REGULATING LUMINOUS GAIN OF IMAGE INTENSIFIER

TECHNICAL FIELD

The presently disclosed measures relates to a control circuit and method for regulating a luminous gain of an image intensifier, and to a night vision device comprising the control circuit and the image intensifier.

BACKGROUND ART

Night vision devices are direct view systems which comprise image intensifiers for obtaining an intensified display of a scene. Such night vision devices are frequently head- or weapon-mounted, and may optionally include an optical or digital overlay of images from a parallel line-of-sight infrared camera, data from a GPS or compass system, etc. The image intensifiers in such night vision devices are constituted by an assembly of components, typically comprised of a photocathode, an electron multiplier, and a phosphorous layer, and integrated into a vacuum tube.

The operation of such an image intensifier may be briefly explained as follows. A scene may be imaged onto the photocathode, e.g., by focusing the scene thereon via an optical lens. The light from the scene may cause photoelectrons to be emitted from the photocathode, thereby creating an electron image. The electron image may be accelerated by a first electric voltage, being in a specific example 200V to 800V, and proximity focused onto an input face of the electron multiplier, being typically a Micro Channel Plate (MCP) electron multiplier. The electron multiplier may intensify the electron image by secondary multiplication driven by a second electric voltage, being in a specific example 800V, which may be applied between the input face and the output face of the electron multiplier. The multiplied electron image may then be accelerated by a third electric voltage, being in a specific example between 4000V and 7000V, and proximity focused onto a phosphorous layer of an anode. The phosphorous layer, also referred to as phosphorous screen, may then convert the high velocity electron image back into a visible image to obtain an intensified display of the scene.

Modern image intensifiers provide luminous gains of typically 10,000 to 40,000 cd/m^2/lux. The main elements which contribute to this luminous gain may be:

1. The sensitivity or quantum efficiency of the photocathode;
2. The net electron gain of the electron multiplier, e.g., expressed as the ratio of (electron) output current divided by (electron) input current; and

3. The efficiency of the phosphorous layer, expressing how efficiently the kinetic energy deposited by incoming electrons is converted to luminescent energy.

The luminous gain of the image intensifier may be adjusted by adjusting the electron gain (also referred to as 'electron multiplication gain') of the electron multiplier. The electron gain may be adjusted by adjusting the voltage over the electron multiplier. This voltage is typically provided, and thus may be adjusted, by a Power Supply Unit (PSU). The relation between electron gain and the voltage may be almost exponential in its normal range of operating voltage and gain setting. For example, the electron multiplier may be set to an operational voltage of 800V to obtain a 10,000 luminous gain of the overall image intensifier. By increasing the operational voltage by 50V, i.e., to 850V, the luminous gain typically doubles. The electron gain of the electron multiplier may also be adjusted by adjusting a duty cycle of the voltage which is applied across the electron multiplier, e.g., by rapidly switching off and on said voltage at a switching frequency higher than the equivalent frequency of the human eye response time. The duty cycle represents the fraction of time voltage is applied to the electron multiplier, calculated as the ON time divided by the total cycle time, i.e., the sum of ON and OFF times. Such adjusting of the duty cycle is also referred to as gating. The luminous gain of the image intensifier may also be adjusted by gating the photocathode voltage.

In known image intensifiers, the PSU provides at least two reference settings, namely one for setting a reference intensity gain (GAIN) and another one for setting a Maximum Output Brightness (MOB). These reference settings may be obtained by calibrating each individual image intensifier, i.e., with its individual photocathode, electron multiplier and phosphorous layer characteristics. The reference setting for the reference intensity gain may for example be calibrated by illuminating the input face of the image intensifier on an optical bench with a calibrated light source of a fixed brightness while measuring the output brightness of the image intensifier, and adjusting the voltage across the electron multiplier until the output brightness is within a desired range. Here, the desired range is one in which maximum intensity gain is obtained while simultaneously limiting artifacts such as noise to an acceptable degree. The resulting calibrated value of the voltage for GAIN may be stored as a reference setting in the PSU. The setting for the MOB may subsequently be determined by limiting the anode current from the PSU to a maximum value that corresponds with the maximum allowable brightness measured on the same optical calibration bench. Conventionally, the PSU is then sealed and GAIN and MOB setting are made inaccessible for any adjustment by the end-user. The image intensifier switches ON upon applying a battery voltage to the two battery contacts or wires of the image

intensifier. In some cases an additional so-called External Gain Control (EGAC) option is available on the night vision device by which the user can reduce the gain of the tube using a third contact electrode or wires to the image intensifier.

