Development of a Test Method for Image Stabilizing Systems

Diploma Thesis at the Department of
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Entwicklung eines Verfahrens zur Qualitätsbeurteilung der bildstabilisierenden Systeme

Diplomarbeit im Fachbereich
Photoingenieurwesen und Medientechnik
an der Fachhochschule Köln

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Abstract

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Summary

Image stabilization in digital imaging gets more and more popular. This fact is responsible for the increasing interest in the benefits of the stabilizing systems. The common standards provide neither binding norms nor recommendations for the evaluation. This thesis' objective is the development and implementation of a test device and a test procedure for qualitative analysis of image stabilizing systems under reproducible and realistic conditions. The basis for these conditions is provided by the studies of physiological properties of human tremor and the functionality of modern stabilizing systems.

Kurzbeschreibung

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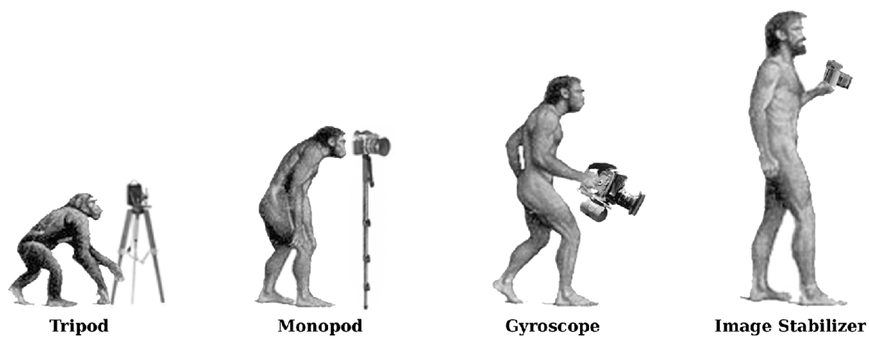
Zusammenfassung

Mit dem zunehmenden Einsatz der bildstabilisierenden Systeme in digitalen Kameras rückt immer häufiger die Frage nach ihrer Qualität in den Vordergrund. Die aktuellen Normen sehen weder verbindliche Testverfahren noch Empfehlungen vor, die eine Auswertung dieser Systeme ermöglichen. Ziel dieser Arbeit ist die Entwicklung und Realisation eines Testverfahrens, das einen qualitativen Vergleich verschiedener Systeme unter reproduzierbaren, realitätsnahen Bedingungen ermöglicht. Die spezifischen physiologischen Eigenschaften des menschlichen Zitterns und die Funktionalität der momentan verfügbaren Bildstabilisatoren bilden dabei die Basis für die Entwicklung.


Tripod
Monopod
Gyroscope
Image Stabilizer

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1 Introduction

In the photographic practice, whether digital or analogue, the handshake of the photographer often results in a disturbing blur. In medicine, the phenomenon of rhythmic, involuntary muscle contractions, occurring in all healthy individuals, is known as physiological tremor [1].

Recently many camera and lens manufacturers have developed various stabilizing systems to compensate for handshake.

The objective of this diploma thesis is the development of a test method in order to evaluate the quality of image stabilizing systems. The measurement is based on automated, reproducible mechanical simulation of human tremor followed by resolution measurement of captured images.

In order to determine the basic test conditions, Bradley J. Davis' and John O'Conell's [2] method of amplitude measurement of human physiological tremor was adopted with regard to holding photographic cameras. The ascertained values were used for the tests.

This paper describes in detail the basic approaches and considerations of the measurement method, followed by results from exemplary tests. The basics of the modern stabilizing systems' functionality and the physiologic properties of human tremor, which were considered for the development, are also discussed.

In the following, the term STEVE is used when referring to the developed apparatus. STEVE is the abbreviation for "Stabilizer Evaluation Equipment".

2 Basics

This chapter provides an overview of the functionality of different image stabilizing systems. Furthermore, the basic principles of gyroscopic sensors used to detect the handshake in the camera or lens, as well as the definition of blur are discussed. The last section describes the method for measuring the spatial resolution in digital still images that are used for the evaluation of stabilization benefit.

2.1 Image Stabilizing Systems

Even before Garret W. Brown applied for a SteadiCam patent in 1977 [3], there were several considerations about compensation for a disturbing blur due to handshake, occurring while holding the camera in the hand. Ever since cameras were so small, that one could take photographs holding them in the hand, tripods and monopods had been utilized to capture sharp images.

The development of integrated image stabilizers started in 1980's. Canon was the first manufacturer to introduce an interchangeable zoom lens for 35mm SLR, featuring image stabilization in 1995. Many manufacturers also set off engineering researches and invented their own concepts for stabilization, like CCD-Shift or Digital Stabilizers.

Handshake detection via sensors integrated in the camera or lens, rapidly moving mechanic elements and digital signal processing with complex algorithms, became state-of-the-art. These systems are more or less effective against the motion blur caused by camera shake – but motion blur effected by object's movement can obviously not be recognized and reduced. And since the camera shake is detected by built-in sensors, panning the camera could falsely be interpreted as camera shake.

This chapter explains basic functionality of today's stabilizing systems using some examples. The examples are chosen as representatives on account of a diversity of monthly increasing stabilizers.

2.1.1 Optical Image Stabilization

Figure 1: VR Element [4]

This kind of image stabilizer can be implemented in both still- and motion-picture cameras. To compensate for handshake, this system, sometimes referred to as optoelectronic image stabilization, uses the optical path. A movable lens group or a prism with movable surfaces shifts the optical path in order to avoid blurring. The correction element's motion is perpendicular to the optical axis in opposite direction to the handshake.

Built into the lens, the optical image stabilizer (OIS) detects camera shake using two angular velocity sensors – one for pitch- and one for yaw-axis. The same method of camera shake detection is used in electromechanical stabilization.

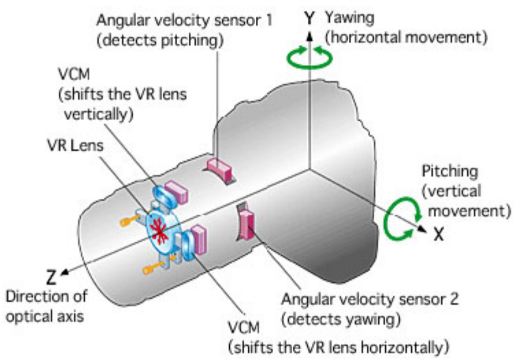


Figure 2: Optical Image Stabilizer [4]

A microprocessor calculates the correction amount and direction and sends it to the control system. In addition, the control unit gets the movable lens group's position data measured by sensor elements.

The control system generates the motion parameters for the lens group out of this data and drives a voice-coil motor (VCM), piezo-element or another actuator, which is used to move the correction element.

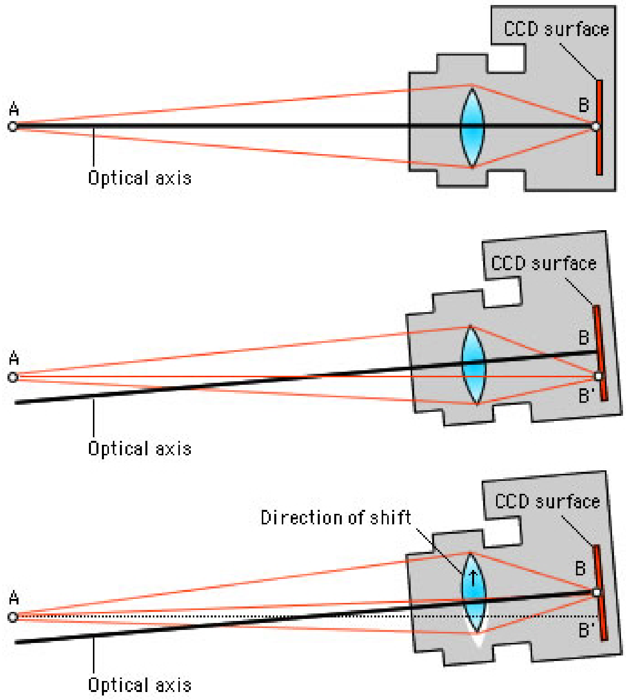


Figure 3: Lens Shift Technology [5]

The function of OIS is very similar to the electromechanical stabilization (EMIS). The main difference is the element being moved. In EMIS the CCD assembly is used for this purpose. In OIS it can be a lens group or a prism element. Such fluid prisms consist of two elements connected by flexible bellows and filled with high refractive liquid. When moving the elements, the angle between them changes, correcting the light path. Canon's Vari-Angle Prism System for binoculars, high-end camcorders and movie cameras is larger and more expensive than lens-shifting but it also compensates in a larger handshake range

[7]. On the other hand, this system generates chromatic aberration from the center of the image to the borders while stabilizing [8].

