dots v_i \dots, \ v_{22})$ where the v_i represent the parameters predefined previously. This vector corresponds to a possible solution to the calibration problem and is part of the set of potential solutions V.

$$V = \{v : v_i \in [v_i^-, v_i^+]; i = 1, 2, \dots, 22\} \quad (5)$$

Where v_i^- and v_i^+ are the bounds of the variation interval given to each camera parameter. An optimal solution of v can be obtained in minimizing the evaluation function.

4.3. Evaluation Function

4.3.1. Principle

The F evaluation function that measures the fitness of an individual v of the population is based on the following principle: «We consider the set of coordinates of 3D points M_i that have been provided to our method. We calculate the coordinates of 3D points corresponding estimated M_i' according to the parameters given by v».

4.3.2. Calculate the $\mathrm{M_i'}$ 3D points estimated

For a given 3D point M_i, we calculate the 3D point estimated M_i' corresponding as following, one

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considers the torque of matching (m_{li}, m_{ri}) that the projection of M_i in the left and right image, the estimated point M_i' is obtained by the estimate of the intersection between the two 3D lines corresponding. Evidently, it is unlikely that to two 3D lines intersect perfectly (Figure 3), we calculate the intersection point by triangulation using the optimized parameters of cameras and the two matched points.

The intersection is perfect if the difference between the coordinates of the real 3D point and the coordinates of the 3D point estimated is null.

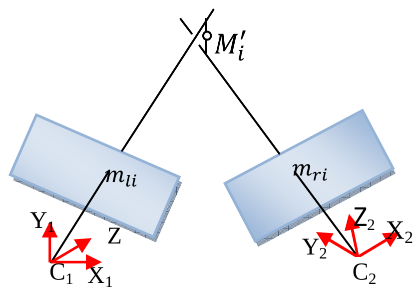

Figure 3. Imperfect Intersection Of 3D Lines Defining The Position Of Point M_i' In Space

4.3.3. Evaluation function

The evaluation function that one seeks to minimize with N control points correspond to the mean error between the coordinates of real 3D points $M_i = (a_i, b_i, c_i)^T$ and those the estimated 3D points $M_i' = (a_i', b_i', c_i')^T$ is given by:

$$\begin{cases} F(v) = \dfrac{1}{N}\sum_{i=1}^{N}[(a_i - a_i')^2 + (b_i - b_i')^2 + (c_i - c_i')^2] \\ \qquad\qquad v \in V \end{cases} \quad (6)$$

The estimation the parameters of the two cameras thus consists to minimize the evaluation function described in equation (6).

4.4. Hybrid Modified Genetic Simplex Algorithm For Camera Calibration

In this article, one seeks to minimize the cost function described in equation (6) by a hybrid optimization algorithm between the simplex algorithm and the modified genetic algorithm to estimate the intrinsic and extrinsic parameters of cameras. We describe the genetic operators necessary for build a modified genetic algorithm thus the Simplex method lastly the hybrid algorithm the Simplex method and the modified genetic algorithm.

4.4.1. Modified genetic algorithm

The genetic operators necessary to form a modified genetic algorithm are:

a. Non linear selection

To select the best individuals we adopt in this approach a non-linear selection, is the card of individuals following: $pop = \{v^1, v^2, \dots v^i \dots, v^P\}$ with P the size of the population, we distribute the probability of each individual from best to worst by a non-linear function, so that the probability of selection of the individual v^i is:

$$p(v^i) = \frac{\beta(1-\beta)^{i-1}}{1-(1-\beta)^P} \quad (7)$$

Where β the selection probability of the best individual, i is the serial number of the individual.

Once the probability of each individual in the population is determined, the roulette selection is used to select individuals excellent.

b. Crossover

The crossover of our approach is as follows: Suppose v^i and v^j two potential solutions to a generation $\rho(i \# j)$. A the generation $\rho + 1$ four son individuals v^{1a}, v^{2a}, v^{3a} and v^{4a} can be generated by crossover by next formulas:

