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Automatic exposure control in network video cameras

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Automatic exposure control in network video cameras (Automatisk exponeringskontroll för nätverkskameror)

Abstract
The overall objective of this study is to describe, analyse and suggest improvements on existing automatic exposure control systems in selected network video cameras. Since an image sensor has a limited dynamic range[1] compared to a real scene[2] , it is necessary to automatically control the exposure level and thus adapt to the amount of light in the scene. This can be done by adjusting parameters such as exposure time, gain and variable aperture in an automatic control loop. The two cameras in this study run different implementations of such a control loop and the topic of this study is to test their performance, to review their implementation of automatic exposure control, to comment on their implementation from a theoretical stand point, and to suggest improvements. The most focus has been correction of integrator function or adding of integrator functionality to the controllers to remove steady state errors. Integrator windup was solved for two cases. Some other minor bugs giving unwanted behavior such ass finite word length in the integrators. Also improving gain scheduling and correction of clamping of signals are suggested. A suggestion for smear control improvement is to use feed forward the changes
when changes are needed to exposure, this enables to control faster and still limit the impact on the picture quality.

[1]The largest possible signal divided by the smallest possible signal a sensor can generate.
The largest possible signal is directly proportional to the full well capacity of the pixel and the lowest signal is the noise level when the sensor is not exposed to any light
[2]How the human eye comprehend to a scene

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Contents

Chapter 1

Introduction

1.1 Background

In our modern society network based camera surveillance technology is used in many different areas, ranging from property security to industry process supervision. In all areas image quality is the most important feature. Many factors influence the image quality, everything from sensor characteristic to image compression. One of the most important factors the automatic exposure system. Being able to automatically adapt to light changes in a scene is of crucial importance to retain a good constant image quality and, on the basis of this, an investigation and evaluation of such a control system is of utmost importance when it comes to development of new and better cameras.

1.2 Objective

The overall objective of this study is to describe, analyze and suggest improvements on existing automatic exposure control systems in selected network video cameras. Since an image sensor has a limited dynamic range [1] compared to a real scene[2] , it is necessary to automatically control the exposure level and thus adapt to the amount of light in the scene. This can be done by adjusting parameters such as exposure time, gain and variable aperture in an automatic control loop. The two cameras in this study run different implementations of such a control loop and the topic of this study is to test their performance, to review their implementation of automatic expo-

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[2] How the human eye comprehend to a scene

sure control, to comment on their implementation from a theoretical stand point, and to suggest improvements.
Introduction of a variable aperture in an automatic control system can be a challenge since some typical variable apertures have characteristics that can be hard to control. It is therefore of special interest in this project to analyze the impact such a component has on the control system.

1.3 Approach

This section will describe the approach, the alignment and the limitations of the project. Since the authors of the thesis did not have any theoretical background regarding camera technology and image processing, the first approach was to understand the fundamentals of them. The main parts of the project can essentially be divided into five parts.

1.3.1 Part 1. Literature studies

To understand the need of automatic exposure control and how it works, the first part was to study literature in this area. The studies involved fundamentals facts about digital video cameras and image processing. It was important to understand how a camera works, and how different camera parts affect the image quality, to be able to understand how an exposure system works. The camera studies involved parts as understanding how an objective, a shutter and a variable aperture works and how they collaborate to produce an image. The studies also involved basic facts about sensor characteristics, such as the difference between CCD and CMOS sensors.

It was also important to get basic knowledge of the effects image processing has on the final image quality and to understand this, studies of histogram structure, noise estimation, white balance and influences of image parameters such as the gamma curve was performed.

A lot of time was also used to search for facts about previous performed work regarding automatic exposure control, together with an variable aperture, but it did not result in any useful information. The interesting information had a tendency to be patent stamped and thus not available for the public.

1.3.2 Part 2. Analysis of exposure system

To understand the design of the exposure system and how the implementation actually works, the software had to be analyzed. The analysis was done on two different software, running on two different cameras. The cameras will further on be known as Camera 1 and Camera 2. Camera 1 is a high-performance fixed network camera, with a CCD sensor, used in areas with high demands on security, such as airports and bank offices (Figure 1.1). Camera 2 is a fixed dome network camera, with a CMOS sensor, and has a protecting dome case and is used in surveillance of areas such as schools and stores (Figure1.2). The cameras run different implementations of the exposure control but almost the same control for the variable aperture. Camera 2 uses a newer software which was under development during the project and as the project ran parallel with that, the authors had to check out a software release in the beginning of the project and then stuck with that release during the whole project, even if there were several software updates during the project.

The first step in the analysis was to read the implemented software code. All the code was written in the programming language C and as the authors did not have any experience in C, it took some extra time to understand the software structure.

To get an good overview of the the whole exposure system, two types of Unified Modeling Language diagrams was used, activity and class diagrams. The activity diagrams was used to get a good understanding of what is happen during an execution and the class diagrams was used to get a good overview of the most important classes and functions.

The code analyze of Camera 1 was the most time demanding part due to the very complex software structure. It has been developed during many years and many developers have been involved. It has resulted in large code segments and the analysis also showed that old code, which has no longer any function, is still left in the software. All this made it very complicated to understand the software design and a lot of time was spent on the software analysis of Camera 1. The software analysis of Camera 2 was however much more straight forward and as it was under development during the project, many people were up to date with the implementations which made the analysis much easier and less time demanding.

For the interested reader simplified activity diagrams can be found in Appendix A.

1.3.3 Part 3. Test of exposure system

To really understand how the exposure system works and what happens in the software during an execution, the cameras were tested in a light lab. The light lab consisted of a fixed scene and a lot of light sources that could

Figure 1.1: Fixed network camera

Figure 1.2: Fixed dome network camera

be turned on and off and in this way change the illuminance level [3] in the scene (Figure1). The testing was performed by changing the illuminance level in the scene and at the same time printing out debug data from the two cameras. The debug data was generated both from built-in debugging features and by own implemented debug code. The catching of debug code was different between the two cameras. On Camera 1 was a serial port used to collect the data stream while on Camera 2 the collecting was done directly through a network port. A network port was also used on both the cameras to flash new software[4].

After every software change the software had to be re-built to create a software file that could be used by the camera. The re-building was a very time demanding procedure and a lot of time was spent on changing parts in the software and then re-build and test the performance.

The tests were mainly performed as step responses, such as going from a really dark scene to a very bright scene. All tests were performed on two cameras for each camera platform to assure correct test results. There is three types of step responses that are of special interest in the project:

1. Large illuminance change - really dark to really bright

[3] Measure of the intensity of the incident light of a surface. SI unit = lux (lm/m2)
[4] Transfer and install a new software through Telnet

2. Medium illuminance change - really dark to medium bright

3. Small illuminance change - light bright to medium bright

A large change is when the illuminance level changes from 0 lux to 500k lux. A medium change is a change from 0 lux to 60k lux and a small change is when the illuminance changes from 40k lux to 60k lux.
To collect the debug data from the cameras a Linux computer was used which communicated with the cameras through a Serial port (Camera 1) or/and a network port (Camera 2). The data stream from the cameras was piped to a text file on the computer. The data stream consisted of more information than just the debug data and a bash script was used to sort out the unnecessary information and produce a separate text file for every debug parameter.

Examples of debug parameters:

Parameter	*Description*
y	Average brightness
err	Brightness discrepancy
$ctrl$	Variable aperture control signal
$ctrlint$	Variable aperture controller integral size
$DCactive$	Variable aperture control status
$ExpStatus$	Exposure control status
$inthp$	Exposure controller integral size
ix	Current exposure level
$SubStopLine$	Exposure time (measured in lines)
cbs	Smear algorithm status
$SmearRef$	Reference value smear

After the debug data had been collected it was analyzed in KST [5] and Matlab. Plots and analysis of step responses can be found in Chapter 5.

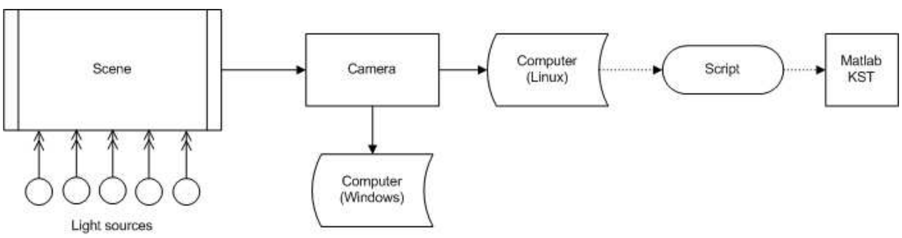

Figure 1.3: Test arrangement

[5]Linux program for plotting and looking at data streams

1.3.4 Part 4. Evaluation of exposure system

Simultaneously as the analysis and the testing were performed the exposure system was evaluated. The authors evaluated the structure of the software and the implementation of the algorithms on the basis of automatic control principles. The evaluation was not only done theoretical but also practical by changing parameters and limitation intervals in the software and testing the changes. The exposure and variable control was also inactivated to confirm their importance.

1.3.5 Part 5. Suggestion of future control systems

The last part of the project was to give suggestions on future control systems. Suggestions and thoughts about this can be found in Chapter 6. The suggestions are based on automatic control solutions and the work has comprised discussions and thoughts around different automatic control applications and usage areas. The work has demanded the authors to get to know about the exposure problematics and concurrently analyze and understand the demands the user has on a network video camera.

Focus has been on solutions that will optimize the two cameras usability and the work has involved solutions that will make the user more involved in the exposure behaviour and by this achieve the most optimal exposure control for a specific situation.

The most suggestions need a completely new control design and many factors beside the exposure must be taken into consideration. The suggestions should therefore really be considered as future suggestions.

1.4 Limitations

Due to the complexity of the project and the many different topics and possible angles of approach, the study has had several limitations to not deviate from the subject and keep focus on the project's objective . The project has had the following limitations:

- Analysis of exposure control and variable aperture control
- No investigation of exposure tables
- No analysis of image processing impact
- No analysis of communication between hardware and software

- No analysis of real-time aspects
- No implementation of new control algorithms

As the project has been limited to exposure control and variable aperture control it has not consider other control implementations, for example white balance control. The exposure control uses tables, with exposure time and gain values, to select the exposure level but the construction of these tables has not been investigated and the only information the authors has had is that the tables are discrete and linearized.

Image processing is a part that has a major impact on the image quality but as it has no impact on the exposure control, its impact has not been investigated.

The data communication between hardware and software is another part that has not been investigated and the authors has been been guaranteed data availability every new exposure and also real-time stability.

1.5 Thesis outline

Chapter 1 - Introduction

Describes the background, objective and approach of the project.

Chapter 2 - Theory

Describes the fundamental theory of digital network video cameras and automatic control principles.

