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Selected methods for quality improvement of images and video sequences

Summary

The article attempts to present the methods and opportunities to improve the quality of images and video footages. Three main groups of methods used for this purpose were described, i.e. geometric transformations, point transformations and filtering. In order to present the capabilities and limitations of various research methods, the author applied them in a number of experiments, involving the use of digital materials (photographs and video sequences), prepared under the conditions resembling as nearly as possible actual casework. The digital files were registered with the use of three recording devices: mobile phone, digital camcorder and a professional camera. Research methods tested during the study have contributed to minimizing the noise in the registered materials, which led, inter alia, to the successful reading of the vehicle's license plate numbers. Based on the experiments carried out, three main groups of factors having an impact on improving image or video footage quality were indicated, including technical parameters of the test material and recording device as well as the human factor.

Keywords video, image, compression, resolution, methods for improvement of video recording quality, digital signal processing

1. Introduction

With the rise in popularity of registering events through photographic cameras or camcorders, e.g. the streets of cities, business and family meetings, it occurs that also legally prohibited acts can be accidentally registered, such as: theft, burglaries, robberies, etc. The recorded materials may be distorted, which can significantly impede the proper interpretation of recorded data. This results in an increase in demand of law enforcement authorities for actions aimed at improving the quality of such recordings.

Due to the diversity of interferences, a multitude of recording devices, file formats, compression levels or optical tracking qualities, there is no one universal method that allows increasing the readability of the registered materials. The devices used for data recording include extremely popular smartphones, usually with two or even three digital cameras, digital cameras, various types of camcorders and CCTV (Closed Circuit Television) video surveillance systems [7]. For these reasons, each case should be interpreted individually, including the adaptation of the specific solution. Practice shows that the vast majority of the material has been created and saved in digital technology. However, one should not forget an analogue recording, for example, on VHS (Video Home System), tapes which may continue to be submitted for analyses [6]. Procedures for improving such materials after digitization do not differ significantly from the methods used to analyze materials originally created with the use of digital techniques.

This article attempts to present modern digital methods of improving the quality of images and video sequences. It discusses a range of typical interferences that impede the proper interpretation of the recording (such as blurs, perspective errors, recordings made under insufficient lighting conditions – an error quite frequently encountered in photographs or video recordings), along with the technical possibilities of their correction.

The author interchangeably uses the terms "photograph" and "digital image", and "video sequence" and "video recording", in relation to the video footage.

2. Digital image

The digital image is a discrete representation of a natural picture, obtained as a result of the acquisition process.

A scheme of image acquisition from analog form (which constitutes a continuous, two-dimensional function O(x,y) of the distribution of brightness in the spatial coordinates belonging to the domain of the image) to digital form, is shown in the following diagram [3,12].

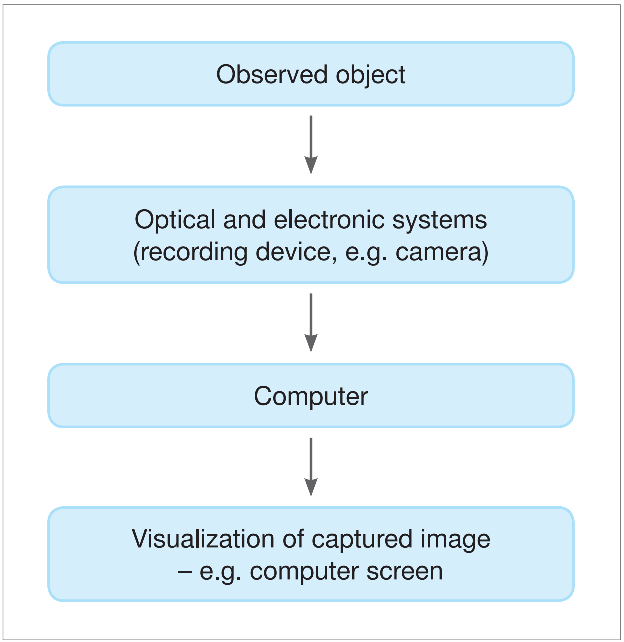

Fig. 1. Visual tracking for image processing into digital form.

An analog image undergoing a transformation as shown in figure 1 is called a digital image, i.e. an object with the spatial coordinates subjected to sampling and with quantized O(x,y) values [1]. The digital image can be seen as a matrix consisting of rows and columns, where the point of intersection identifies the smallest area of the image, that is 1 pixel, according to the following relationship [12]:

$$O_{digital}(x,y) = \begin{bmatrix} O(0,0) & \cdots & O(M-1,0) \\ \vdots & \ddots & \vdots \\ O(0,N-1) & \cdots & O(M-1,N-1) \end{bmatrix}, \quad (1)$$

where M, N are the numbers of columns and rows, M x N determines the total number of pixels (picture element), which corresponds to the image resolution.

The so presented digital image carries certain amount of information, expressed through the spatial resolution, that is, the density of sampling points and resolution of brightness levels (for monochrome image) or by trichromatic resolution (in the case of the acquisition of a color image) [4].

The quality of both static and moving pictures is influenced primarily by the optical properties of the recording device and by preprocessing the test material and saving it to the file. In the first case, a decisive role is played, inter alia, by the quality of the optics, i.e. the ability to best reflect the spectrum of colors, parameters of the matrix (e.g. its resolution), resistance to errors in perspective reflection (spherical aberration) or resistance to chromatic aberration. In the second case, it is primarily a recording format, including the compression level and resolution (pixel x pixel) [5]. In simple terms, the term image compression should be understood as the removal of "redundant" information in such a way that the viewer has the impression that no data have been removed [11]. Certainly, such an impression can be very deceptive, because, with the exception of lossless compression carried out with the use of probabilistic and predictive methods (such as TIFF, RAW), any other recording format causes the loss of details in the image. The most common formats of lossy compression are JPEG (Joint Photographic Experts Group) for still images and MPEG (Moving Pictures Experts Group) for moving pictures [4]. The general principle of operation of a JPEG encoder is shown in figure 2, while an exemplary use of this type of encoding is presented in figure 3.

