DEVELOPMENT OF THE SIMULATION SOFTWARE PACKAGE TEST POERF RAW

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Abstract

In contributions [1, 2, 3] there are presented the basic possibilities of simulation program Test POERF. This program serves to simulate functions of the range channel core of the passive optoelectronic rangefinder (POERF). It allows verifying the quality of algorithms for a target slant range finding from taken stereo pair images of the target and its surroundings. These images are generated by a special images generator in the program as a virtual reality. The actual contribution presents consequential simulation software package Test POERF RAW which works with taken images of a real scene. The package presently consists of three separate programs: the editing program RAWedi, the main simulation program RAWdis and the viewer RAWpro. The editor RAWedi allows editing of stereo pair images of individual targets and supports the creation of a Catalogue of Targets. The simulation program RAWdis serves for testing algorithms for estimation of horizontal stereoscopic disparity which are convenient for the use in POERF. Simulation experiments can also help to solve problems in the development process of the software for a future POERF prototype.

Keywords: Passive optoelectronic rangefinder, target slant range, stereo pair images, stereoscopic disparity, simulation software package Test POERF RAW.

Presenting Author's biography

Vladimír Čech. He was born in 1953. In 1977 he graduated from the Brno Military Academy; Ph.D. – the Brno Military Academy 1983, associate professor – the Brno Military Academy 1989; habilitation in the field: the Military Technology – the Weapons and Ammunition – the Brno Military Academy 1993. Since 1983 – teacher at the Brno Military Academy; since 1991 – head of the department; since 1994 – Vice-Rector – at the Military Academy in Brno, since 1998 – General Director of the Personnel and Social Policy Department of CR DoD, since 2002 – Management and Consultancy Services in the field the Weapons Systems, Educations and Personnel Systems. Since 2003 he has worked on the projects of the POERF research and development.

1 Introduction

At the end of the year 2008, a demonstration model of the passive optoelectronic rangefinder (POERF) was finalized as the main output from industrial research project of MIT CR with the code designation FT – TA3/103. The POERF demonstration model (Fig. 1) was refined yet and within the final opponent proceeding in March 2009 it proved that has satisfied all predetermined requisitions. A basic description of the demonstration model is published in [5]. The detailed description together with overview of utilized references (143 items) can be found in [4].

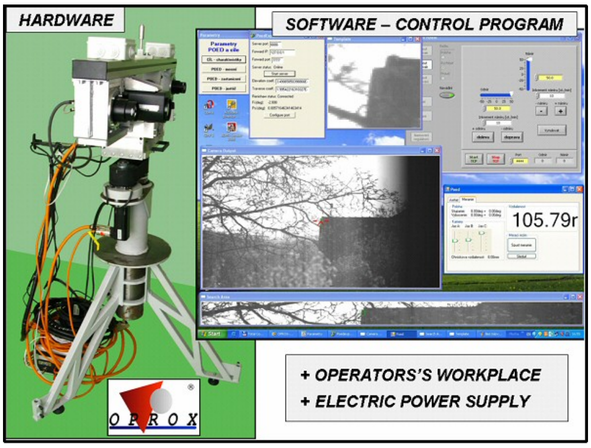

Fig. 1 Passive optoelectronic rangefinder (POERF) – the demonstration model 2009 [4, 5]

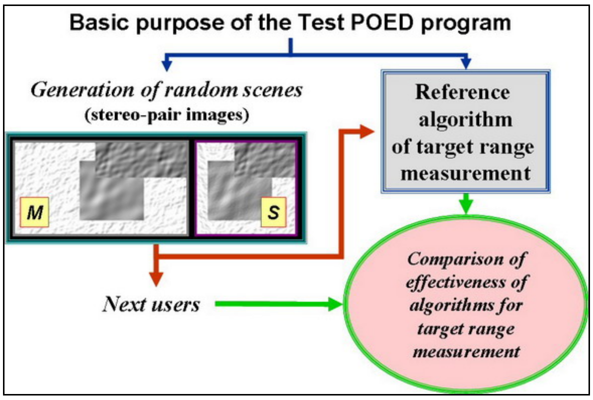

Fig. 2 The basic purpose of the Test POERF program [1, 2, 3]

In the year 2009 consequently, the firm OPROX, a.s. has obtained grant support from MIT CR for program project of research and development with the code FR – TI 1/195, which core is the next development of POERF in conjunction with supporting research. Development of a collection of algorithms for speed and fine measurement of the target slant range is ranked among continuous and fundamental problems. These algorithms form the software core for POERF range channel. The simulation program Test POERF (Fig. 2) has contributed (and henceforth it will contribute) to their development and testing. Properties and structure of this program were published in [1, 2, 3].

Full functionality of the POERF demonstration model enabled creation of database of horizontal stereoscopic pairs of choice real targets (buildings) within the summer 2009. Thus, the creation of a Catalogue of Targets was started.

The simulation package Test POERF RAW serves the same purpose as the original simulation program Test POERF, but with the difference that it works with horizontal stereo pair images of real objects that are added to the Catalogue of Targets by piecemeal.

2 Catalogue of Targets

One of the most important algorithms for a target slant range measurement is the algorithm for a horizontal stereoscopic disparity determination of images T'_1 and T'_2 of the target point T representing a target. In publications that deal with problems of stereoscopic disparity determination there is constantly emphasized the deficiency of quality stereoscopic pairs of varied object images, which are indispensable to testing the functionality and quality of various algorithms under real conditions.