Chapter 3 - Current control systems

Describes the current exposure system on the basis of how it is designed and how it works.

Chapter 4 - Improvements to current exposure systems

Contains suggestions of improvements to the current exposure system.

Chapter 5 - Suggestions to future exposure systems

Discusses future exposure systems.

Chapter 6 - Conclusions

Summarizes the thesis.

Chapter 2

Theory

2.1 Digital network video camera fundamentals

A digital network video camera is a combined camera and computer. It captures images and transmits them as a video stream over an IP-network. It consist of three main parts: an objective lens, an image sensor and an embedded system. Figure 2.1 shows a cross-section figure of a digital network camera.

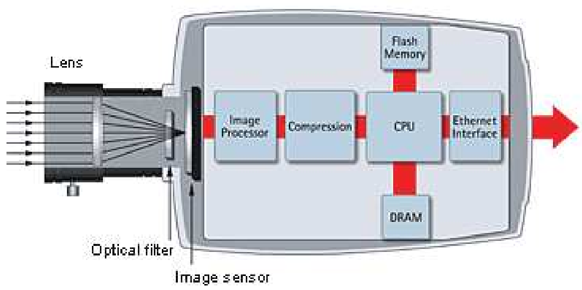

Figure 2.1: Cross-section of a digital video camera

2.1.1 Objective lens

An objective lens has the largest effect on the image quality. It consists most often of several lens elements, a shutter and a diaphragm. It has the functionality to direct the incoming light rays so the scene is recreated as accurately as possible on the image sensor. It has two main optical parameters; aperture size and focal length. The focal length determines, together with the size of the image sensor, the angle of view[1] (Figure 2.2). The focal length also decides at what distance, to the objective lens, an object must be to be in focus when the focal length is held constant. The distance from the lens to the object, and the distance from the lens to the image plane, are related to the focal length by the thin lens formula seen below. Where S_1 is the distance to the object, S_2 the distance to the image plane and f the focal length. Figure 2.3 shows the relationship.

$$\frac{1}{S_1} + \frac{1}{S_2} = \frac{1}{f}$$

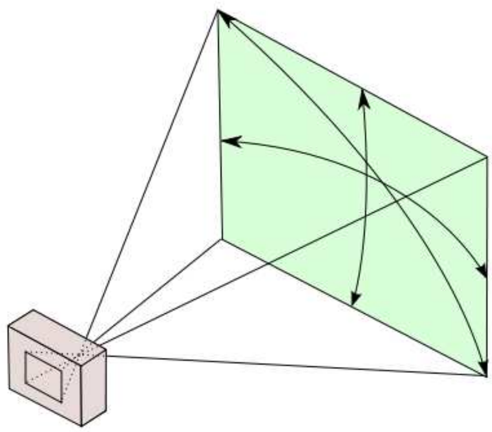

Figure 2.2: Angle of view

An objective lens has an opening in the beginning, an aperture, through which light is admitted. An aperture is most often variable and it consist of two or more variable metal blades that control the amount of light that reaches the image sensor (Figure 2.4). A variable aperture is commonly known as an iris and it affects, together with the focal length, the image depth of field[2](DoF). A small iris opening increases DoF and lets objects at a longer distance to be in focus, while a large opening decreases DoF and keep focus on objects close to the objective.(Figure 2.5). Depending on the optics different iris positions can also increase the resolution of lens.

[1]Measure of how much a lens converges or diverges incoming light

[2]DoF is a measure of how far away, or how close, an object must be, to the objective lens, to be in focus.

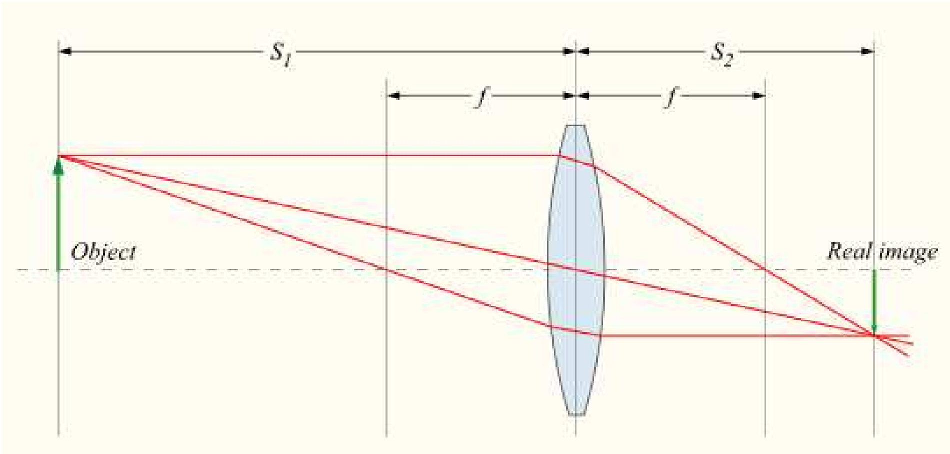

Figure 2.3:

An objective lens can also have a shutter which has a similar design as an iris, but instead of determine the amount of light that reaches the image sensor, it determines how long time the sensor is exposed to light. The shutter speed in an objective lens refers to the time the shutter is open and it is measured in seconds with standard speeds between 1/1000 s and 1 s. I this case there is no shutter.

An objective lens can introduce optical phenomenon such as spherical aberration. Spherical aberration is a result of imperfections in the lens. As the construction of a lens surface is different on the edge compared to the center, the refraction of the incoming rays becomes different and the rays do not beam together at the same focal point(Figure 2.5). The result is an unsharp image.

A other significant phenomenon is purple fringing. The reason for this is that different wavelengths of light bends different in the same medium. This gives a purple glow to certain parts of an image. This can be reduced buy shutting the aperture slightly.

2.1.2 Image sensors

An image sensor converts an optical image to electrical signals which an embedded system uses to recreate the optical image as accurate as possible. A sensor consists of many pixel sensors that capture the incoming light and convert it into electrical signals. There are two types of sensors; CCD and CMOS. The largest difference between a CCD and CMOS sensor is how a captured pixel value is converted. For a CCD sensor there are four steps in

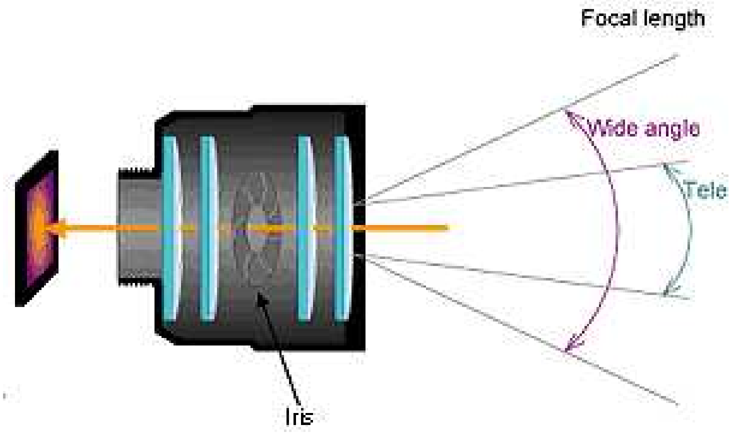

Figure 2.4: Variabel aperture - Iris

reading out a pixel value:

1. Convert light into electrons (Coulombs).
2. Transfer electrons across a chip to an analog amplifier.
3. Measure a charge at one corner of an array (Voltage).
4. Convert an analog voltage into a digital number, A/D converter (ADU).

The pixel readout for a CMOS sensor is almost the same but instead of summarize all pixel values at a corner of an array, a CMOS sensor reads every pixel value individually. As each pixel value can be measured individually a CMOS sensor can produce many different resolutions and it makes it more flexible. For example, by decreasing the resolution a higher frame rate can be achieved and it can be very useful in situations with lot of movements.

A CCD sensor has a large benefit in comparison to CMOS sensor. It is much more light sensitive and that is a major benefit in a noise perspective, especially when the environment is dark. The reason a CCD sensor is more light sensitive is that the image sensor is strictly used to capturing an image. In a CMOS sensor is noise filtering and other functions done in the same circuitry that captures the image and that reduces the light sensitivity.

A pixel has in an exposure point of view values that symbolize completely black and completely white. The values are often related to values between 0 and 255 in a brightness histogram.

If a pixel is exposed to too much light it can be saturated [3]. Saturated pixels give rise to smear or black-sun effects, depending of sensor type. Smear arises on CCD sensors and is visible as white vertical lines in the image (Figure 2.4). Black-sun is a phenomenon on CMOS sensors and as the the name indicates, the phenomenon turns the sun or other extremely bright light sources into black spots (Figure 2.5).

Figure 2.5: Smear effect

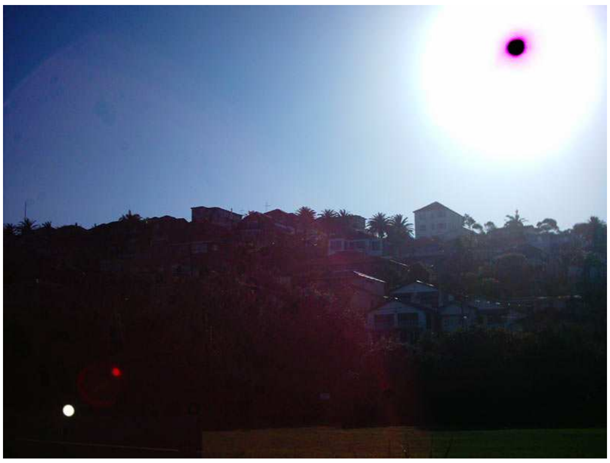

Figure 2.6: Black-sun effect

[3]Information overload which results in a completely white pixel

2.2 Automatic exposure control fundamentals

Automatic exposure control has the functionality to automatically adapt to luminance changes in the scene. The goal is to make the scene appear equally bright regardless of the illumination. The brightness in the scene shall also be comparable to what the eye comprehend to when looking at the scene. The luminance in a scene is measured by using a captured raw image file or by an internal light meter[4].

An exposure control system consists of three actuators; Exposure time, gain and a variable aperture (iris).

2.2.1 Exposure time

Exposure time is the main parameter in an exposure control system. It is proportional to time the shutter lets light reach the image sensor. How long the exposure time should be depends on the scene type. A bright scene needs a fast shutter speed (short exposure time) to avoid an over exposed image. A dark scene, on the other hand, needs a long shutter speed to produce an image.

Exposure time is also related to the blurriness in an image. If there is a lot of movements in the scene the exposure time needs to be short to avoid the image to be blurry.

2.2.2 Gain

Gain is the second important parameter in an exposure system and it is used for compensation of dark images in low-light situations.

