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MEASUREMENT OF CROSSHAIR SHIFT ON MAGNIFICATION CHANGE IN FIELD-CONDITIONS

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Abstract: Crosshair shift with changing magnification of VIS camera is investigated in this article. The shift is a real problem that can significantly worsen fire-control system performance. The main condition of this measurement is ability to perform it on mounted devices in real fire-control system in field condition, it means that the measurement is adjusted to be done with accessible equipment. To measure this shift it is important to design target image which enables the shift measurement. Inaccuracy of this measurement is also discussed. The theoretical solution of the problem is demonstrated on experimental measurement.

Keywords: Hit probability; Crosshair shift; Aiming, Optics; Fire-control system; Optical measurement.

1 INTRODUCTION

Today, light reconnaissance battle vehicles are parts of every modern armed forces. They are equipped with remote controlled weapon station (RCWS) with a equivalent of 12.7 mm or 7.62 mm machinegun, laser rangefinder (LRF), VIS cameras, and IR cameras. (1)

Information from all these sources is combined in fire-control unit (FCU) which provides output to operator display and then enables operator to shoot on the target. (2)

Reconnaissance cameras have two main tasks- to find a target, and to identify it to allow operator to lead the fire on it. Therefore, the camera needs to have great zoom interval on the one hand with a wide field of view (FOV) and low magnification and on the other hand with narrow FOV and great magnification.

To find a target it is needed to have wide field of view. To identify a target, you need to have a great zoom to be able lead a fire on an effective weapon range.

With a great zoom interval, there is difficult to stabilize real boresight with crosshair provided by FCU. This difference can negatively affect LRF, or weapon hit probability.

It is needed to be able to measure this shift on a real mounted weapon station in field conditions.

2 DETERMINATION OF BASICS PARAMETERS

To measure crosshair shift, there was chosen daylight camera from a reconnaissance vehicle used by armed forces. RCWS uses heavy machinegun .50 BMG M2 QCB, it has a day CCD camera, IRC and LRF, information from these sources is displayed on a FCU unit display. The FCU display limits the resolution of a camera to 0.05 mrad at a maximum magnification. (3)

Rectification of the RCWS is done with rectification target with set maximal magnification on distance l=15 m.

Table 1 Camera properties

Spectrum	FOV	Magnification	Display resolution
VIS/NIR	1.7-45°	1.2-30x	640x480 px

Source: author.

FCU uses 4 different types of crosshairs, the crosshair is displayed over the final image with exact width of line of 1 px. This property is used when measured its shift in the image.

Crosshair midpoint when rectified lies on the optical axis of the day camera. When the elevation of the camera is 0° the crosshair midpoint aims on the same point in the target independently on a magnification.

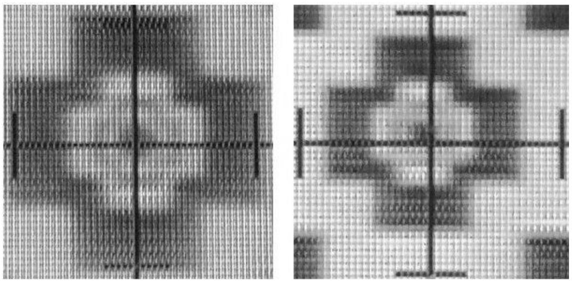

Fig. 1 Crosshair shift with change of magnification
Source: author.

Due to various influences, there is recognizable crosshair shift when magnification is changed. This shift can cause targeting error when LRF or weapon is used. To measure this shift in field conditions it is needed to use target image suiTab. for the RCWS.

The final image is captured by frame grabber or camera and then the shift is measured in the picture.

3 TARGET DESIGN

In the beginning of a target design, it is needed to know the distance to the target. Then there is important to know the magnification steps. It is not possible to have a target for every possible magnification because of unclarity of the final target image. On the other hand, the target image must be detailed enough to enable shift measurement on a camera resolution level, that means 1 px on the screen.

It is favoured to be able to measure shift in both axes at once, that can be done when the target shape consists of isosceles crosses lying within each other. Their size corresponds to 3 px on each side to enable shift measurement in x and y axes.

