DEVELOPMENT OF ALGORITHMS OF THE FOREGROUND OBJECTS EFFECTS COMPENSATION FOR THE PASSIVE OPTOELECTRONIC RANGEFINDER

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ABSTRACT
The principle of the passive optoelectronic rangefinder (POERF) is known since the second half of the 1950’s. Publications about research and development of POERF do not exist practically. Presumptive causes are presented in this article. We deal with POERF research and development since year 2003. The last fully functional demonstration model is from the year 2009. We present firstly its brief description. In the next part of the article, we briefly specify problems pertinent to a suppression of the influence of stationary foreground objects on the accuracy of ranges measurement. The last part is focused on the problem of tracking moving target. This article deals with principles, which are exploited in individual algorithms. Detailed description of these algorithms requires several separate articles in congruous specialized journals.

KEY WORDS
Passive optoelectronic rangefinder (POERF), stereoscopic disparity, foreground object, occluded area, real time system.

1. Introduction
This contribution aims to achieve these four objectives:

1. The passive optoelectronic rangefinder (POERF) is a specific measuring system and simultaneously a mechatronic system which is not described in more detail in technical publications. The goal is to give flash information about requirements imposed on POERF and about potential ways to their fulfillments. The effective solution presupposes the development of special hardware and software. Let us remark that commonly published algorithms can not be adopt for computing stereoscopic disparity, just like related algorithms for suppression of influence of so-called occluded areas.

2. The 3rd and 4th sections of this article are focused on problems pertaining to algorithms for suppression of impacts of occluded areas. We do not describe or analyze any concrete algorithm, but the goal is to explain specific properties of occluded areas in our application and fundamental possibilities for solutions of relevant problems. We outline the problem in the following example:

The distance between POERF and a building (the target) is 1 000 m. Commonly available algorithms solve e.g. the situation that the building is partially hidden by another lesser building which stands c. 50 meters in front of it, i.e. the difference between ranges of buildings is only 5% of the target range. The occluded areas will prove during images processing as thin strips on the outer contour of the nearer building in the disparity map.

In our case, the nearer object is frequently a tree, whose branches occlude the target partially and “discontinuously” (Fig. 8), whereas the range of the tree from POERF is e.g. 50 to 200 m. It comes to this, that the difference of ranges of the target and the branches is usually 80 to 95%. Occluded areas (the second – undesirable – projection of the images of branches) are fully separated from their images in the disparity map, they are markedly shifted. So, it is difficult to identify occluded areas and to bracket them to their own image (Fig. 7, 8, 12), which is the basic precondition to the suppression of their influence on the measurement accuracy of the target range. It is necessary to underline that branches generate gross errors in the range measurement.

3. The principle of algorithms used for the suppression of described influence of occluded areas depends on the fact, whether or not POERF and respectively foreground objects and the target (e.g. a car) move relatively towards themselves.

The goal of the third section of this contribution is a brief analysis of the situation, where all objects – POERF, the foreground, e.g. branches, and the target – do not move mutually (the stationary situation – model).

The goal of the fourth section is to explain briefly the algorithm for the case, when mutual moving exists (the dynamic situation – model).

4. We had to evolve a special simulation tool for the development of algorithms, which are convenient for the stationary model. This tool allows to insert images of a twiggy into stereo pair images by a controlled manner. We are able to generate branches both to recorded images of a real scene (Fig. 9, 10) and to generated images of a virtual scene (Fig. 5). It allows us to evaluate correctly the algorithms for suppression of foreground objects. We are
also able to offer such stereo pair images to eventual applicants.

Consecutively, we have created simulation applications for development and testing of the software for the estimation of disparity of the target, which is hidden partially by a twiggery. The further goal of the third section is to inform briefly about these tools.

2. POERF as a Mechatronic System

The topographical coordinates of an object of interest (the target), which is represented by one contractual target point \( T = (E, N, H)_T \) – UTM coordinates, need to be determined indirectly in many cases that occur in practice, because an access to respectively the target and the target point \( T \) is disabled due to miscellaneous reasons at a given time.