A digital camera has both analog and digital gain. The digital gain is an image processing parameter and it is not affected by the exposure control. The exposure control uses only analog gain that is produced by an amplifier placed on the image sensor.

The impact of analog and digital gain differs between CCD and CMOS sensor, particular in low-light situations. A CMOS sensor has a larger benefit from increasing the analog gain in a low-light situation while a CCD sensor gives a similar result regardless usage of analog or digital gain.

A major drawback with gain is the noise raising in the image. A very large gain setting can also give rise to clipping. [5].

[4]Device to measure the amount of light in a scene.

[5]Loss of image information due to pixel saturation

2.2.3 Variable aperture - iris

An iris has the functionality to limit the amount of light that reaches the image sensor. It consists of several diaphragm blades that can be adjusted. The most common iris is a DC-iris and it is also the industry standard. A DC-iris is a variable aperture with an electrical direct current motor that opens and closes the diaphragm blades with a constant velocity. The motor has a galvanometer that measures small current changes which give sense winding signals that are used as a feedback in a control circuit. The feedback is a feedback of the velocity and it opens or closes the diaphragm blades with a constant velocity. The feedback makes the control motion smooth. This can effect the optical resolution and focus.

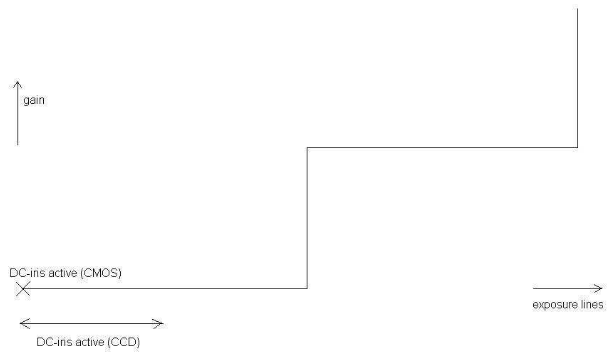

Figure 2.7: DC-iris activation

2.3 Automatic control fundamentals

2.3.1 Controller types

An ordinary control system has three standard controller types; P, PI and PID. The commonly used controller is a PI controller hence it has a simple but yet powerful implementation for the most control systems. It consists of a proportional part, P, and an integral part, I. The proportional part is a gain parameter that applies the current error in the calculation of a control signal. A controller with just a P-part is most often not enough because it always generate a steady state error. To compensate for this, a bias can be added but it is not an optimal solution because a bias does not fit all different control situations. A better solution is to use integral action. Integral action is essentially a low pass filtering of the output from the P-part that is added to the control signal. In other words, an integration of the error over a time period. The integral size depends on the structure of the control system. A large integral part consists of many old values and it will continue to grow as long as there is an stationary error. This will generate an extremely large integral term and it will take a considerable time for the term to reach a normal value. The result will be big overshoots. To avoid the integral to reach too high values, an integral time constant (Ti) can be added. The time constant decides how large influence the current and past errors should have in the calculation of the control signal.

A PI controller is in the most cases an adequate solution and adding a derivative action, a D-part, is often redundant. An introduction of a D-part is made to compensate for overshoots since a derivative term has the ability to anticipates the future and can through this make pre-decisions that will damp overshoots. The main drawback with a D-part is that it is very noise sensitivity and that can result in an unstable system. To avoid such problems a filter can be introduced that limits the influence of the term at high frequencies but allows it to operate normally when the frequencies are low.

The mathematical expression for a PID controller is:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}$$

where K is the gain parameters, e(t) the current error, $\int^t e(s)ds$ is the sum of errors and $\frac{de}{dt}$ the direction of the error.

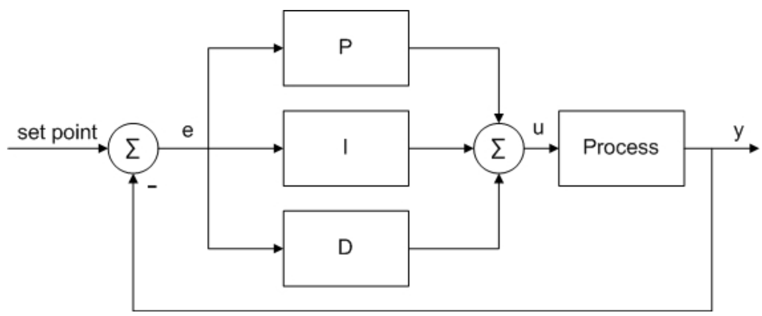

Figure 2.8: PID controller

P - K_p decides the control rapidness. A large K_p gives a fast response for a given change. A too large K_p may result in an unstable, oscillatory, system. On the other hand, a too small K_p results in no control at all and the system will not react on any small error changes.

I - K_i decides how fast the system can reach a steady-state. A large K_i eliminates steady-state errors faster but generates more overshoot.

D - K_d affects the damping of the system. A large K_d decreases overshoot but the transient response becomes slower and larger K_d is more sensitive for noise.

2.3.2 Anti-windup

Windup is a phenomena that occurs due to limitation of an actuator. All psychical actuators have limitations but limitations also arise on non-psychical actuators such as tables. A table has one maximum and one minimum value and a physical actuator as an Iris can not be more open or closed than fully open or fully closed. A PI controller in a saturated system will generate something called integrator windup. It occurs when the output error (e) is large and the control signal (u_c) can not change fast enough. In such a situation the integrator part will reach a very high value and it will remain even if the error reaches zero or if the error sign changes. It will take a considerable time for the integral to reach a normal value again. The result is a big overshoot, a saturated control signal in both directions and a delay in the error convergence. There are two different solutions to avoid such a scenario. The first one is a conditional integration, in other words, the integral part is only allowed to be used if the control signal, u_c, is close to a steady state position. Such a solution can be implemented with one or several conditions that must be fulfilled before the integral is allowed to be used. The solution has the drawback that it is neither easy to implement or efficient. The second solution is a method called tracking. It is easy to implement and it lets the integral part to be active all the time. The method detects when the output of an actuator is saturated and feed backs the difference between the control signal (u_c) before the saturation and the control signal (u) after the saturation to the integral term in the controller.

A control system with saturation and anti-windup tracking can be seen in Figure 1.2.

To avoid that the integrator part becomes very large, it can be reset dynamical with a time constant, T_t. A very small value on T_t may lead to a saturated output, due to spurious errors which leads to a unwanted

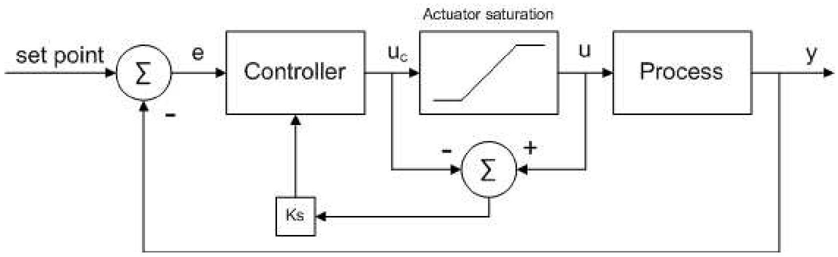

Figure 2.9: Saturated control system with anti-windup tracking

reset of the integrator. A very large value, on the other hand, gives a very slow reaction which results in a decrement of the controller performance. A common design choice is: $T_d = T_i$ or $T_t = \sqrt{T_i T_d}$.

2.3.3 Performance objectives

Automatic control analysis involves parts as rise-time, overshoot, stability, settling time and cost. Other important parts when designing a control system are manufacturability, computational complexity and reliability. How reliable a control system is depends on how often it fails. Control failure, like locking and incorrect control will directly affect the user and it is therefore important to have very reliable controller. It is much easier to achieve a reliable control if the implementation is simple and not to complex. A simple implementation needs also less computer power and memory assignation. Another interesting point is the manufacturability. The control system may have special requirements on the hardware which must be taken into consideration in the design. The control system may also be used on several products and therefore is adaptability important.

The following sections will focus on four main parts when analysing the current exposure system from an automatic control point of view.

The exposure control system is not a critical system. The only one that are affected by a slow or incorrect control is the user. A slow, unstable or incorrect control results in poor image quality. An optimal control for an exposure system should:

- find a correct exposure level in a minimum time
- have no overshoots
- be stable
- have a simple implementation

2.3.3.1 Rise-time

Rise-time is a measure of how fast a system reacts on changes. It is the time it takes for a system to reach a desired value after a perturbation. In an exposure system it is the time it takes for the exposure control to compensate for a luminance change in the scene. In other words, the time it takes for the actual luminance value to reach the desired value when it is a change in the scen. The set point in the exposure system seldom changes.

2.3.3.2 Overshoot

Overshoot refers to an output exceeding a final steady-state value. In an exposure system this is related to over and under exposure. When the light changes in the scene, the control system will compensate and it results in an overshoot. How big this overshoot tends to be depends on the chosen control strategy. A very fast control strategy will result in more overshoot than a slow control. As the overshoot is directly related to the brightness in the image, the user will be visible exposed to the overshoot and a damping of the overshoot is therefore of certain importance. .

2.3.3.3 Stability

The main stability criterion is that the system should not have any oscillations. Oscillations occur when the controller does not find a steady state level, in other words, it does not converge to the desired set point. An example of a situation where oscillations can occur is if there is small luminance changes in the scene and the exposure system tries to compensate for them. The result can be that the system constantly switches between two exposure levels and that will be visible as oscillation in the image.

2.3.3.4 Settling time

Settling time is the time it takes for the system to reach a steady-state point. With that, the fastness of the control system depends on the settling time. The settling time in an exposure control system is the time it takes to adapt to a luminance change in the scene.

2.3.3.5 Cost

Cost is an important factor when designing a control system. The cost of a control system must be put into relation to the performance of the system. A more expensive control system may not generate a noticeable improvement.

Parameter	*Rise-time*	*Settling time*	*Overshoot*	*Stationary error*
K_p	Decrease	Small change	Increase	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small decrease	Decrease	Decrease	None

Table 2.1: Effects of increasing controller parameters

The cost is related to the quality of actuators, sensors and other hardware that is necessary to implement the control system. A camera system that consists of many actuators and expensive components, such as a high resolution sensor, needs more computing power and that sets in its turn higher requirements on the system's hardware components. Therefore it is very important to put the cost in relationship to the performance to make an optimal controller design for a specific product. A basic idea when designing a control system is to choose a system that suits the particular application and implement is as simple as possible.

The first step in the design must be to set system requirements such as maximum overshoot and maximum settling time. The following step should be to implement the control system to achieve this requirement with as less actuators as possible and with as simple code structure as possible.

Table 1.1 shows the effects of increasing respective parameter in a PID controller.

