

Optimizing the Video Recording Settings to Improve Accuracy of Joint Angle Measurements in Gait Analysis Study

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Abstract

Human kinematic analysis remains one of the most challenging tasks for the researchers. In a typical gait analysis study, measurement of various joint angles is carried out with the help of markers attached to the human body. The human activity is captured by a video camera and the video is then analyzed using appropriate software. Locating the markers manually in each frame is cumbersome and may give erroneous results. The problems like, motion blur, scattering, marker occlusion, marker reflection, etc., are also prevalent. The video recording settings play an important role in deciding the marker location precisely. In the present study, the effects of input parameters such as frame rate and shutter speed, on the pixel area of the LED marker were investigated using the Response Surface Methodology (RSM). It has been observed that higher shutter speed time has a negative effect on pixel area of the LED marker and on the area of the bounding box. The experimentation using RSM showed that shutter speed time of 2300 μ sec and frame rate of 60 Frame Per Second (FPS) are required to produce pixel area of bounding box of desired quality.

Keywords

Human kinematic analysis, Active marker, Frame rate, Shutter speed, Object detection.

1. Introduction

Gait analysis is a critical technique for measuring human movement patterns in order to acquire a better understanding of a number of health-related issues, gait recognition, pathological gait, etc. Spatiotemporal gait parameters obtained by gait analysis have clinical and biomechanical research applications. While human kinematic analysis (HKA) is a common biomechanics research topic, numerous approaches for evaluating gait parameters have been developed over the years. Edward Muybridge, a well-known landscape photographer of America, developed the first photographic technique for measurement. He took a bunch of pictures of horse trotting and later proved that there are times when all of horse's limbs are in the air at the same time. Marey refined the process and developed the world's first cine camera (Baker 2007). A method suited to study of gait is described in which the person movements is captured from front and side, with the help of camera. Triangulation techniques are used in obtaining measurements from the captured video. Video captured is then digitize, first technique of digitization found out by (Sutherland and Hagy 1972).

There are many factors, including ambient conditions, that create undesirable effects such as motion blur, scattering, etc., in video recording. Aside from wireless sensors that monitor spatial-temporal parameters or orientation, video recording is a technology that is often used in research and development. A video recording enables for the examination of the same activity by many researchers at different times, as well as the inspection of video at different speeds and settings to show movements that are too quick for the human eye to detect with its normal vision (Egnor and Branson 2016). A new algorithm to calculate gait spatiotemporal parameters by tracking estimated joint locations is presented by (Zhu et al., 2022). A "mobile Video Enhanced Gait Analysis System" (mVEGAS) based on combination of body-fixed inertial sensors and a smartphone camera mounted on the trunk was presented by (Ippisch et al., 2022). The researchers describe the gait analysis device's hardware and software components and its analysis processes for evaluating spatiotemporal gait metrics.

However, despite significant advancements in video-based HKA, the accuracy of the technique remains undetermined. A variety of elements, such as camera configuration, camera resolution, illumination, walking speed, occlusion and background, among others, influence accuracy (Noldus et al., 2002).

In this article, we addressed the most important issues concerned with the use of video recordings to study errors and provide some basic guidelines. The primary goal of this experimental research is to explore the video settings to get better image of the LED marker so that the markers can be automatically tracked. A typical process of identifying the joint angles from a recorded video is cumbersome and time consuming since the markers' positions are to be selected manually, frame by frame. On the other hand, the Python algorithm such as one adopted in the present study, automatically tracks the LED markers; however, needs the video of specific quality. An appropriate video camera settings need be selected while capturing a video to get a sharp image of each markers affixed to body.

This paper consists of six sections. Section 2. provides a brief review of video-based gait analysis techniques. Section 3 deals with experimental setup and design. A comparison between the Python Coding based and other software-based methods is presented in Sec. 4. The section also explores the effect of shutter speeds and frame rates on the marker detection. Section 5 focuses on the results and discussion. Conclusion is provided in Section 6.