Image intensifiers may use an automatic brightness control (ABC) feature to regulate luminous gain. This ABC mode may automatically adjust the luminous gain to keep the output brightness at or below the predetermined maximum output brightness level. Typically, this maximum output brightness level is set well below 10cd/m^2 to facilitate a smooth transition for users when alternating between the night vision device and unaided vision to avoid a need for significant adaptation by the human visual system.

SUMMARY

However, during the operation of a night vision device, abrupt increases in scene brightness, such as flashes from a fire-arm firing or explosions or from a suddenly switched-on light or when entering a lighted interior, can lead to a corresponding spike in output brightness. While the ABC mode may respond by gradually reducing the luminous gain, the inventors have observed that the rapid increase in output brightness can prompt the human eye to employ natural protective mechanisms to adjust quickly to the momentary brighter conditions. Such protective mechanisms may in turn cause temporary night blindness once the ABC mode reduces the luminous gain. Such temporary blindness poses significant risks, particularly in critical scenarios such as when operating machinery, conducting search and rescue operations, or engaging in law enforcement and military activities.

It would be desirable to be able to avoid, or at least reduce the occurrence and/or severity of such temporary blindness during operation of a night vision device.

The presently disclosed measures provide a control circuit for regulating a luminous gain of an image intensifier, wherein the image intensifier is configured to obtain an intensified representation of a scene, wherein the image intensifier comprises:

- a photocathode for creating an electron image from a scene that is imaged onto the photocathode;
- an electron multiplier for intensifying the electron image via electron multiplication, thereby obtaining a multiplied electron image;
- an anode comprising a phosphorous layer for converting the multiplied electron image into a visible light image to obtain the intensified representation of the scene;

wherein the control circuit is configured to perform automatic brightness control by regulating a luminous gain of the image intensifier to maintain an output brightness at or below a desired maximum output brightness level;

wherein the control circuit is further configured to:

- determine a scene brightness, the scene brightness being a brightness of the scene that is imaged onto the image intensifier;
- and when a sudden increase in the scene brightness, the sudden increase being at least a doubling of the scene brightness within less than 10 milliseconds, causes the output brightness to exceed the desired maximum output brightness level:

deactivate the photocathode and interrupt the automatic brightness control;

reduce the luminous gain of the image intensifier in accordance with a first gain reduction parameter; and

after reducing the luminous gain, reactivate the photocathode and resume the automatic brightness control.

The presently disclosed measures further provide a method for regulating a luminous gain of the image intensifier. The method comprises performing automatic brightness control by regulating a luminous gain of the image intensifier to maintain an output brightness at or below a desired maximum output brightness level;

wherein the method further comprises:

- determining a scene brightness, the scene brightness being a brightness of the scene that is imaged onto the image intensifier;
- and when a sudden increase in the scene brightness, the sudden increase being at least a doubling of the scene brightness within less than 10 milliseconds, causes the output brightness to exceed the desired maximum output brightness level:

deactivating the photocathode and interrupting the automatic brightness control;

reducing the luminous gain of the image intensifier in accordance with a first gain reduction parameter; and

after reducing the luminous gain, reactivating the photocathode and resuming the automatic brightness control.

The presently disclosed measures further provide a transitory or non-transitory computer-readable medium comprising data representing a computer

program, the computer program comprising instructions for causing a processor system to perform the aforementioned method.

The above measures concern control of an image intensifier which is configured to obtain an intensified display of a scene. For that purpose, the image intensifier may comprise a photocathode, an electron multiplier and an anode comprising a phosphorous layer. In a specific example, the intensifier may comprise a vacuum tube housing the aforementioned components and thus effectively constitute an image intensifier (I2) tube. It is noted that image intensifiers as described in this paragraph are known per se from the field of night vision devices, and the general aspects described in the background art section may apply to the image intensifier as claimed unless differences have been specifically indicated.

In further accordance with the above measures, a control circuit is provided which is configured to operate in an automatic brightness control mode. When operating in the automatic brightness control mode, the control circuit may regulate the luminous gain of the image intensifier to maintain an output brightness at or below a desired maximum output brightness level. More specifically, the control circuit may determine which luminous gain value to use and control the image intensifier to set the luminous gain accordingly. The desired maximum output brightness level may be a preset level which is known to the control circuit. For example, the desired maximum output brightness level may be determined by the manufacturer or may be user-definable. The control circuit may determine the luminous gain which keeps the output brightness at or below the desired maximum output brightness level using a feedback control scheme. As input to the control scheme, one or more parameters may be used which may be indicative of either the scene brightness or the output brightness. Here, the term scene brightness may refer to a brightness of the scene that is imaged onto the image intensifier. It will be appreciated that one parameter (or value) may be converted into the other by way of the luminous gain. The control circuit may thus be able to regulate the luminous gain of the image intensifier based on an estimate or measure of the scene brightness and/or of the output brightness. To set the luminous gain, the control circuit make use of known mechanisms, for example by adjusting the electron multiplication gain of the electron multiplier, for example by adjusting an operating voltage of the electron multiplier, or by adjusting the duty cycle of the operating voltage which is used to gate the photocathode. Said adjustments may for example be effected by the control circuit controlling the power supply unit.