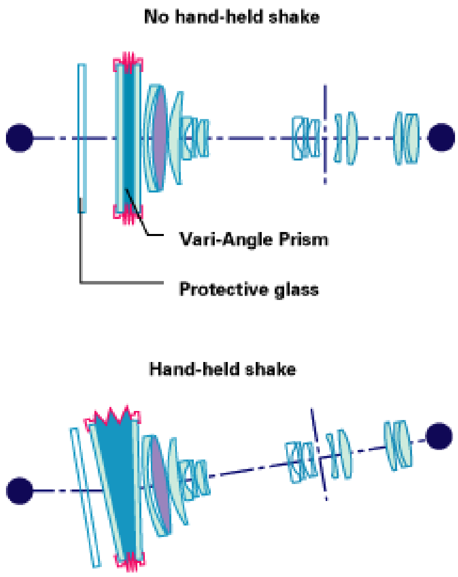


Figure 4: Vari-Angle Prism Image Stabilizer System [6]

2.1.2 Electromechanical Image Stabilization

Electromechanical Image Stabilizing System (EMIS) also referred to as “CCD-Shift Correction Technology”, was first introduced by Konica Minolta. Following Sony Corporation's take-over of Konica Minolta's camera assets in March 2006, this system is featured in some of Sony's new digital cameras, also referred to as Super Steady Shot[1]. Until now, it has only been implemented in photographic cameras, but

[1] Super Steady Shot is a confusing name since Sony uses it in compact cameras for optical and in the SLR Alpha 100 for electromechanical image stabilization.

it is also imaginable to integrate it into a camcorder. The specific feature of this system is imaging chip's movement to compensate for handshake. Unlike optical stabilizers, it is possible to use any lens with the camera body equipped with EMIS.

Figure 6 describes the functionality of Konica Minolta's Anti-Shake system in detail. The handshake is measured using two gyroscopic sensors (Fig. 6, ➔50). This technique is also used in optical stabilizing systems. EMIS is complemented by a Position Sensing Device (PSD) – a magnetic hall effect sensor element determining the position of the image chip (Fig. 6, ➔55). The feedback from this sensor is necessary for a closed loop control of the chip-shifting mechanism. The outputs of all three sensors are processed by a microcomputer in a shake correction section (Fig. 6, ➔91) and the required correction amount is calculated with respect to the chip's current position.

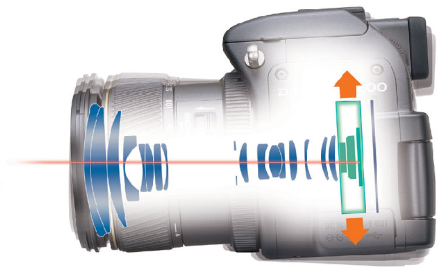


Figure 5: CCD-Shift [9]

The Smooth Impact Drive Mechanism (SIMD) – an essential part of the shake correction unit (Fig. 6, ➔2) – gets the correction information and moves the chip into the calculated position. SIMD consists of two linear piezoelectric actuator devices, one for each axis (Fig. 6, ➔3a, 3b). The advantage of the piezoelectric drive is its small size and fast response. Applying voltage makes it expand, without voltage it contracts very fast. To achieve movement in the opposite direction, the voltage waveform is reversed.

The total travel of the piezoelectric element is physically limited to a few micrometers. To achieve the required displacement of the imaging

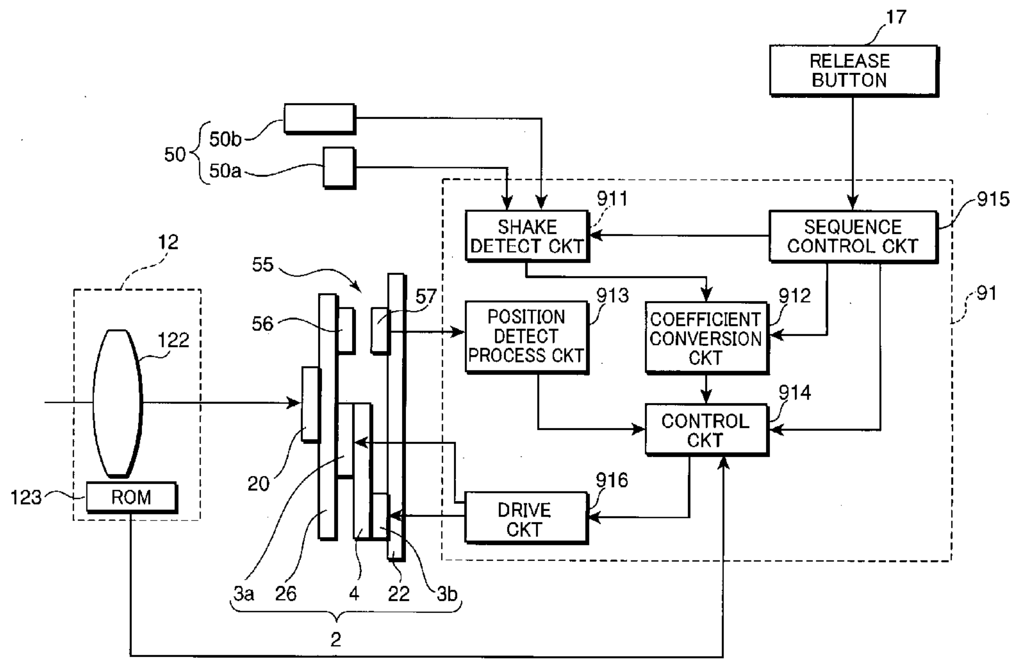


Figure 6: A cross-sectional view of an angular adjustment mechanism [10]

sensor, a mechanical travel amplification, such as a lever, is needed. The Anti-Shake System uses a friction-based system illustrated below.

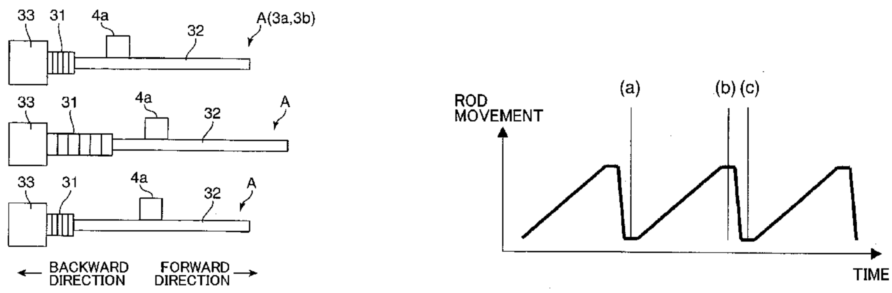


Figure 7: The principle of Minolta's piezo-actuator [10]

The piezoelectric array consisting of many single actors (Fig. 7, →31) is attached to a rod (Fig. 7, →32) with a movable slider (Fig. 7, →4a) settled on it. This slider is a frame containing the imaging sensor. First the piezo device gradually expands at a moderate speed, transporting the slider due to its friction. When the piezo actor contracts quickly, a slippery movement of the slider on the rod does not let it drive back. In this way the slider has been moved forwards from its initial position and the piezo device can expand again.

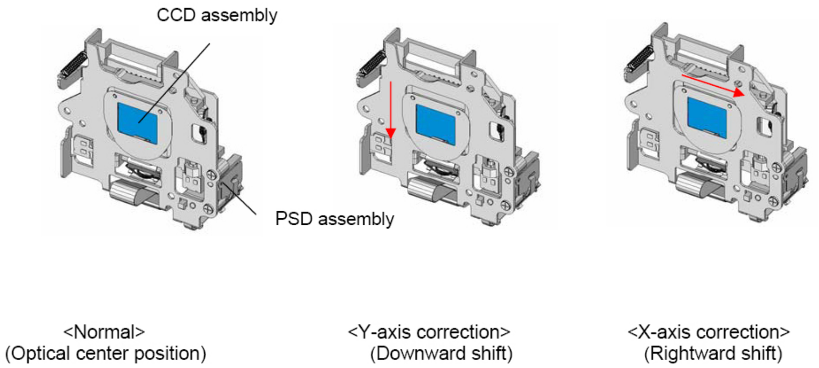


Figure 8: Konica Minolta's CCD-Shifting mechanism [9]

Ricoh also introduced an electromechanical stabilization system – AntiShake – in US Patent Application No. 20020163581. To enlarge the travel of the piezoelectric device (Fig. 9, ➔112) two elastic plates (Fig. 9, ➔118a, 118b) are used. The expansion of the piezo element deforms the plates, which move the assembled image sensor.