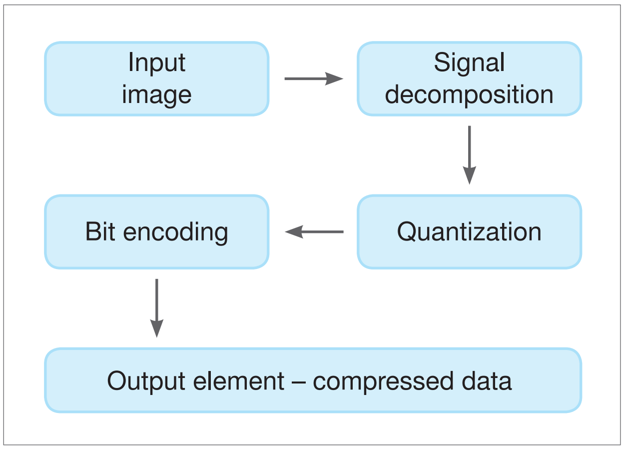

Fig. 2. Principle of operation of a JPEG encoder.

The advantages of lossy compression [3]:

- photograph takes up less disc space;
- enables faster data processing and analysis;
- reduces computer workload.

The disadvantages of lossy compression [3]:

- no possibility to decode the signal to its original (input) form without loss of information;
- partial loss of the image registered by the optical system and, consequently, no possibility of its analysis.

Ideally, the image would be registered at the highest resolution and lowest compression levels, but due to data archiving and storage – related limitations, such a situation is impossible. For example, in the case of image registration (lossless compression) on a standard DVD disc with a capacity of 4.7 GB (assuming 25 frames/sec), about 30 seconds of footage can be

Fig. 3. Exemplary use of JPEG compression a) original image, b) result of lossy compression, quality factor 1 (scale 0-10), recording made in Adobe Photoshop environment.

saved in full HD resolution (1920 x 1080), while using lossy compression, e.g. MPEG, can increase the time of recording to several hours.

3. Selected methods of image processing

The improvement of video quality for forensic purposes focuses, inter alia, on removing noises and improving visibility, for example of the face image, in order to allow performing antroposcopic research, or ensuring the visibility of a given element/object registered on the image (its characteristics, dimensions, etc.) [2]. Another example is the reading of the vehicle license plate numbers or the removal of blurry interferences (error in the recorder's optical system). In order to carry out such actions, the expert applies ready-to-use commercial solutions, including digital filters implemented thereon, or develops own solutions, based on the methods providing for mathematical and statistical description of the operation of digital filters. The basic methods used to improve the quality of digital images include geometric and point transformations as well as digital filtering [10].

3.1. Geometric transformations

A group of geometric transformations is represented, inter alia, by rotations, shifts, stretches, perspective corrections and deformation of the input image, as shown in figure 4. These operations are used as a prelude to the next process of quality improvement of the evidence material [12].

3.2. Point transformations

A point operation is the conversion which attributes a new value to each point of the image, regardless of the neighboring points [4]. Unlike geometric transformation, point operations do not cause any changes in image geometry, but merely modify its parameters, e.g. brightness (to highlight the characteristics of the test object). A very important feature of point operations is their reversibility (assuming the monotonicity of a function). Point operations include: histogram extension and balancing, signal normalization, binarization, creating a negative, gamma correction or image transformations in the field of brightness [9].

Stretching and balancing the histogram is accomplished by increasing the contrast of each group of points on the image and aligning/increasing their brightness levels [2].

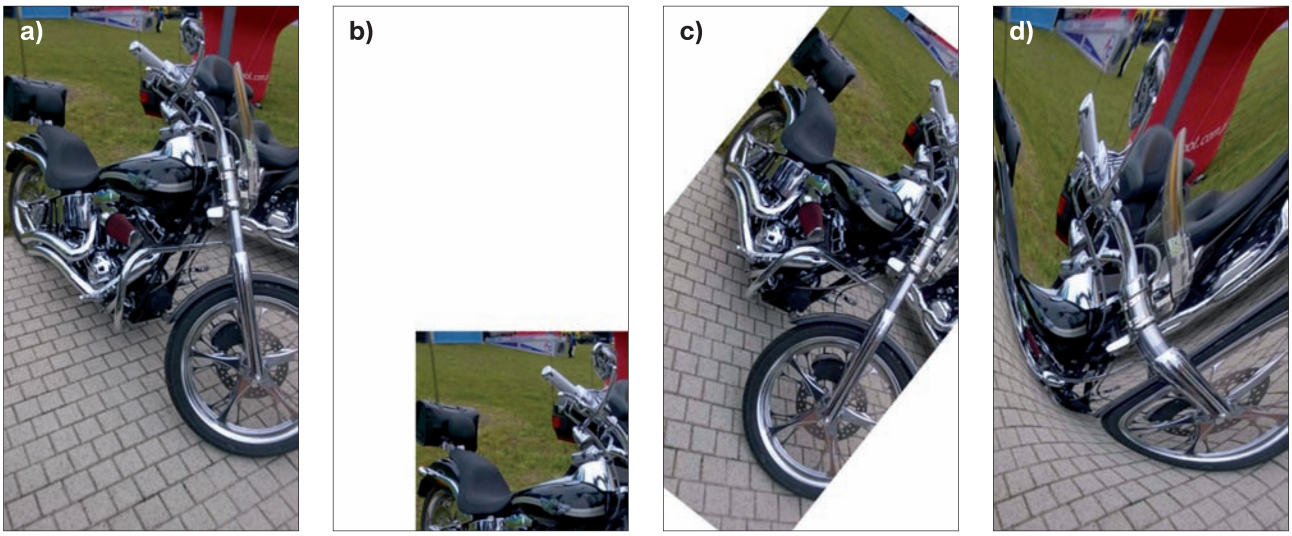

Fig. 4. Exemplary geometric transformations a) original image, b) shift, c) rotation, d) distortion.

Another point operation is binarization, i.e. limitation of the gray levels in the image to 0 or 1 value. This entails a very high reduction of image information, yet allows highlighting its certain features, e.g. contouring [14].

3.3. Digital Filtering

Digital filtering can lead to changes in geometric parameters, modifications of information contained in the image and degradation of the material, but paradoxically, owing to such properties, it is widely used for [7]:

- minimizing a blur effect (e.g. image stabilization or reduction of errors of the type *blur*);
- noise reduction;
- image reconstruction;
- improving images with low contrast;
- highlighting the characteristics invisible to the naked eye.