2. Literature Review

Video analysis, as applied in HKA, can be classified into two types: qualitative and quantitative. The qualitative analysis of sporting activities is the most basic and straightforward method of evaluation, because it is based on the criteria set by the observer. Since it is impossible to obtain absolute measurements from qualitative video analysis, it can be used to review performed motions that are too fast for the human eye to perceive or that are too complex to be observed at a single glance. For example, using qualitative video analysis techniques such as slow motion or stop-action viewing, an athlete can learn about proper technique in a relatively short time and improve their ability (Garhammer and Newton, 2013). The goal of quantitative motion analysis of sport and exercise activities performed using video recordings is to conduct a detailed analysis of the subject's movement patterns in order to reduce the risk of injury to the subject (Bartlett et al., 2007). The fact that video cameras capture sequential two-dimensional images of movement at specific time intervals depending on the camera's speed, quantitative analysis can be two-dimensional (2D) or three-dimensional (3D) depending on the situation (Payton and Burden, 2008). Ergonomist, medical practitioners, sport scientists & coaches could really benefit from quantitative 2D video analysis in a variety of ways. Computers can be extremely powerful, with video capturing and processing capabilities. Overall, video analysis has made it possible for many people with little or no technical knowledge to conduct an investigation using cameras and video processing. It is possible to use computers to measure the location of points on an image such as body segments frame by frame and convert the measurements to digits, a process known as digitization. Digitizing software packages can calculate motion paths and kinematic information by combining data from horizontal and vertical coordinates at known time intervals or frames per second, and then displaying the results (linear, angular position, velocity and acceleration) (Garhammer and Newton, 2013). The bottom line is that today, high-quality video, computer equipment, and 2D video digitizing software are all readily available at a reasonable price. Even open-source software (such as, Kinovea) can be used for this purpose, and it is completely free (Balsalobre-Fernandez et al., 2014). Additional features include the ability to conduct video analysis with minimal interference to the performer, not only in controlled laboratories, but also outdoors or during real competitions.

3. Methods

3.1. Participant

We conducted the experiments with a single male participant (27 years old, height 162 cm, weight 57.5 kg, BMI 23.2 kg/m²), who continued to serve throughout experiments. The activities, such as walking, jogging, and running on an RMS VEGA 201 treadmill, were performed to capture and study the motion involved systematically. The participant did not suffer from a chronic musculoskeletal disorder and was able to complete the task with relative ease.

3.2. Experimental Setup

All of the experiments were carried out in a laboratory with mixed lighting (ambient plus artificial) of average 253 lumen. For all the activities, the computerized treadmill at different speeds was used. The speeds for normal walking, jogging, and running were set at 1.12 m/s, 1.56 m/s, and 2 m/s respectively. The recording is carried out with a FASTEC HS7-HM08 camera equipped with an MH9X sensor. The camera was placed perpendicular to the treadmill at a distance of approximately 2040 mm and at a height of 700 mm from the ground, with the lens pointing in the perpendicular direction of the treadmill (Figure 1.). A two-sided tape is used to attach the LED markers to the strap, and the strap is then attached to clothing of the participant. The markers are attached approximately at the joint positions for (hip joint, knee joint and ankle joint). Further two more markers are attached on lower extremity one is at abdomen and other is at foot. For each joint, ankle joint, a standard for local axis system is followed which is used to locate the joint positions. These axes then standardize the joint coordinate

system, guidelines provided by (Wu et al. 2002). The location of the joints is indicated by LED markers in a video footage.

