Hyper Focal Distance Application for Long Range Surveillance Camera Zoom Lens Focusing Settings

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***Abstract*—Modern multi sensor surveillance systems integrate several multispectral imaging channels, laser range finder and positioning sensors (digital magnetic compass – north finding sensor and GPS sensor). Imaging channels use motorized zoom lenses providing convenient and fast field of view –FOV change. The fast FOV change to desired value keeping optimal image sharpness is provided through selected FOV pre-set settings using zoom lens position setting to desired values. In addition to FOV settings it is useful to pre-set lens focus motor position. The zoom lens hyper-focal distance determination for selected FOV and lens focusing motor position setting accordingly is used as pre-set lens parameter definition. The short review of the motorized zoom lens design and their basic properties is presented. The lens depth of field and hyper focal distance are discussed and basic formulas are derived. The zoom lens based imaging channel calibration procedures selection depends on application. We presented in detail hyper-focal distance based focusing motor parameter setting as one of the calibration procedures used in our multi sensor imaging systems.**

***Index Terms*—Surveillance systems, imaging system calibration, motorized zoom lens, depth of field, hyper focal distance**

I. Introduction

Multi sensor – multi spectral surveillance system users prefer application of the zoom lenses in the built in camera systems. Motorized zoom lens provides flexibility and controllability of the imaging conditions: changing the focal length, focusing distance, and aperture value to suit different fields of view (FOVs), depths of field (DOFs), and lighting conditions. Digital image sensor and application of the computer for surveillance system control provides technical means for convenient and accurate imaging data analysis and camera operation control using pre-set and calibration data generated in the laboratory.

Zoom lens calibration is described in open literature mainly for zoom lens application in photogrammetric measurement and machine vision application [1-8]. Camera calibration is a prerequisite for 3D imaging applications, providing data for 3D reconstruction. The calibration procedures could be identified as: standard calibration, self-calibration, photometric calibration and stereo-setup calibration. There are a lot of techniques applied for specific applications, but calibration of the surveillance zoom camera aimed for object pointing and tracking is poorly covered in the open literature. In this application [9] the most important is so called "zoom to FOV" calibration, involving lens optical axis stability calibration and line of sight – LoS control, using position control of the sighting reticle. Zoom lens focal length and image focus is set with digitally controlled positioning motors. "Zoom to FOV" calibration provides connection between motor position digital data and related zoom lens focal length or camera FOV. LoS stability control against zoom motor position is provided using data of optical axis displacement versus zoom motor position. This zoom lens calibration in surveillance systems provides accurate system aiming and target tracking. Sharp image is provided by additional camera focus control.

The long range surveillance system should provide wide field of regard – FOR (target search over wide area and different ranges) and possibility to provide high magnification in the same time. High magnification means that imagers use narrow field of view that is incompatible with wide FOR. This discrepancy could be overridden using zoom function. FOR search is done using wide FOV for target detection, and switch to narrow FOV for target recognition and identification. Human operator is usually involved in the system control chain. To support fast switching from wide FOV to suitable narrow FOV several zoom (FOV) pre-set positions are defined. To avoid additional time loss for focus adjustment it is convenient to pre-set focus motor position and provide sharp image immediately after switching to desired FOV. One of the possible solutions is to use idea about hyper-focal distance that is widely used in the cinema industry and photography [10].

In this article we are describing the basic design and properties of the motorized zoom lenses. We are pointing out zoom lens specifics leading to imperfections that should be corrected by calibration, together with definition of the main geometrical relations in the camera system. Also we described our simplified model for hyper-focal distance calculation applied for motorized zoom lens cameras used in our systems. The methodology for implementation of these results to camera pre-set parameters is explained.

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In the case of zoom lens calibration and set-up, common camera calibration should be conducted first. Camera calibration is the process of determining the intrinsic parameters of the camera, including back focus distance.

A zoom lens contains moving lens groups providing focal length change that could be moved using linear or rotational stages powered by electrical motor. To provide high effectivity of zoom lens controllability, lens calibration and initial set-up should be performed.

The focus adjustments for selected zoom pre-set positions is the last step in camera setting.