Considering the POERF specifics, we have decided to create own database of horizontal stereo pair images of targets with accurately known geographic coordinates – shortly the “Catalogue of Targets”. We have selected image formats REC (a special variant of RAW format) and BMP – Fig. 7. The catalogue is a live system to which images of additional targets can be appended. For the present, we work with a database that was created during July to September 2009. The initial set has 76 stationary targets (buildings) and several other records with moving objects, especially vehicles. Hereafter, we will be dealing just with stationary objects.

The demonstration model of POERF was placed in the 7th floor of A1 building of FME Brno UT in altitude c. 310 m above sea level.

The stationary “targets” (73 targets) were chosen, so that on the one hand they cover slant ranges from c. 100 m to c. 4000 m (plus 3 targets in greater ranges for system adjustment), see Fig. 3, 4, 5 and 6, and on the other hand their appearance and placement should be convenient for unique determination of their stereoscopic disparity. Records of horizontal stereo pair shots of scenes were elected so that every target lies near to the centre of cameras field of vision (suppression of possible distortion of objectives) and the number of successive stereo pair images of every target is minimally 512, which is precondition for statistical processing of results of simulation experiments. Because of achievement of the record rate c. 10 image-pairs per second, the vertical binning was used, i.e. every two rows were aggregated into one row in all image (a special loss compression for RAW data) – Fig. 7; this compression technique does not influence the size of horizontal stereoscopic disparity.

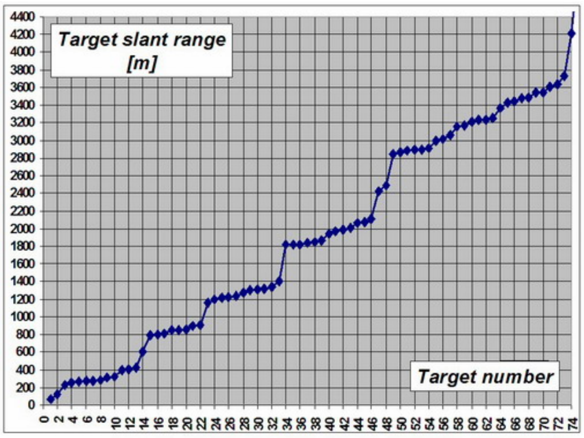

Fig. 3 Choice of targets for the Catalogue of Targets with regard to their slant ranges

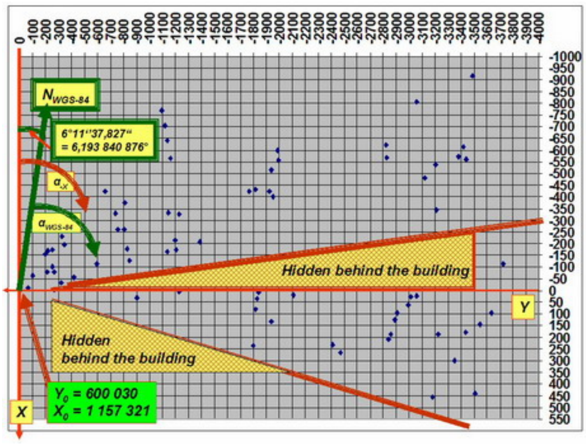

Fig. 4 Choice of targets for the Catalogue of Targets with regard to their positions

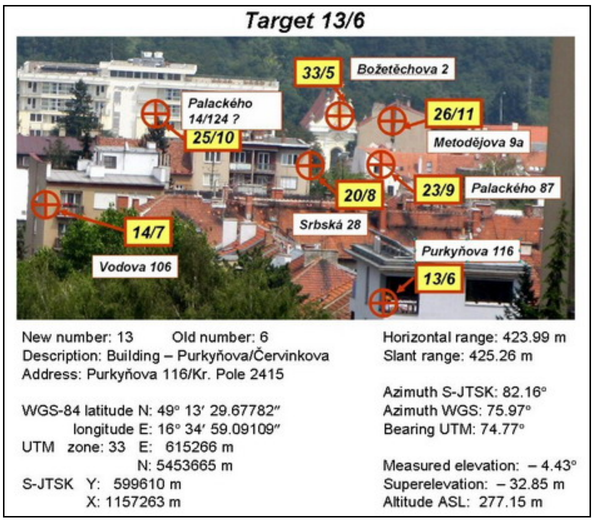

Fig. 5 Sample of one item from the text part of the Catalogue of Targets – the target No. 13