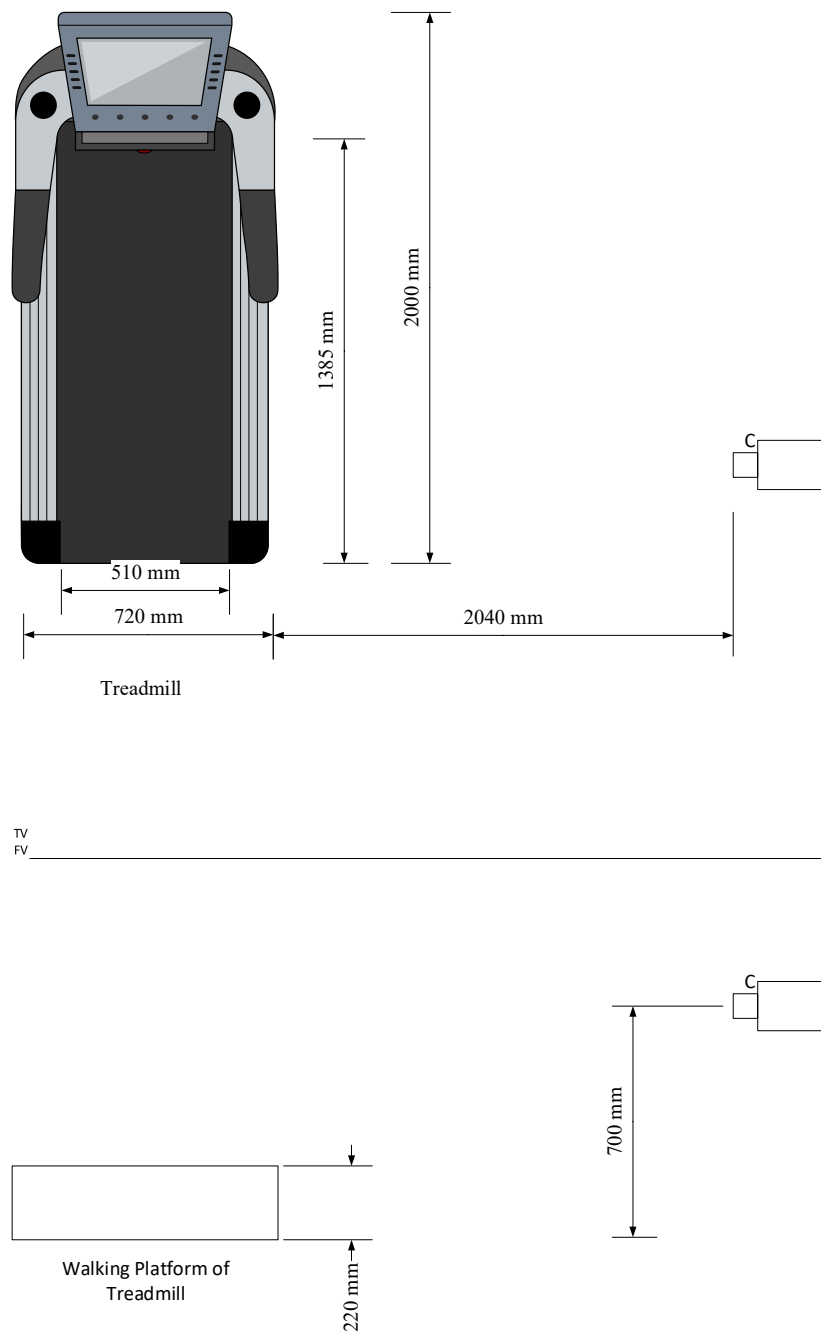


Figure 1. Schematic Representation of the experimental setup, Note: C=FASTEC HS7 camera

3.3. Experimental Design and Procedure

There are two input factors that have been taken into consideration, viz. frame rate (FPS) and shutter speed (μsec) of the camera. The frame rate is divided into six levels: 30 FPS, 50 FPS, 100 FPS, 300 FPS, 500 FPS and 700 FPS. Beyond 700 FPS the device would become prohibitively expensive and would be unsuitable for the entire experiment as well as the fulfilment of the objective. The shutter speed has seven levels: 1000 μsec , 1200 μsec , 1300 μsec , 1422 μsec , 1994 μsec , 2982 μsec and 7739 μsec . The levels for FPS and shutter speed time were chosen based on the default settings of the camera. The objective of the study was to explore the effects of FPS and shutter speed time on three responses, namely, area of bounding box, total bitrate and number of frames available for right leg swing phase, i.e., from toe lift to heel strike. Response surface methodology (RSM) with randomized custom optimal design was adopted to understand the effect of the two factors on the three responses.

Since the input factors (frame rate and shutter speed) have different levels. Frame rate has six levels and shutter speed has seven levels. The optimization was carried out using the software DESIGN EXPERT (V 11.0).