Chapter 3

Current control system

This chapter gives a basic understanding of the control system in each camera. It describes how the exposure system is built up and how the exposure control and iris control are implemented. It also gives an insight in which classes and functions that are of most importance.

The luminance in a scene is measured by using a captured raw image file which is linear and can have an offset but it is not influenced by any image processing The raw image file consist of gathered pixel values from the sensor and an average brightness value is used as the main input signal to the system.

3.0.4 Exposure time

The exposure time is directly related to the frame rate in the video stream as long as the exposure time is longer than 1/30 seconds ($T_{exp} \gg \frac{1}{30}s$). An exposure time longer than 1/30 seconds decreases the frame rate which can result in a blurry image if the scene has a lot of movements. A dark scene generates lower frame rate than a bright because a short exposure time needs a bright scene.

The exposure time is measured in exposure lines where one exposure line is one row of pixels. The exposure time is then related to the time it takes to read out one row of pixels. How many lines, or row of pixels, an image sensor has depends on the sensor size. A wide image sensor consists of more lines than a small. Figure 3.1 shows an image sensor where each small square represents a pixel and the lines go vertically over the sensor. The total number of lines generates one frame (Figure 3.1) and it takes always one frame before a new exposure can be done. For example, if the total number of exposure lines is 1200 and the exposure time is set to 600 lines it will still take one frame before next exposure.

3.0.5 Variable aperture - DC-iris

The iris component is of the type DC-iris and it is only used when the scene is very bright. It has the functionality to compensate for smear and black sun effects. Depending on which sensor type the camera has, the iris is active in different intervals. For CMOS sensors the iris is only active when the scene is extremely bright and the exposure time is as short as one exposure line, $T_{exp} \leq 1$ exposure line (Figure 3.4). For CCD sensors the Iris is active more often and compensates for smear within a certain interval, $T_{exp} \leq 0,5$ frame time.

3.0.6 Interaction of the three actuators

The three actuators are only used one at a time. The first actuator to adjust is always the exposure time. It is the actuator that has the fastest response which does not introduce any noise [1]. The second one to adjust is the gain and it starts to increase when the exposure time is larger than one frame time, $T_{exp} \gg$ maximum exposure lines (Figure 2.7). Such a long exposure time indicates that the scene has a low light intensity and the gain has been increased to compensate for it. The gain is only increased up to a specific level, a noise threshold, where a further increment results in a decrement of the image quality, due to the noise amplification (Figure 2.7).

The last actuator to use is the variable apertures and it is only used when the scene is very bright and in such a situation the exposure time and gain are as small as possible.

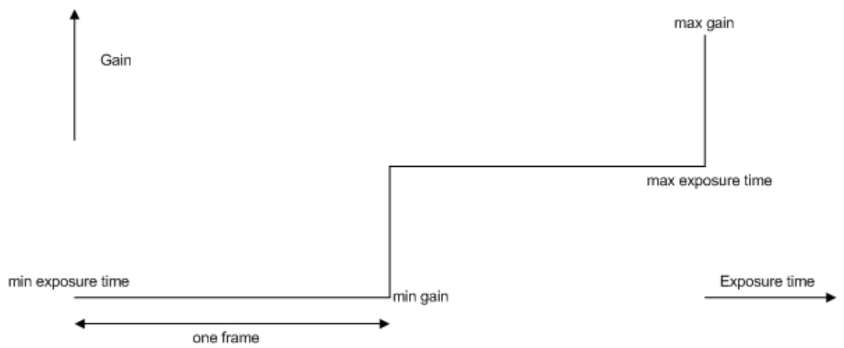

Figure 3.1: One frame

[1]Blur in the image is not considered as noise

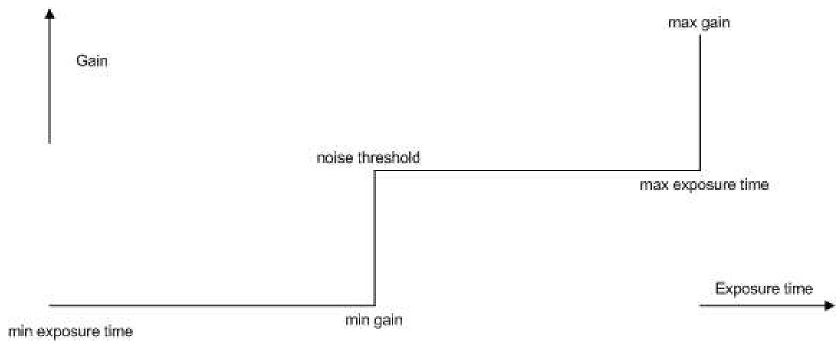

Figure 3.2: Noise threshold

3.0.7 Load disturbance based system

The control system is a system based on suppressing of load disturbances (Figure 3.5). The system has an almost constant reference value that the user selects. The user can select a value between 0 and 100 percent where 0 refers to a very dark image and 100 to a very bright image. The default value is 50 percent and it corresponds to a medium brightness, that has a value of 128 in a luminance histogram that stretches from 0 to 255 (Figure 3.6). As long as the scene has a normal brightness the reference value is constant but if the scene becomes very dark, the value is counted down to better represent the dark scene and reducing the noise level. The value is also recalculated if backlight compensation [2] has been activated by the user.

The disturbances that affect the system are luminance changes in the scene. The changes can be both transient and persisting and varying in size. They affect the system before the process and after the controller (Figure 3.7) which results in that the controller controls around old luminance values.

The controller consists of two different control loops, one for the exposure control and one for the iris control (Figure 3.8). A switch between the loops chooses which loop that should be used at the present time.

The output from the control system is the brightness in the image and it has a set point of 128 under normal settings and conditions.

[2]Compensation for light sources in the scene that are not well represented for the average brightness in the scene

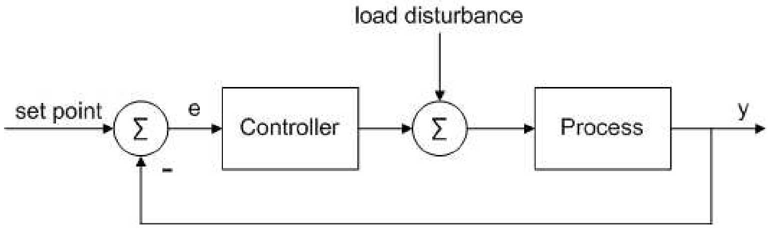

Figure 3.3: Load disturbance based system

Table 3.1: Input and output signals

Controller input signal	**Description**
r	Reference value
s	Smear value
blc	Backlight compensation value
Controller output signal	
t_{exp}	Exposure time
g	Gain value
i	Iris control signal
Process output signal	
y	Image brightness

3.1 Camera 1

3.1.1 MIMO controller and MISO process

The exposure system for Camera 1 consists of a Multi-input Multi-output (MIMO) controller and a Multi-input Single-output process (Figure 3.9). The controller has three in signals and three outputs and the process has one output (Table 1.2).

The output signal is a value of the average brightness in the image and it is taken directly from the sensor hardware. Before it is used in the control loop it is however recalculated to fit the current implementation.

The smear value indicates if there is smear in the image. If that is the case the value triggers a smear control loop to start.

The backlight compensation is a value that is used to compensate for light sources in the image that are not well represented for the entire scene. For example, if a person walks into a low-light room with a flashlight. Without backlight compensation the camera will believe that the entire scene has become brighter and the exposure control will start to adjust for it and the whole image will become darker and that is not a desired behaviour. Backlight compensation prevents this by calculating a weighted average luminance value based on saturated pixels. This value is then used as reference value for the system.

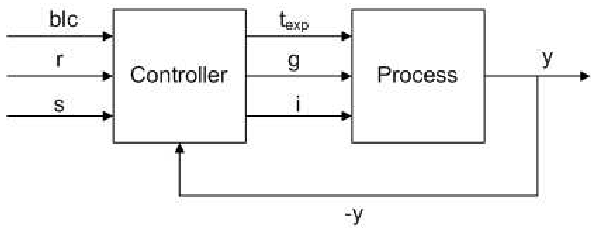

Figure 3.4: MIMO/MISO control system

3.1.2 Software structure

The software has many years on its neck and has undergone many improvements during these years. This has resulted in a very complex code structure that is far from straight forward to understand. Figure 3.3 shows the main classes and functions used in this project.

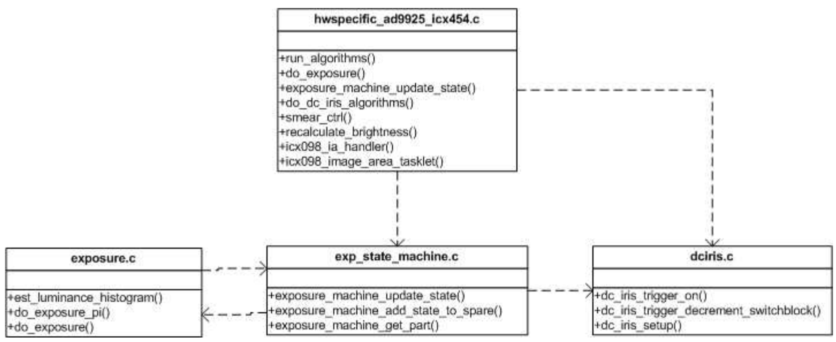

Figure 3.5: Class diagram Camera 1

The exposure control loop has a PI controller that generates a control signal which is used to search for a correct exposure level in the exposure tables. The control algorithm is called every time data is available from the hardware and the control signal (u_{exp}) is limited to be between -127 and

Table 3.2: Class table Camera 1

Class	Decription
hwspecificadd9925icx454.c	Main class. It determines the control strategy, if exposure control or iris should be used. It recalculates the average luminance value, if the current scene is too dark and it performs smear detection and calculation. The class is also responsible for writing data to the hardware
expstatemachine.c	Generates a state machine with five different states, A, B, C, D and E. It calculates the exposure index (level) and it calls the iris control.
exposure.c	Calculates the control signal for the exposure control and recalculates the average luminance value if backlight compensation is enabled.
dciris.c	The class to control the iris. It can be called from both *hwspecificadd9925icx454.c* and *expstatemachine.c* and it has the brightness error as input signal.

127. If there is a very large positive luminance change in the scene, u_{exp} sets equal to -127 and the exposure algorithm takes a very large step towards a shorter exposure time. This is done to get a fast control when the scene has large positive luminance changes. The large step is not used when there is large negative luminance changes because it may introduce oscillations in the image and that must be avoided in every possible way.