Digital filtering can be divided into spatial transformations (linear and non-linear contextual filtering) and transformations in the frequency domain, the most common being the removal of blur and motion blur effect [8].

3.3.1. Spatial filtering – contextual transformations

The last method, or more specifically, a group of methods, listed in this article, are contextual operations. These transformations are much more advanced and require expert knowledge and commitment to research – both concerning the above mentioned geometric operations, based on simple shifts, rotations, etc. as well as single-point operations. Context-sensitive filtering consists in determining the new value for a given pixel on the basis of analysis of multiple surrounding pixels (the principle is shown in figure 7) [12]. This type of filtering will not produce the expected results in relation to the edge area of the image, due to the lack of a surrounding environment for these pixels – figure 8.

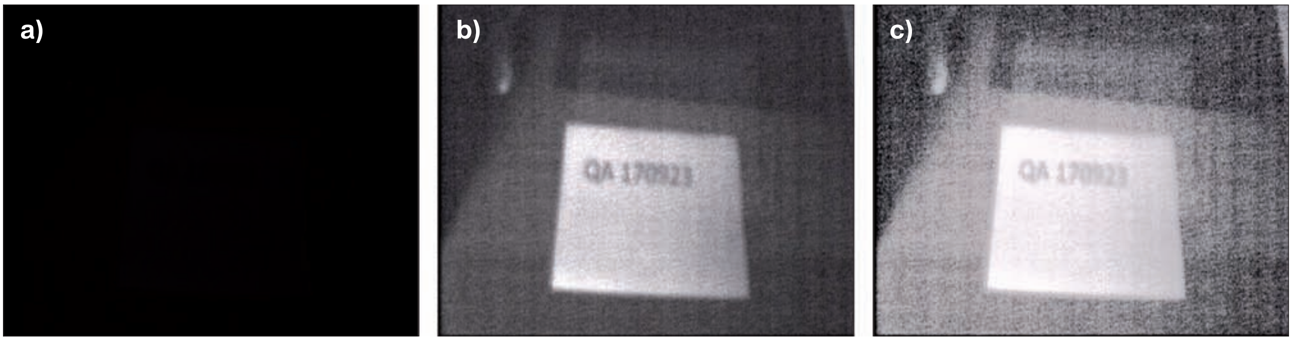

Fig. 5. a) Image captured under insufficient light conditions, b) image undergoing a process of histogram balancing, c) output image after histogram balancing.

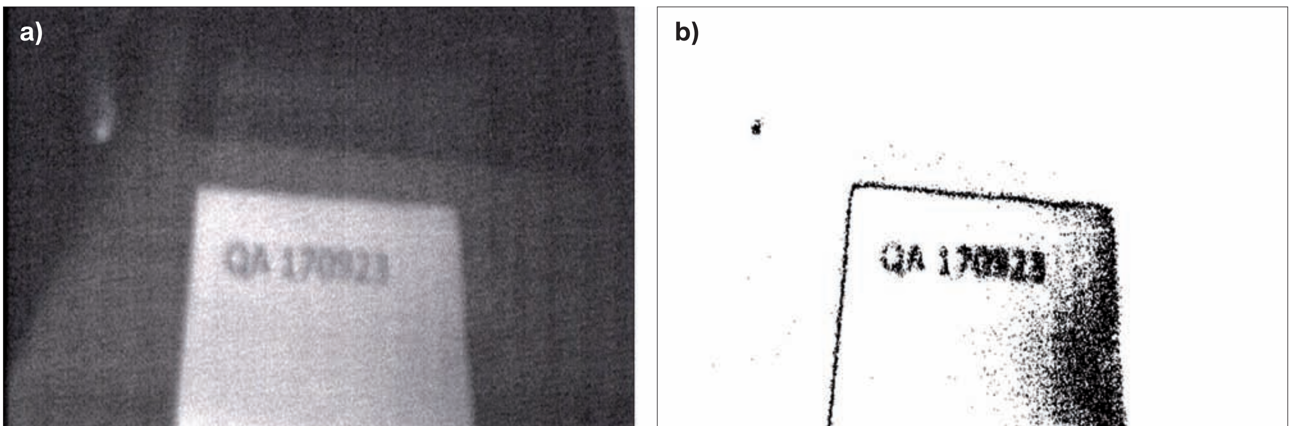

Fig. 6. a) Original image, b) image after binarization with clearly visible contouring.

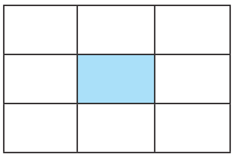

Fig. 7. Principle of calculating the new pixel value based on it surrounding environment.

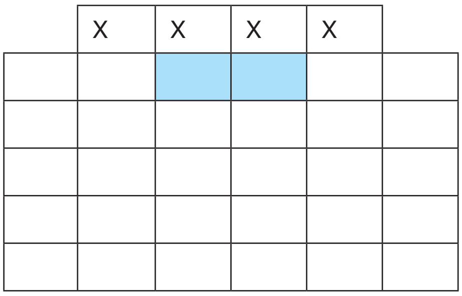

Fig. 8. Inability to perform contextual operation. An „x" denotes the lack of arguments needed for proper performance of the method.

Contextual transformations can be divided into: linear filtering (all pixels processed on the basis of the same function), during which the analysis is carried out in accordance with a linear combination of the input pixels and non-linear filtering where the calculations are based on a non-linear combination [10].

3.3.1.1. Linear Filtering

Contextual filtering is referred to as linear when it meets the condition of additivity and uniformity. Linear spatial filtration can be performed using a combination of functions (convolution) [12]:

$$g(x) = (f \text{ x } h)(x) = \int_{-\infty}^{+\infty} f(x - t)h(t)dt, \quad (2)$$

In order to fulfill the filtering condition (for function h to become a filter) the status must be reached wherein the combination g is defined across the whole set of R values, and the product of f(x – t)h(t) is integrated on the whole set R.

In both of the above cases, linear filtering is divided into low-pass filtering, in which the higher frequency components (e.g. sets of points exhibiting rapid changes in brightness) undergo a reduction, and high-pass filtering, in which the reduction pertains to the lower frequency components [8]. This group of filters includes operations aimed at the detection of the edges as well as the Laplace transform. The result of applying a low-pass filtration in the form of an averaging convolution filter is shown below.