4. Data Analysis

4.1. Time study of video analysis

The recorded videos, using different settings of FPS & shutter speed time, were processed using three methods- (i) specially developed Python code, (ii) Skillspector (V 1.3.2) software, and (iii) Kinovea (V 0.9.5) software. The purpose of video processing was to locate the positions of markers, in each frame, by splitting the video (automatically) into appropriate number of frames. When softwares (i.e., Skillspector & Kinovea) are used, the marker position needed to be manually marked in each frame. However, with the Python code, this task of locating markers in each frame is automatically carried out. We conducted stop watch time study to find the time taken by each of the steps in video processing results of which are shown in Table 1. A single video file of 17 seconds recorded at a total bitrate of 30324 kbps, resolution of 720×480 pixel, FPS = 30 was subjected to analysis. The average time of 10 trials for each step was considered for the comparison. It is clear that the python code can process the video in 22% of the time taken by Skillspector and Kinovea.

Table 1. Video processing time study

S.No.	Step in Video Processing	Observed Time (minutes:seconds:milliseconds)		
		Python Coding	SkillSpector	Kinovea
1.	Opening of the software and initial setup	00:26:46	00:18:74	00:03:26
2.	Initial procedures before loading video file	12:59:67	01:36:07	00:41:09
3.	Video file loading time	00:05:59	00:05:00	00:04:95
4.	Marking LED markers	00:01:00	55:33:48	55:38:52
5.	Calibration of video	NA	00:34:19	NA
6.	Final analysis output window	00:02:05	00:16:79	00:06:79
7.	Final results obtained (position of knee in direction of Y)	NA	00:11:90	00:02:90
	Total	13:28:00	58:27:00	57:58:25

4.2. Analysis of different shutter speed times for same settings of frame rate

Primary objective is to detect and track the LED marker, which is attached to the ankle joint and foot. In a video file object detection and tracking is done with the help of Python coding with OpenCV libraries. More focus is given to the ankle LED marker and foot LED marker, as in swing phase there are chances of motion blur. The primary goal is to clearly see the ankle and foot joint LED marker, which will be used for further analysis of joint angle parameters as well as estimation of various gait parameters after that. High shutter speed time cause motion blur phenomenon to occur, which results in errors in the calculation of HKA. Walking speed is maintained at 1.12 m/sec. At the same frame rate, three different shutter speed time are employed.

All the markers in the region of interest must appear against a black background in order for them to be visible. Furthermore, because the ankle and foot markers move so quickly, motion blur occurs, causing marker detection and tracking to become erratic at certain points. Motion blur causes marker detection to occur more than once at a single instant of time (Figure 2), resulting in multiple instances of marker detection. As a result, inaccuracies in the final calculation occur. Besides this, there is reflection of markers on the ground (Figure 3), which results in the detection of another marker, which is a false detection.



Figure 2. Multiple marker detection



Figure 3. Reflection of marker

Reducing the shutter speed time value in Fastec HS7 camera to less than 33327 μsec (Table 2) gives corresponding bounding box area in (pixel). The reflection of the marker on the surface of treadmill continues to be a problem. However, overall accuracy has enhanced. Because the motion blur effect is minimal, and multiple object detection is almost non-existent. Different shutter speed time at mid swing of the right foot shows different results (Figure 4, Figure 5 and Figure 6)