Typical measured ranges interval for ground targets is from 200 to 4 000 m and for aerial or naval targets from 200 to 10 000 m or more.

Active rangefinders for measurement of longer distances of objects (targets), e.g. pulsed laser rangefinders (LRF), emit radiant energy, which conflicts with hygienic restrictions in many applications and sometimes with given radiant pollutions limitations, too. In security and military applications there is a serious defect that the target can detect its irradiation. The use of POERF eliminates mentioned defects in full.

The passive optoelectronic rangefinder (POERF, Fig. 1, 2, 3) is a measurement device as well as a mechatronic system that measures geographic coordinates of objects (targets) selected by an operator in real time (in online mode). In the case of a moving object, it also automatically evaluates its velocity vector \( \mathbf{v}_T \) and simultaneously extrapolates its trajectory.

In general, the POERF (Fig. 4) continues to measure the UTM coordinates of a moving target with rate from 10 measurements per second or more and extrapolates its trajectory. All required information is sent to external users (clients) via the Internet in near-real-time whereas the communications protocol and the repetitive period (for example 1 s) are pre-concerted. The coordinates can be transformed to the coordinate system WGS 84 and sent to other systems – in accordance with the client’s requirement.

The POERF is able to work in two modes: online and offline (processing of images saved in memory – e.g. on
the hard disc). The offline mode enables to measure the distance of fleeting targets groups in time lag to approx. 30 seconds. The active rangefinders are not able to work in a similar mode.

Presumed users of the future system POERF are the police, security agencies (ISS – Integrated Security Systems, etc.) and armed forces (NATO NEC – the NATO Network Enabled Capability, etc.).

Figure 4. The principle of information processing by POERF

The POERF measurement principle is based on the evaluation of information from stereo-pair images obtained by the sighting (master) camera and the metering (slave) one. Their angles of view are relatively small and therefore a spotting camera with zoom is placed alongside the sighting camera – Fig. 1, 2, 3. This spotting camera is exploited by an operator for targets spotting. After operator’s steering the cameras towards a target, the images from the sighting camera serve to evaluate angle measured errors and to track the target automatically.

The patents of POERF components have been published since the end of the 1950’s but there are no relevant publications dealing with the appropriate research and development results. We have not found out that similar device development is being carried out somewhere else. The problem itself consists particularly in users’ unshakable faith in limitless possibilities of laser rangefinders and probably in the industrial/trade /national security directions.

The development was conditioned primarily by progress in the areas of digital cameras and by progress in miniature computers with ability to work in field conditions (target temperature limit from –40 to +50 °C, dusty environment, etc.) and to realize the image processing in the real-time (frame rate minimally 5 to 10 frames per second, ideally 25 to 30 fps).

Similar principle is applied to focusing system of some cameras as well as mobile robots navigation/odometry systems. Measured distance range is within order one up to tens of meters, therefore the hardware and software concepts in these systems are different from concepts in the POERF system. Sufficient literature sources cover these problems.

From the system view, the POERF as a mechatronic system is composed of three main subsystems: the range channel, the direction channel and the system for evaluation of the target coordinates and for their extrapolation [1], [2] – Fig. 1, 2, 3, 4.

The task of the range channel is on the one hand automatic recognition and tracking of the target which has been selected by the operator in semiautomatic regime and continuous measuring of its slant range $D_T$ and on the other hand the evaluation of angle measured errors ($e_\phi, e_\psi$) that are transferred to input of the direction channel – Fig. 5.

Figure 5. Relation between the image of the real target in the sighting camera, the target point $T$ and 2D model of the target – fixed window/template (the program Test POERF – see [3])

The algorithm for computation of estimate of a slant range $D_T$ is based on solution of the telemetric triangle that lies in the triangulation plane (triangulation algorithms). The input data are ordinal numbers $c_{T1}, c_{T2}$ of columns of matrix sensors in which images $T'_1, T'_2$ of the target point $T$ are projected. In particular, it is sufficient to determine their difference $\Delta c_T$ (horizontal stereoscopic disparity) that is proportional to the appropriate parallactic angle $\beta$. Therefore algorithms for computation of estimate of the difference $\Delta c_T$ are crucial (the correspondence problem algorithms).