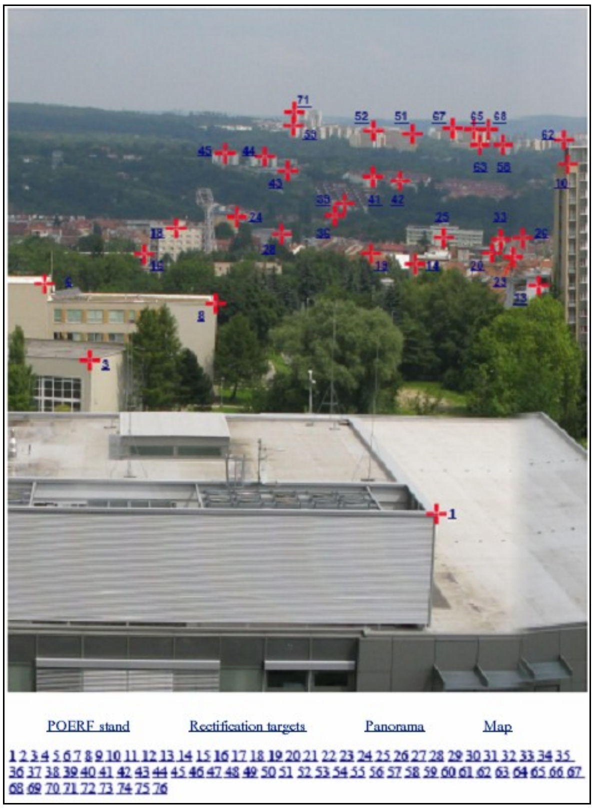

Fig. 6 The middle panorama section of the Catalogue of Targets

3 Simulation package Test POERF RAW

In the present stage of development, the package Test POERF RAW consists of two simulation tools – programs RAWedi and RAWdis – and of a viewer for stereo pair images – the program RAWpro.

The program RAWedi, which will be only shortly described here (for a more detailed description see [6]), serves primarily to create horizontal stereo pair images of targets (Fig 7) from shots that have captured wider area of a scene (a “standardization” of horizontal stereo pair images of targets and their nearest surroundings or the target image cut outs). These stereo pairs form a database part of the Catalogue of Targets. Simultaneously it allows editing stereo pair images for other purposes. The program is an analogy of the part of older program Test POERF, which is denoted as a generator of stereo pair images – Fig. 2.

The program RAWdis that corresponds to the core of program Test POERF serves to determine the horizontal stereoscopic disparity from catalogue of stereo pair images and to estimate consequently the target slant range. It processes a pre-select number of stereo pairs of one target, e.g. 512, and generates relevant statistics in consequence.

3.1 Program RAWedi

The input to the program RAWedi is a set of – usually minimally 512 – stereo pair images taken by the POERF demonstration model in the format REC (1296×514 pixels after compression by vertical binning, 8-bit brightness range). The program outputs are “standardized” stereo pair images in formats REC and BMP – Fig. 7. All needed information is included in supporting output text file with extension .INF. It is possible to save either a selected stereo pair of the target image or the complete set of stereo pair images of the same target (e.g. 512 pairs of shots) where all shots are modified (“standardized”) strictly in the same way.

The process of shots standardization is divided into six steps:

1. Choice of a set of shots.
2. Compensation of “Dark Frame”.
3. Compensation of “Flat Field Frame”.
4. Cut outs.
5. Additional editing.
6. Results saving.

A transition among particular steps of the standardization process performs through the buttons “Next step” and “Back step”.

The touch of button “Next step” means the actual step termination and saving of useful intermediate data. Repeated touch of button allows skipping appropriate process steps. The touch of button “Back step” annuls results and operation performed in the actual step.

In the first step, after a selected REC file opening, two new windows will appear besides the window “Editor...”, namely “Sighting camera shot – S” and “Metering camera shot – M”. In the left upper part of these windows there is placed the table “Shot parameters” with statistical data summary of shots and with actual state of performed adjustments. Alongside the table there is placed the grey level histogram. Due to comfortable work with the program, monitors with resolution 1600×1200 pixels (i.e. mode UXGA) are convenient. On monitors with less resolution there are displayed parts of shots only, and especially vertical reduction is significant.

The second and third steps serve to compensate systematic errors in the record of shots which are caused by real properties of cameras and objectives – more closely in [4]. Corrections take effect in small change of grey levels in individual pixels and also as a small left shift of the histogram in conjunction with a change of its shape.

In the second step, the spatial offset uniformity (denoted as a dark signal) is eliminated with using the average dark frames. Pixels grey levels in the average dark frame are computed as the mean of grey levels in corresponding pixels in dark frames from the recorded set of shots.

In the third step, an influence of varied signal amplification from individual pixels is compensated. The causes of differences are on the one hand the objective vignetting and on the other non-uniformities in electric properties of a digital matrix sensor (photo response non-uniformity, spatial gain non-uniformity). The average flat field frames are used for compensations. These frames are computed from a set of flat field frames analogously to average dark frames.

Sets (always more then 512 stereo pair images) of partial dark frames and flat field frames were procured by the help of the POERF demonstration model on September 4, 2009. The images of “flat field” were taken as shots of uniformly fogged sky (sky flats).

The fourth step of the standardization process serves to perform the extraction of image sections (cut outs). The primary intention is a size reduction of saved data files. Besides, as shots preparation for input to the program RAWdis, the cut out of the shot from sighting S-camera (Master camera) is adjusted, so that satisfies requirements posed on 2D model of the target (the reference image) [1, 3, 4]. The shot from metering M-camera (Slave camera; Matching image) is modified depending on the cut out of S-camera shot – Fig. 7.

In the fifth step of stereoscopic images processing it is possible to adjust brightness (grey levels) and contrast of both images by the use of linear or exponential transform. These corrections appear also as changes in the shape of histograms.