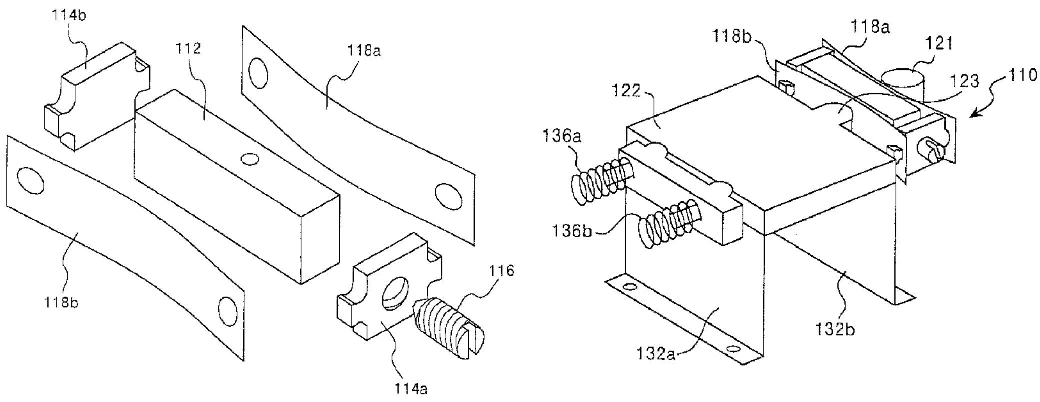


Figure 9: Ricoh's piezo actor [11]

Pentax is a further manufacturer featuring an electromechanical stabilization called Shake Reduction. The principle is similar to Konica Minolta's AntiShake. However the movement of the image sensor is alternatively achieved by electromagnetic, and not piezoelectric actors. The imaging sensor is attached to a platform supported by a ball-bearing plate.

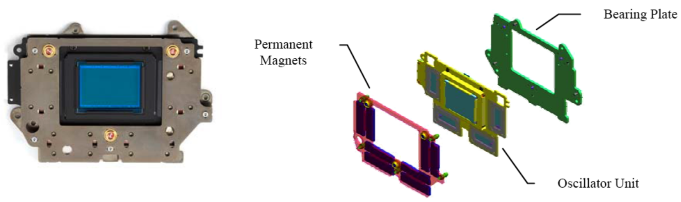


Figure 10: Shake Reduction unit by Pentax [12]

2.1.3 Electronic Image Stabilization

This kind of stabilization can only be implemented in devices with electronic imaging sensor such as CCD or CMOS. The electronic image stabilization (EIS) does not use the optical path to eliminate the effect of handshake on image sharpness. Instead of correcting the image on its way to the sensor, this kind of stabilization uses software algorithms and a bigger sensor imaging plane to process the pictures after they have been captured. The transformation takes place within the period of time after the image has been captured and before it is recorded.

Sometimes Electronic Image Stabilization is also referred to as Digital Image Stabilization. Making use of electronic signal processing results in low production costs and a small size of a stabilizing system. However, this kind of stabilizing systems is mostly implemented in camcorders since it mostly uses image sequences and not still images produced by most photographic cameras.

Handshake can be recognized as it is captured on the image sensor. In this case some distinctive image areas are tracked in the sequence of several frames. The difference between the positions of these areas can be interpreted as handshake. Disadvantage of such detection is that large moving objects in the scene can be interpreted as camera shake. Another way to detect camera shake is to supply the capturing device with motion sensors. These sensors are discussed in detail in the chapter 2.2 Gyroscopic Sensors. Their functionality strongly depends on the algorithm quality, and many manufacturers claim that their systems are able to distinguish between camera shake and panning.

Electronic stabilization can be implemented in the way of “panning and scanning” over the image and moving the pictures to their proper place, according to information about displacement from a row of frames. This process is demonstrated in Figure 11.

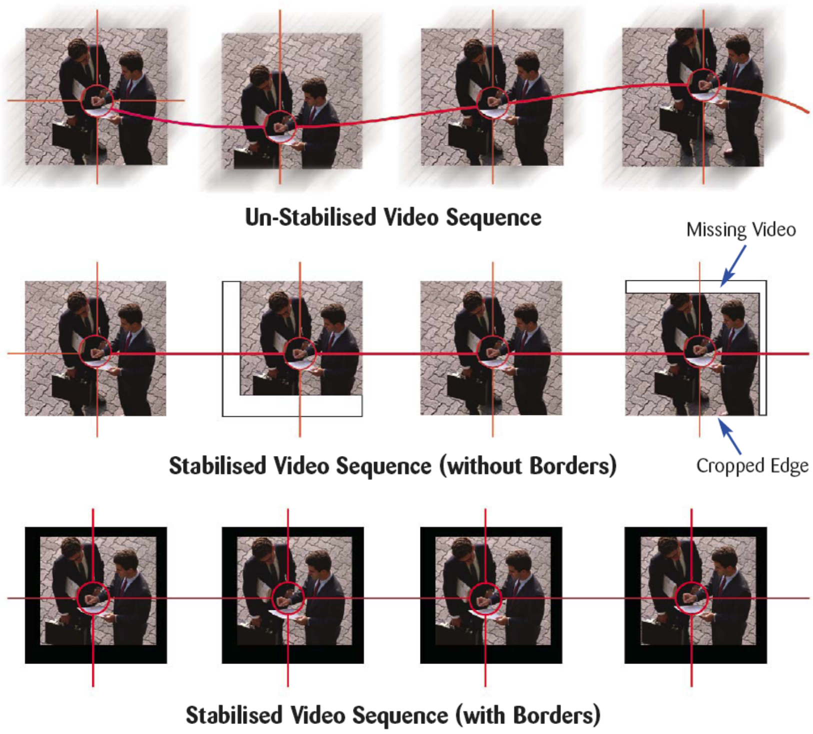


Figure 11: Functionality of EIS for motion pictures [13]

To move the single frames, it is necessary to have margins. This can be achieved by digital magnification ("digital zoom") or by an oversized image sensor (Figure 12). In this case the image focused on the sensor plane is smaller than the sensor itself. The image "floats" over the sensor as the camera jitters. The system digitizes the entire sensor area including the guard band border area. Due to this area signal processing unit can digitally implement a compensating shift on the captured image data [7]. Each method has its disadvantages: digital magnification crops image bor-

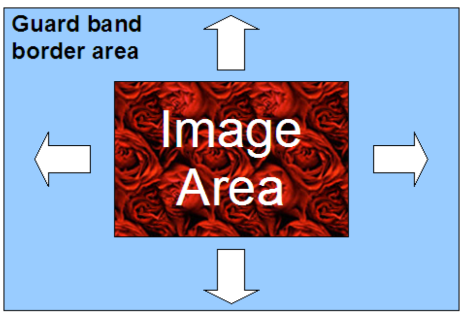


Figure 12: Oversized image sensor

ders and blows up the rest of image, which leads to particular loss of visual information and decreases the quality, whereas oversized sensors are more expensive. In the case of sensors with a larger surface area, the amount of image stabilization is limited by the provided margins.

Electronic Image Stabilization can be integrated in the capturing device, but it can be used as an external upgrade as well. Figure 13 shows how this potential can be used exemplified by a Closed Circuit Television (CCTV) application.

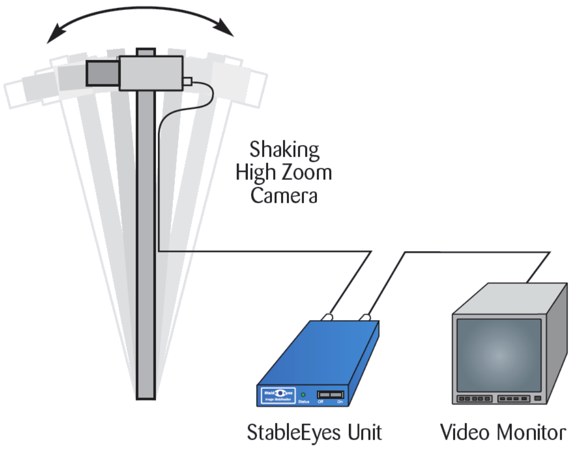


Figure 13: External Electronic Image Stabilization [13]

However, external electronic stabilization can obviously only use the method of digital magnification.
Some manufacturers of digital still cameras also use the benefits of the electronic stabilization. Samsung invented a system called ASR (Advanced Shake Reduction) for its digital still cameras. Two shots of a scene are taken for the stabilization – one blurred picture with the required slower shutter speed to acquire the color and luminance values and a darker one, using shorter exposure time with sharp edges.

