# Reliability Evaluation of Multi-Camera Motion Detector by using Monte-Carlo Simulator

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Abstract. Motion Detectors (MD) utilizing one digital camera, are well-known and widely used for detection of physical objects intrusion into protected zone. However, one-camera MD operation is limited to the protection of 2D region of fixed size, which significantly limit practical usage of MD of this kind. Stereo Motion Detectors (SMD utilizing two video cameras, can detect physical violation of the user specified 3D volume, but, as it was shown by earlier research, two-camera setup has low reliability for some motion paths, which lower total SMD reliability. In this research reliability of Multi-Camera Motion Detector (MCMD was evaluated by using Monte-Carlo software simulator (implemented by using MAPLE script). Reliability of a number of practically interested setups was analyzed.

Keywords: Image Processing, 3D Imaging, Stereo Camera, Motion Detector, Monte-Carlo simulation, MAPLE

## 1 Introduction

Motion Detectors (MD) utilizing one digital camera, are well-known and widely used for detection of physical objects intrusion into protected zone [1]. For most MD any significant change in the content of the frame grabbed by digital camera is treated as “security violation event”. This means that MD operation is limited to the protection of 2D region of fixed size, which significantly limits practical usage of MD. Stereo Motion Detectors (SMD) utilizing two video cameras, can detect physical violation of the user specified 3D volume [2,3], but, as it was shown by earlier research, two-camera setup has low reliability for some motion paths, which lower total SMD reliability [4]. Constantly dropping prices on high-resolution digital cameras makes implementation of Multi-Camera Motion Detector (MCMD) practical, at least for the case of 3 or 4 digital cameras [5]. It seems obvious that increase in the number of cameras increases MCMD reliability, however, not every multi-camera setup is practically feasible because of camera(s) calibration need. Operation of SMD and MCMD in most cases requires some kind of calibration, which, in some cases, is problematic in the real-life conditions. Hence, it would be preferable to utilize setups that can be aligned during assembly, thus, effectively eliminating need for "after-assembly" calibration. In order to evaluate accuracy and reliability of the selected "aligned" MCMD setup, software simulator was designed and implemented by using MAPLE.

## 2 SMD and MCMD Exemplary Setups

Simple exemplary scene selected for this research is shown on Fig. 1. “Gold Ring” is the object to be protected. No “alarm” must be raised when visitors are moving in the vicinity of the “Glass barrier”. “Alarm” must be raised only if the physical object (say, hand of the visitor) is moving through the plane of the “Glass Barrier”.