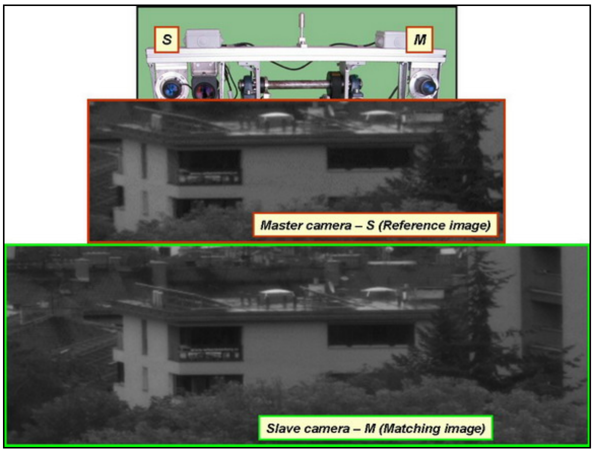

Fig. 7 Example of the stereo pair shots (target No. 13) – a part of the Catalogue of Targets

3.2 Simulation program RAWdis

The program RAWdis that corresponds to the core of program Test POERF serves, as mentioned above, to determine the horizontal stereoscopic disparity from catalogue of stereo pair images and to estimate consequently the target slant range.

We suppose that the simulation program RAWdis will be further developed and supplemented by new functions. This paper contains program outputs of the program version from the May 2010.

After program starting, the main window (see Fig. 9) has a single (unfilled) form. A set of shots of a selected target must be chosen initially from the Catalogue of Targets. After opening the file with this set, the working window with both images from the stereo pair is displayed (Fig. 8). At the same time there is loaded the data from the information file (supporting output text file from the application RAWedi) due to right coordinates interlocking of the both shots with their primary uncut originals and simultaneously the data about the target slant range D_T exact value together with the data about the POERF parameters is loaded and shown. Consequently, it is necessary to elect *the 2D target model*, i.e. a rectangular area that represents adequately characteristic "surroundings" of the target point T in which values of the matching cost function $S(k)$ are computed. Coordinates of the center of the rectangular in the reference image and the sides of this rectangular in pixels are entered – Fig. 8.

The maximum computing speed is required primarily, in order that about 30 range measurements per second are necessary in our applications (POERF). Therefore, we prefer simple (and hence very fast) algorithms. Random errors of measurements are compensated during statistical treatment of measurement results.

Two types of the matching cost function $S(k)$ are used in the meantime (in general both types are pixel-based matching costs functions): the sum of squared intensity differences SSD (or mean-squared error MSE) and the sum of absolute intensity differences SAD (or mean absolute difference MAD).

The computation of matching cost function $S(k)$ proceeds in two steps. Firstly, its global minimum with one-pixel accuracy is calculated (the tabulation over all admissible horizontal shifts of the target model on the matching image, the variant SSD/MSE is used) – Fig. 9. Besides the graph of matching cost function, the relevant histogram of brightness differences on corresponding pixels can be displayed (see Fig. 10).

At the second step, the global minimum is searched with sub-pixel accuracy for both versions SSD/MSE and SAD/MAD (the sub-pixel refinement stage, the golden section search technique is used for optimization) – Fig. 11. The appropriate estimates of disparity and slant range D_T are calculated and displayed.

It is possible simultaneously to display course of the appropriate matching cost function on the sub-pixel level – Fig. 11. The size of the sub-pixel step is selectable – Fig. 9.

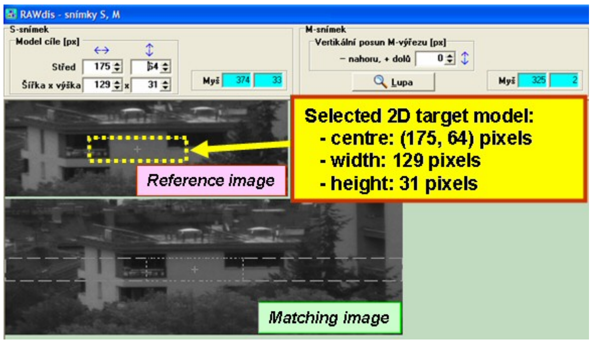

Fig. 8 The window with shots of a target from the Catalogue of Targets – a selected model of the target No. 13

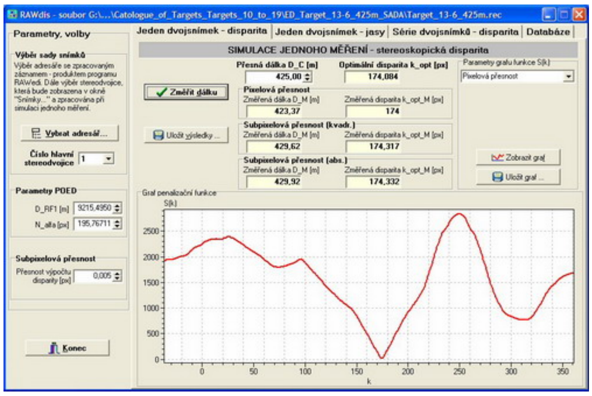

Fig. 9 The main window of the program RAWdis – the state after opening a file with shots from the Catalogue of Targets (the target No. 13) and after calculation of the target slant range estimate from one stereo pair images

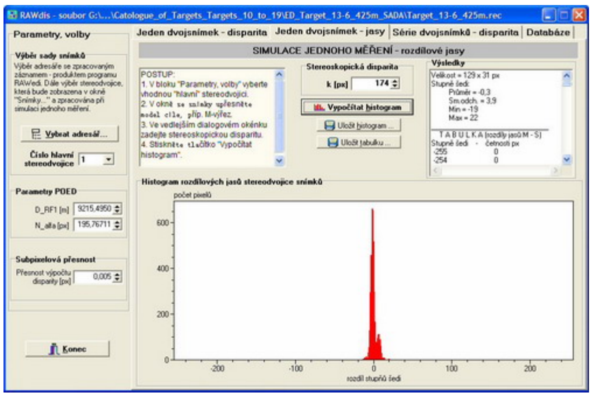

Fig. 10 The histogram of brightness differences on corresponding pixels after finding integer disparity of the target model (calculations for the area of the selected target model)

It is known from the literature and our experiments have verified that the usage of matching cost function based on normalized cross-correlation methods gives results of the same accuracy, but the computation speed is generally lower [3].