$$v^{1a} = [v_1^{1a}, \dots . v_{22}^{1a}] = \frac{v^i + v^j}{2} \quad (8)$$

$$v^{2a} = [v_1^{2a}, \dots . v_{22}^{2a}]$$

$$= v^+(1-\mu) + max(v^i, v^j)\,\mu \quad (9)$$

$$v^{3a} = [v_1^{3a}, \dots . v_{22}^{3a}]$$

$$= v^-(1-\mu) + min(v^i, v^j)\,\mu \quad (10)$$

$$v^{4a} = [v_1^{4a}, \dots . v_{22}^{4a}]$$

$$= \frac{(v^+ + v^-)(1-\mu) + (v^i + v^j)\mu}{2} \quad (11)$$

$$v^+ = [v_1^+, \dots, v_{22}^+] \quad (12)$$

$$v^- = [v_1^-, \dots, v_{22}^-] \quad (13)$$

Where $\mu \in [0\ 1]$ weight, $max(v^i, v^j)$ is the vector of each element obtained by taking the maximum between the corresponding elements of v^i and v^j. For example $max\ ([1\ -2\ 4], [2\ 1\ 1]) =$

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[2 1 4]. The same $min(v^i, v^j)$ denotes the vector obtained by taking the minimum values. Among these four individuals son, both having a higher fitness value are considered descendants of the crossover operation.

c. Mutation

Different from the uniform mutation of simple genetic algorithm, the mutation operation with adaptive change of scaling of mutation is used in this article. Supposing $\delta \in [0\ 1]$ the scaling of the mutation. The element $v_k (v_k \in [v_k^-, v_k^+])$ selected in the individual $(v_1, v_2, \ldots, v_k, \ldots, v_{22})$ is to be mutated with a mutation probability P_m, the original value of v_k must be replaced by the new value mutated v_k^{new} chosen in the interval:

$$v_k^{new} \in \left[max\left(v_k - \delta\frac{v_k^+ - v_k^-}{2}, v_k^-\right), min\left(v_k + \delta\frac{v_k^+ - v_k^-}{2}, v_k^+\right)\right] \quad (14)$$

With uniform probability. Based on the concept that the mutation scaling δ is decreasing gradually during the process, a monotonically decreasing function of the mutation scaling δ is built:

$$\delta(\tau) = 1 - r^{(1-\frac{\tau}{T})^2} \quad (15)$$

Where T is the number of generation or iteration τ the current iteration, and the weight $r \in [0, 1]$.

4.4.2. Simplex algorithm

In the simplex algorithm, the new individual is generated by reflection of v^j (parent individual) by the following formula:

$$v^{jnew} = v^c + \alpha(v^c - v^j), j = 1, \ldots, h \quad (16)$$

Where $v^c = (v^1 + \cdots + v^h)/h$ is the individual centroid, h number of individuals, α random number.

4.4.3. Hybrid modified genetic simplex algorithm (HMGSA)

To improve the capacity of local the tuning of the GA and of MGA and speed up the convergence speed, we combine the MGA with the SA for forming a hybrid optimization algorithm to optimize the function of evaluation described in equation (6). All individuals of the current population (of P size) are ranked from best to worst, the new population in the next generation is generated in three steps.

a. Elitist

In this step, the first n of high-ranking individuals (elites) are directly reproduced in the next generation, for that these elites can not be destroyed by the operations of the GA.

b. Simplex

The $S\ (S > n)$ superior individuals of the population produce the $(S - n)$ new individuals by the formula described in equation (16).

c. Modified genetic algorithm

The remaining son $P - S$ in the new generation are created by the operators of the MGA.

Figure 4 describe the diagram of the hybrid optimization algorithm for camera calibration. We can refer to the hybrid degree (S/P) by using the percentage of population to which the algorithm simplex is applied. From it we can see that the hybrid algorithm will become a real-code MGA when the hybrid degree (S/P) is zero; while the hybrid degree (S/P) is equal to 100%, the algorithm will turn into the algorithm simplex. Generally S is around 20 percent of the size P.