We work with algorithms [15] for an estimate of $\Delta c_T$, which involve the definition of 2D model of the target image (shortly “target model", „template”). We use a rectangular target model for the present – Fig. 5. The positive value $d_T = (C_{RF} - \Delta c_T)$ is usually regarded as the disparity [5]. The sign convention is elected so that $\Delta c_T \geq 0$ is valid for $D_T \geq D_a$, where $D_a = b/tan \alpha_2$. The size of the convergence angle $\alpha_2$ (resp. $\alpha_1$) is chosen with respect to the requirement that the measurement of the given minimal range $D_{T\text{min}}$ of the target should be ensured. In our case $D_a = c. 50$ m.

The basic equation for approximate computation of the slant range is
\[ D_T = \frac{D_{RF1}}{C_{0RF} - \Delta c_T}, \]  
where  
\[ \Delta c_T = c_{T2} - c_{T1}, \]
\[ D_{RF1} = \frac{b \cdot f_a}{\rho(c)}, \]
\[ C_{0RF} = \left(\frac{f_a}{\rho(c)}\right) \cdot \tan \alpha + \Delta c_{021} = \left(\frac{f_a}{\rho(c)}\right) \cdot \tan \alpha_\Sigma, \]
\[ \Delta c_{021} = c_{20} - c_{10}. \]

The columns \( c_{20}, c_{10} \) determine the horizontal position of the principal points of autocolimation/projection of slave and master cameras [6]. If the target is in infinity (the Sun, the Moon, stars), then its disparity is just \( \Delta c_T = C_{0RF} \). The rated value \( C_{0RF} = 190.317 \) pixels.

The size of \( C_{0RF} \) is determined by the mechanical – hardware adjustment in conjunction with the electronic – software one.

The rangefinder power (constant) \( D_{RF1} \) is the basic characteristics of potential POERF accuracy [15]. With increasing value of the power, the accuracy of measurement increases too. The rated power of POERF demonstration model is \( D_{RF1} = 9 \) 627 m. The size of \( D_{RF1} \) depends on the width of rows of pixels \( \rho(c) = \rho \), on the absolute value of the image focal length \( f_a \) and on the size of the base \( b \) (Fig. 2).

The actual values of constants \( D_{RF1} \) and \( C_{0RF} \) are determined during manufacturing and consecutively during operational adjustments [3], [12].

The maximum computing speed is required primarily, in order that about from 10 to 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 (extrapolation process).

The matching cost function \( S(k) \) is used for disparity \( \Delta c_T \) evaluation in the meantime (in general it is pixel-based matching costs function) – the sum of squared intensity differences SSD (or mean-squared error MSE) [3], [5], [10]. The computation of matching cost function \( S(k) \) proceeds in two steps. Firstly, its global minimum with one-pixel accuracy is calculated. In the second step, the global minimum is searched with sub-pixel accuracy while using the polynomial approximation.

While 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 – Fig. 5. This precondition is equivalent to the hypothesis that these pixels depict immediate neighbourhood of the target point \( T \) representing the target and this neighbourhood appertain to the target surface (more accurately all that is concerned the image \( T_1 \) of this point and its neighbourhood). These algorithms belong to the group referred to as local, fixed window based methods [5], [10].

It is necessary for the sake of reliable functioning of the system that the image of a target should be of size \( 16 \times 16 \) pixels minimally [1].

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 (Fig. 9), 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. Adduced precondition can be frequently satisfied by a suitable choice of size and location of the target model (i.e. by the aim of a convenient part of the target) – Fig. 5, 9. The choice is performed iteratively by the operator for the real POERF.

![Figure 6. Dependence of the normed disparity \( \delta_d \) on the normed target range \( \delta_D \)](image)

It is evident from the above that the choice of the position and the size of 2D target model/template 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.