3.3.1.2. Non-linear filtering

The group of non-linear filters includes median filters, used for noise removal from captured images (example shown in figure 10), assigning a new pixel value on the basis of the median (i.e. the midpoint value of the analyzed image area) [1].

Another example of contextual non-linear transformation is adaptive filtration, in which the filter mask changes its parameters depending on the analyzed image area. Adaptive filters work in two stages. During the first stage, the parameter is calculated (e.g. pixel brightness level) that classifies the area concerned along with its edges. During the second stage, averaging filtration is performed (only in

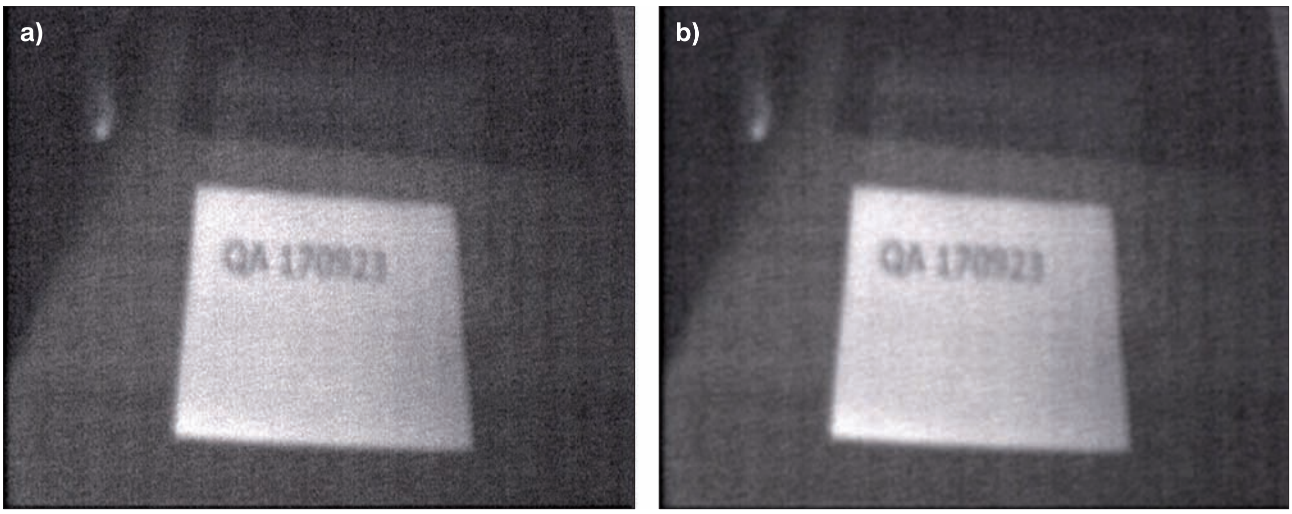

Fig. 9. a) Original image, b) result of averaging filtration – visible noise reduction together with the effect of smoothing out the edges of the object.

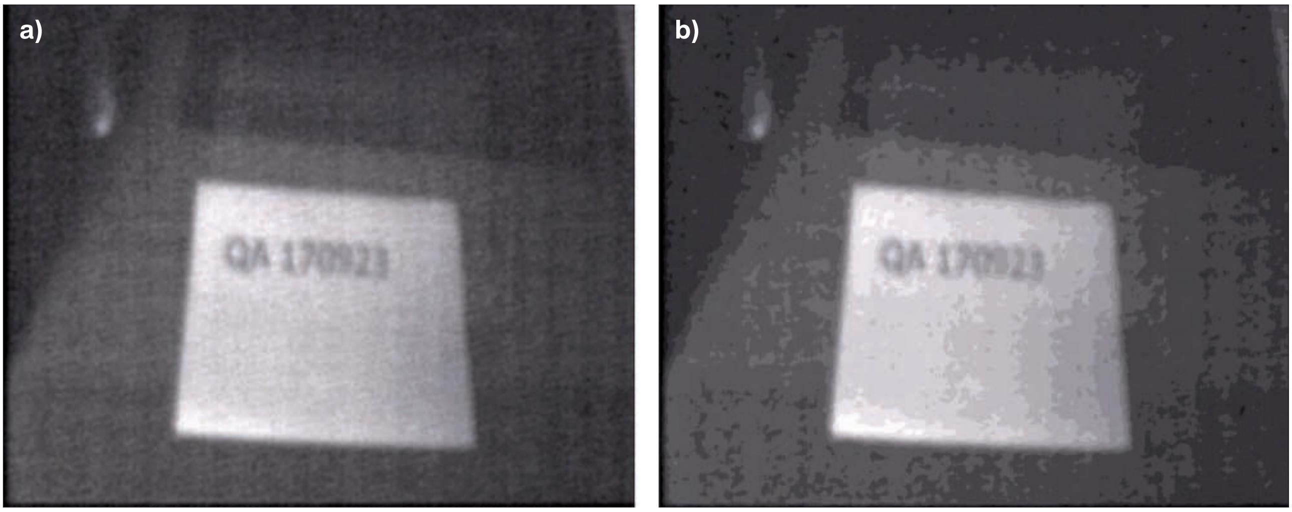

Fig. 10. a) Original image, b) result of median filtration with visibly smoothened edge of the object.

relation to the points located outside this area, which allows to avoid an internal blur effect) [13].

3.3.2. Filtering in the frequency domain

This type of filtration is mainly used to improve the so called "blurred images", to highlight the characteristics invisible in the spatial domain and to filter out periodic noise. Filtration is achieved by applying the Fourier transform [12, 15], i.e. converting the image from time domain into frequency domain, in accordance with the relationship:

$$F(\xi) = \int_{-\infty}^{+\infty} F(x)e^{-2\pi jx\xi}\, dx, \text{ for all } \xi \in R \quad (3)$$

Figure 12 shows an example of the use of low-pass frequency filtering (Butterworth filter), performed in order to reduce interferences of the type *blur*.