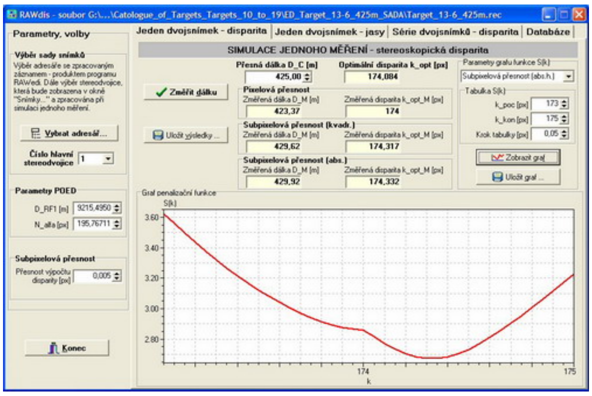

Fig. 11 Example of a course of the matching cost function $S(k)$ for sub-pixel accuracy (SAD/MAD algorithm)

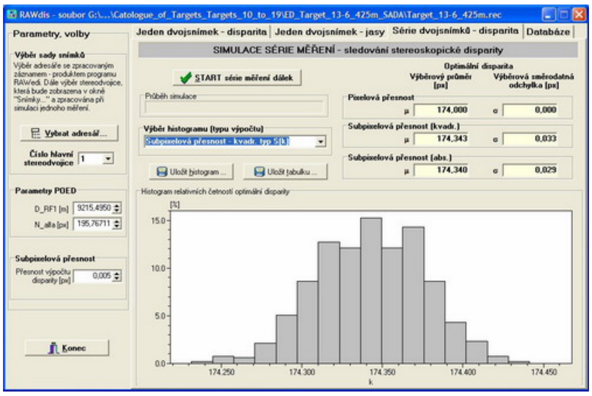

Fig. 12 The histogram of target slant range estimates (512 measurements) for the matching cost function generated from squared intensity brightness differences (SSD/MSE) on areas of the target model and the matching image (Fig. 10)

Besides computation of the disparity and the target slant range estimates from the only one stereo pair images, it is possible to compute and analyzed estimates over all stereo shots of the given target which are at the disposal, e.g. 512 stereo pairs – Fig. 12.

Thus computed estimates of disparities can be loaded into the database – Fig. 13. This database allows saving data about up to 100 targets – Fig. 14. It can be saved data corresponding with 30 different 2D target models for every target – Fig. 8. Usually, records evaluated from c. 512 stereo pair shots pertain to every choice of 2D target model, which corresponds with c. 1.5 million individual records of disparity triplets (one integral pixel estimate and two sub-pixel ones). The work with the database is as usual (including and excluding records, etc.).

Two linear regress models are used for the statistical data processing of the database of targets disparities. The main goal of this evaluation is finding the optimal values for the pair of POERF adjustment parameters: D_{RF1}, $C_{0RF} = N_\alpha$, whose knowledge is necessary for recalculation of the estimated disparity Δc_T to the estimate of corresponding target slant range D_T [4, 5]. A detailed analysis of this problem exceeds domain of this paper.

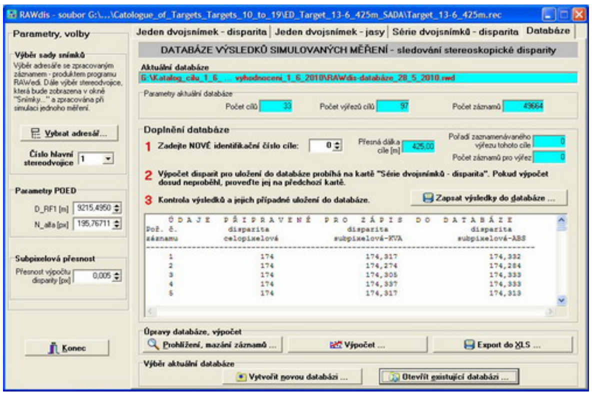

Fig. 13 The window for data input to the database of disparities of targets from the Catalogue of Targets

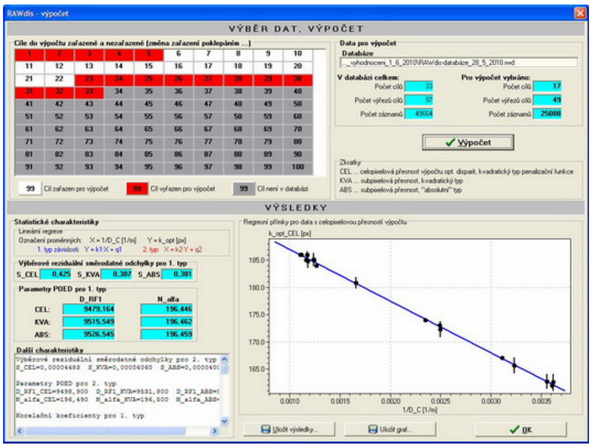

Fig. 14 The window with demonstration of the main data processing results from the database of targets disparities

4 The problem of the choice of 2D target model

In using above-mentioned algorithms, it is always presumed that the same disparity $\Delta c_T = \text{const}$ is for all pixels of 2D target model. This precondition is equivalent with the hypothesis that these pixels depict immediate surroundings of the target point T represented the target and this surroundings appertain to the target surface (more accurately all that is concerned the image T'_1 of this point and its surroundings). These algorithms belong to the group referred to as local, fixed window based methods.