These two images are then processed by the camera software to reconstruct one blur-free picture out of their data.

Some manufacturers refer to electronic image stabilization in their cameras (e.g. Anti-Blur by Fuji) which can suppress both motion blur caused by handshake and by moving objects in the scene. The background of these deceptive statements is the amplification of the image signal achieved by increasing the ISO speed. The effect is the shortening of the exposure time, which makes the influence of handshake almost imperceptible. A faster shutter speed also “freezes” the moving objects in the scene. Strictly speaking, this technique can not be called image stabilization. This is just a marketing trick intended to give a new name to the old technique due to the stabilizer trend. Furthermore this method can have an impact on the image content according to the coherence of shutter speed, aperture and the depth of field. The loss of resolution and the gain of noise are some more consequences of high ISO speed.

2.1.4 Mechanical Image Stabilization

This is probably the oldest way to reduce camera shake. It is obvious that the simplest way to avoid disturbing handshake is to resign holding the camera in the hand. This way of stabilization has an effect on the whole capturing device, not just some parts of it. It can be used for still image photographic cameras and for camcorders as well. The oldest and usually cheapest way to support cameras is a tripod or monopod. However, camera shake on tripod can also occur due to mechanical movements inside the camera (quick-return mirror or shutter curtain). This camera shake has a different character than handshake and can also be eliminated using some optical stabilizing systems (according to manufacturers' claims).

There are also other devices such as SteadiCam or Gyro Stabilizer. Since the stabilizer is not built into the camera body or lens, all kinds of cameras can be supported.

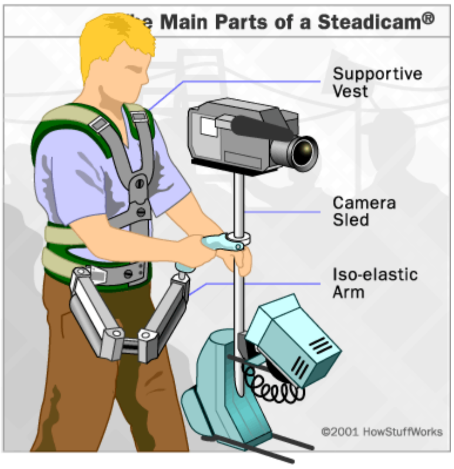


Figure 14: Main parts of SteadiCam [14]

SteadiCam is a system designed for operators of motion pictures or video cameras. Camera, monitor and battery are fixed on a sled supported by an elastic spring-loaded arm with complex assembly. The arm is attached to a vest, worn by the camera operator. The weight of such system can easily amount to several kilograms. The price is very high and can amount to €50,000. The success of this kind of stabilization depends on the operator's skills [15].

Figure 15: SteadiCam Components – sled, arm and vest [16]

Gyroscopic Stabilizers are a compromise between tripod and hand-held cameras. Kenyon Laboratories LLC offer this kind of stabilizers. The pod-like helium-filled housing contains two rotating gyroscopic wheels (see 2.2 Gyroscopic Sensors), rotating about axes, opposing each other. Operating at 22,000 rpm they resist the pitching and yawing of the attached camera. This system can be used for a whole range of camera types – from still image cameras to cinematographic ones. It can also be combined with other stabilization systems e.g. with SteadiCam (Figure 16). Admittedly this expensive kind of stabilization (approx. $1,000 – $7,000) is not a low-noise one. It needs a power supply of 115 VDC and 400 Hz and has run up and shut down times of several minutes. These properties make gyroscopic stabilization unattractive for consumer electronic products.

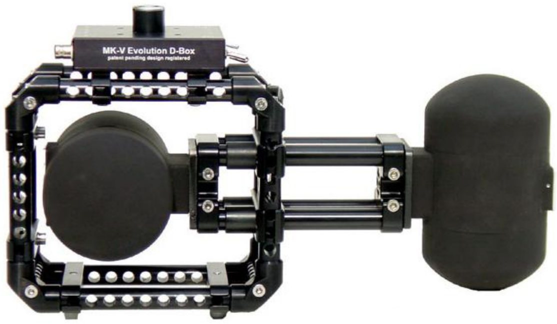


Figure 16: Steadicam sled provided with gyroscopic stabilizers [17]

2.2 Gyroscopic Sensors

The output signal of gyroscopic sensors is proportional to the rate of rotation. It makes them suitable for detection of rotating handshake motions in image stabilizing systems. The vast majority of stabilizing systems uses the benefits of such sensors.

Gyroscopic sensors (gyros), also referred to as angular velocity or angular rate sensors, are inertial sensors. They use the property of bodies to maintain velocity (linear or angular), unless disturbed by forces or torques as described in Newton's first law (law of inertia). Gyroscopic sensors have their origins in mechanical spinning mass gyroscopes, often used in aerospace applications. An essential part of these gyroscopes is a rotor on an axle which, once spinning, tends to maintain its position in space if the outside gimbals change.

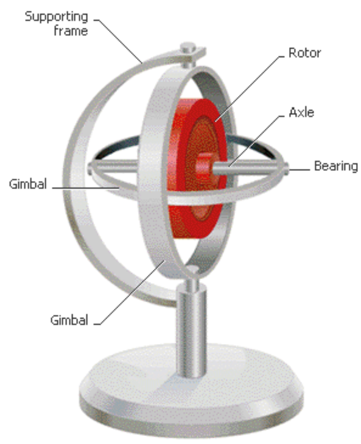


Figure 17: Mechanical Gyroscope [18]

Since the invention of Micro Electro-Mechanical Systems (MEMS) and lithographic technologies, it is possible to miniaturize gyros and make them affordable. Another important reason for miniaturizing gyros is the vibrating gyros technology. No bearings are needed to support the mechanics because the rotor is replaced by a vibrating element. In general, a distinction is drawn between optical and mechanical gyros, whereas only mechanical ones can be miniaturized. That makes them interesting for consumer electronic applications such as image stabilizing systems in photographic cameras, camcorders or mobile phones.

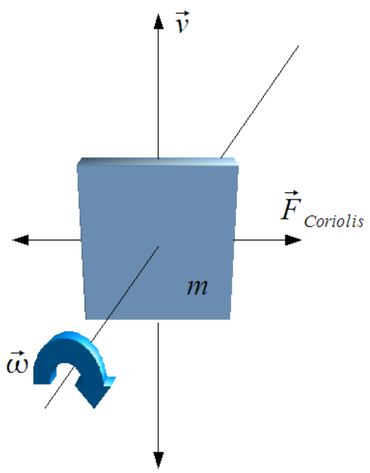


Figure 18: Coriolis force

The technique can be explained with a body with the mass m brought into vibration with the velocity $\vec{v}$. When the gyro is rotated with the angular rate $\vec{\omega}$, the mass will experience an additional displacement caused by the Coriolis force $\vec{F}_{Coriolis}$. The direction of this small displacement is perpendicular to the original displacement and to the axis of rotation [19]. The Coriolis force is given by:

$$\vec{F}_{Coriolis} = -2m(\vec{v} \times \vec{\omega}) \quad (1)$$

Various MEMS gyros architectures are available, using quartz, silicon or piezoelectrical ceramic for the vibrating resonator. The advantage of silicon is that it is more suitable for the Integrated Circuit (IC) Technology and the resonators are smaller than quartz ones.