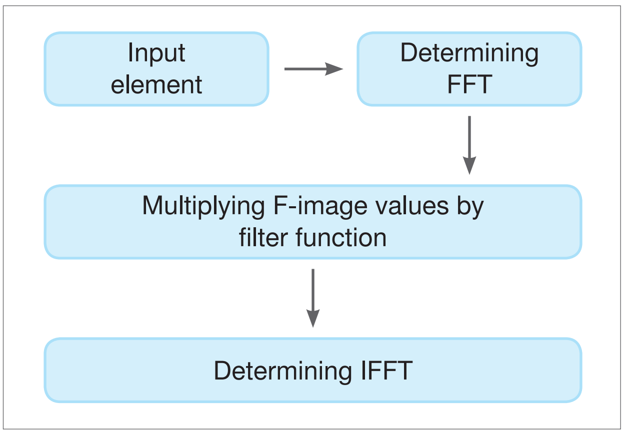

Fig. 11. Principle of filter operation in the frequency domain.

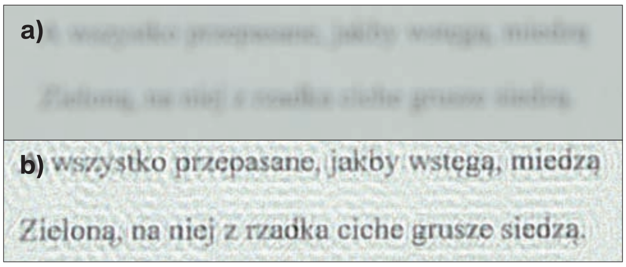

Fig. 12. a) Original image, b) result of frequency filtering.

4. Study methods and results

Table 1 summarizes the parameters of materials subjected to quality improvement with the use of methods described in the previous section. The activities undertaken aimed at obtaining the best possible clarity and readability of the content, while maintaining the balance between the degrading effect of digital filtration and the object's clarity. The research material consisted of digital images and video registered using three digital devices: Nokia's Lumia line smartphone, SONY camcorder and Canon's EOS line camera. The materials have been prepared in such a way as to expose the most frequently encountered by experts subject of research, i.e. the distortions. Photographs and video recordings were taken under natural conditions, resembling as closely as possible real casework environment.

Figures 13-16 show the results of the quality improvement of digital material, carried out in order to facilitate the recognition of license plate numbers (fig. 13-14) and printed text (fig. 15-16). These cases represent a situation in which, due to the different speeds of movement of the recording device, four different materials were obtained of varying degrees of degradation. This phenomenon is called a motion blur and the degree of distortion of the recorded material is dependent on the speed of the moving object (recording

Table 1. Technical specifications of test materials.

Recording device	Main technical specifications of test material		Purpose of analysis
Nokia phone	Name: Format: Resolution (pixels): Exposure:	Plik1_test.jpg (Fig. 13a) JPEG 3072 x 1728 1/25s, f/1.9, ISO 400	Improving visibility of license plate numbers
	Name: Format: Video codec: Resolution: Image aspect ratio: Number of frames/s: Scanning: Bit rate:	Plik2_test.mp4 (Fig. 14a) MPEG – 4 AVC (*Advanced Video Coding*) 1920 x 1080 16:9 30 Progressive 16583 kbp/s	Improving visibility of license plate numbers
Canon camera	Name: Format: Resolution (pixels): Exposure: Focusing:	Plik3_test.jpg (Fig. 15a) Plik4_test.jpg (Fig. 16a) JPEG 3504 x 2336 1/160s, f/5.0, ISO 100 Manual mode	Improving the quality of printing, depending on the degree of blurring of the moving object
	Name: Format: Resolution (pixels): Exposure: Focusing:	Plik5_test.jpg (Fig. 17a) Plik6_test.jpg (Fig. 18a) Plik7_test.jpg (Fig. 19a) JPEG 3504 x 2336 1/160 s, f/5.0, ISO 100 Manual mode	Improving the quality of printing, depending on the degree of an optical distortion of the type *blur*
Nokia phone	Name: Format: Resolution (pixels): Exposure:	Plik8_test.jpg (Fig. 20a) JPEG 1200 x 800 1/25 s, f/1.9, ISO 400	Improving the quality of printing on the material subjected to preprocessing (lossy compression JPEG)
Sony camcorder	Name: Format: Video codec: Resolution: Image aspect ratio: Number of frames/s: Scanning: Bit rate:	Plik9_test.avi (Fig. 21a) AVI (*Audio Video Interleave*) DV (*Digital Video*) 720 x 576 16: 9 25 with interleaving 24441 kbp/s	Improving visibility of printing on a moving object
Canon camera	Name: Format: Resolution (pixels): Exposure:	Plik10_test.jpg (Fig. 21c) JPEG 3504 x 2336 1/160 s, f/5.0, ISO 100	Improving visibility of the object
Sony camcorder	Name: Format: Video codec: Resolution: Image aspect ratio: Number of frames/s: Scanning: Bit rate:	Plik11_test.avi (Fig. 23) AVI (*Audio Video Interleave*) DV (*Digital Video*) 720 x 576 16:9 25 with interleaving 24441 kbp/s	Improving visibility of printing
Canon camera	Name: Format: Resolution (pixels): Exposure:	Plik12_test.jpg (Fig. 24) JPEG 3504 x 2336 1/160 s, f/5.0, ISO 100	Geometric measurements

device or recorder object) as well as on the settings of optical parameters (exposure time, aperture value and sensitivity of the sensor) [3].

In order to improve the visibility of the materials recorded, a motion blur reduction (in the frequency domain), a context-sensitive linear filtering (averaging filter, increasing sharpness using the Laplacian transform) as well as geometric (rotation) and point (inter alia edition of the histogram) transformations were performed. The parameters of the digital filters were chosen individually for each case in such a way as to maximize visibility while reducing the side effects of digital filtration, i.e., the introduction of distortions or artifacts into the material being analyzed.

Fig. 13. a) Photographic material before the quality improvement process, b) after the filtering process.

The steps undertaken allowed a complete reading of license plate numbers “LZ 57919” in the case of the photograph (fig. 13) and a partial reading, i.e. “LZ 579(?)?? in the case of the video recording (fig. 14). The analysis of the text visible on figure 15 allowed a complete reading, i.e. “*Litwo! Ojczyzno moja! Ty jesteś jak zdrowie, Ile cię trzeba cenić, ten tylko się dowie”* [a well-known Polish poem – translator’s note], while for the text visible on figure 16, only a partial reading was possible (success rate: 50-60%). The effectiveness of the reading was calculated on the basis of the ratio of the number of correctly read characters to the number of all the characters, determined on the sample of 4 persons. A partial reading effectiveness of data contained in the images was caused by excessive degradation of digital material, regardless of good technical parameters, such as e.g. the resolution. Moreover, the effectiveness of a motion blur reduction was affected by the speed of movement of the recording device and by insufficient quality of the optics, which, taking into account data compression, has not allowed the registration of better quality images, in addition to introducing extra geometric distortions.