Table 2. Bounding box area for different shutter speed: FPS=30

Shutter Speed time (μsec)	Bounding Box area (pixel)
33327	64
20000	32
7739	16

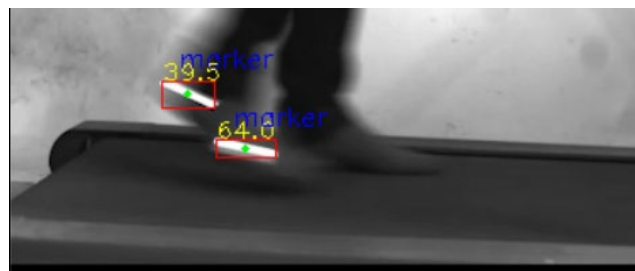


Figure 4. Bounding box size at 33327 μsec



Figure 5. Bounding box size at 20000 μsec

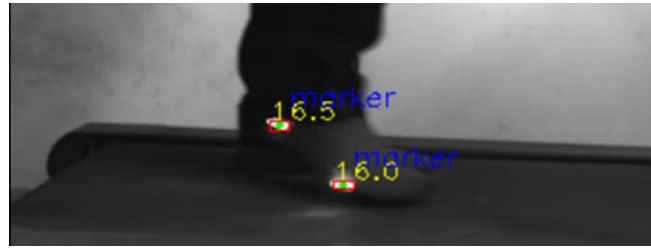


Figure 6. Bounding box size at 7739 μ sec

4.3. Analysis of different frame rate for same settings of shutter speed time

Analysis of videos in Python coding, videos captured at the same shutter speed time (7739 μ sec) but at different frame rates, such as 30 FPS, 50 FPS, and 100 FPS. There is little difference between the results of this video analysis on Python coding. All of the errors are the same as they were in the 30 FPS recording with 7739 microseconds. The reflection of the marker on the ground floor continues to be an error. The only advantage of a high frame rate is that there are now a greater number of frames available for viewing at the same time. As a result, more accurate results are obtained in the calculation process. The number of frames has been calculated and it is shown in Table 3. The number of frames or the number of images has been increased as the level of the frame rate is increased (Figure 7, Figure 8 and Figure 9). For the purpose of calculating the ankle joint angle or the knee joint angle, we now have 36 to 38 multiple images of the right leg in the swing phase, as opposed to 11 to 12 images previously available. An increase in the number of images increases the accuracy (Yao et al. 2021). It has been concluded that for more accurate results, a lower shutter speed time and a higher frame rate are required. The problem of motion blur and marker reflection does not get any better by increasing the number of frames.

Table 3. Comparison of different properties

Properties	Video file -3	Video file -4	Video file-5
Video recorded at frame rate (FPS)	30	50	100
Video file recording time (seconds)	23	19	43
Total number of frames calculated	700	596	1296
Number of frames calculated for a mid-swing of right leg (approximately)	11 to 12	17 to 18	36 to 38

Table 4. Bounding Box area for different frame rate: Shutter speed time=7739 μ sec

Frame per second (FPS)	Bounding Box area (pixel)
30	16
50	22
100	36.5



Figure 7. Bounding box size at 30 FPS

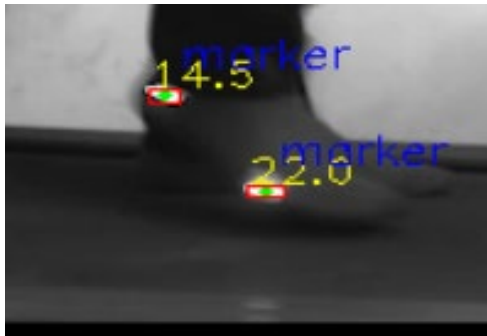


Figure 8. Bounding box size at 50 FPS



Figure 9. Bounding box size at 100 FPS

4.4. Data Processing and Statistical Analysis

Video files processing in OpenCV: The primary goal is to process video files after they have been loaded into the OpenCV algorithm. It is necessary to recognize the LED markers. The first and most important operation is to make everything as simple as possible by selecting the Region of Interest (ROI). The lower body is the area of interest in this case, and how much movement is there in the lower body throughout the entire frame. Second, we employed threshold operation to detect the presence of LED marker lights (ELHarrouss et al. 2015). This is due to the fact that white LED markers stand out against a dark background. Prior to performing the threshold operation, change the ROI from BGR (Color) to grey. After performing the threshold operation and entering the required value. The primary function of a threshold is to convert a greyscale image or different gradients of a greyscale image to only white and black. Further, while using the OpenCV application to detect objects, contour of each LED marker is observed. Each LED marker is surrounded by boundaries, and the area of each boundary is calculated in pixels.