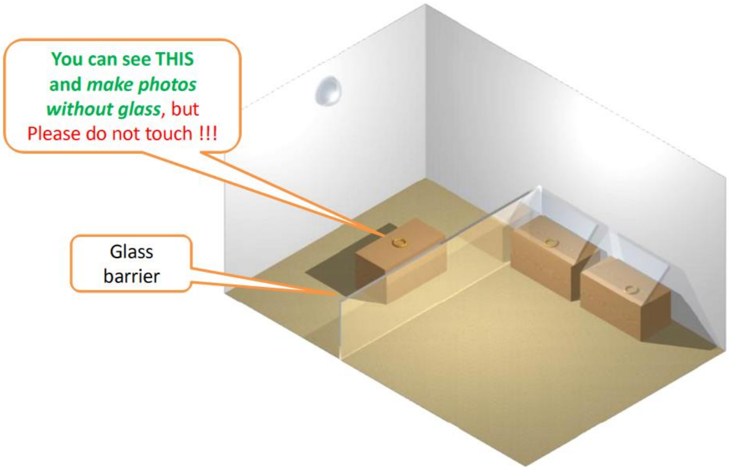


**Fig. 1.** Exemplary scene.

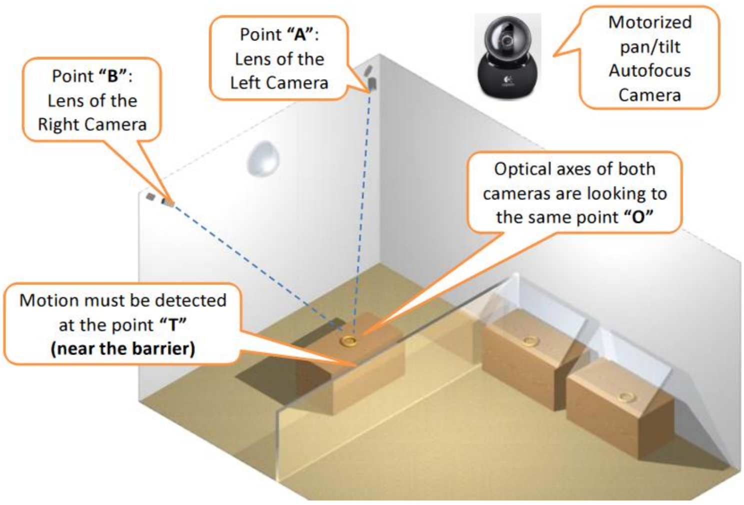


**Fig. 2.** Exemplary two-camera (SMD) Configuration

On the Fig. 2 exemplary two-camera (stereo) SMD setup is presented. This setup was analyzed in the previous work [3, 4]. Important that main optical axes of both cameras pass point “O” (origin) selected by operator during alignment step. This alignment can be easily achieved with adequate accuracy by using motorized cameras (as shown in Fig. 2).
Fig. 3 presents geometry of SMD setup in the XY plane (created by points {“A”, “B”, “O”}). From this figure relations between physical coordinates {X,Y} of the exemplary point “T” and columns of the image of the point “T” on the sensors of the Left and Right cameras {ColR, ColR} can be derived (Fig.4). Camera parameters {W, FL, FR, ps} are known from camera specifications. In the frames of “Alignment Instead of Calibration” approach, geometric distances of the setup (like AC, BC) are not measured, but assumed as known with some tolerance.

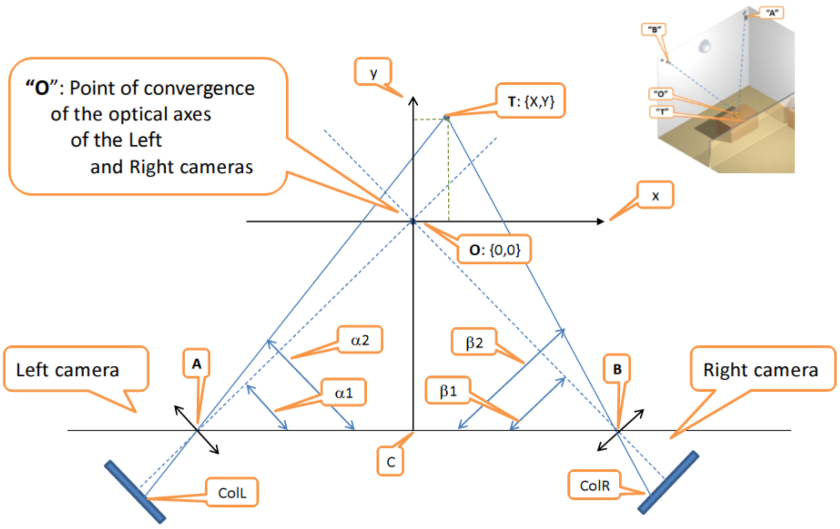


**Fig.3.** Two-camera Setup Geometry (XY Plane)

$$Equ1 := \frac{\frac{OC+Y}{AC+X} - \frac{OC}{AC}}{1 + \frac{(OC+Y)\,OC}{(AC+X)\,AC}} = \frac{\left(ColL - \frac{1}{2}\,W\right) ps}{FL}$$

$$Equ2 := \frac{\frac{OC+Y}{BC-X} - \frac{OC}{BC}}{1 + \frac{(OC+Y)\,OC}{(BC-X)\,BC}} = \frac{\left(\frac{1}{2}\,W - ColR\right) ps}{FR}$$

**Fig.4.** Equations {X,Y} ←→ {ColL, ColR}

Geometry of the setup in the Z plane and relevant equations are trivial (standard lens equations) and thus not shown here.
By using equations presented on the Fig. 4 and equations for the Z plane, we can evaluate physical coordinates of the exemplary point “T” {X,Y,Z} by row and columns of the image of this point on the sensors of both cameras {RowL, ColL} and {RowR, ColR}.
When point “T” is moving, {RowL, ColL} and {RowR, ColR} are changing, and thus, we can detect if motion in the user specified region was happen. However, from the analysis of Fig.2 and Fig. 3 can be seen that if point T is moving in the direction close to the direction optical axis of the (say) Left camera, changes of {RowL, ColL} and very small. In this case, 3D motion detection become non-reliable: actually, 3D two-camera setup operates as 2D one-camera setup.
In attempt to eliminate the problem of this directional sensitivity, three-camera MCMD setup (see Fig. 5) was tested. It is clear, that three cameras operates like three SMD: SMD#1 (Left and Right Cameras), SMD#2 (Left and Central Cameras), SMD#3 (Central and Right Cameras). In this situation, motion in the direction of the optical axis of (say) Left camera makes operation of the SMD#1 and SMD#2 non-reliable, but SMD#3 operates in the reliable way. So, in case one of tree SMD raises “alarm”, violation is considered as detected.
In order to validate this statement for the selected scene and for the selected setup in the quantitative manner, Monte-Carlo software simulation was executed.