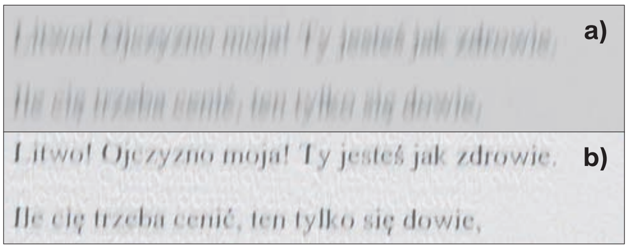

Fig. 15. a) Original image, b) image subjected to the filtering process consisting in the reduction of “motion blur” – type interferences.

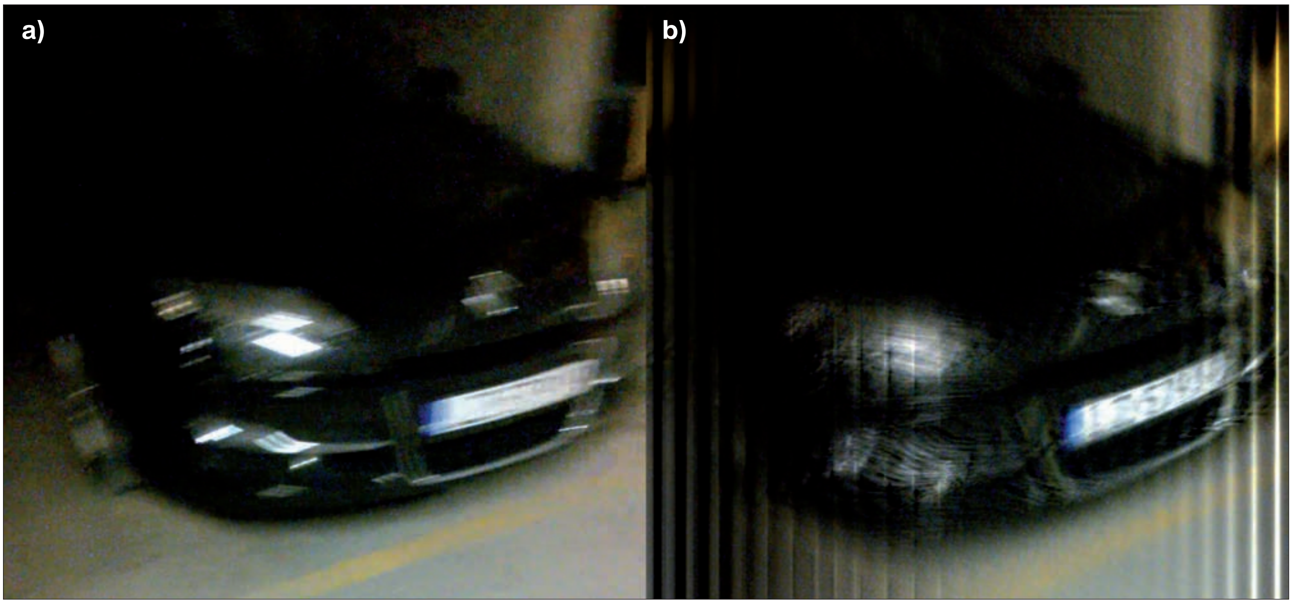

Fig. 14. a) Video material before the quality improvement process, b) after the filtering process.

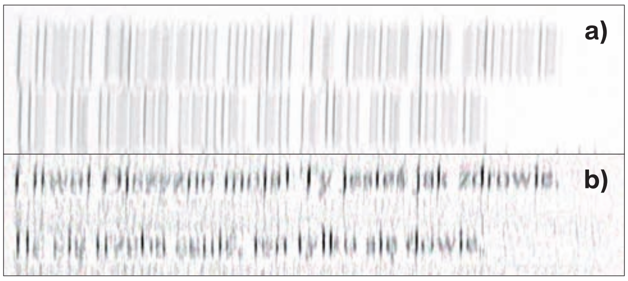

Fig. 16. a) Original image, b) image subjected to the filtering process consisting in the reduction of "motion blur"-type interferences.

Figures 17-19 show the result of the reduction of the "blur" – type distortion. This distortion results from an incorrectly selected distance between the optics of the recording device and the object to be registered; the greater the distance, the more pronounced degradation is observed. This phenomenon can have two causes. The first cause can result from an incorrect focus selected in manual mode by the photographer or camera operator. The second arises from the malfunctioning of autofocus, i.e. automatic focusing function, which occurs during registration under insufficient lighting conditions or focusing at a different point than desired by the user (one should be aware that the autofocus function is fully automatic, so it cannot predict the user's decision. Consequently, the photo taken may be clear and sharp, but not within the desired area) [9]. In the case of the images in question (fig. 17-19), a manual focus adjustment mode was applied, whereby the parameters were selected in such a way as to obtain different degrees of degradation.

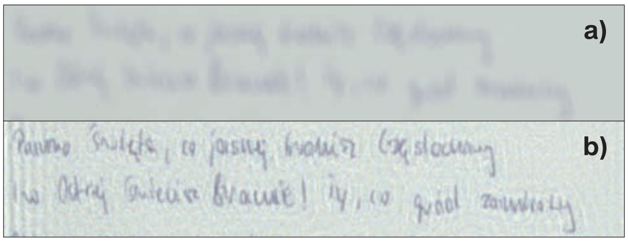

Fig. 17. a) Original image, b) image subjected to the filtering process consisting in the reduction of "motion blur" – type interferences.

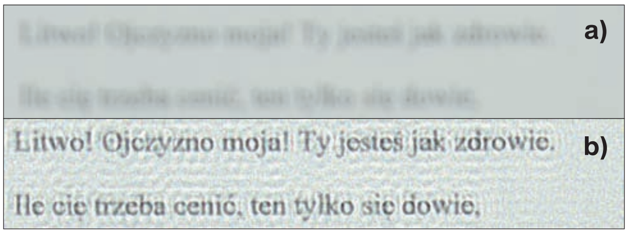

Fig. 18. a) Original image, b) image subjected to the filtering process consisting in the reduction of "motion blur"-type interferences.