Linear regression analysis. As a result, the bounding box area is in the middle of the swing phase of the foot LED marker. Because the foot marker in the middle of the swing is distorted the majority of the time, errors such as motion blur, scattering, and reflection occur only in that region. As illustrated in Table 2, it can be seen that the values obtained with different shutter speeds are calculated. With the help of linear regression, the values of different bounding box area at different shutter speed time as well as frame rate, are estimated (Table 5). All

values are calculated for different frame rate 30FPS, 50 FPS, 100 FPS, 300 FPS, 500 FPS, and 700 FPS. In order to obtain the values from linear regression, at least three values must be known. After obtaining all of the possible combinations, a table is created, and the responses values are entered into it.

Table 5. Predicted value by linear regression

Predicted value of bounding box area by linear regression for different frame rates							
S.no.	Shutter Speed time value	FPS=30	FPS=50	FPS=100	FPS=300	FPS=500	FPS=700
1.	1000	0.8781	3.5577	4.4954	15.2522	17.784	17.495
2.	1200	1.2548	4.110	5.453	17.6759	21.8723	21.9009
3.	1300	1.4431	4.3861	5.9318	18.8877	23.9164	24.1038
4.	1422	1.6729	4.723	6.5759	20.3662	26.4103	26.7914
5.	1994	2.7503	5.500	8	18	28	30
6.	2982	4.6111	10	15.5	50.5	70.5	72.5
7.	7739	16	22	36.5	94.9872	153.440	164

5. Results and Discussion

5.1. Analysis of each response

Bounding Box Area: According to Design Expert V11.0 software, analysis of variance is performed after selecting the suitable model terms. ANOVA test is performed on individual terms as well as to test the whole model. The interaction plot (Figure 10) clearly demonstrates that the upper red color line (shutter speed time 7739 μ s) represents the upper limit of bounding box area, beyond which no values are present, and the lower black color line represents the graph's lower limit boundary (shutter speed time 1000 μ s). The middle green dots represent the mid values of (shutter speed time 2982 μ s). It can be observed that, for the same value of frame rate, the bounding box area increases as the shutter speed time value is increased. The fluctuations of input factors on the bounding box are depicted by a single factor plot (Figure 11.). Even though we are using the same shutter speed duration (7739 μ s), the bounding box area increases with increase in frame rate value.