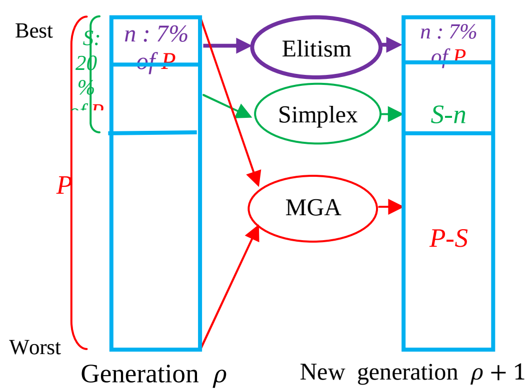

Figure 4. Diagram of the algorithm HMGSA

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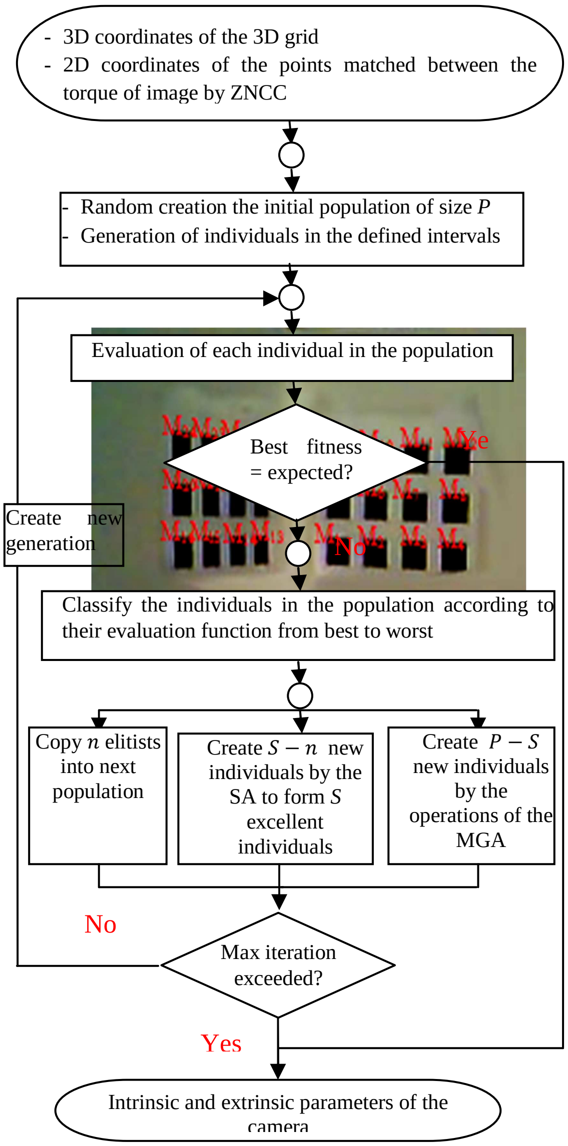
Figure 5. HMGSA for camera calibration

Figure 5 shows the general flowchart of the hybrid algorithm between the Simplex algorithm and the Modified Genetic Algorithm for estimating the intrinsic and extrinsic parameters of cameras used.

5. EXPERIMENTAL RESULTS



To show the robustness of our camera calibration method based on hybrid optimization algorithm between the simplex and modified genetic algorithms. We defined the necessary inputs to obtain the best accuracy. The parameters to be estimated are encoded by real values in a vector of 22 parameters, so we need at least 11 points of reference to calibrate the camera. To simplify the calibration we will use a special 3D grid characterized by the known coordinates (Figure 6)

Figure 6. Calibration grid used

Knowing that the number of control points of the target is large, we cite only the coordinates of the points that are at the top left of each square of the grid. Table 1 shows the coordinates of these points.

Table 1. 3D points of grid

point / coordinates	1	2	3	4	5	6	7	8	9	10	11	12
x	40	120	200	280	40	120	200	280	40	120	200	280
y	0	0	0	0	0	0	0	0	0	0	0	0
z	80	80	80	80	160	160	160	160	240	240	240	240
point / coordinates	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
x	0	0	0	0	0	0	0	0	0	0	0	0
y	80	160	240	320	80	160	240	320	80	160	240	320
z	80	80	80	80	160	160	160	160	240	240	240	240

The input data of our method are a set of coordinates of 3D points previously detected in a grid (Table 1). And the coordinates of 2D points are detected and matched in the image couples, these points are detected by the Harris detector (Figure 7[2, 22, 30] and matched by a ZNCC correlation measure (Figure 8) [2, 22, 30].

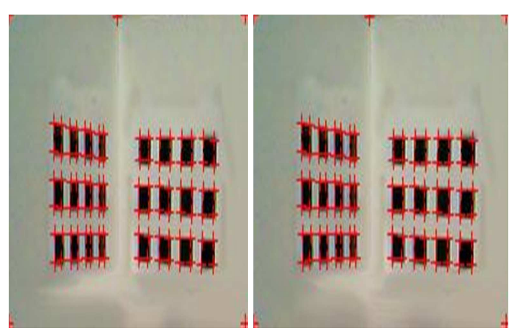


Figure 7. Extraction of interest points by Harris in the image couple

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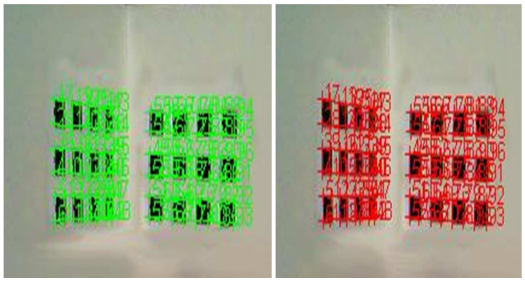