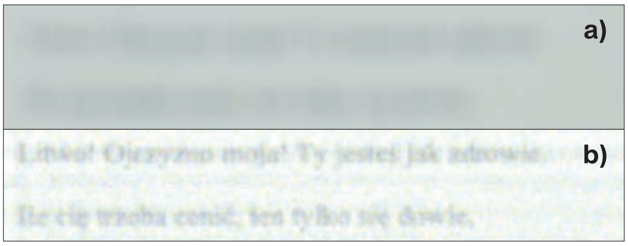

Fig. 19. a) Original image, b) image subjected to the filtering process consisting in the reduction of "motion blur"-type interferences.

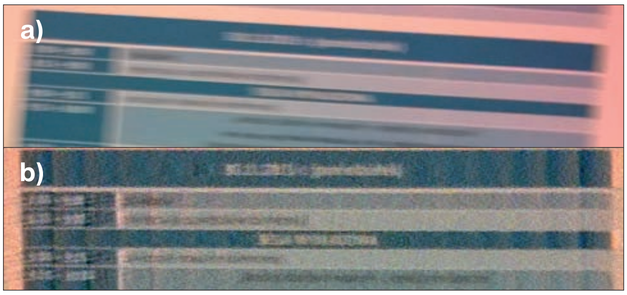

Fig. 20. Attempt at reduction of "motion blur"- type interferences in material after secondary compression: a) input image, (b) image after the digital filtration process.

In order to reduce the distortion, a low-pass frequency filtering (Butterworth filter) as well as a context-sensitive linear filtration (increasing sharpness by the Laplace transform) were applied, whereby the parameters of the digital filters were tuned for maximum readability and minimum impact of correction algorithms on the quality of the images to be analyzed. The examples below show the effectiveness of the reduction of distortions. In the case of two of the materials (fig. 17b and 18b), the reading of the entire text: "*Litwo! Ojczyzno moja! Ty jesteś jak zdrowie, Ile cię trzeba cenić, ten tylko się dowie"* was possible, while the last material (fig. 19), could be read only partially (the correct interpretation of the content was 60–70%), which was due to a high degree of degradation. The reading of the text shown in figures 17–19 was done by a group of 4 persons. The success rate was expressed as the ratio of the number of correctly read characters to the number of all the characters.

Figure 20 presents the result of the quality improvement of the image registered with a Nokia mobile phone camera, subjected to the secondary process of lossy compression JPEG (quality factor 4 on a scale of 0 to 10, a recording made in Adobe Photoshop). For the purpose of correcting the distortion, a frequency filtering and a contextual frequency filtering were applied. Due to a small amount of information contained in the image, the steps undertaken did not allow the correct interpretation of the recorded content.

The analysis conducted with respect to the materials indicated on figure 21a (sample frame exported from

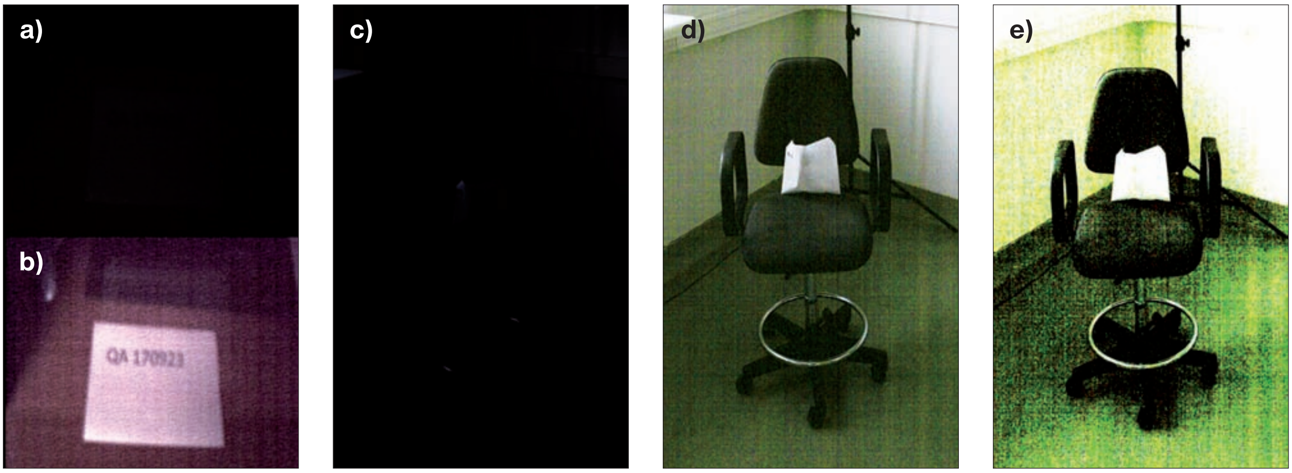

Fig. 21. Result of video recording (panel b), and image (panel d, e) quality improvement for events registered under insufficient lighting conditions.

video footage, the registration of a partially filled A4 page) and figure 21c (image), was aimed at reading the content and visualizing the shapes of objects registered under inadequate lighting conditions [14]. The results of the performed analyses correspond to:

– contextual digital filtration and point transformations (histogram stretching) – fig. 21b;
– edition of brightness levels – fig. 21d;
– binarization (point transfromations) – fig. 21e.

As per content on figure 21a, the following string was read: QA170923;

As per content on figure 21c, an object's shape (contouring) was visualized, while the reading of the content on the white object was unsuccessful.

The above results were mainly influenced by the resolution of the image and the degree of lossy

Fig. 22. View of the white object from fig. 21d and 21e.