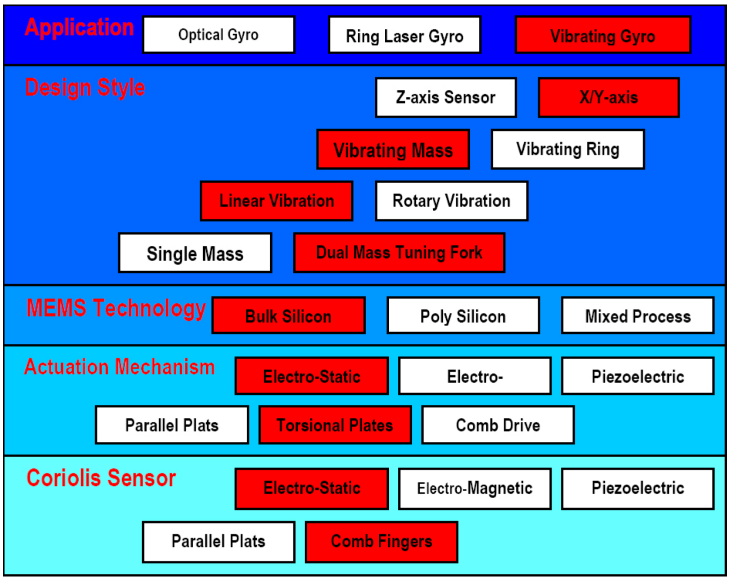
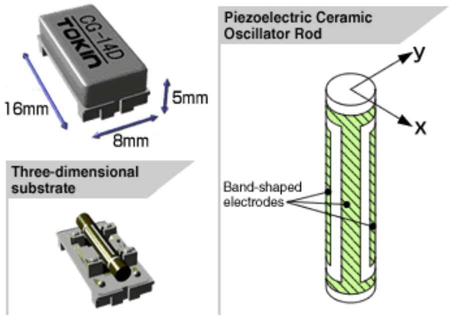
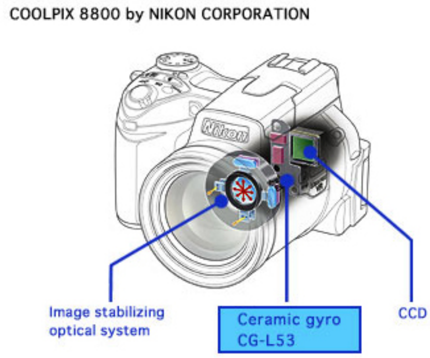


Figure 19: Variety of gyroscopic sensors [20]

For example, Nikon Coolpix 8800 uses gyroscopic sensors CG-L53 by NEC TOKIN (similar to the gyro shown in Figure 20). These sensors utilize piezoelectrical ceramic in the vibrating resonator.



(a)



(b)

Figure 20: (a)NEC TOKIN CG-14D (b) Nikon Coolpix 8800 [20]

A vibrating gyroscope (Figure 21) generally consists of a resonating mass, flexibly mounted in a frame (e.g. with some springs). This frame is also flexibly mounted on a substrate, moving perpendicularly to the resonator's motion. The mass and the substrate are fabricated from silicon and the mass can only oscillate along one direction. Both inner frame and substrate have sensing elements to detect the amount and direction of Coriolis force, measuring the change of capacitance in between. The capacitance changes accordingly to the change of the gap between the “sense fingers”.

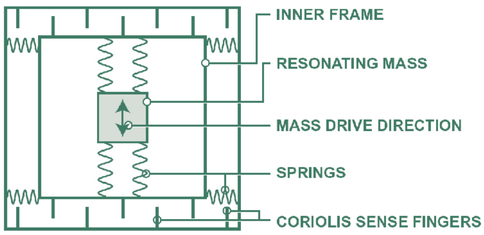


Figure 21: Schematic of the gyro’s mechanical structure [21]

The gyroscopic precession – the reaction of a gyro to a tilting force – is illustrated in Figure 22. When the gyro is rotated, the vibrating mass is exposed to the Coriolis force, which causes a secondary vibration orthogonal to the original oscillation and to the axis of rotation (compare Figure 18).

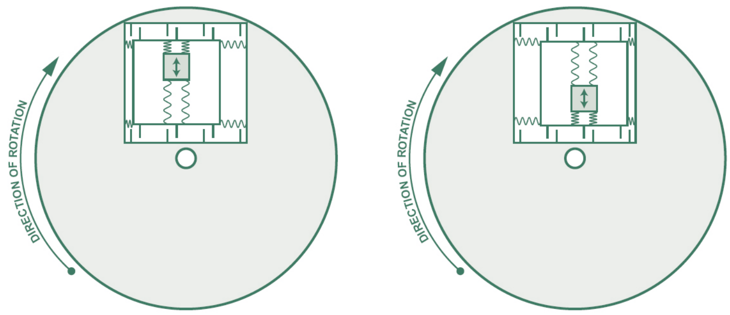


Figure 22: Gyroscopic precession [21]

An architecture of such a single axis sensor could look like the illustration in Figure 23.

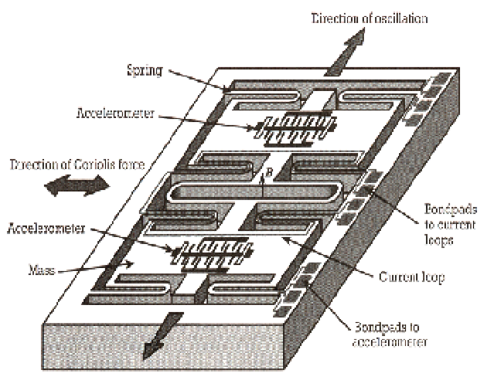


Figure 23: Yaw-rate gyro by Robert BOSCH GmbH [22]

A gyroscope with one sensitivity axis (e.g. X-Gyro), can also be utilized to measure other axes by mounting it referring to the desired axis (Figure 24). This illustrated gyro is a yaw-axis gyro, but positioned the other way, it measures the rotation about the roll axis. There are also gyroscope ICs able to measure rotation of about up to three axes. Admittedly they are too expensive for consumer electronic applications.

The output is measured in millivolts per degree per second (mV/deg/s). The sensitivity of MEMS gyros varies according to application range. For example the single axis sensor used in Nikon Coolpix 8800 detects motion in a range of 0.1° to 1500° per second and outputs 0.66 mV/deg/s [23]. The power consumption of gyroscopes used in consumer electronics is lower than 10mW. They cost less then $10, having worldwide annual quantities of over 1 million pieces. Compound annual growth rate is about 15% (according to Yole Development & Wicht Technologie Consulting / Nexus) [22].

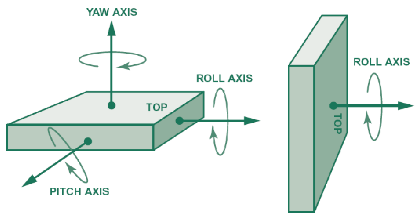


Figure 24: Mounting of a gyroscope [21]

2.3 Blur

Blur is “something vaguely or indistinctly perceived” [24]. Image blur can be categorized into motion blur and out-of-focus or defocus blur.

In the case of out-of-focus blur, only objects in the focal plane are captured sharp. Other objects are blurred proportional to their distance from the focal plane. Due to this fact defocus blur can provide useful information about the depth in the scene.

Handshake causes motion blur due to the camera's motion relative to scene object(s). That is the reason why motion blur is more relevant with regard to the image stabilization and is treated in greater detail here.

Motion blur is related to the exposure time. If this time is long enough for the points in the scene to move far enough relative to the camera, then their corresponding projections on the image plane also travel several pixels. That way several scene points are projected onto a single pixel during the exposition. They all contribute to this pixel's final brightness. This one-dimensional blur only exists along the moving direction [25].

Formally this process can be expressed as

$$P_{i,j} = \frac{1}{k} \sum_{n=1}^{k} C_n \tag{2}$$

with

$P_{i,j}$ - brightness value of the pixel with coordinates i, j

$C_1 \ldots C_n$ - brightness value of the scene point k

k - amount of scene points contributing to blur

A blurred image $b(x, y)$ can be mathematically described as a result of convolution of the sharp image $i(x, y)$ with the Point Spread Function (PSF) $h(x, y)$ of the imaging system (Formula 3).PSF is an imaging system's response to an ideal point source input. In this way PSF describes the transfer properties of the system.

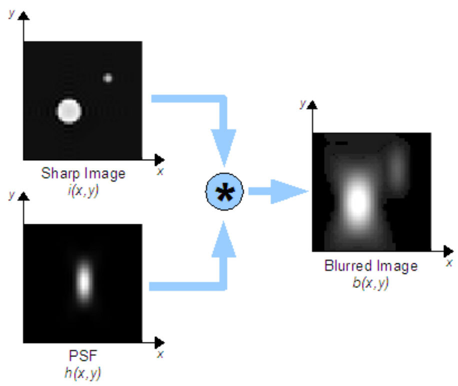


Figure 25: Convolution of a sharp image with a PSF

$$b(x,y)=i(x,y)*h(x,y) \tag{3}$$

Motion blur is characterized by its angle α and length $d=V_t\times T_e$. The length describes the amount of scene points affecting a single pixel. PSF of motion blur can be written as

$$h(x,y)=\begin{cases}\frac{1}{d}, & 0\leqslant|x|\leqslant d\cdot cos(\alpha) \quad y=d\cdot sin(\alpha)\\ 0 & otherwise\end{cases} \tag{4}$$

2.4 Modulation Transfer Function (MTF)

The “Fit Method” (to determine the spatial resolution of digital cameras) is used for blur estimation in this work. This method was developed in cooperation of Cologne School of Applied Sciences and Image Engineering Dietmar Wueller, in the context of a diploma thesis by Anke Neumann. The result of this method is a diagram of the Modulation Transfer Function (MTF) - contrast curves plotted against the spatial frequencies.