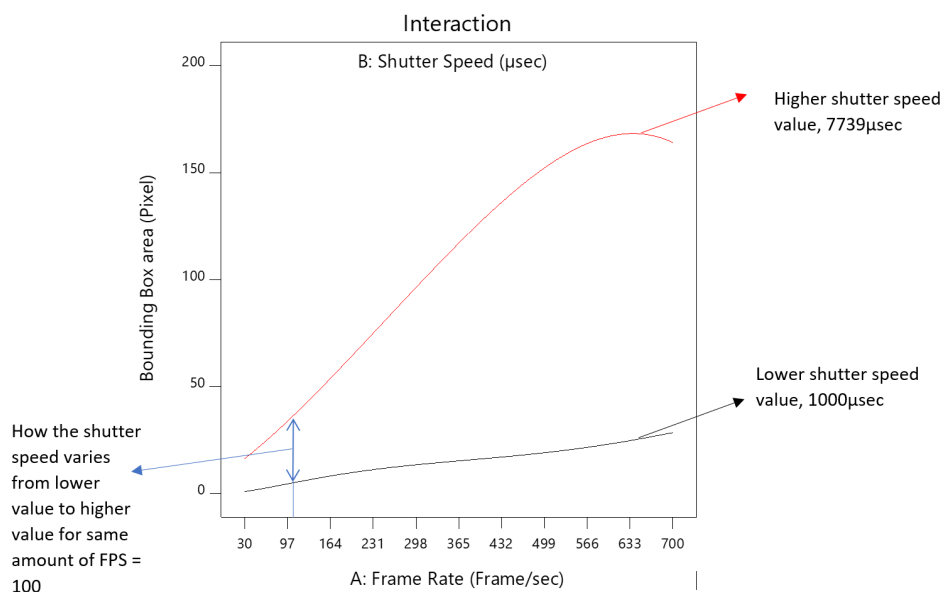


Figure 10. Interaction plot for frame rate and shutter speed

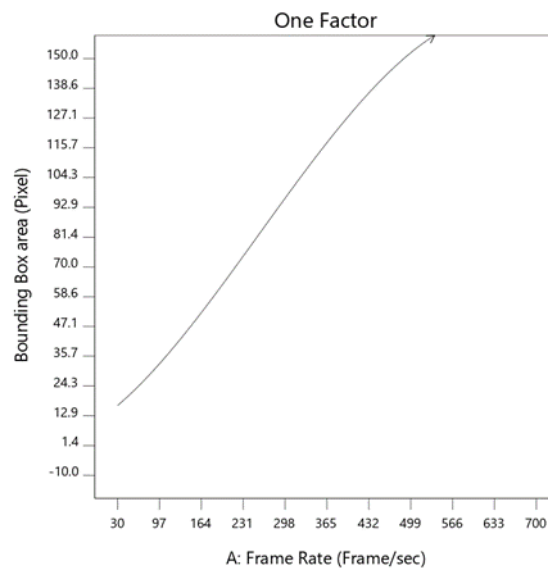


Figure 11. One factor plot for frame rate

Number of frames available for one gait cycle: As evident in Table 4, with the increase in frame rate (FPS) number of frames for right leg swing phase increases. With a greater number of frames, a more complete and comprehensive gait description can be obtained. As can be seen in Figure 12, the number of frames in a single gait cycle varies linearly with frame rate.

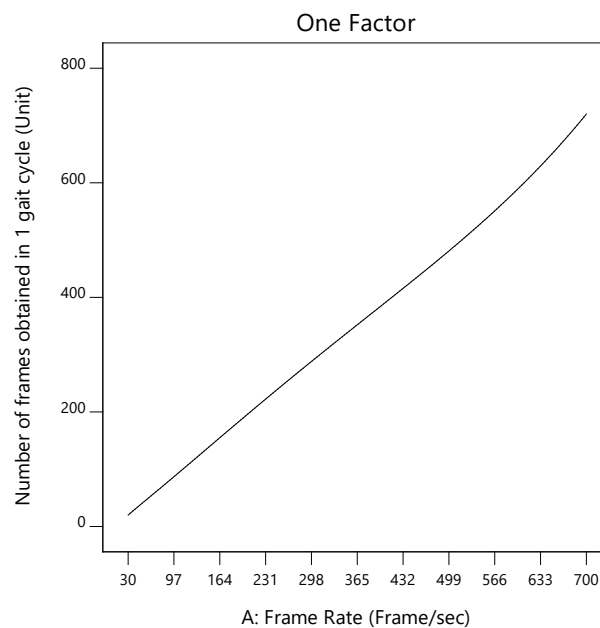


Figure 12. One factor plot of Frame Rate

Total Bitrate: Third response also suggested quartic model in fit summary. Higher order polynomial is selected. ANOVA is performed after selecting suitable model terms. Total bitrate shows the decreasing effect, (Figure 13) with increase in frame rate (FPS). However, the decrement is not linear but follow a higher degree polynomial.