Adduced precondition can be frequently satisfied by a suitable choice of size and location of the target model – Fig. 8. The choice is performed iteratively by an operator for the real POERF [4].

Usual shapes of a target surface (e.g. balconies on a building facade, etc.) have only a little influence on the above-mentioned precondition violation, because the range difference generated by them is usually less than 1 to 2 percent of the "average" target slant range D_T evaluated over the target surface represented by the 2D target model.

Operations over the set of pixels of the 2D target model that generate the matching cost function $S(k)$ and the procedure of its minimum searching can be counted as a definition of special moving average, and – as a consequence – the whole process appears as a low-frequency filtration. The influence of size of 2D target model is evident from graphs on the Figure 15.

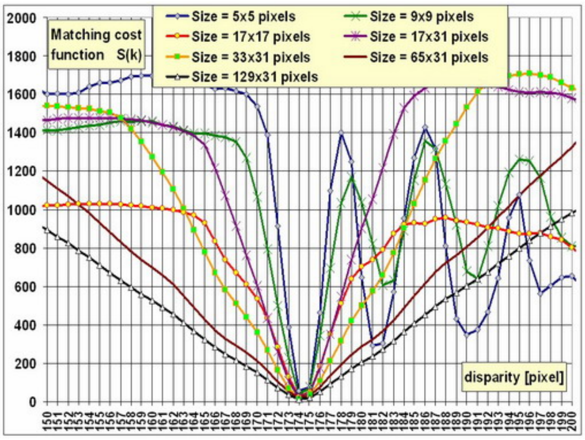

Fig. 15 Influence of size of 2D target model on the course of the matching cost function $S(k)$ in a neighbourhood of its global minimum for the target No. 13 (Fig. 7, 8) – the minimum corresponds with the integral pixel disparity estimate (the 174th column in the Fig. 9, size = width × height in the Fig. 8)

It holds generally that if respectively the meteorological visibility is low and the atmosphere turbulence is strong, then it is necessary to choose a larger size of the 2D target model, i.e. to filter out high spatial frequencies loaded by the largest errors and to work with lower spatial frequencies.

Problems of the size choice for the 2D target model are closely analyzed in [4].

In many cases there is inevitable that some pixels of the 2D target model record a rear object or a front object instead of the target – Fig. 16.

Simulation experiments with the program Test POERF showed [1] that farther objects have minimal adverse impact on the accuracy of the range measurement, in contrariety to nearer objects that induce considerably large errors in the measurement of the target range. From the problem merits, these errors are *random* blunders. Their greatness depends on the mutual position of the front object and the target – Fig. 16. This finding has been also verified in computational experiments by the help of the program RAWdis – examples see in the Figures 17 and 18.

The front object (Fig. 16) usually causes that the set of pixels of the 2D target model is not connected (it is the union of several connected subsets). In many situations, the number of "effective" pixels in this set can be less than it matches with the evaluation of the shot from the sighting camera only and it is the source of mentioned problems.

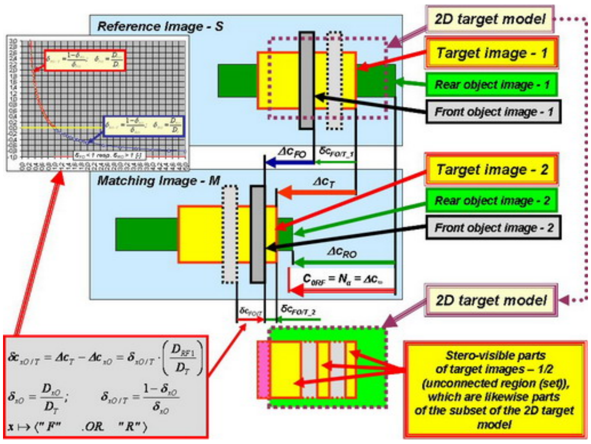

Fig. 16 The front object influence on the distortion of results of the target range measurement

The concrete example of described phenomenon is introduced in the Figure 17. The effect evinces on the graph deformation of the matching cost function $S(k)$ in a neighbourhood of its global minimum – Fig. 18. The graph "Target" (D_T = 245 m) corresponds to the choice of 2D target model, where all its pixels depict surface of the target – the building (accurately measured range of the target) and the graph "Light pole" (D_F = 178 m) corresponds analogically to the choice, where all pixels depict surface of the front object (accurately measured range of this object). Each of these graphs has the only one "decided" local minimum which is simultaneously the global minimum. The graph "Wrong estimation" (D_{Twrong} = 193 m) corresponds to so chosen position and size of the 2D target model that a part of pixels displays an image of the target and the rest displays an image of the front object. The graph has two local minima which are shifted against the positions of minima of two basic graphs. Besides, a concrete random choice of the position and the size of 2D target model decides which of two local minima will be the global minimum. In reality, the structure of disconnected set of "effective" pixels can be considerably complicated, e.g. due to branches of trees – Fig. 19.