To determines the exposure level the control system is implemented as state machine based on interrupts. The machine has five different states; A, B, C, D and E. Each state is related to a table that can consist of both exposure time and gain or just exposure time values or gain values. The user can indirect choose which states that should be active and the table constructions through a graphical user interface in the camera s software. The indirect settings means that the user does not choose that a specific state should be active or a specific table construction but by setting for example maximum exposure time and maximum gain some of the states become active and some not.

When the scene changes the machine gets an interrupt and shifts state depending on the current change. It is possible to go from, for example, state A to state E or state B to E in one step. Figure 3.4 shows the state machine and Figure 3.5 shows how the states are represented in an exposure time and gain table. When the iris control is active the machine is in state A and then only the iris is used, not exposure time or gain. If the machine is in state B or D, exposure control uses a table with just exposure time to set the exposure level. When the machine is in state C or E the exposure control uses a table with only gain values to set the exposure level.

The controller has an anti-windup feature to avoid windup problems when the end of the exposure table is reached. When such a situation occurs the integral part is reset to zero. The feature uses a status variable that indicates if the end of the exposure table is reached or if the state machine is frozen. If the machine is frozen, the exposure level sets to a fixed level.

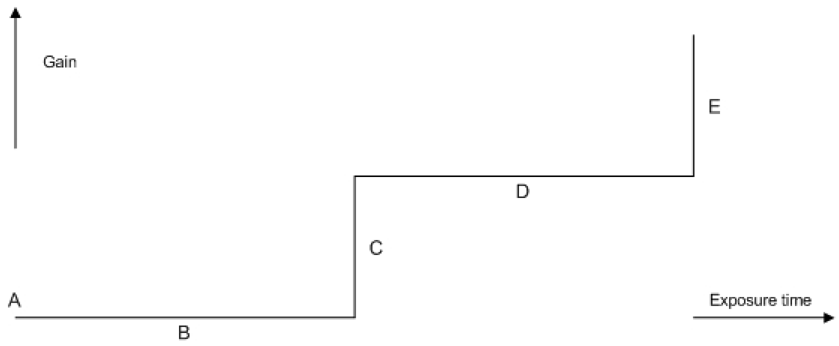

Figure 3.6: Exposure table

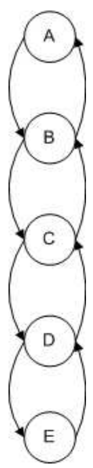

Figure 3.7: Exposure machine

3.1.2.1 Smear control

Smear control is used to avoid smear effects in the image. The effects are avoided by activating the Iris when the scene is very bright and letting it compensate for the high scene luminance by making the aperture opening smaller.

The smear control uses two smear windows located on the upper and right side of the image sensor (figure 3.6) to detect the smear. The windows are divided into fourteen sections which are individually compared with a reference window that is not exposed to any light.

The smear algorithm runs every time the exposure algorithm is called and it performs the following steps:

1. Reads the accumulated pixels in one of the fourteen sections and stores the values in an array
2. Iterates until all fourteen sections are read
3. Starts the smear calculation which searches for the largest value in the first array that is greater than the value of the reference window
4. If such a value exists it sets a smear value which is the difference between the found value and the reference value
5. Iterates until all smear is found or all fourteen arrays are searched

When smear is found the control loop starts. It uses an algorithm with two variables; one to change the exposure level for the next loop, if the Iris control is active, and one variable to start the Iris control if it is not already started. The algorithm introduces an error in the image by changing the exposure level which the Iris reacts on. As the Iris starts to close, to limit the amount of light, the exposure level must be changed to remain a correct brightness in the scene as less luminance needs longer exposure time and higher gain. The result is a hunting effect where the Iris hunts the introduced error and the exposure level is adjusted by one level each loop.

3.2 Camera 2

3.2.1 Software structure

The exposure control is done in an application, Imaged, outside the driver (Figure 4.1) instead of in module directly in the driver as it is for Camera 1.

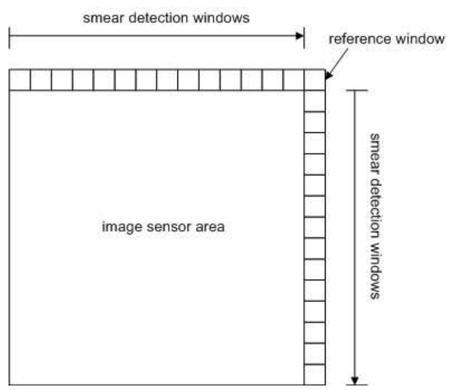

Figure 3.8: Smear detection

Imaged has the functionality to control both the exposure and white balance but this project is only investigating the exposure control.

Figure 3.7 shows the main classes and the most important functions.

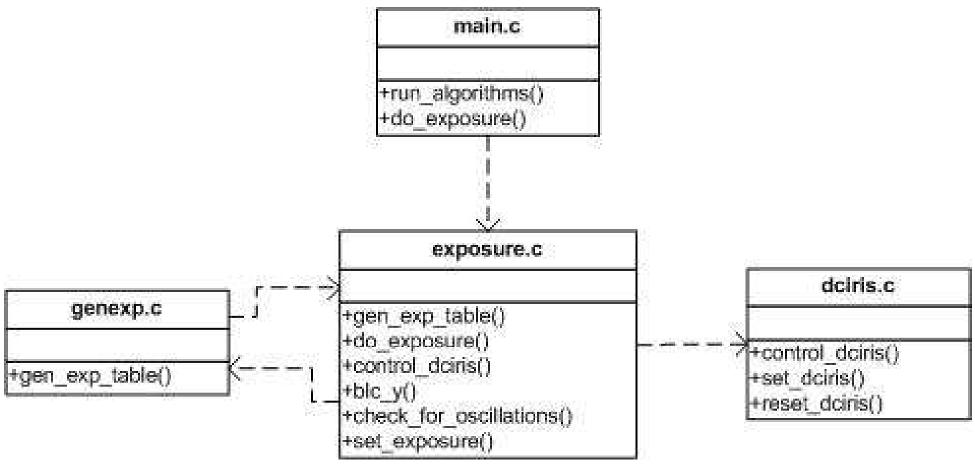

Figure 3.9: Beyond platform

As in Camera 1, the user affects the structure of the table by different settings in a graphical user interface. As in Camera 1 the control consists of two control loops, one for the exposure control and one for the control of the variable aperture (iris). The system can be seen in figure 3.3. The Iris is in this system is used when exposure and gain actuators have reached their limits. Figure 4.1 shows the exposure control together with the DC-Iris control. There is a switch between the two control loops to avoid the loops to be active at the same time.

Class	Description
main.c	The main class. It determines the control strategy, if exposure control or iris should be used. It recalculates the average luminance value, if the current scene is too dark, and it performs smear detection and calculation. The class is also responsible for writing data to the hardware.
genexp.c	Generates an exposure table with exposure time and gain values.
exposure.c	Does all calculations and sets the exposure level.
dciris.c	Controls the iris and it can be called from *exposure.c*. It has the brightness error as input signal.

Table 3.3: Class decription

3.2.2 Exposure control

The exposure control is done in the *exposure.c* class and uses the *genexp.c* class to generate the exposure table. It consists of several functions and algorithms and the control has a loop that checks for histogram data from the hardware. Every time data is available the exposure control is performed. The first step when data is available is to set a value of the brightness error[3], y_{diff}. After the calculation of y_{diff} the control checks for oscillations in the image and if oscillations are found the speed of the control is set to *slow*. The control has three different speeds;*slow*, *normal* or *fast*. *Fast* is used if the control error is is large and if the error is normal and there is no oscillations the speed is set to *normal*. After the control speed is selected, the control signal is calculated. If the image is completely white (over exposed) or completely black (under exposed) the control signal is set to predefined values. If the image assumes to be normal the control signal is calculated by some mathematical operations. After the control signal is set an exposure algorithm starts to search for a new exposure level in a table. Instead of having five tables for five different states, as in Camera 1, Camera 2 has only one table with all different exposure levels. The search through the table is linear and after finding an accepted level there is delay before the exposure is

[3]The deviation between the system's reference value and the brightness in the scene.

Control speed	Condition
Slow	$y_{diff} - \|q\| \gg beh$ (6 times in a row)
Normal	$y_{diff} \leq 100 \|\neq$ oscillations
Fast	$y_{diff} \geq 100$

Table 3.4: Control speeds

set. The delay is implemented to avoid changing the exposure level if there are very temporary disturbances.

The functions and algorithms to find and set the exposure level consist of many logical rules in combination with a P controller. Both the rules and the controller have several hysteresis implementations and limitations. For example, the brightness error has a hysteresis to avoid changing exposure level to often because it can result in oscillations in the image. The brightness error hysteresis, *beh*, limits the exposure level to change if the brightness deviation is smaller than ten.

The controller has a limited output. It is limited to a minimum and a maximum value that depends on two parameters, *wantedchange* and *unboundedchange*. These parameters are also used in the calculations of the control signal and in the logical rules that are used to set the correct exposure level.

3.3 DC-Iris control

The control system for the iris is a closed loop system with a velocity feedback. It has a PI controller and together with logical rules, to handling some different situations, it generates a signal that gives the iris a constant speed to either open or close. The iris operates on discrete signals in the interval 0 to 255 and has a equilibrium level at 165. Before a signal is sent to the hardware it is recalculated to be between 0 and 100 which is related to predefined voltage value. The recalculation from 0-255 to 0-100 is done to ensure comparability between different camera and lens systems.

The control system has two logical loops that are used in combination with the controller. The first one is a loop for deactivating the iris if the error in the image persists for more than 60 loops, and one loop for pushing the Iris to open completely if it for some reason has frozen. The first described loop has a gain scheduling that is dependent on previous gain and how long the error has been persisted. The second loop has a combined anti-windup

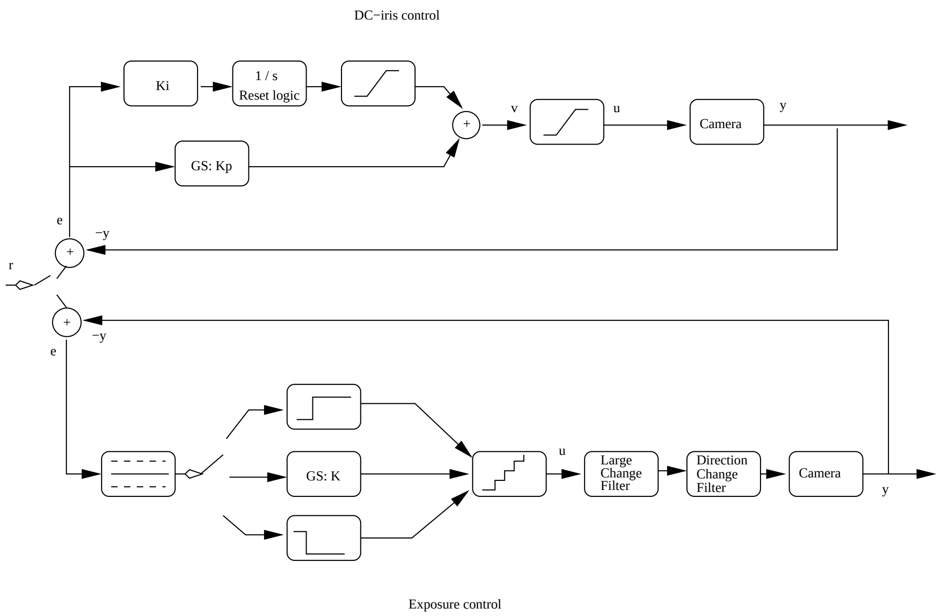

Figure 3.10: Exposure control system

and push feature which tracking if the error has persisted for more than 30 loops. If it has, the integral is reset to zero, if the error is negative, and it is multiplied with two, if the error is positive. The reason for this implementation is to make sure the iris really gets a push to be fully open.