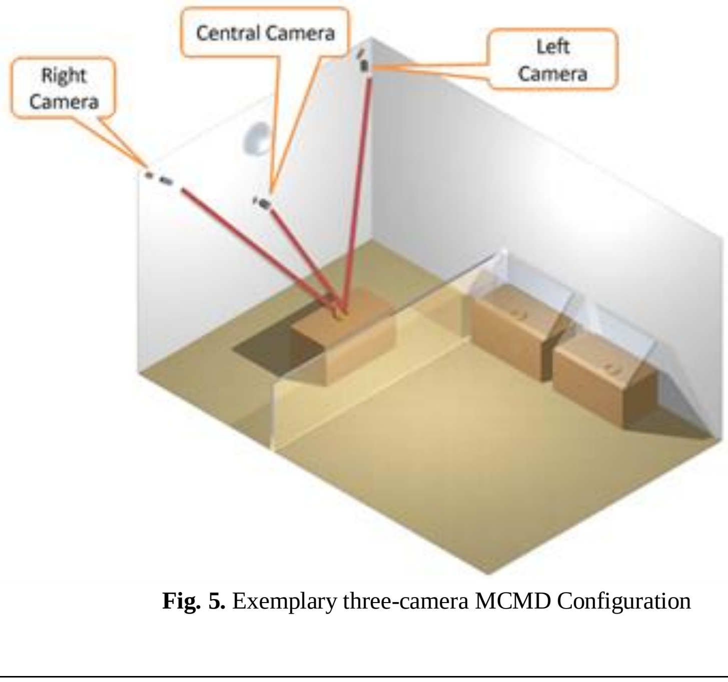


**Fig. 5.** Exemplary three-camera MCMD Configuration

## 3 Monte-Carlo Simulation Procedure

In order to evaluate the feasibility of the selected “Alignment Instead of Calibration” approach, for the MCMD configuration in test, MAPLE-based software simulations were performed. On the first stage, developed simulator calculates series of digital images of the objects of the scene including “violating object” for all three cameras. By using calculated coordinates of the “violating object” in accordance with selected “violation path”, pseudo-video of the violation is generated for all three cameras as a sequence of digital images (frames) in accordance with equations presented on Fig. 4. The simplest one-camera motion detector detects motion of the “violating object” by processing images created as pixel-by-pixel differences of the consequent frames. In case no changes in the scene happened, difference image is “black”. Practically, camera noise is present. This noise is one of the factors leading to lower reliability of the camera-based motion detector [1].
On the next step, positions of “non-black” regions of two cameras images are used to evaluate {row-column} pairs and their correspondent {X, Y, Z} coordinates. In case any of {X, Y, Z} is inside the user defined protection zone, “alarm” must be raised. Simulator takes into account camera' parameters and noise, effect of digitization and assembly errors of MCMD setup. Well-known mathematical models of different 3D setups cannot be used directly to evaluate accuracy and reliability of MCMD, because a number of parameters cannot be measured exactly for non-calibrated setup. Thus, classical Monte-Carlo approach was used to evaluate accuracy and reliability of the MCMD configuration in test. Simulator is operated a number of times, while, for every simulation run, values of the selected set of setup parameters are modified in a pseudo-random way. User can select parameters and assembly tolerances of the selected MCMD setup, geometry of 3D volume to be protected, intrusion object size and its motion path. As stated before, first unit of this simulator generates plurality of digital images in the situation when 3D object of specified size and shape is moving over specified 3D path. First unit utilizes a pseudo-random set of parameters – emulating assembly errors. “Restoration” is executed by operating the second simulator unit using “exact” setup parameters – as if assembly was ideal. This organization enables to estimate as accuracy as reliability of the “Alignment Instead of Calibration” approach. Simulation results in evaluation of the "true positive", "true negative", "false positive" and "false negative" of the selected setup. Additionally, results of simulations can be organized as a set of 2D and 3D plots enabling to recommend customer-tailored MCMD configuration for the specified volume to be protected.

## 4. Simulation Results

It is clear that absence of calibration leads to “Fast Positive Error”: protected volume was not violated, but “alarm” was raised. One of the goals of the Monte-Carlo simulator was to evaluate “False Positive Rate” (FPR). In the following example FPR was evaluated for the distances AC, BC, OC 5m with 2% tolerance (10 cm assembly error). Camera with 10 mm (10% tolerance) lens having VGA resolution was used. Error in point “O” alignment was set as 10 pixels; error of motion detector was set to 10 pixels. Simulator was operated 5000 runs. In case “dangerous zone margin” was set to 1cm, FPR value was 0.42 (that is in 2088 of 5000 cases motion detector generated false “alarm” – which is unacceptable). However, for the “dangerous zone margin” 10 cm, FPR was 0 (for all 5000 runs result was correct). For the specific example (see exemplary scene of Fig. 1) 10 cm accuracy can be considered as more than adequate.

## Conclusions

Monte-Carlo simulator enables to evaluate accuracy and reliability of the three-camera MCMD, thus, eliminating the need for the tedious field tests. Accuracy and reliability of the three-camera MCMD in the selected exemplary configuration was estimated as adequate for the exemplary practical scene presented at Fig. 1. Usage of modern high-resolution cameras will additionally increase accuracy and reliability of MCMD.

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