II. Zoom Lens Design and Basic Properties

Imaging zoom lens is capable of producing, on a fixed plane (image plane), images whose magnification is continuously variable between two extreme values. The variation in magnification is achieved by changing the relative positions of the lens elements or lens groups built in the zoom system. The zoom lens design is complex [11-18], including complicated mechanical motion system design and optical design and optimization, depending on dedicated zoom lens system application. Because of that, zoom lenses were not considered for high quality imaging application until 1960, when started wider application in commercial photographing systems.

Two broad classifications of the zoom systems recognize the mechanically compensated type and the optically compensated type. In mechanical compensation design, the motions given to the elements are such as to ensure exact constancy of focal position, these movements being non-linear and achieved by complicated camera mechanisms. In an optically compensated design the motion of all moving elements is identical and linear, but desired focus can be achieved only at a finite number of zoom positions.

The development of the digital imaging sensors leading to the small sensor size accompanied with aspherical lenses provides leads to the much wider applications of the zoom lens systems [14]. Long range surveillance application in visible and infrared region, requiring continuous focus caused that mechanically compensated zoom lens using fine motorized controls dominates in practical applications.

The zoom lens generalized structure is presented in Fig.1 showing the key fixed and moving (controllable) components. The illustration of complexity of zoom lens design is shown in in Fig.2.

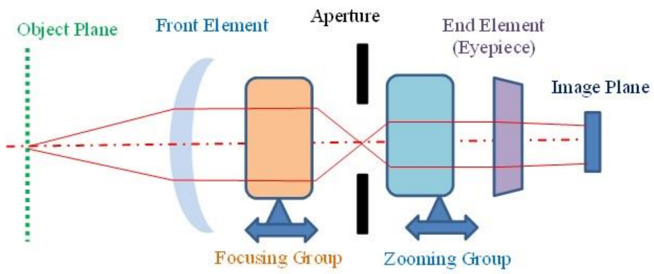


Fig. 1. Zoom Lens generalized structure

Zoom lens elements are grouped to provide basic functions: focusing group, magnification variation group, correction group and image formation group. The magnification variation group and correction group could be moved during zooming. Focusing group could be moved during focusing process that could be performed simultaneously or follow on zooming. Image formation group is usually fixed and belong to the end piece of lens, providing enough space to image plane where imaging sensor is placed (back focus distance).

Back focus distance is the distance along optical axis from the apex of the rearmost glass surface to the focal plane when a lens focused to infinity.

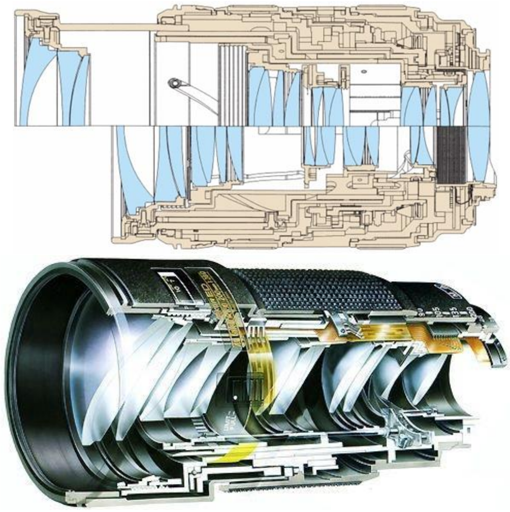
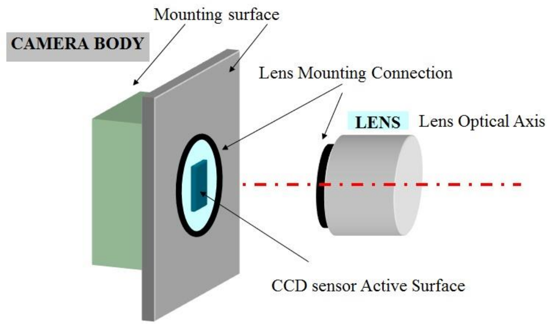
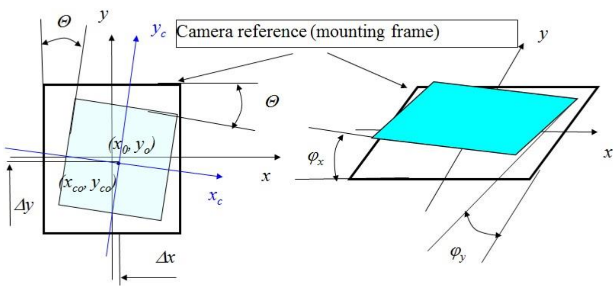