The iris has only velocity feedback and not a feedback of the position. It can therefore not be determined how open or closed it is. On the basis of this the iris has a large limitation in control ability. The component is also non-linear and has a dependence of friction, temperature and wear and tear. How it behaviours differs also between objectives which makes it even harder to find a control strategy that fits all camera types. An effect of the temperature dependence is drifting. The component has a tendency to drift when it is supposed to be completely still. How much it drifts depends on the environment temperature.

3.4 Computer-controlled system

The embedded camera system is a real-time system with demands on real-time stability and it involves parts as A/D and D/A conversion, sampling, computational delay and quantization. Conversion between analog and digital values can cause problems due to round-offs and quantizations. Sampling is another thing that can cause problems if the sampling time is too long. Delays in computational calculation is also a problem a computer controlled-system must handle. Investigation in this area has however not been performed as the authors have, as mention in the beginning of the report, been guaranteed that all executions are performed in time.

3.4.1 Nonlinear effects

The system has nonlinearities such as saturation, discrete levels and finite word length. The nonlinearities arise due quantizations of parameter values and limitations on the actuators. Quantizations can be found in several parts in the two systems. There are three extra interesting quantizations that cause problems.

The first one is caused by the discrete steps in the exposure tables. As the values are discrete, an exact exposure level can not be found for every scene type. The problem is special noticeable when flicker-free [4] mode is activated. If flicker-free is activated the discrete levels in the tables are reduced and only a few levels are used. The result is very large discrepancies between the levels which results in big jumps when the scene changes. To compensate for this, the software changes the chip gain and expanding the hysteresis on the error (allow a larger stationary error). To increase the chip gain is not an optimal solution because an increment of the gain gives more image noise. Adjustment of the chip gain is also done to compensate for quantization problems that occur when the scene is extremely bright. In such a situation it is impossible to find an adequate low exposure level and the only solution is to decrease the chip gain. Another nonlinearaty in the exposure tables are very short exposure time. Usually one can only change exposure in different multiples of exposure lines. This gives a nonlinearaty since the difference between one and two exposure lines is twice the exposure, in comparison the difference between 1000 and 1001 is only a per mil.

The second interesting quantization is the mapping of the data values for the iris voltage. As the iris operates on a velocity reference values that are mapped from 0-255 to 0-100, which in its turn is mapped to predefined voltage values, errors will be introduced. Also there are different friction effects in the iris component.

The third and last interesting quantization is the limitations in word length. The limitations can result in large problems. An example of this is the limited integral part in Camera 1, before it was changed during the project. The limitation resulted in windup problems but this was solved

[4]Eliminate flicker caused by fluorescent lamps, 50 or 60 Hz

during the project by letting the integral part grow to larger values.

Chapter 4

Comments and suggestions to current control system

This section covers ideas and suggestions to the current control systems. It evaluates the performance of the entire exposure system on the two cameras on the basis of automatic control principles. It also comments the implementation of the individual parts such as the iris.

4.1 Camera 1

4.1.1 Performance

Benefits:

- Short rise-time
- Small overshoots when there are small luminance changes

Drawbacks:

- Large overshoots when there are large positive (dark to light) luminance changes
- Long settling time when there are positive luminance changes (dark to light)
- Smear algorithm

The exposure system has a small rise-time as Figure 5.1 shows. It is approximately 0,5 sec[1] which must be counted as a fast response. The short

[1] 1 sec = 15 fps

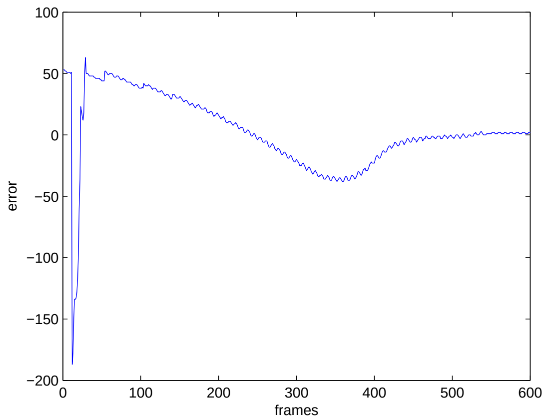

Figure 4.1: Large step from dark to light

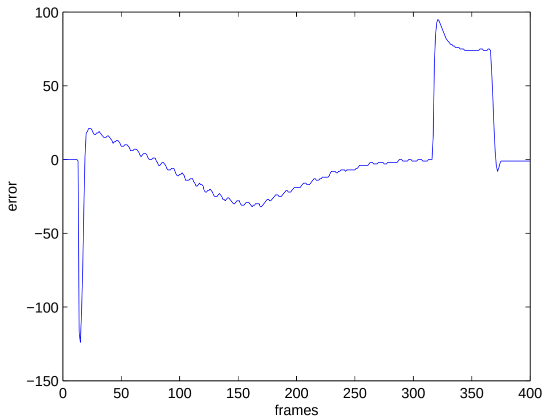

Figure 4.2: From dark to light smal step, light to dark smal step

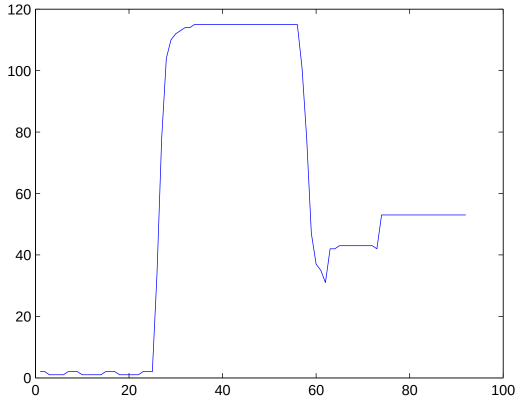

Figure 4.3: Light to dark

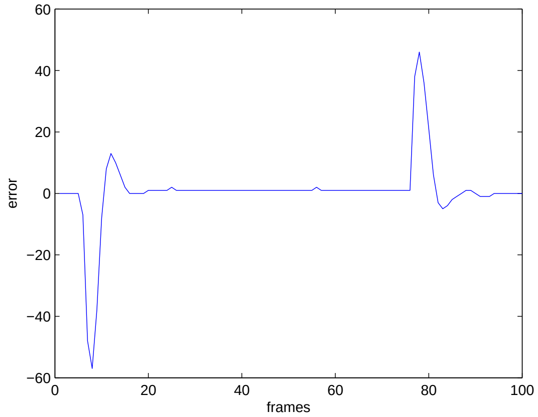

Figure 4.4: Smal load gives a smal overshoot

rise-time is a result of an well balanced P-part. The P-part has different gains depending on the size of the luminance change and for small luminance changes the part is well chosen. To increase the gain for this scene situations, and try to make the rise-time even shorter, is however not advantageous because it will result in larger overshoots and maybe an unstable system.

The system has relative small overshoots when the scene has small luminance changes. Figure 5.2 show when the scene changes from a low light scene to a medium light scene and the step response generates only a small overshoot, approximately 12.

The system has large problems when the scene changes from really dark to really bright. One problem in such situations is the large overshoots (Figure 5.1). The large overshoots are the result of a too aggressive gain parameter. A large gain has the benefit to give the system small rise-times but often at a cost of larger overshoots. As an overshoot is more visible for the user than a long rise-time damping of overshoots should be prioritized. To have short rise-times is however not unimportant as it is a measure of how fast the control system reacts on luminance changes but when choosing between large overshoots and small rise-times, small overshoots must be prioritized.

Besides generating overshoots a too high gain parameter can make the control system to sensitive and it will then react on small luminance changes that i should not react on giving them overshoot as well see figure 5.4. This can, and is, however solved by having different gains depending of the luminance size and also by introducing hysteresis on the brightness error.

Figure 5.1 shows a very long settling when the scene changes from completely dark to really bright. The long settling time is a result of the smear control. The implementation of the smear algorithm gives a very slow control and it takes a considerable time before the system reaches a correct exposure level. When the scene changes from completely dark to really bright the iris component is fully open and the pixels on the image sensor becomes saturated during such a change. The saturated pixels indicates that smear is found and the smear control starts.

As Figure 5.3 shows the control system does not have large overshoots or long settling time when the scene changes from really bright to completely dark. The system does neither have this when there are small luminance changes in the scene (Figure 5.3). The system is in these two cases relative fast bearing in mind the sensor size and sensor characteristics together with the hardware platform.

4.1.2 Correct anti-windup in the exposure control algorithm

The limitation in the exposure table and on the control signal from the PI controller give rise to windup problems. The implementation has an anti-windup feature that resets the integral part if the end of the exposure table is reach or if the exposure machine is frozen. The feature works fine for the described situations but it does not solve the problem with windup due to the limitation on the the control signal. As the signal is limited to ± 127 and the integral term is not reset, the term continuous to grow without affecting the control signal, when it has reach its maximum value. The solution for this would be to use an anti-windup feature with tracking (Figure 5.5). This would improve overshoots and know bugs due to windup. Such an implementation can also be used to avoid the windup problems in the exposure table, instead of automatically reset the integral term. It is more preferable to keep the integral value when the control signal reaches its maximum value. This to ensure

The automatically reset of the integral term when the exposure machine is frozen is however a good solution because the term has no function in such a situation.

4.1.3 Big step implementation

In the big step implementation there are two hard code features. This could be improved by making some of these adaptable to the different situations. First the delay is equal to two captures. At first glans this might not be so bad the problem is that it gives very different behaviour at different exposure times. The given delay will be dependent of the exposure time. This means that if in the 30 fps mode the delay will be 2/30 s. But in the longer exposure times it could take as long as 2/5 s. The delay should be set to a set time winch will adapt to the different exposure times so the delay will be the same every time. The delay is there to prevent transient disturbance to move the exposure level to far. If transient the delay will be time dependent not capture dependent. Else the wait will be to long and the operator will notice. There has been trouble reports on this property of the exposure.