It is evident from the above that the choice of the position and the size of 2D target model is not a trivial operation and it is convenient to entrust a man with this activity. The operator introduces a priori and a posteriori information into the measurement process of respectively the disparity and the range of a target and this information can be only hardly (or not at all) obtained by the use of fully automatic algorithm.

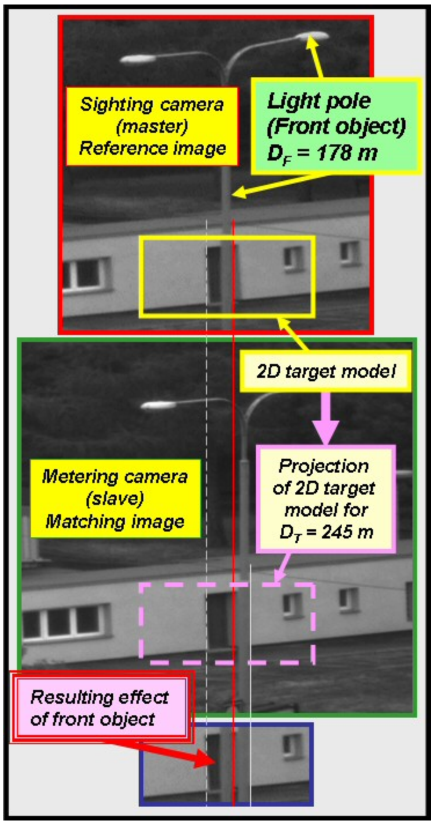

Fig. 17 The example of a front object influence on the creation of disconnected set of "effective" pixels on the 2D target model displaying the surface of the target No. 4 – a building

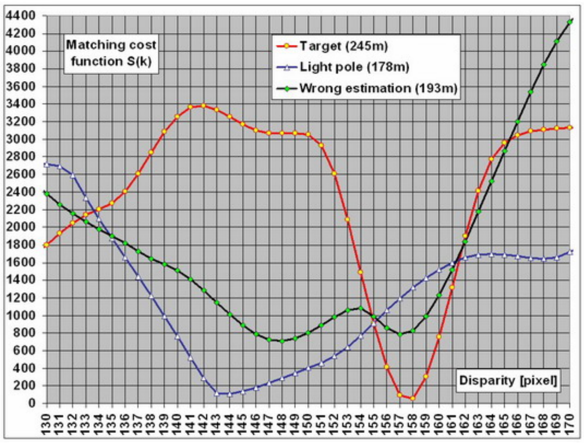

Fig. 18 Simulation results from the program RAWdis for the example presented in the Figure 17

Algorithms commonly published for the stereo correspondence problem solving are altogether fully automatic – they use the information included in the given stereo pair images, eventually in several consecutive pairs (optical flow estimation). Therefore, it is possible to inspire by these algorithms, but it is impossible to adopt them uncritically.

On the present, we work on algorithms that suppress influences of near objects and that simultaneously work in the iterative mode – a dialog with the operator. This work could be started not before the Catalogue of Targets creation and completion of the basic version of the program RAWdis. Therefore, we only formulate some problems in this paper, without indication methods for their solutions. The functionality of algorithms will be verified by the help of advanced versions of programs RAWdis (real scenes) and Test POERF (virtual scenes).

Fig. 19 The second example of a front object influence (branches of trees) on the creation of disconnected set of "effective" pixels on the 2D target model

5 Spatial noise

Errors in a scene record (distortion of its image in the shot) are on the one hand gross and systematic, and on the other random (spatial noise).

The gross errors are removed by the procedure referred to as „pixel mapping". The systematic errors are eliminated with using the average dark frame and the average flat field frame, as it was explained in the section 3.1. These compensations take effect as the substantial reduction of the spatial noise standard deviation, e.g. from $\sigma = 11.8$ to $\sigma_{SN} = 1.4$ – see Fig. 20.

This residual value σ_{SN} characterize the random error component denoted as the spatial noise. At laboratory conditions, two quantities are used to its characterization: dark signal non-uniformity (DSNU) and photo response non-uniformity (PRNU). These quantities characterize the noise properties of respectively the digital matrix sensor (DMS) and the whole record chain. This spatial noise component can be suppressed by digital matrix sensor cooling, in contrast with the noise component which is determined by the atmosphere turbulence level.

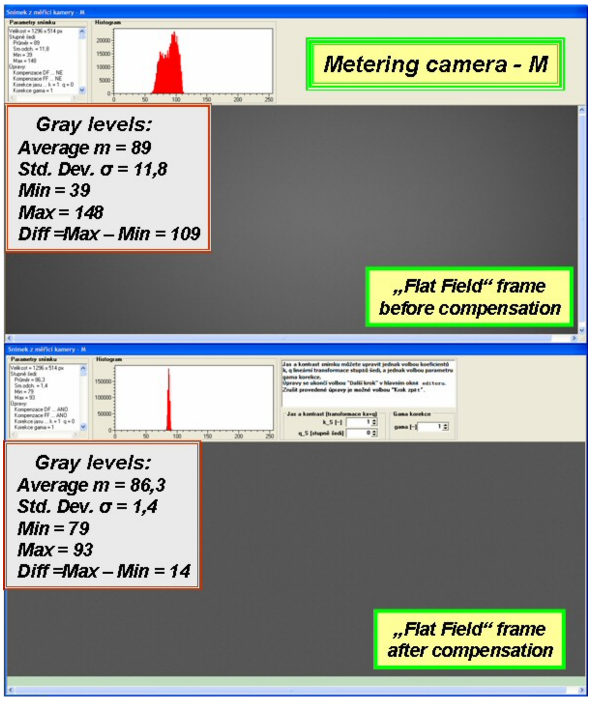

Fig. 20 Example of systematic errors compensation in the image record by the procedure described in the section 3.2 (“Flat Field” frame was randomly chosen from the set of 512 pair shots taken in September 4, 2009 – sky flats)

In the course of a scene record for use in measurement of a target range, the atmosphere turbulence – as a dynamic process running in the transmission channel [4] – influences the size of the spatial noise significantly. Its share in the spatial noise cannot be separated from the share of the own recording device only by the realization of special experiments [4].