Fig. 2. Zoom lens design example illustration (cross section)

The advances in the optical design and manufacturing process [19], provides high quality for manufactured zoom lenses, but there are still imperfections that remain and that should be corrected during initial lens calibration. Some of them are caused by zoom lens mounting, as illustrated in Fig.3



(A)



(B)

Fig. 3. Zoom lens mounting (A) Back focal distance; (B) Imperfections (Image sensor rotation and tilt)

In the case of surveillance cameras the position image sensor center and optical axis are the most important [20].

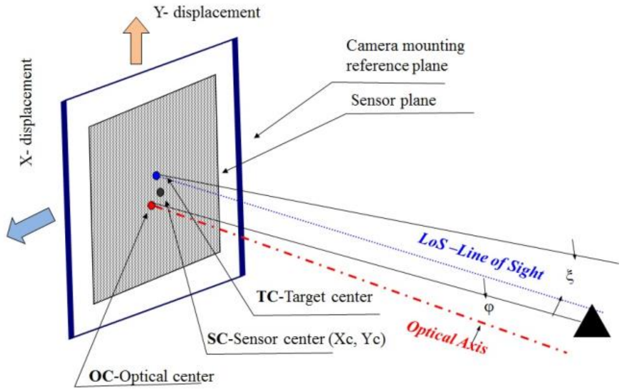


Fig. 4. Zoom lens camera calibration parameters geometry

The fusion of digital image, zoom lens magnification and focus digital control, provides the basis for development of the different calibration procedures that contribute to the effective zoom lens operation in related applications [20-25].

In this article we are dealing with zoom lens calibration to provide reasonably sharp image (according to allowable tolerances of focus [26]) during zoom focal length change but avoiding manual focus fine adjustment. This is of importance in the long range surveillance system application when fast reaction increase system efficacy.

Motorized zoom lenses have great potential in the applications long range surveillance systems providing object of interest - target and visual perception (detection, recognition, identification) and tracking. In such applications, the aperture, zoom, and focus of the lens can be controlled to adapt to different lighting conditions or to obtain the desired field of view, depth of field, spatial resolution, or focused distance. Calibration of a motorized zoom lens is extremely useful but not an easy job. The goal of motorized zoom lens calibration is to determine the relationship between the lens position settings (control parameters for the driving motors) to provide proper imaging performances. In our case we are establishing lens position settings for selected pre-set positions to provide sharp image immediately after zoom position change. In that case zoom lens is treated as mono-focal lens for selected FOV.

III. Hyper-focal Distance and Depth of Field

To provide calibration and set-up procedure we selected to explore the idea of hyper-focal distance that was widely used in first half of twentieth century for focus setting in photography and cinema industry [10, 27]. It is still explored in photography for achieving of the special effects in artistic photography.

Hyper-focal distance can be defined as distance in front of camera upon which all objects in front of that distance and up to infinity appears sharp in image. In other words, if you want everything to be acceptably sharp from infinity to as close as possible to the camera you should focus on the hyper-focal distance.

As a first step we need to discuss some important parameters:

Stop diaphragm - aperture: The opening which adjusts the diameter of the group of light rays passing through the lens. The zoom lens maximal aperture is limited by lens entrance element diameter. To provide possibility to regulate amount of the light the controllable stop diaphragm – iris is built in lens system to limit light bundle passing through lens but not disturbing image. In modern digital cameras aperture adjustment is commonly controlled automatically using command from image sensor to avoid sensor saturation. The control could be complex because saturation is controlled by exposure time, too.

Focal length: When parallel light rays enter the lens parallel to the optical axis, the distance along the optical axis from the lens' second principal point (rear nodal point) to the focal point is called the focal length. In simpler terms, the focal length of a lens is the distance along the optical axis from the lens' second principal point to the focal plane when the lens is focused at infinity.