The big step size is pre determined. The main reason is to not go to far, overshoots dose not look good for end user. The upside with moving to shorter exposure times fast is that control is faster since the capture rate increases. A suggestion would be to make a very simple gain scheduling that will increase the proportional gain when the error is increased. This will give a similar effect to larger steps and will still be possible to set the max step.

The maximum step will be largest error times its chosen proportional gain.

To prevent overshoot when there are large disturbances it might be a good idea to not let the integral part be active on large errors. This is not the convectional way of implementing a controller but the main purpose of the integral part in this application is used to remove steady state errors of a certain magnitude.

4.2 Camera 2

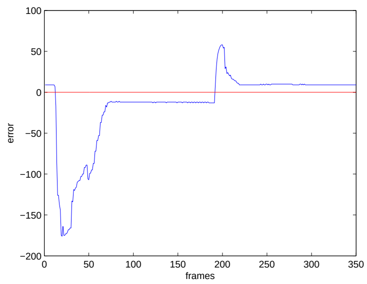

Figure 4.5: Step respone withuot intergral part, figure 5.5

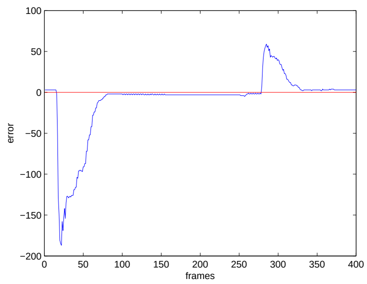

Figure 4.6: Step response with integral part, figure 5.6

4.2.1 Integral term in the exposure controller

At the beginning of this project the exposure control algorithm did not have any integral term in the controller. The main drawback with that loss was that the system did never reach a correct exposure level after a perturbation and it had always a stationary error (Figure 5.5). It was therefore necessary to get an integral implemented and the current controller has an integral part and it is built up around some logical rules. Figure 5.2 shows the improvement with the integral term implemented. As the figure shows, the process has still a small stationary error but it is a result of an hysteresis on the brightness error to avoid oscillations. The hysteresis was large, ± 10, in the beginning of the project to avoid oscillations in the image. The drawback with such a solution is a constant stationary error. After the implementation of the integral term in the exposure controller, the hysteresis was decreased to ± 3 to minimize the stationary error. The integral part was very slowly acting and only when a stationary error of a certain magnitude was left not to small or large. If the error is to small it is not corrected since it might cause oscillations between two different exposure levels.

The property of the actuators is a bit more complex than used fixed levels. The difference between one and two exposure lines is a doubling of the exposure time. But between one 100 and 101 is only a one pro cent increase. To over come this gain is used in between. This only has certain levels. The hysteresis could be changed depending on how big the difference is to the next exposure step.

There is also a limitations so the integral part will not be used when the error is large. This might be good since if not limited it might give a small overshoot. This is common to have but in a camera it will be very noticeable since it is a fast luminance change. Camera 1 has this and has received complains for this property.

The current integral part is very slow acting on the stationary error. With a small Ti, for this application it is suitable. The human eye is sensitive to fast luminance changes but will not notice small ones over time. It is not very sensitive to stationary errors if they are not persisting. If the stationary errors would be persisting different cameras would give different images in the same situations this would be very noticeable.

4.2.2 Large change filter

This part is basically the same as the delay in the big step implementation section. For the same reasons this should be recalculated so that the large change is delayed the same amount of time not captures.

4.2.3 Performance

The exposure control has a very robust design that makes the control stable and it removes large stationary errors. The implementation is designed to fit a wide range of different products and as the products have different performance and usage areas. Since the system is mounted at a stationary area and is intended for viewing to remove as fast as possible is not always wanted. The system is good with small transient errors since for the beholder it looks better if the exposure dose not change at the first small change in the image. In very specific situations it might be good to have increased exposure speed, but it is not very common.

Benefits:

- Stable
- Removes stationary errors
- No overshoots
- Adaptability

Drawbacks:

- Large rise-time
- Large settling time

Rise-time

A small rise-time is of course preferable but it may need a high gain value which can result larger overshoots and also a more unstable system. Therefore it must be an adjustment between rapidness and stability when the control system is designed. A too high gain parameter may result in a control system that is to sensitive and will react on small luminance changes which it should not react on. This can be avoided by introducing gain scheduling and hysteresis which let the gain parameter be different depending on the size of the luminance change.

Overshoot

The proportional part in the controller is the largest factor which contributes to the overshoot. A compensation for this is to use a derivative part which will damp the generated overshoot but a drawback with such a solution is a more unstable system with faster reaction time. It might also introduce a small ringing in the step response.

Stability

An unstable, oscillating, system will be very visible for the user. Another aspect of stability is robustness. The control system should not react on luminance changes that it should not adjust for. If the control system does this it will generate errors which will be visible for the user.

Settling time

This has been mentioned before in rise time. Settling time souled be minimized but not at the expense of ringing in the image. When the error is small it doesn't matter if it takes some time before it has reached steady state.

4.3 DC-iris

4.3.1 Gain scheduling

The gain scheduling for the DC-iris has a built in memory of past control signals. It bases the new proportional gain based on passed control signals used. This gives rise to a kind of windup in the proportional part. This leads to overshoots and sometimes instability, it is an unwanted behaviour. Instead using gain scheduling of the current error should be used. This is the classical way and sets a larger proportional gain match to the error.

4.3.2 Integral part

There is no anti-windup in the dc-iris controller, this is hard to make optimal since there is no position feedback to tell if the actuator has reached its limits. In this situation it might be useful to recall the integral based on the control signal. If the control signal reaches its limits 0 or 255, the integral is recalculated so the maximum control signal is used. This will speed thing up if the error changes direction.

The integral part is limited to +-20 in the final control signal. This is about seven pro cent of the possible signal. If the steady state error is larger than this it will not be compensated. The suspected reason for this is to limit overshoot especially in the closing direction since friction might prevent the iris from opening again. This can be solved buy using conditional integrator, this means only using the integrator if the system is close to steady state. For example the error has not changed for some time.

If the error persists for more than two seconds, usually 60 samples, the iris is switched off. When doing this the control signal is set to fully open 255. The integral control signal is set to zero but the integral part that is summed up over time is not reset. This means that the next time the iris is called the first sample integral will be zero, the second one it will be set to maximum on the side that the error had before the iris was switched of. This is properly not intended and there for a bug.

4.4 Smear control

The current smear control is slow, this is not only bad since the human eye is sensitive to large disturbances. It could how ever control faster dependent on the amount of smear present in the scene. In the current way it has a slow speed regardless of the error. If smear is in the extremes the picture is not usable and i those situations it should react faster.

To make faster control possible it might not be a good idea to use the control to close the iris based on the error introduced by changing the exposure time. Instead feed forward the error to start moving the iris and then next exposure follow with exposure time. This is not totally simple since the exposure time changes are not linear in the case of few lines. But the gain would be the possibility to feed forward and move a bigger step, to remove smear faster. When down to acceptable levels remove it slowly.

A problem that no solution was found for is the friction in the iris. This gives rise to an uneven exposure that oscillates somewhat and is very noticeable. There are several ways to combat friction components but with out feedback of position, very different response from individual iris and heat dependency it is not easy to do. To counter this problem feedback for the iris position is needed. If this would be possible other control strategies would be made possible.

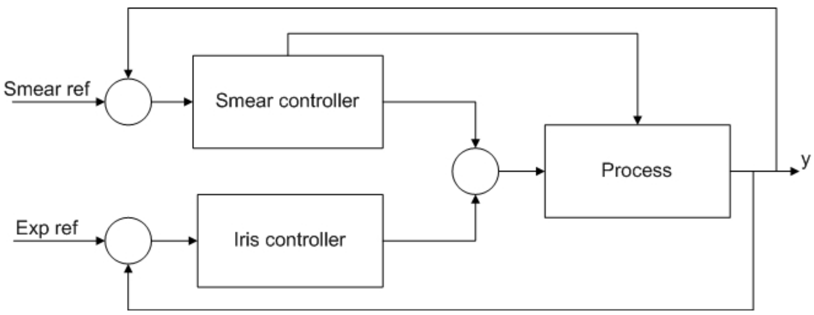

Figure 4.7: Current smear control

4.5 Computer-controlled system

A very important part when it comes to the rapidness of the exposure control is the hardware's ability to produce a high frame rate (fps) and simultaneous estimating the average brightness and calculating the exposure level. The two systems in the project produce 15 respective 30 fps. Improvement of the

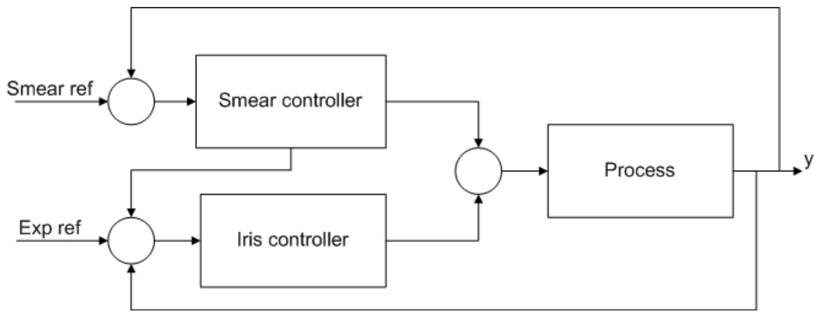

Figure 4.8: Future smear control

hardware will have a significant effect on the control rapidness. For example, if a camera shows 30 fps but has the ability to produce 60 fps the control loop will have two more values per visible frame to control around and this will have a sharp increase of the control performance.

Since the exposure time dictated the sample rate it is possible that the sample rate for the system changes. This changes the rise times and other system responses. The regulator values used can be recalculated aiming to achieve same system response with different sampling times. To get the sample time use the exposure time set in the last signal and recalculate the controller parameters according to forward difference, backward difference or Tustin's approximation. If this is not done the exposure will behave different in different exposure times.

4.5.1 Quantization

The quantization problems in the camera system is worst for exposure time. The time possible to set is discrete with the minimum size of one exposure line. The difference between exposure lines is bigger the less exposure lines used. Apart from that problems rise from the main current at 50 and 60 Hz. To avoid get flickering in the image only exposure times that are a multiple of the main current is used. This give rise to very few exposure levels to use. To build in between digital gain is used. This how ever introduces noice in the image at light levels where it would not be necessary. Instead if one could use the iris the noice levels would decrease. Digital gain is currently also used to solve the problem when changing from one line of exposure to two.