Algorithms commonly published for the stereo correspondence problem solving are altogether fully automatic [5], [9] – they use the information included in the given stereo pair images, eventually in several consecutive pairs (optical flow estimation). Therefore, it is possible to get inspired by these algorithms, but it is impossible to adopt them uncritically [15].

In conclusion it is necessary to state that these automatic algorithms are determined for solving the dense or sparse stereo-problems [10], whereas the POERF algorithms estimate the disparity of the only point – the target point \( T \), but under complicated and dynamically varying conditions in the near-real-time.

Yet another difference exists between POERF and other devices exploiting stereo correspondence algorithms for the range measurement of objects. These devices can have usually relatively large basis \( b \) and consequently \( D_{RF1} \), too towards the extent of measured ranges (Fig. 2),
and so – from the view of triangulation algorithm – they work in the “left” branch of hyperbolic dependence between the range $D_T$ of objects and corresponding disparity $d_T$ ($d_T = C_{RFR} - \Delta c_T$) – Fig. 6. It means that small changes of $D_T$ induce large changes of $d_T$ (the system is very sensitive to changes of the range).

Such solution is not possible for POERF, because its sizes and weight would be unacceptable. Consequently, the POERF works in the “right” branch of mentioned dependence – Fig. 6. Thus, it is very insensitive to changes of the range, which produces exceptional demands on accurate estimate of the disparity $\Delta c_T$. The situation is moreover complicated by the noise impact [1], [3], [11].

3. Development of Algorithms of the Foreground Objects Effects Compensation

In many cases it is inevitable that some pixels of the 2D target model record a rear (background) object or a front (foreground) object instead of the target. Simulation experiments with the program Test POERF [3] showed that farther objects have minimal adverse impact on the accuracy of the range measurement, contrary 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 foreground object and the target. This finding has been also verified in computational experiments by the help of the program RAWdis [3]. The foreground object usually causes that the set of pixels of the 2D target model is not connected (it is the union of several connected subsets) – Fig. 7. In many situations, the number of “effective” pixels in this set can be less than it matches with the evaluation of the image from the sighting camera only and it is the source of mentioned problems. As it is obvious, this case is a special implication of the well-known problem referred to as “occluded areas” [7], [9].

If any object moves relatively towards the POERF at another velocity than objects in the foreground, then algorithms utilizing computed optical flows can be used for discrimination of pixels which represent foreground objects. A solution, which is developed for POERF, is explained in the 4th section.

If objects do not move relatively one another, then the situation is considerably complicated as it is shown hereinafter.

The concrete example of described phenomenon is introduced in the Fig. 8. The effect evinces on the graph deformation of the matching cost function $S(k)$ in a neighborhood of its global minimum. 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” ($D_T = 178$ m) corresponds analogically to the choice, where all pixels depict surface of the foreground object (accurately measured range of this object). Each of these graphs has the only one “decided” local minimum which is simultaneously the global minimum.

![Figure 7. The front object influence on the distortion of results of the target range measurement](image)

![Figure 8. The example of a foreground 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 [2], simulation results from the program RAWdis and the second example of a foreground object influence (branches of trees – cluttered foreground)](image)
disconnected set of “effective” pixels can be considerably complicated, e.g. due to branches of trees – Fig. 8.

At present we are working on algorithms that suppress influences of foreground objects and that simultaneously work in the iterative mode – a dialog with the operator – such as the algorithms SIOX [4]. It is concerned about a special application of algorithms for foreground extraction from 2D target model [4], [7], [8]. The fact that foreground objects belong to “cluttered foreground” category needs to be considered too [7] – Fig. 1, 8, 10.

The functionality of algorithms is verified by the help of advanced versions of programs RAWdis (real scenes) (Fig. 9, 10, 11, 12) and Test POERF (virtual scenes) – Fig. 5.