F-number – F#: For zoom lens having aperture with diameter *d* and focal length *f* related lens F-number is defined as:

$$F_{\#} = \frac{f}{d} \tag{1}$$

Circle of confusion – CoC: Since all lenses contain a certain amount of spherical aberration and astigmatism, they cannot perfectly collect rays from a subject point to form a true image point. In addition, diffraction widening also contributes to the focused spot size. In the case of infrared lenses diffraction limited lenses are more often case. Since the image becomes less sharp as the size of these dots increases, the dots are called "circles of confusion". The advancement of the optical design and manufacturing technology practically eliminate the aberrations influence on CoC through proper compensation and optimization in design process, but diffraction influence could not be eliminated.

Diffraction limited resolution is defined by so called Rayleigh's criterion [28, 29] defined by diameter of the first Airy disk on point spread function. In that case one can to define that minimal value of CoC is equal to:

$$c = CoC = 2{,}44 \cdot \lambda \cdot F_{\#} \tag{2}$$

Sensor size: Imaging focal plane array contains the matrix of detectors – pixels having limited size, *p*. The final factor determining hyper-focal distance is the size of your digital sensor. A larger digital sensor will result in a closer hyper-focal distance.

Depth of focus is a space around focal plane in which acceptable sharp image could be achieved. Depth of focus in the image-space is related to how the quality of focus changes on the sensor side of the lens as the sensor is moved, while the object remains in the same position. Depth of focus, δ, could be calculated as:

$$\delta = 2 \cdot F_{\#} \cdot s \tag{3}$$

Where s *is* resolution limit ($s=p$ – detector limited, $s=c$ – diffraction limited)

Depth of focus characterizes how much tip and tilt is tolerated between the lens image plane and the sensor plane itself. As $F_{\#}$ decreases, the depth of focus does as well, which increases the impact that tilt has on achieving best focus across the sensor. Without active alignment, there will always be some degree of variation in the orthogonality between the sensor and the lens that is used. It is generally assumed that problems involving depth of focus only occur with large sensors.

Depth of field – DoF: The space in front of and behind an imaged object having sharp focus, image also appears sharp. In other words, the depth of sharpness to the front and rear of the subject where image blur in the focal plane falls within the limits of the permissible circle of confusion. Depth of field (as illustrated in Fig.5) varies according to the lens' focal length, aperture value and object distance (D_{pof}), so if these values are known, a rough estimate of the depth of field can be calculated using the following formulas:

$$D_{near} = \frac{f^2 \cdot D_{pof}}{f^2 + F_{\#} \cdot c \cdot (D_{pof} - f)} \quad (4)$$

$$D_{far} = \frac{f^2 \cdot D_{pof}}{f^2 - F_{\#} \cdot c \cdot (D_{pof} - f)} \quad (5)$$

$$DoF = D_{far} - D_{near} \quad (6)$$

$$D_{HF} = \frac{f^2}{F_{\#} \cdot c} \quad (7)$$

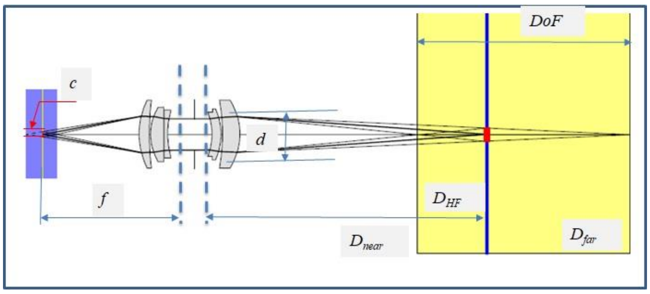


Fig. 5. Depth of focus and depth of field definition

Hyper-focal distance is a distance of object whose image is sharp same as all other far objects up to infinity and other near objects up to half of hyper-focal distance. It depends of the same three factors that determine depth of field.

Hyper-focal distance allows precise setting of the focus so that everything between half the hyper-focal distance and infinity is acceptably sharp. That means if one set proper focus of object placed on hyper-focal distance then all objects placed at distances from half of hyper-focal distance to infinity will have acceptable sharpness.