Figure 8. Matching of interest points by ZNCC

5.1. Parameterization Of Optimization Algorithms

Made to identify any improvement due to improved genetic operations and the hybridizing with the simplex algorithm, first we execute the SGA and MGA to minimize the evaluation function to estimate the cameras parameters.

The execution of the HMGSA is similar to that of MGA except the number S of the individuals high-ranking in the population, for the MGA the number S is equal to zero, while in the HMGSA the S is equal to 20% of the population size (P), the SGA shall adopt only the traditional genetic operators, such as tournament selection, arithmetic crossover and mutation uniform (M.Merras and al., 2012; Savii, 2004).

To estimate the cameras parameters by minimizing the evaluation function expressed in (6), we attribute some parameters to each algorithm.

5.1.1. For the simple genetic algorithm

We executed the SGA under the following parameters (Table 2).

Table 2. Parameters of SGA

Population size	Crossover probability P_c	Mutation probability P_m	Number of iterations T
200	0.80	0.1	120

5.1.2. For the modified genetic algorithm and HMGSA

- ✓ Population size : $P = 100$
- ✓ Selection probability the best individual: $\beta = 0{,}1$
- ✓ Crossover probability: $P_c = 0{,}8$
- ✓ Mutation Parameters: $P_m = 0{,}1, r = 0{,}6$
- ✓ Number of iterations: $T = 100$
- ✓ The hybridization degree: For MGA: *S=0* is the simplex members and *n=0* is the elites numbers. For HMGSA: *S=20%*, *n=7%* of the population size

5.2. Estimation Of Cameras Parameters

In order to obtain the good values of the intrinsic and extrinsic parameters of the two cameras, we gives to the algorithm the initial bounds for the parameters to be estimated which limiting the search space for the optimal solution. The large bounds can be defined for the unknown parameters to obtain a good accuracy. Table 3 shows the executions results for three optimization algorithms (SGA, MGA and HMGSA).

Table 3. Parameters estimation of the camera

Parameters of cameras	Large Bounds $[v^-, v^+]$	Estimated value by SGA	Estimated value by MGA	Estimated value by HMGSA
f_g	[10,100]	65.00	63.00	61.00
k_{xg}	[50,90]	68.16	69.50	69.00
k_{yg}	[50,90]	70.25	70.00	70.25
x_{0g}	[200,280]	258.00	254.00	252.00
y_{0g}	[190,220]	204.00	200.00	202.00
t_{xg}	[-400,400]	-100.00	-98.09	-97.00
t_{yg}	[-400,400]	-81.44	-84.00	-80.00
t_{zg}	[700,2000]	1800.00	1810.00	1802.00
ω_g	[-π, π]	0.481593	0.504528	0.500234
$\varnothing_g$	[-π, π]	0.019343	0.025461	0.020134
θ_g	[-π, π]	0.050192	0.049990	0.043671
f_d	[10,70]	64.30	64.00	61.50
k_{xd}	[50,90]	68.00	69.00	68.20
k_{yd}	[50,90]	79.50	71.00	70.00
x_{0d}	[200,280]	259.00	253.00	250.00
y_{0d}	[190,220]	203.00	201.00	201.00
t_{xd}	[-400,400]	-97.40	-98.00	-96.50
t_{yd}	[-400,400]	-79.79	-80.20	-80.00
t_{zd}	[700,2000]	1844.36	1840.50	1841.46
ω_d	[-π, π]	0.523599	0.534588	0.512679
$\varnothing_d$	[-π, π]	0.027453	0.023835	0.024671
θ_d	[-π, π]	0.049072	0.044892	0.046237

Genetic algorithms following spoke on a potentially stochastic solution to the problem of calibration, they perform the optimization by the repeat of genetic operations until the stopping criterion is satisfied. The stopping criterion is that the minimum evaluation function (F_{min}) remains the same for a given time and also the number of iterations. The best individual is then defined as the optimal solution to the calibration problem. When the evaluation function remains minimal for a given time, so the camera parameters are most or least constant, Figure 9 presents some focal length values of the left camera according execution time of these three optimization algorithms.