MTF describes a contrast decreasing extent in a output spectrum compared to the input. The two methods to measure MTF described in ISO 12233 have several disadvantages. The visual evaluation method's results can vary depending on the person performing the measurement. The Spatial Frequency Response method (SFR) provides moderate results using consumer digital cameras if they have no access to the raw image data and if the automatic sharpening function can not be disabled [26].

The test chart used in this work consists of nine identical Siemens stars ordered in three rows. The stars are periodically sine modulated in the radial direction (Figure 26). Sixteen gray fields in the corners of every star provide a reference for linearizing the image data according to the Opto-Electronic Conversion Function (OECF). The black and white sectors in the middle provide an additional high-contrast area for the camera's auto focus.

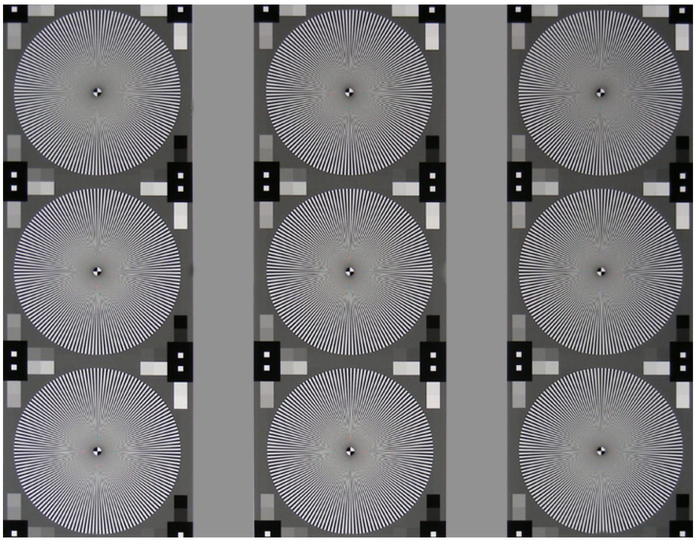


Figure 26: Test chart

The evaluation of the middle star is made with a MATLAB based software by Image Engineering. Once the image is read, the OECF determination occurs using the gray fields in the corner. Due to the OECF values, the pixel value data is linearized.

The linearized image is divided into 24 segments and many radii. For each segment and each radius the closest pixels to the radius are located avoiding interpolation, to achieve better results (Figure 27). Their positions (angles) and values are stored in the software for further evaluation.

The twenty-four segments are then summarized to eight, averaging pixel values of every three neighboring segments. These bigger segments are used for the resolution measurement in four directions – horizontal, vertical and two diagonals.

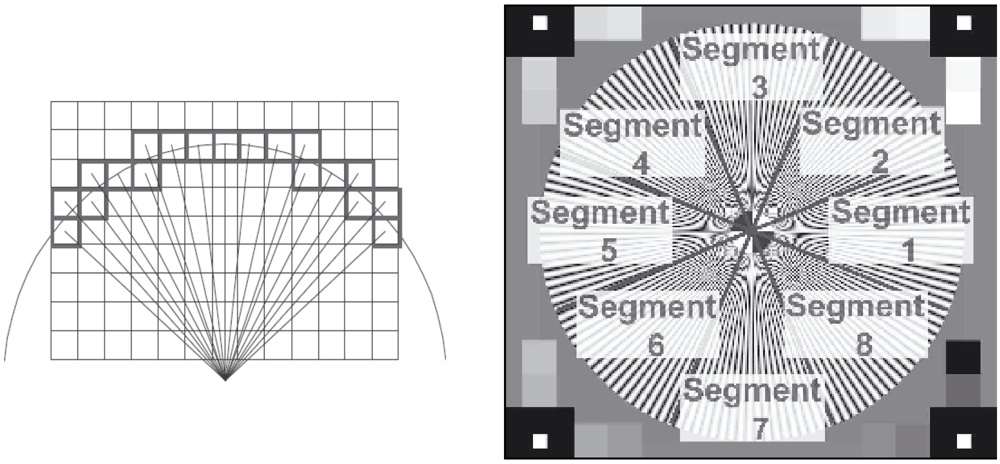


Figure 27: Pixel localization and averaging of segments[26]

The digital values of the pixels are plotted against their angles, which results in a “noisy” sine wave (Figure 28). A regular sine curve is fitted into the plot with least minimum error. This sine wave is later evaluated for the MTF calculation.

This procedure is done for every segment in the Siemens star. Formally the function of this regular harmonic sine wave is given as

$$f(x) = a + b \cdot cos\left(\frac{2\pi}{g} x\right) \tag{5}$$

with a representing the mean value, b the amplitude and g the spatial period in the sine signal (Figure 28).

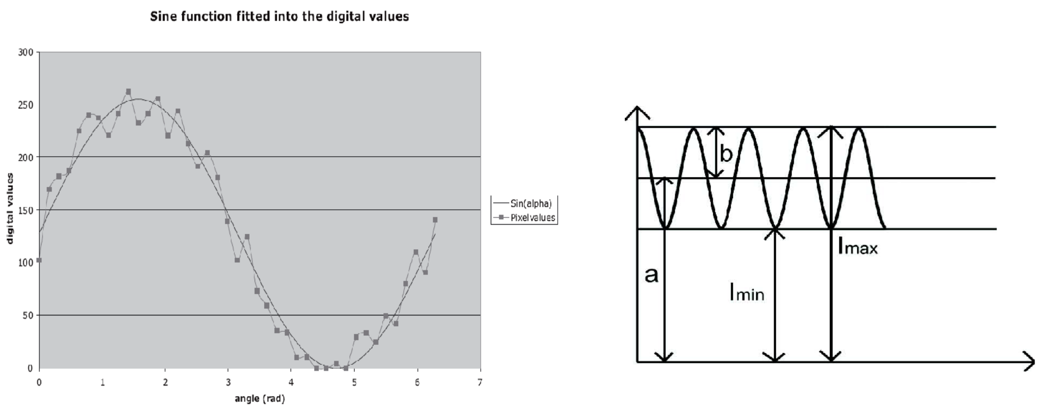


Figure 28: Sine function fitted into the digital values [26]

The intensity as function of the angle is respectively described as

$$I(\phi)=a+b\cdot cos\left(\frac{2\pi}{g}(\phi-\phi_0)\right) \quad (6)$$

The angle belonging to the pixel can be calculated as

$$\phi=arctan\left(\frac{x}{y}\right) \quad (7)$$

where x_0 and y_0 stand as reference for the coordinates of the center of the image. Because the phase of the sine signal in formula 6 is not known, an approximation has to be made [27]:

$$I(\phi)=a+b_1\cdot sin\left(\frac{2\pi}{g}\cdot\phi\right)+b_2\cdot cos\left(\frac{2\pi}{g}\cdot\phi\right) \quad (8)$$

Then b can be calculated as:

$$b = \sqrt{b_1^2 + b_2^2} \tag{9}$$

After a and b have been calculated, the modulation can also be determined according to following equation:

$$Modulation = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} = \frac{a + b - (a - b)}{a + b + (a - b)} = \frac{2b}{2a} = \frac{b}{a} \tag{10}$$

The MTF is then given as the quotient of the modulation in the captured image and the modulation in the test chart.

$$MTF = \frac{Modulation_{Image}}{Modulation_{TestChart}} \tag{11}$$

3 Tremor

To understand the functionality of image stabilizing systems it is important to know some basics about handshake – the reason for the existence of such systems. Research into the nature of human handshake was the first step for designing stabilizing systems.

All humans, not only those with various diseases but even absolutely healthy individuals tremble more or less under certain circumstances [1]. In medicine this phenomenon is also known as tremor, which is the most common movement disorder. Tremor is a rhythmic, involuntary, oscillatory movement of body parts [28]. It can occur in isolation or as a part of a clinical syndrome. Tremor comes into being when muscles contract and relax repetitively. Involved body parts are usually hands, lower arms and head. There are more than 10 various pathological tremors [29]. Probably the best known tremors are symptoms of Parkinson's disease or multiple sclerosis. They are signed by uncontrollable shaking movements.