However, sharpness does not depend on focus setting alone. Camera motion, subject motion by wind, quality of the lens, weather, and other factors can greatly impact the sharpness of the image.

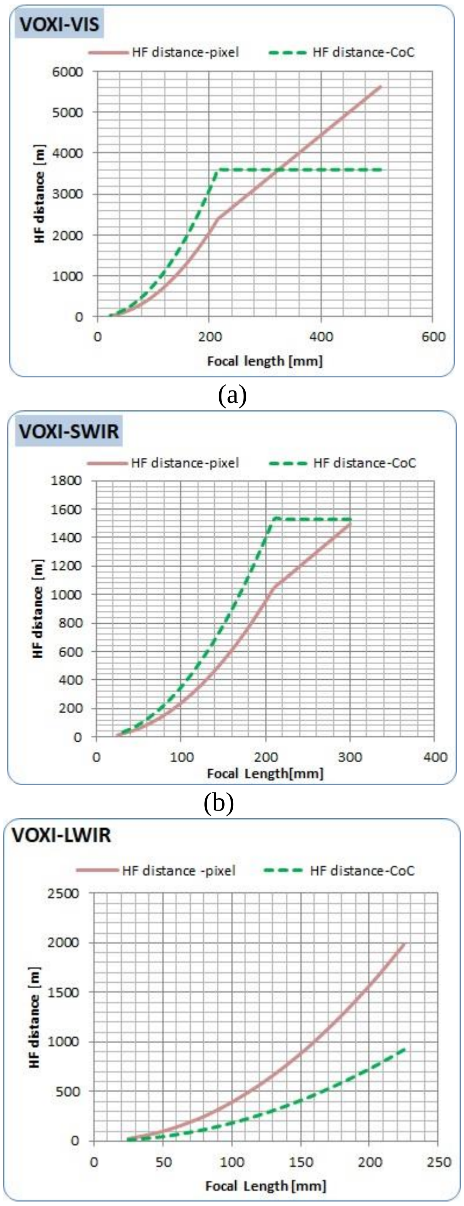
IV. Long Range Zoom Camera Focus Settings

The calculations of the hyper focal distance against focal length setting using equitation (7) were applied for selected cameras having characteristics listed in TABLE I.

TABLE I
CONDENSED REVIEW OF THE IMAGER BASIC PARAMETERS

System Type	Focal Length [mm]		F#		Pixel Size	Center λ
	min	max	min	max	[µm]	[µm]
VOXI-LWIR	25	225	1,5	1,5	17	10
VOXI-SWIR	25	300	2,8	>30*	15	1,5
VOXI-VIS	23	506	3,1	>30*	6,25	0,55
C225	23	506	3,1	>30*	8,3	0,55
C1200	12	1680	4	18,2	5	0,55
C2500	33,4	2000	3,5	16	5	0,55

Note: * - *with iris control*



(c)

Fig. 6. Calculated hyper-focal distance value versus lens focal length for different cameras (VIS –visible, SWIR- short wavelength infrared, LWIR – long wavelength) in VOXI system

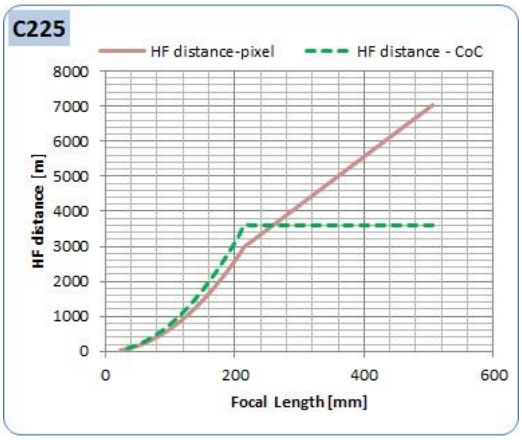


Fig. 7. Calculated hyper-focal distance value versus lens focal length for VIS camera in C225 system