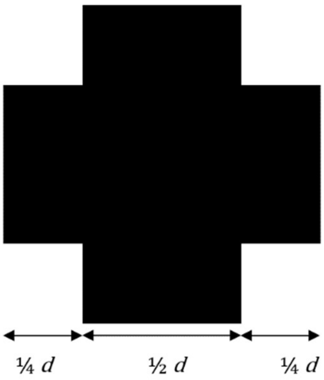

Fig. 2 Cross element from a target image
Source: author.

$$\frac{\mathrm{d}}{2} = \mathrm{n} \cdot \tan\left(2\omega \cdot \frac{\Gamma_{\max}}{\Gamma}\right) \cdot \mathrm{l}\ [\mathrm{mm}], \qquad (1)$$

where d is cross element width, n is number of pixels on the screen, 2ω is maximal pixel resolution in mrad, $\frac{\Gamma_{\max}}{\Gamma}$ is ratio of maximal magnification and corresponding magnification, and l is the distance to the target. (3) Final example of a target image is shown in the Fig. 3

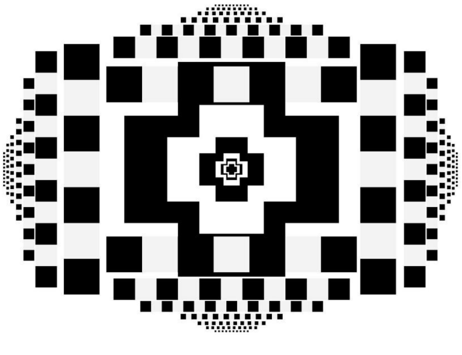

Fig. 3 Final target image with side rulers
Source: author.

For rough estimation of the shift in field conditions it is possible to add sidebar rulers.

4 CROSSHAIR SHIFT MEASUREMENT

To determine shift it is needed to set the starting point of the crosshair. Consider that elevation must be set to 0, maximal magnification and crosshair must aim to the middle of the target. Capture the displayed image to have starting condition image. Then zoom out to the next designed magnification, capture the image, and continue till the maximal zoom out.

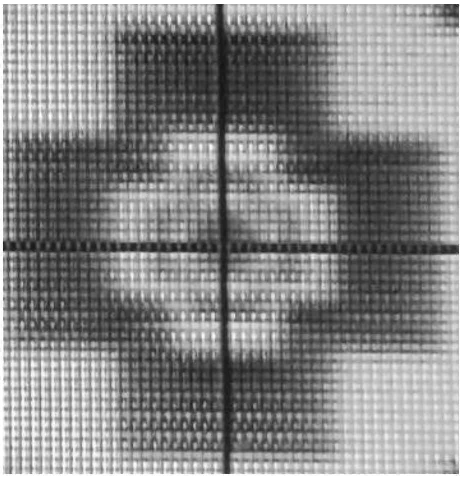

Fig. 4 Default condition image
Source author.

Captured images are analysed with ImageJ program (4) that enables to perform measurement in the image with known distances. There is determined crosshair midpoint on each captured image which is confronted with starting position crosshair midpoint. Distance of these two midpoints is the wanted crosshair shift.

Measurement example is shown in the Fig. 5, where the distance is the red segment nr. 1.

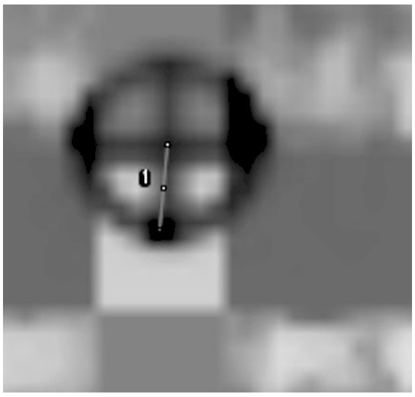

Fig. 5 Measured shift distance
Source: author

Measured distances across zooming out shows the crosshair shift in both axes of target plane.

5 DEMONSTRATION EXPERIMENT

5.1 Experimental measurement

To demonstrate shift measurement in real conditions it was used target situation with following properties, l = 17 m, magnification interval Γ∈<1.2:30>, zoom out step is irregular because of autofocus properties of used camera.

Camera was rectified according to standard instructions. Elevation was set to 0°, the middle point of crosshair was set to the middle of the target image (Fig. 4).

Then the camera zoomed out in steps and then the image was autofocused. No change in elevation and traverse was made. After each step the autofocused image was captured.

Measurement of the shift is done in ImageJ program (4), measured data are processed in Matlab environment.

In the captured image it was measured the distance from the crosshair to the default crosshair point. Measured distances are shown in the Tab. below. Angular shift is determinated as an angle of shift on the distance l.

$$\Delta\varphi = \frac{\Delta x}{l}; \Delta\theta = \frac{\Delta y}{l} \text{ [mrad]}, \qquad (2)$$

Table 2 Measured crosshair shift

Magn. Γ	FOV [°]	shift Δx [mm]	shift Δy [mm]	shift Δφ [mrad]	shift Δθ [mrad]
1,2	44,2	-32,50	21,31	-1,91	1,25
1,9	27,4	-18,04	30,68	-1,06	1,80
2,9	17,4	-9,94	18,36	-0,58	1,08
4,4	11,5	-8,44	15,76	-0,50	0,93
9,4	5,4	-3,92	7,18	-0,23	0,42
18,9	2,7	-1,50	1,53	-0,09	0,09
23,2	2,2	-0,96	1,17	-0,06	0,07
30,0	1,7	0,00	0,00	0,00	0,00

Source: author.