3.1 Physiological Tremor

Healthy people also exhibit a so-called normal physiological tremor which is not pathological in its nature. Most of the people are unaware of this phenomenon, because it is usually not visible [28]. This kind of tremor affects both men and women regardless to their age. Physiological tremor can be classified as an action postural tremor which means that it occurs in action, while a limb (e.g. an arm) is maintaining position against gravity (e.g. holding a photographic camera). That is why it is important to understand why and how handshake happens.

Physiological tremor is characterized by relatively high shaking frequency of 8-12Hz, which is rather constant, and variable amplitude. There are many ways to diagnose tremors such as electro-physiological determination (e.g. positron emission tomography (PET), single photon emission computed tomography (SPECT)) [1] or magnetic resonance imaging for checking brain function. Probably the simplest way to observe tremor is to hold a laser-pointer in an outstretched hand and to watch the laser-ray trace.

Usually physiological tremor is not a bother and can't even be seen by the naked eye. But it can be exacerbated by some factors. First there are some medications (e.g. anti-depressants or anti-psychotics) which can intensify tremble activity. Some stimulants and toxins like caffeine also have similar effects. And finally there are physiological (e.g. narcotic or alcohol withdrawal, hypoglycemia) and emotional (e.g. excitement or fright) states, which have a negative impact on tremble as well.

3.2 Amplitude Measurement

Physiological tremor comes into being due to various factors such as mechanical-reflex system and external disturbance [2]. Many attempts have already been started to measure tremor amplitude. There have been studies using accelerometers, digitizing tablets, methods that mimic micro surgical techniques and laser-based systems [2].

Many studies focused on single joints such as wrist or did not treat the case of mechanical load held against gravity like holding a photographic camera. This fact makes a measurement necessary, which has been adapted to a specific tremor characteristic while taking photographs.

The objective was to measure the amplitude of physiological tremor in the upper limbs exhibited by healthy normal persons holding a camera in their hands. The methods should be as simple and comprehensible as possible.

3.2.1 Subjects and materials

Six normal healthy persons aged 17-35 years were studied. None of the subjects had visible pathologic tremor symptoms. No subjects were taking any medication known to suppress or exaggerate tremor.

A laser penlight weighting 35 g was used for this experiment. A DIN A3 landscape formatted target, consisting of a grid with 1x1 cm squares was used. In the middle of the target, a cross rule with millimeter-steps was used for further evaluation of the laser light path. The width of the laser light at the target was about 1 cm at the distance used in the study.

For the evaluation of results a mask file was made. This mask consist of five concentric circles. The diameter of the smallest circle is 3.49 cm. The other diameters are larger with factors 2 to 5. These circles correspond to the 0.2° to 1.0° deflection, referring to the distance between the test person and the target. The mask layer was placed over the photographs and made the evaluation with a graphic editor easier.

Two digital photographic cameras were used to observe the tremor amplitude under three different conditions. A Nikon D2X with AF-S Nikkor 17-55mm 1:2,8 G ED represented a heavy DSLR with an average size lens. In this case the camera is held with both hands and additionally stabilized by the head of the test person looking through. Nikon Coolpix 8400 was representative of a viewfinder camera and was used in two ways – aiming the target through the viewfinder and using the LC-Display. In both these cases, the camera was held with one hand only. The difference between them was the additional stabilization by the head while using the viewfinder.

Another digital viewfinder camera, HP Photosmart R927, was used to take photographs of the laser light path on the test target.

3.2.2 Protocol

Test subjects stood 10 m from the target – far enough to achieve desired accuracy of measurements. This is the distance used for the calculation of the circle sizes in the mask file. They held the cameras either with both hands (Nikon D2X) or with their dominant hand (Nikon Coolpix 8400), aiming at the center of the test target. The path of the laser light was captured with the HP Photosmart R927 fixed on a tripod. For measuring the maximum amplitude, an exposure time of 5 s was chosen to integrate the light path deflection over a longer time period.

Each person was tested under three different conditions described above. The three trials were spaced at intervals of 3 minutes.

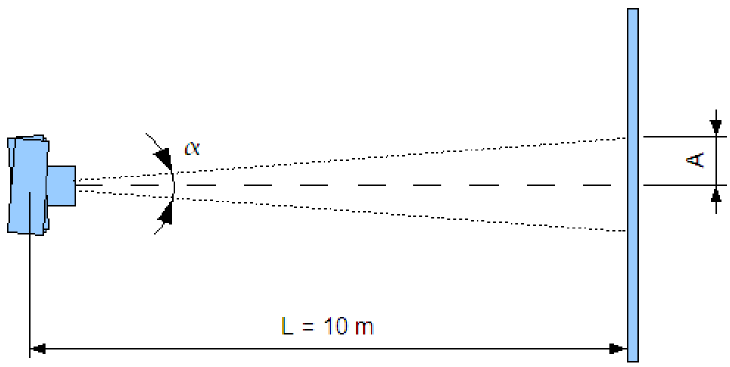


Figure 29: Measurement of the angular amplitude

The maximum amplitude was measured, evaluating the photographs with help of the graphic software Adobe Photoshop CS and OpenOffice Draw 2.0. The ratio between the maximum deflection of the light path from the center of the target A and the distance between the test person and the target L was calculated (Figure 29). The degree of deflection is given by the arctangent of this value. The evaluation mask gave a quick overview of deflection's dimension.

$$\alpha = 2 \cdot \arctan\left(\frac{A}{L}\right) \quad (12)$$

3.2.3 Results

The images were visually evaluated using the mask, and the estimated angle values were averaged. Figure 30 illustrates one test image superposed by the evaluation mask.

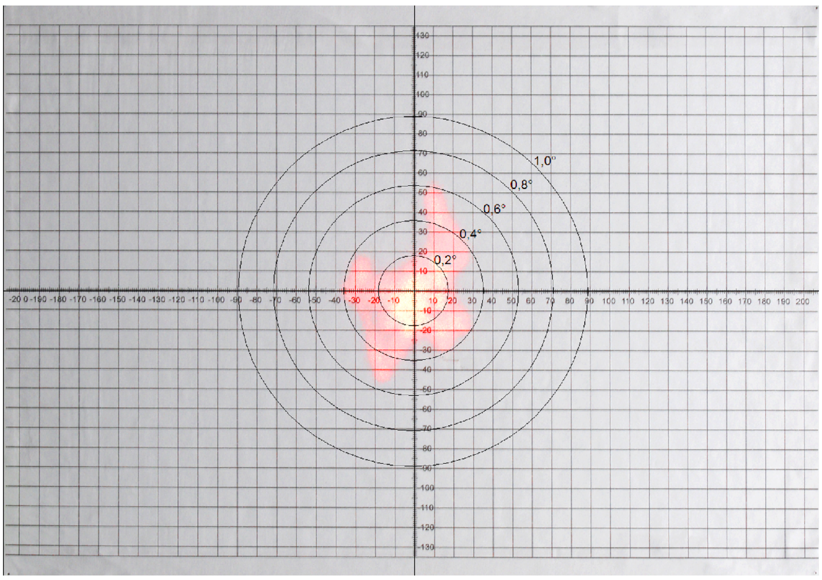


Figure 30: Exemplary test image - Nikon D2X, 5 s exposure

It is evident that in this case the maximum angular amplitude amounts nearly 0.6 degrees. After the evaluation, the maximum required angular travel of the vibrating unit of STEVE was approximated to 0.01 radians, which is nearly 0.57 degrees.

Table 1: Measurement of the maximal tremor amplitude

Test Person	Nikon D2x		Nikon Coolpix 8400 (LCD)		Nikon Coolpix 8400 (Viewfinder)	
	Yaw, °	Pitch, °	Yaw, °	Pitch, °	Yaw, °	Pitch, °
1	0.4	0.6	0.4	0.4	0.8	0.8
2	0.5	0.3	0.4	0.4	0.4	0.5
3	0.4	0.3	0.6	0.6	0.5	0.5
4	0.4	0.5	0.4	0.6	0.5	0.5
5	0.4	0.6	0.4	0.6	0.4	0.4
6	0.5	0.5	0.4	0.5	0.5	0.5
Mean Value	0.43	0.47	0.43	0.52	0.52	0.53

Mean Yaw:	0.46°
Mean Pitch:	0.51°

3.2.4 Discussion

The test method described above is generally applicable when measuring the maximum angular deflection holding a camera in the hand. The estimation of the amplitude of a single tremor oscillation is not possible due to the long time exposure of five seconds. To measure this quantity, it is necessary to choose shorter exposure time to match the tremor frequency. The tremor has its peak value at about 8-12 Hz frequency (see chapter 3.1 Physiological Tremor). The required exposure time is respectively 1/10 s. This part of amplitude analysis was omitted due to measurements made by engineers of Ricoh Company Ltd. and published in the US Patent No. 20020163581 - "Imaging apparatus, and method and device for shake correction in imaging apparatus". Figure 31 shows exemplarily the determined angular camera displacement due to handshake with respect to the camera axis.