Figure 9. Original stereo-pair images (a window of the program RAWdis), Target No. 10/3 – a building ($D_{T_0} = 320.6$ m) of Catalogue of Targets

Figure 10. A modified stereo-pair of images (Fig. 9) from sighting (master) and metering (slave) cameras; a window of the program RAWdis [3]

Firstly, we have developed a generator of “twiggery”, where all requisite parameters can be chosen and so we can probe the effectiveness of algorithms for suppression of influence of foreground objects (we accurately know ground-truth disparity map). It can be defined up to 20 layers of “branches” in different distances in front of the target. Random parameters for shapes and brightness levels (means and dispersions) of branches can be defined for every layer. In the Figures 10, 11, 12 two layers are used.

The effect of “twiggery” is obvious from the example of the course of the matching cost function $S(k)$ – Fig. 11, 12. A description of used algorithms transcends the scope of this article.

The algorithm for the suppression of the influence of foreground objects makes use from the iterative work of the operator at defining a filter – foreground masks for master and slave camera images – Fig. 12. Yellow pixels are depicted to the operator (Fig. 12), if the difference of brightness levels from the master camera $L_1(r_1, c_1)$ and slave one $L_2(r_2, c_2 + k)$ for the given disparity $k = \Delta c = F(D)$ is

$$\varepsilon_k \leq L_1(r_1, c_1) - L_2(r_2, c_2 + k) \leq \varepsilon,$$

where $\varepsilon$ is an elective boundary, its default value is 2 for 8-bit resolution. This proposal is restricted to disparities $k$, which corresponds with marked minimums of the matching cost function $S(k)$ – Fig. 11. The operator arbitrates – on account of other information – if he files the given set to foreground masks (the union of pixels
subsets for different disparities $k$). The resulting mask in the Fig. 12 is formed by the union of two sets of pixels that correspond to disparities/distances 85 and 169 m.

At present, we are transferring procedures, which were debugged in the program RAWdis to libraries of the POERF software – demonstration model 2012. The main attention is focused to the GUI development especially.

The low level of the automation of the algorithm does not interfere for the present because it serves for measurement of a stationary target from the immovable POERF. It follows that the operator has ample time for measurement, whereas the accent is on the accuracy of measurement and on prevention of blunders. Nevertheless, we are intending to automate next operations which are typical for choice standard situations (poles, branches without leaves, bunches of trees, etc.) in the next period.

4. Moving Target and Foreground Mask

In cases where the target is moving, tracking algorithm has to be utilized for continual localization of the target in the sequence of images from the spotting or sighting (master) camera. Numerous methods for this task have been proposed in recent years; a good introduction can be found in the survey paper [13]. In the computer vision community, one of the most popular approaches for visual tracking is based on a variant of the particle filter – Bootstrap algorithm with template-based image features [14].

In our case, the reference template is defined as an array of grey-level values inside the selected bounding box (2D target model) with a foreground mask of the same size. The foreground mask is established automatically by subtracting the current frame from the initial frame when the predicted and initial pose of the target are different enough with respect to the size of the target. Until this condition is met, only intensity matching error defined as a sum of squared differences (SSD) is used as similarity metrics for tracking purposes.

Once the foreground mask of target is obtained, it is used in the process of suppression of influence of non-target pixels on the distance estimation of the target (as was mentioned in section 2). When the position of the target in the current frame is known (provided by tracking algorithm), same principle as in the initial step is employed for establishing the current foreground mask. Nevertheless, this foreground mask can be affected by other moving objects. Therefore, the intersection between the initial target’s foreground mask and the current foreground mask is obtained by $min$-pixel wise operator (see Fig. 13).

The extracted intersection is delivered to POERF algorithm and is utilized for discrimination of pixels on target or non-target pixels. However, the further processing has to be performed because of the image source which is the spotting or master camera; mask does not correspond exactly with the image from the slave camera. This part of the complex solution for dealing with moving targets is currently being addressed.

5. Conclusion

Described algorithms will be components of the firmware of POERF, whose next demonstration model is scheduled for completion in December 2012. In 2013, we will start works on the second version of the software. The attainment of planned parameters is expected in the second half of the year 2015.

References