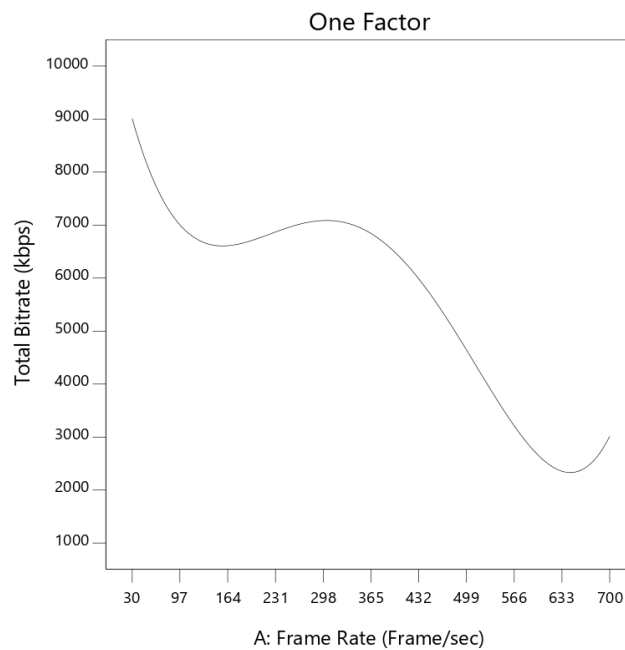


Figure 13. One factor plot for frame rate

5.2. Numerical Optimization

After ANOVA of each response, bounding box area, Number of frames available for one gait cycle and total bitrate individually. Now combined effect of all responses is studied. Optimization of one response i.e., bounding box area. The numerical optimization is the process of determining the best available values from the given input values. Entering the value in the range of lower limit and upper limit. Final output is in the form of ramp graphs in which optimal factor settings is shown. (Figure 14.). Dots in the ramp graph shows the input and the output factor. All the ramps represent the higher and lower values of factors and responses. The peak ramp shows the targeted value of the response. Ramp graph which is upward, shows maximizing the results and graph which is slanting in downward position shows minimizing the results.

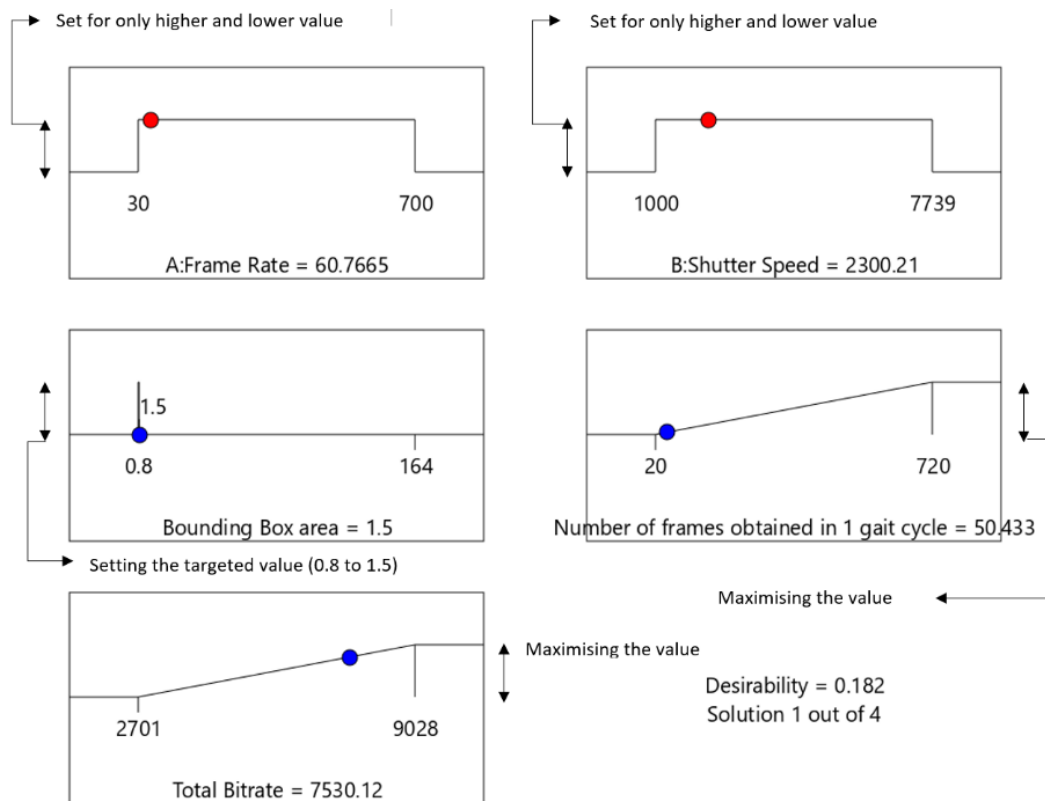


Figure 14. Numerical Optimization of bounding box area

6. Conclusion

The effects of motion blur, dispersion, and reflection of the LED marker on the overall accuracy of object detection in video footage are all significant. In this experiment, it was discovered that by using lower shutter speed time settings, the sharp LED object in a video frame is produced. Furthermore, as the frame rate value is increased, the bounding box area increases as well. The number of frames grows in proportion to the increase in the value of the frame rate. Finally, the optimal value of the input parameters is established, which results in a sharp image of the LED marker as well as the optimal conditions in which the LED marker image can operate.

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