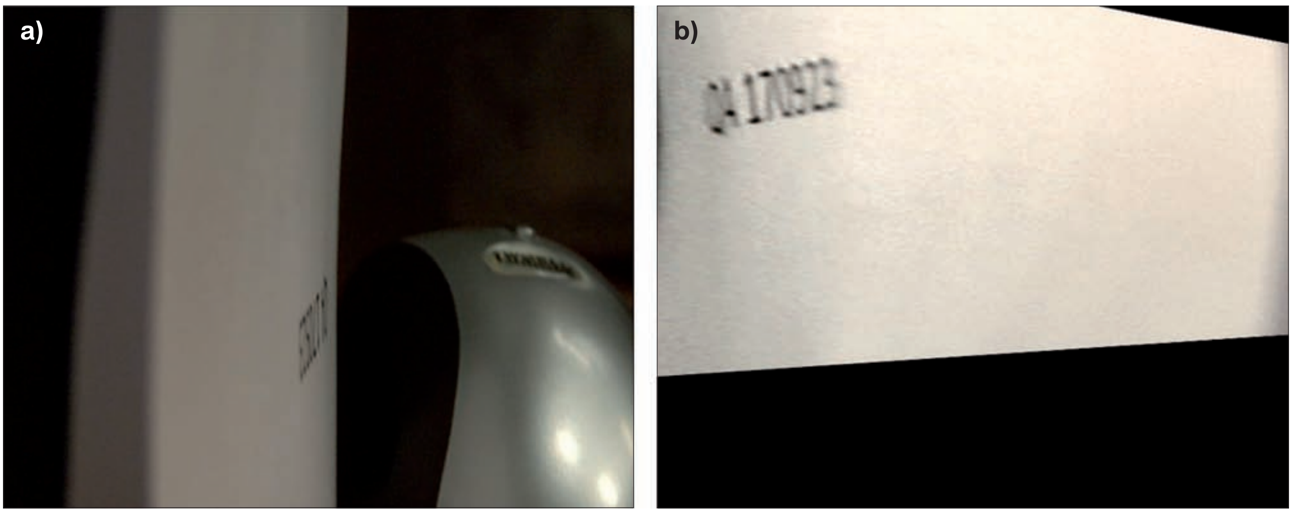

Fig. 23. a) Image registered with perspective errors, b) result of applying geometric transformations and point operation.

compression Certainly, the resolution can be increased by using a different hardware, however, it will rarely result in increasing the readability of the image details. Such procedure is presented in figure 22, however, due to the lack of sufficient information, it did not produce the expected results.

Figure 23b shows the result of geometric transformations (rotation, perspective correction) and point operations (histogram balancing). These procedures can be very effective, for example, in minimizing the impact of the human factor.

In addition to the abovementioned methods of digital filtering and point and geometrical transformations, also geometric measurements of objects serve as a useful tool for experts [4]. The following measurements can be performed by an expert:

- 1D – measurement in one plane (the user specifies one reference dimension);
- 2D – measurement in two planes (e.g. measuring the distance between the phone lying on the floor and the table), where an operator specifies two reference dimensions in the x and y axes;
- 3D (fig. 24) – measurement carried out in three planes: x, y and z. To perform a 3D measurement, it is required to provide three reference dimensions, one for each of the x, y, and z planes.

In the case shown in figure 24, the dimensions have been specified with an error of about 3 mm. The values measured for white color were ~ 217.9 mm and ~ 213.2 mm (the original dimensions: 215 mm and 210 mm, respectively). The described functionality appears to be very helpful, for example, when it comes to estimating the height of the characters in the image. However, it should be born in mind that this type of analysis is very strongly correlated with the quality of the test material, and therefore it can end in failure in the case of low resolution images.

5. Summary and conclusions

This article presents a review of the methods of improving the quality of images, along with examples In order to diversify their quality, the test materials were prepared using three types of devices: a phone, camera and camcorder. Figures 13-24 show the results of research undertaken in order to obtain the greatest possible clarity and readability of the content stored on the registered digital files.

In most cases, the digital filters applied minimized the interferences, allowing for reading the content or parts thereof. None of the tests performed has led to the total elimination of interferences. Based on the results obtained, it is possible to identify three broad groups of factors having an impact on the ability to achieve image quality improvement and obtain satisfactory results:

a. **Technical parameters of the test material** – mainly the compression level and image resolution, both determining the amount of information included. For example, noise reduction of the type "blur" (fig. 18) and the so called "moved image" (fig. 15) would not be possible when saving data at a higher compression level, due to lower amount of information. The effect of the amount of information contained in the image on the feasibility of testing is shown in figure 20.
b. **Technical specifications of the recording device** (particular attention should be paid to optical and electronic systems) affecting the correctness of capturing the scene. The reduction of noise caused by the camera's optics errors is possible to a certain point threshold, above which improving the perspective of the analyzed object would lead to excessive distortion. A similar situation occurs in the case of geometric measurements, that will be impossible to carry out due to too high

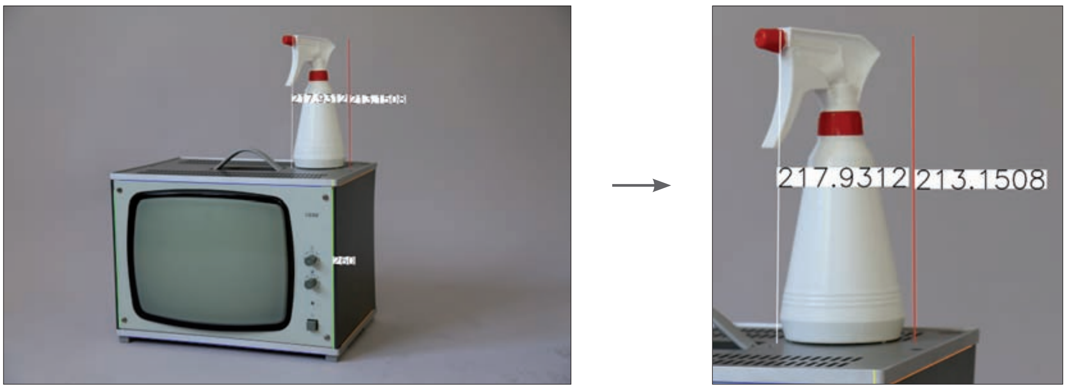

Fig. 24. Result of 3D measurement of the white object.

probability of obtaining erroneous result, while not being able to estimate measurement error. The exemplary perspective improvement procedure is presented in figure 23, and geometric measurements in figure 24.
Obviously, it should be born in mind that the technical specifications of the recording device, such as signal processing system determining the recording format and compression level, clearly affect the parameters of the recorded material. Therefore, both of these factors are inseparable and influence each other.

c. **Human factor** plays a very important and perhaps even the most important role at the time of material registration, as well as at the analysis and improvement stages. It is particularly essential in the case of recording devices with low quality optical tracking and image processing systems.

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