As in all implemented digitized systems there are other quantization in calculations of the algorithms and the actuators there are different word lengths. This has to be taken into account. The only improvement here is to use larger word lengths for the integral parts since or be aware of this risk of involuntary clamping. There has been such problems in the software but it was resolved during the project.

4.5.2 Real time system

This is not a real time system, there are no guarantee that the control signal is sett before the next capture. This kind of system is often referd to best effort, how ever not so much happens if the new signal is not set the old is still used by the sensor. It is not a critical system that will spiral out of control, and usually the is not some much CPU load so the signal will be calculated on time. For many sensors it is not good to set a sensor setting mid capture so exposure changes are only made mid frame. If needed it is possible to correct the picture after capture with digital gain.

Chapter 5

Improvements and suggestions to future control system

5.1 DC-iris improvements

The current iris component has as described in Chapter 3 a limited controllability and it can therefore not be used in an optimal way. To be able to design a control system with the iris more involved, the component needs improvement in form of a position feedback. Such an improvement can be achieved in two ways. The first and easiest solution is to use the current iris together with a galvanometer that can estimate a rotor position and in this way get a feedback of the iris position. The second solution is to change the entire iris component to an iris that uses a stepping motor. The benefits and drawbacks with the two different solutions are discussed in the next sections (Section 5.1.1 and Section 5.1.2).

5.1.1 DC-iris with hall effect

The iris component can be improved by using a galvanometer with hall effect[1]. By detecting the hall effect the rotor position on the DC-motor can be estimated and used to calculate the position of the iris. To know the position of the iris would result in a completely different control strategy compared to the one implemented today. A position feedback makes it possible to use the iris to control for example depth of field or compensate for quantization problems or optical phenomenon such as spherical aberration. The current system compensates for quantization problem by changing the

[1] Hall effect is based on potential difference between two sides of a conductor when current flows through

chip gain but if the iris has had a position feedback it could solved these problems instead. Also spherical aberrations could be avoided if the motor could close the iris to a specific position. The most important feature would be to improve the optical resolution by choosing the optimal iris setting this would be maximized.

The implementation of a DC-iris with hall effect can be done in the current system without any large changes. The difficulty would be to linearized the iris position but if this is done in an good way the iris control will be very fast and correct. The problems with the temperate is possible to correct in the hardware to minimize the drifting on the new feedback electronics. A certain allowance can be made for the accuracy but hopefully the feedback position will be correct.

5.1.2 Iris with stepping motor

An iris with a stepper motor[2]would give a very precise control. A stepper motor is generally used in a open loop then a feedback of the motor position is often unnecessary because of the motor's fixed steps and the possibility to calibrate against one of the sides.

Like a dc-iris with hall effect, an iris with a stepper motor can be used to control depth of field, compensate for optical phenomenon and quantization problems. A stepper motor might be slower than a DC-motor but if it should only be used to control depth of field it will give a very good control because of the fixed steps that can be mapped to different object distances. It also have superior accuracy for optics that is unforgiving in its optical design.

5.2 Adaptive learning control

The main thought behind adaptive learning control is to let the controller learn from previous control situation and by this get a faster automatically adaption when the scene changes. Adaptive learning can be useful in many different ways and the following sections describe how an adaptive learning control can be implemented in the system today and also how a more advanced adaptive system can be implemented in the future.

[2]A stepper motor is an electric motor that has a rotation that is divided into a large number of steps.

5.2.1 Adaptive exposure steps

A simple but powerful adaptive algorithm implementation in the current system would be an adaptive exposure step. If the system is affected by very large load disturbances that make the image completely white or completely black, the current control system makes a large jump of a predetermined step size in the opposite direction as the error. Instead of using such a predetermined large step every time it is a large disturbance, it is possible to let the system adapt to previous levels and adjust the step size according to these. Such a system will find a correct exposure direct and with a short settling time and a small overshoot. There is a requirement for this type of solution and it is that the process has to be exposed to repetitive disturbances of same size. A practical example of where this type of implementation will generate a great benefit is when a camera is placed in a room where the lights are switched on and off. The camera would in this situation be able to reached a desired exposure level direct and the effect would be a great benefit for the user then the switch will be almost unnoticeable.

The implementation can have the following pseudo code:

1. Remember the current exposure level
2. Make a jump with the current (or default) step size
3. If the error in the image is small enough, start the PI control
4. When the system has reach a steady state, remember the current exposure level
5. Calculate the step size
6. Evaluate if the step size has been changed and needs to be updated
7. Set the current step size to default step size

There are some possible additions to the algorithm to make sure the step is used in a correct way and does not affect the robustness of the system. If the exposure index (exposure level), before the big jump is saved, the algorithm can check that the current exposure index is in the vicinity of the index the adaptive step is to be taken. Suc an addition enhances the chance that the adaptive step is done as a reaction to the same type of load disturbance. When the exposure level has reached its steady state, the exposure index is saved and then compared to previous index.

Introducing a status variable that identifies if the algorithm should use several different jumps may also be a good implementation to try to identify more adaptive levels to jump from and to. Together with a status variable it is interesting to keep track of how often different jumps occur to make a correct decision regarding the adaptive step.

A last addition to the implementation is a method for resetting and forgetting the steps. The algorithm must at some time be able to reset the current adaptive steps in a correct way to maintain a correct and stable exposure control system.

An adaptive step like the one described would generate a large benefit in certain situations. The settling time would be extremely low without any overshoot. Another example of a usage area where this type of control would be very effective is when a PTZ camera is used to surveillance different scenes with very different light levels. I such situations would an adaptive exposure step find a correct exposure level directly in all the directions and the user will almost not notice the luminance changes in the image.

The large limitation with an adaptive step like the one described is that it only works when the system has repetitive disturbances of the same size but the implementation would be a very good complement to the current large step feature.

5.2.2 Scene classification

A more complicated adaptive learning control would be a system based on classification of different scene types. The main purpose of such an implementation would be to make the camera able to automatically adapt to different scene types and in such a way get an optimal control for every individually scene.

Scenes have different types of load disturbances and require therefore different control strategies and controller designs. The scenes are depending on the environments where they are located and it affects the type of the load disturbances. On the basis of this, it is difficult to to find a control system that fits all different scene types and such a control system will only perform "well enough" in the different scenes and not optimal for every individually scene. To achieve a system that is optimal for each scene, the control system must have several control strategies and controller designs. The design could be done with predetermined scene types which the user can choose in the settings or by letting the camera itself adapt two different scenes and do all the settings. To design a control system that can automatically adapt to different scenes through an adaptive learning process is a first and big step forwards to a more advanced exposure control system.

To implement a system that can separate scenes from each other is not straight forward. The method discussed is based on tracking load distur-

Scene type	Indoor	Carport	Nightclub
Load disturbance size	Large	Large	Small-Medium-Large
Load disturbance frequency	Low	Low	High
Load disturbance duration	Long	Short-Long	Short
Brightness	Medium	Low-Medium-High	Low-Medium-High
Motions	Greatly	Few	Greatly
Dynamic range	Limited	Large	Limited
Depth of field	Short	Short	Short-Long

Table 5.1: Classification of scene types

bances and saving facts about the disturbances such as how long the disturbances have lasted and how frequent they are. Such an information can then be used, together with the exposure index, to make a good assumption on what type of environment and scene the camera is placed in and from this decide a control strategy. Another information input to such an system could be image processing information, for example motion detection.

Table 5.1 shows examples of scene classifications for three different scene types.

An indoor environment has most often a relative constant light level and the disturbances that occur are large and low frequent and they have a long duration . An example of an indoor environment is a room where the light i switch on in the morning and off at the night and the time between the light level is constant. An indoor environment has often a medium brightness level and it can have a lot of motions, for example a store where people come ad go. An indoor environment may also have fluorescent lamps and that sets requirements on the control to handle a flicker-free mode.

As the light level most often is constant and the camera is not exposed to very bright light sources in an indoor environment, the current iris is active very rarely in such an environment. If the position of the iris would be controllable the iris could be used to compensate for quantization problems in the flicker-free mode and also optimize the depth of field for the scene.

A carport has often, as an indoor environment, a light-to-dark or dark-to-light changes but it has also a longer luminance changes, day to night and night to day. This demands both a fast and a smooth control. The largest problem for carport is to handle the situation when the camera is blinded by a car light. Such a situation results in smear and black sun effects and the control system must be able to handle this and at the same time be fast.

A nightclub environment has many light sources and the light is far from constant. The load disturbances have large variations, from reflections in a disco ball to blinking light from a stroboscope. This sets demands on the control to handle many different disturbances and do it very fast. The most effective control strategy in such a environment would be to choose a fix exposure level and let the iris compensate for large luminance changes in the scene.

Use the scene classification as means to make a installation guide to customize image parameters.

5.3 Feed forward and gain scheduling

There are several different events that could be feed forward to the controller. Some of which could switch for instance the proportional part so that exposure would settle faster. Examples of this is day night switch when removing IR filter, starting external lighting or IR lamps or the movement of the camera as for pan tilt and zoom cameras. If position iris is changing or the user is changing the exposure sett point. When users changes sett points or other parameters it doesn't really matter if it is fast but it gives a more professional appearance.

5.4 Other inputs and reference signals

There might be other inputs to use for control other than mean values of the luminance. To instead capture the images so a certain amount of pixels are saturated and to use gamma curve to brighten up the darker parts. The upside to this is to get more visibility in the image. The luminance value might be of but then it can be corrected in the after processing. This approach would try to maximize the visibility in the image.

There are other parameters as well for increase trying to automatically remove backligth from the reference values always so for instance headlights in a car would not be taken in to account.

Chapter 6

Conclusions

The main conclusion for this thesis is that an automatic control application differs a lot between the practice and the theory. All the knowledge the authors had from their studies was not possible to use. The most advanced controller in the project was a basic PI controller but it had a lot of logical rules to make a well functioning system.

The project has been very interesting and rewarding. The authors have had to learn a completely new system from the beginning and that has been a challenge. The authors have done the analyze as simple and understandable as possible and have not used more advanced theoretical approaches than were necessary.

Two systems have been analyzed and the authors have concluded that the system for Camera 2 is better system in many ways. For the first it has a more simple implementation which makes it much more understandable. The system can also be easily adapted to different camera models. The system is also much more stable than the system for Camera 1.

The smear control implementation needs to be updated. It needs do be much faster to fulfil future demands

A new updated iris is a must if it should be used in a more advanced control system such as depth of field control. An update is also needed to let the iris compensate for quantization problems and optical phenomenon.

Some errors of the integral part of camera 1 will solve the problems with windup. There are also solutions for the overshoot seen.

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