During recording of scenes for the Catalogue of Targets creation in September 4, 2010, it was overcast, the temperature was c. 20 to 23 °C and a soft wind blew and so, for these reasons, the impacts of atmosphere turbulence were maximally reduced compared with conditions in previous days in which measurements were realized too. For all that, it has shown in simulations with the program RAWdis that the residual level of the spatial noise, albeit low, distorts substantially the course of the matching cost function on the sub pixel level – Fig. 21, and so the sub pixel estimates of disparities are wholly unreliable – Fig. 22. The reason consists in random “rolling” of the function S from one stereo pair to the other one for the given position and size of the 2D target model.

Consequently, the real range of the demonstration model POERF is now given by the accuracy of finding the integral pixel disparity, by the length of used base $b = 860$ mm (base of telemetric triangle – the distance between cameras – Fig. 1, 7), and by the value of POERF power constant D_{RF1} [4, 5].

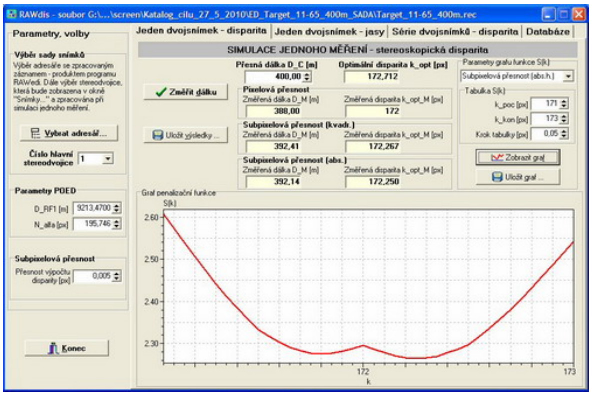

Fig. 21 Example of the course of the matching cost function S for finding sub pixel minimum

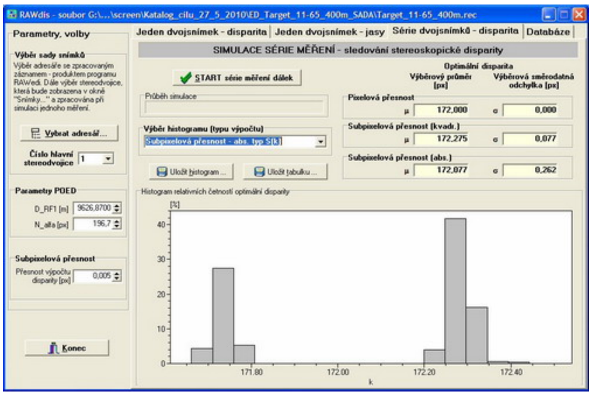

Fig. 22 Example of the effect of the spatial noise on the histogram of “sub pixel” disparities determined by the SAD algorithm for the target No. 11 ($D_T = 400$m)

The effect of the spatial noise is known for us for a long time [1, 2, 3, 4]. The generator of the spatial noise – as a component of virtual scenes generator – was build into the simulation program Test POERF in the first version already. In previous simulation experiments – on the basis of data from the literature – we have undervalued characteristics of its two-dimensional power spectral density (PSD), as it is quite evident now, after experiments with the real shots.

Our nearest aim is to find the real values of parameters of the spatial noise PSD from the shots filed into the Catalogue of Targets and also from the shots taken in days with higher level of the atmosphere turbulence.

In the following step – with the use of simulations programs Test POERF and RAWdis – we plan to develop and to test fast algorithms for the suppression influence of the spatial noise on the disparity determination with sub pixel accuracy (the system must work in real time with frame rate 30 fps minimally).

The effectiveness of appropriate algorithms influences significantly the size of POERF base *b*, and herewith overall dimensions and the mass of the POERF – Fig. 1. Higher effectiveness of algorithms allows shorter base *b* [4, 5].

6 Conclusion

Following development of the simulation program RAWdis will involve e.g. next types of matching cost functions. But the main attention will be paid to the convert from using of simply connected rectangular regions (the target models) to more general regions and even unconnected regions – it is given by requisite for an elimination of influence of objects standing before the target (branches of trees, poles, etc.) – see the section 4.

As the permanent task we consider searching of algorithms for the suppression influence of the spatial noise on the disparity estimates with sub pixel accuracy. It has the key influence on the accuracy of the target range measurement, especially during strong atmosphere turbulence – see the section 5.

We will also attend to the simulation process of range measurement of moving targets that disappear temporarily behind barriers (fleeting targets). Related records are already filed in the Catalogue of Targets.

The effective development of relevant algorithms is practically unthinkable without their testing by the help of (step by step improved) simulation tools – the programs Test POERF and RAWdis.

We can acquaint interested persons with planned new release of the program in the appropriate manner.

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