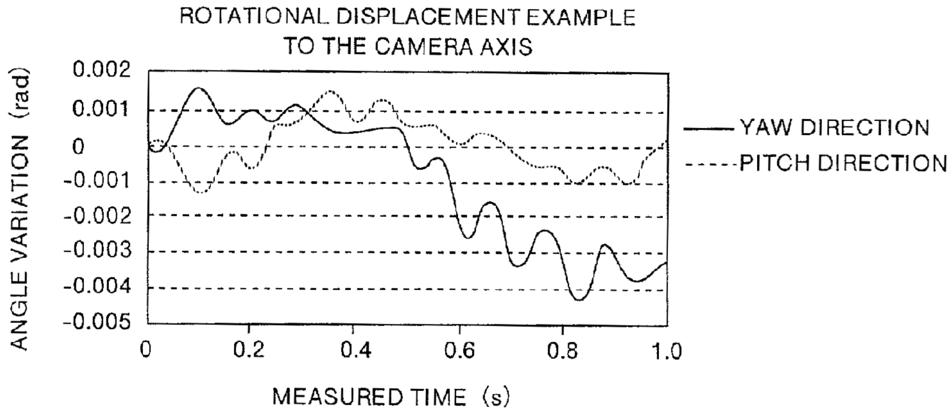


Figure 31: Angular camera displacement due to handshake [11]

The displacement in this measurement amounts to nearly 0.002 rad, which is approximately equivalent to 0.115 degrees.

4 Test Bench

The following chapter describes the determined specifications of STEVE as well as basic considerations of the design. The physical fundamentals and the calculations of mechanical properties are discussed in detail. Furthermore, the essential design components are reviewed.

The last section handles the completion of the design, including some mechanical details attention has to be paid to. The configuration of the control unit and the structure of the program files is also treated.

4.1 Specifications

The vibration unit is designed for the reproducible simulation of human handshake. In connection with the measurement of the resolution of captured images, it is used to analyze the quality of stabilizing systems. It does not matter, which one of the methods described in chapter 2.1 Image Stabilizing Systems is used to compensate for handshake.

The device shakes the camera in defined directions[2] with user-defined frequency and amplitude. It is possible either to simulate handshake about two axes simultaneously or to use only one single motion direction.

The controlling of STEVE and parameter inputs are effected by the user via computer.

The vibration unit operates within the frequency range of 0..15 Hz and is able to achieve angular motion amplitude of more than 1°. It

[2] „Pitch“ - rotating about the horizontal axis and „Yaw“ - rotating about the vertical axis

suits both light weighted and heavy DSLR cameras and provides enough space to mount any kind. It is possible to adjust the mounted camera to match its center of gravity in order to achieve reproducible motion.

4.2 Calculations

4.2.1 Moments of Inertia

Moment of inertia in the rotational motion is an analog of mass in the translational motion – it quantifies the inertia of a rigid body with respect to the motion. The mass as quantity is not enough to describe how difficult it is to induce a rotational motion about a certain axis. The distribution of this mass with respect to the axis of rotation is also important. The moment of inertia must therefore be specified for each chosen axis. In general, the moment of inertia I for a point mass m with the perpendicular distance to the axis of rotation r is defined as

$$I = mr^2 \tag{13}$$

For the body consisting of n mass points it is

$$I = \sum_{i=1}^{n} m_i r_i^2 \tag{14}$$

When the mass is continuously distributed it is

$$I = \int r^2 \, dm \qquad (15)$$

Since the integration for complex bodies is very time-consuming, already derived equations (e.g. equations 16 below), provided by technical literature, make it easier to calculate the moments of inertia by approximating the observed rigid body to a simpler one, e.g. a solid cuboid. Figure 32 shows such a cuboid with the rotational axes through its center of mass perpendicular to the surfaces and the side lengths a, b and c.

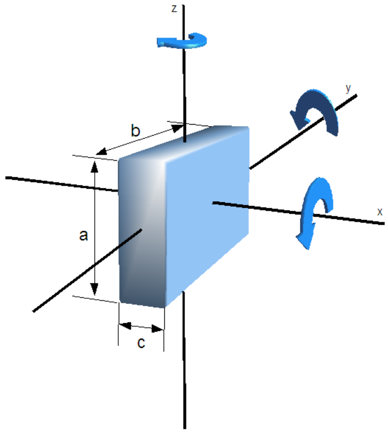


Figure 32: Cuboid with its axes of rotation (according to [30])

The equations (16) describing its moments of inertia were partially used for the aluminum profile elements in the construction.

$$\begin{aligned} I_x &= \frac{1}{12} m_{total} (a^2 + b^2) \\ I_y &= \frac{1}{12} m_{total} (a^2 + c^2) \\ I_z &= \frac{1}{12} m_{total} (b^2 + c^2) \end{aligned} \qquad (16)$$

To determine the moment of inertia about any other axis, the parallel axes theorem can be used. This theorem is often referred to as Steiner's Theorem. When the moment of inertia of the body about the axis through its center of mass M is I_M, then its moment of inertia about a parallel axis in distance d is given by

$$I = I_M + md^2 \tag{17}$$

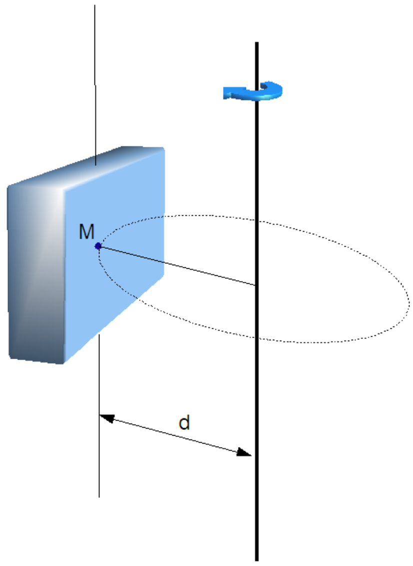


Figure 33: Parallel axes theorem (according to [30])

To calculate moments of inertia for a complex body about a certain axis it can be split up into several simple bodies, the moments of inertia calculated for each one of them according to the parallel axes theorem and then the partial moments of inertia added up.

5 Conclusion

The aim of this diploma thesis was to develop a reliable test method for the measurement of efficiency of image stabilizing systems integrated into digital still cameras or lenses.

An analysis of the functioning of recent stabilizing systems was performed. Further studies and measurements of human physiological tremor were carried out in order to define basic conditions for the tests. The gathered findings provided a basis for the design of a mechanical device simulating human handshake. A prototype device called STEVE – Stabilizer Evaluation Equipment – was constructed.

Several initial tests were performed on STEVE in order to achieve oscillations comparable to human handshake. Several cameras were exemplarily tested to demonstrate the workflow.

The test results pointed out the limits of recent stabilization systems. The oscillations with the angular amplitude of 0.2° can barely be stabilized when combined with handshake frequency of 10 Hz.

A closer examination of different stabilizing concepts and a reliable comparison was not possible during the time which was available for this work. This should be reviewed once more in detail.

An improvement of the test method can be achieved when considering the suggestions below.

First, more detailed examinations on different subjects with different camera types (SLR or compact) should be performed to determine statistically firm handshake properties. In order to do this, some additional equipment such as an accelerometer would be necessary.

An automatic release of camera's shutter would decrease the testing time, advancing the workflow. If connected to the control unit the shutter release can be actuated in the exact moment when the oscillation parameters (velocity and acceleration) conform to requirements. This would make the test results more comparable. An additional permanent effort of measuring the shutter delay would be caused by this improvement. This delay time must be considered when actuating the shutter release button.

A graphical user interface (GUI) can be developed to simplify user parameters input and program updates of the control unit. Full automated tests combining automatic shutter release and controlling program, simulating different oscillation conditions in series, would be possible.

A visualisation concept for the test results can be developed in order to represent the acquired MTF values in one single chart. For example, a 3D surface chart is imaginable, representing the dependance of the resolution limit frequency, providing only 10% of the contrast on oscillation's amplitude and frequency.

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