Magnification 30 is the default condition with 0 shift. Measured shift is approximated by Smoothing spline. (5)

$$p \cdot \sum_i w_i \cdot (y_i - s(x_i))^2 + (1-p) \cdot \int \left(\frac{d^2 s}{dx^2}\right)^2 dx, \qquad (3)$$

where graph smoothness p=0.9 and weight w=1 is chosen.

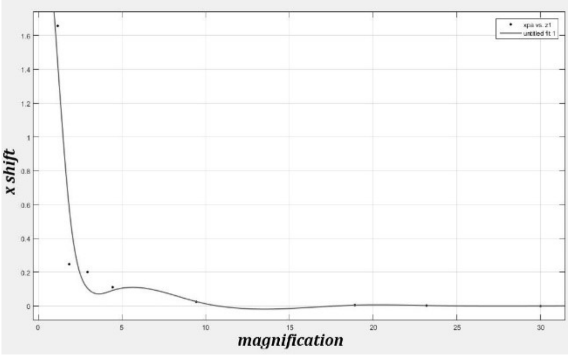

Fig. 6 Measured angle shift in x axis
Source: author.

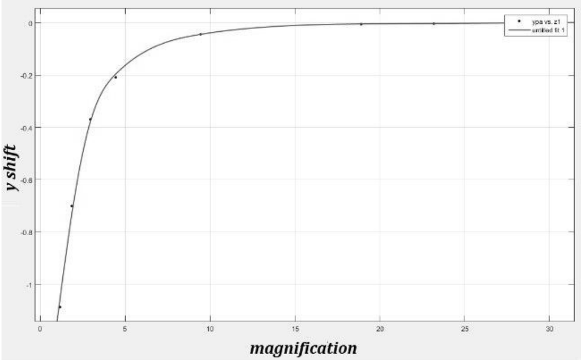

Fig. 7 Measured angle shift in y axis
Source: author.

For the lowest magnification the shift is the greatest, it can be caused by stopping mechanism of the zooming element of the camera.

6 MEASUREMENT ACCURACY

This field-condition measurement is affected by several conditions. The biggest source of inaccuracies is the fire-control unit and its display, which shows the target image and creates the crosshair. It has low resolution display which makes the main part of the inaccuracy. It is possible to determine the distance with accuracy of $u_2 = 2$ px in the display (1 px for each edge).

Second significant part of the inaccuracy is the in-image measurement of crosshair middle point. It is possible to identify the midpoint with accuracy of $u_1 = 0{,}5$ px.

Resolution of the capturing system is order of magnitude higher than the display, so it can be omitted, also measurement of the distance l and accuracy of the printed target is negligible.

Inaccuracy of the measurement for both axes is then

$$u_x = u_y = \sqrt{\left(2\omega \cdot \frac{\Gamma_{max}}{\Gamma} \cdot u_1 \cdot l\right)^2 + \left(x_{min/px} \cdot u_2 \cdot \frac{\Gamma_{max}}{\Gamma}\right)^2} \qquad (3)$$

where $x_{min/px}$ is width of 1 px in the target image.
(3)

Inaccuracy for the maximal magnification is then determined with $\Gamma_{max} = \Gamma$ and $x_{min/px} = \frac{0{,}001}{12}$ as

$$u_x = \sqrt{\left(0{,}00005 \cdot \frac{30}{30} \cdot 0{,}5 \cdot 17\right)^2 + \left(\frac{0{,}001}{12} \cdot 2 \cdot \frac{30}{30}\right)^2} = 0{,}46 \text{ mm} \approx 0.27 \text{ mrad} \qquad (4)$$

To decrease measurement inaccuracy, it is needed to have higher resolution display. In-image measurement accuracy depends on precision of the program and operator.

7 CONCLUSION

This article presents problematic of crosshair shift with change of magnification. This problem can be crucial in combat situation when the fast and accurate hit is needed.

It shows possible way of crosshair shift measurement. It can be stated that crosshair shift is a real problem that can leads to fire-control system inaccuracy or aiming failure. Crosshair shift about the size of 1 mrad can transfer the impact area of fire up to 1 m on the 1 km distance.

Next important part of the article shows the way of tailoring target image to camera system which can be used not only for day cameras but also for image intensifiers-based night vision devices.

This article presents measurement of this shift in field-conditions enabling to perform measurement of mounted devices in real fire-control system. It is possible to measure this shift with accuracy better than 0.3 mrad.

This problematic can be developed further by comparing crosshair shift on different types of vehicles. Evaluation of the shift from the image could be performed by machine learning to decrease measurement inaccuracy. For the exact influence of this shift, it is needed to experimentally compare it to real shooting experiment.

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