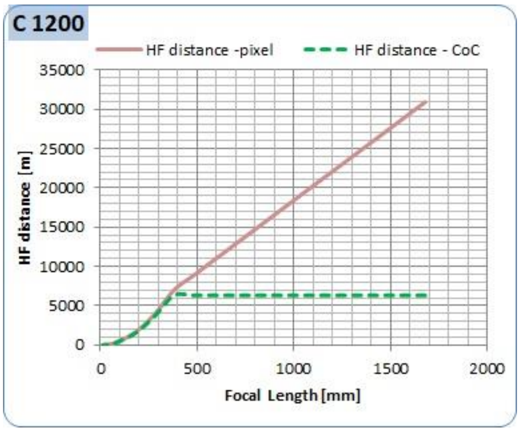


Fig. 8. Calculated hyper-focal distance value versus lens focal length for VIS camera in C1200 system

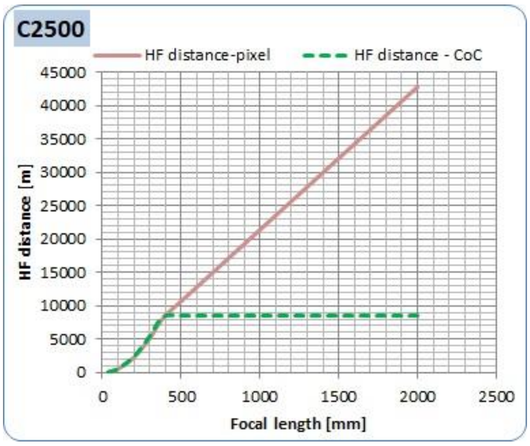


Fig. 9. Calculated hyper-focal distance value versus lens focal length for VIS camera in C2500 system

The results of hyper-focal distance calculations for medium range surveillance system and different imagers are shown in Fig.6. These results show that application of proper set-up will be effective in all three channels.

The results of hyper-focal distance calculations for long range systems (VIS imagers with different magnification) are shown in Fig 7 to Fig.9. These results show that hyper-focal distance based focusing setting could be useful for wide FOVs (focal lengths up to 400 mm) but for narrow FOV it is good enough to use just infinity focus settings.

The application of hyper-focal distance based zoom lens focusing parameter settings can contribute to improvements to system performances but have limited capabilities: (a) calibration process could be applied only for limited and predefined pre-set FOV positions; (b) it is effectively applicable only for zoom lens wide FOV pre-set positions; (c) practical implementation is not easy and reliable enough; (d) the influence of temperature on zoom lens focus stability is not involved in the procedure.

The good news is that additional manual focus setting is always allowable to system operator to try to improve image sharpness.

The application of collimator for focus setting following hyper-focal distance data is not practical in the case of long range imagers, so determination of the imager focus setting should be performed using real objects imaging in the field.

The setting procedure could be established as follows: (I) select the object in the field on the distance that is approximately as calculated hyper-focal distance for selected pre-set FOV (focal length); (II) starting from infinity focusing settings, change the focus setting to get selected object properly focused; (III) continue changing focus setting keeping object focused same as all other objects far from selected object; (IV) at the moment when very far objects (infinity) start to loose sharpness but selected object is still sharp record focus settings. This value could be set as selected focus setting for the FOV pre-set value according to hyper-focal distance.

V. Conclusion

Video channel functional parameter optimization is not simple task, but possibilities depends on image formation process knowledge including lens properties, imaging sensors properties and incorporated camera controls including image processing algorithms.

Application of the zoom lenses in the long range imaging systems is convenient for search and track task over all ranges but diffraction effects at high zoom degrades imaging sensor resolution. Image blurring is inherent to high magnification imaging systems due to lower contrast and high level of diffraction and atmospheric influences. Initial zoom lens set up can help but problem could be solved only by additional image processing algorithm application.

Motorized and controllable zoom lenses together with digital image allow wide range of computer application for application of digital controlled calibration procedures contributing to image quality/sharpness improvements. Camera focusing parameter set-up using hyper-focal distance is calibration process.

The application of the hyper-focal distance concept for camera initial set up provides faster and more comfort operation, but could not contribute alone to image quality/sharpness improvement.

Digital image quality and sharpness depends on lot of factors and could be improved by application of the de-blurring algorithms using the knowledge about physical process causing image blur.

Acknowledgment

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