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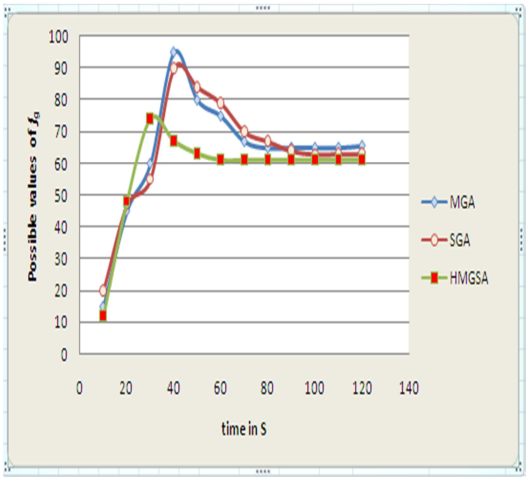

Figure 9. Values of f_g according to the time of three algorithms

We notice that the value of f_g more or less constant from 60s for HMGSA. For the MGA, f_g is constant from 80s and for SGA from 100s, f_g is constant. We find that the HMGSA algorithm converges quickly to an optimal solution compared to other algorithms. Genetic algorithms are stochastic methods. Unlike conventional methods known, the GA doesn't necessarily give the same result after two executions having identical inputs and parameters, so we need to test the robustness of the optimization algorithms during successive executions.

5.3. Robustness Of The Three Algorithms And Variation Of Camera Parameters

The stake is to measure the variation of the results, and to judge if the accuracy (difference between the Min and Max of variation) is acceptable. So we have made turn our optimization algorithms for camera calibration 10 times, by having the same input parameters. We have then traced a graph for each relevant parameter of the camera for each optimization algorithm, Figure 10 shows the variation of the focal length f_g of the left camera depending 10 runs for the three algorithms.

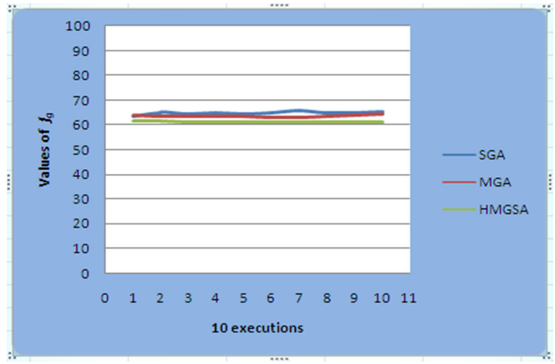

Figure 10. Variation of f_g according 10 runs of the three algorithms

We have calculated the difference between the maximum and the minimum variation of the focal length f_g during 10 executions of these three algorithms, Table 4 displays the results.

Table 4. Difference between the maximum and minimum of variation in the focal length f_g

Optimization algorithm	SGA	MGA	HMGSA
Variation of f_g (Max-Min)	2,083 mm	1,291 mm	0,7 mm

We find that the variation of the focal length f_g don't exceed 2 mm, the variation found demonstrates the robustness of the three optimization algorithms. Indeed, the precision of these algorithms optimization is linked to the initial bounds, this is logical because the genetic algorithm has less chance to generate values very far removed from the optimum. In the real case, to be able restrict the interval of the initial bounds, several successive executions of algorithms are possible in order to channel this restriction closest to the real configuration of the cameras.

The analysis of Table 4 and Fig. 9 shows that the hybrid optimization algorithm for the camera calibration is most robust in term of convergence time and quality of the precision, This is logical because this hybrid algorithm combines the simplex algorithm which is a local search method which have the simple and efficient computation advantages, and modified genetic algorithm which is a global search algorithm, it avoids be trapped in local minimum but the convergence time high. The hybridization of these two algorithms allows to accelerate the speed of convergence and of avoid local minima which render the results of this optimization algorithm more precise and robust.

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6. CONCLUSION

In this paper, we treated a technique of camera calibration with varying parameters by a hybrid optimization algorithm between the simplex and the modified genetic algorithms, the proposed approach can avoid being entrapped in a local minimum and converge quickly to the optimal solution without initial estimation of the cameras parameters, and with a minimum number of points. We have shown that the accuracy of the algorithm is the best comparatively to the size of the initial bounds used. The obtained results show the performance of the proposed technique in terms of convergence and precision.

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