In further accordance with the above measures, the control circuit may be configured to respond beyond the normal operational boundaries of the automatic

brightness control mode if the scene brightness suddenly surges. In a specific example, the surge may be defined as at least a doubling of the scene brightness within less than 10 milliseconds. The occurrence of a surge may for example be determined by determining a minimum value of the scene brightness in the last 10ms and comparing the current value of the scene brightness to the minimum value, and if the current value is at least double the minimum value, determining that a surge in scene brightness occurred. However, other definitions of 'surge' may equally be employed. For example, a surge may be defined by a 1.5, 3x, 4x, 5x, 10x, 20x, 50x, 100x, etc., increase in the scene brightness in less than a time period. The time period may for example be 0.1ms, 0.5ms, 1ms, 2ms, 5ms, 10ms, 20ms, 50ms, 100ms, etc.

A surge in scene brightness may, when not otherwise addressed, cause a corresponding surge in output brightness. The inventors have recognized that in reaction to a surge in output brightness, the human eye may employ a protective mechanism, by which the iris may constrict and the rods in the eye may temporarily become inactive due to a rapid enzymatic response. When in reaction to the surge in scene brightness the automatic brightness control mode lowers the luminous gain, and thereby the output brightness, the user may experience temporary blindness. Such temporary blindness may be caused by the human eye adjusting more slowly to decreases in brightness, with the rods regaining sensitivity gradually through a slower enzymatic process. Temporary blindness is highly undesirable, as also explained in the background section of the present specification.

The inventors have devised to address this problem by, once a surge in scene brightness is detected, promptly switching off the photocathode. The switching-off of the photocathode effectively disables the image intensification and thereby avoids, or at least strongly reduces the severity, of triggering the protective mechanism of the human eye. Having disabled the photocathode, the luminous gain of the image intensifier may be reduced step-wise in accordance with a first gain reduction parameter. The first gain reduction parameter may be chosen such that the likelihood of the output brightness still exceeding the desired maximum output brightness level is relatively minor. For example, the first gain reduction parameter may be chosen to be inversely proportionate to the sudden increase in scene brightness at which the disabling of the photocathode is triggered. To enable the enhanced adjustment of the luminous gain, e.g., beyond the normal operational boundaries of the automatic brightness control mode, the automatic brightness control may be interrupted, and only after the luminous gain is reduced, the photocathode may be switched back on again and the automatic brightness control may be resumed by the control circuit. Such

interruption of the automatic brightness control may also be referred to as a temporary pausing or temporary stopping of the automatic brightness control.

The above measures thereby avoid, or at least reduce the occurrence and/or severity of temporary blindness during operation of a night vision device. In particular, the inventors have recognized that the measurement of the scene brightness may in many cases be an indirect measurement which may be delayed with respect to the actual current scene brightness. The regulation of the luminous gain by the control circuit, either in the automatic brightness control mode or beyond the normal operational boundaries of the automatic brightness control mode, may thus be reactive and subject to a delay. This delay may result in the output brightness still exceeding the desired maximum output brightness level for a short period before the photocathode is switched off. By rapidly deactivating the photocathode upon detecting such a surge, it can be ensured that the triggering of the protective mechanism of the human eye is kept to a minimum. In addition, the rapid deactivation facilitates the initiation of inverse physiological responses as promptly and effectively as possible, primarily by avoiding the provision of any stimulus to the eye. Effectively, by way of the above measures, an artificial undershoot is introduced to remedy the physiological effects of the momentary overshoot in output brightness as much as possible.

It will be appreciated that such step-wise reduction may be employed if the output brightness significantly exceeds the exceed the desired maximum output brightness level. For that purpose, an absolute or relative margin may be applied, in that the step-wise reduction in luminous gain may only be triggered if the desired maximum output brightness level is exceeded by at least said margin. For example, the margin may be relative to the desired maximum output brightness level, for example 100% or 200%, so that the photocathode may only be switched off if the output brightness would exceed 2x or 3x the desired maximum output brightness level.

It is further noted that it may be known per se to deactivate the photocathode as an operational measure to protect components of an image intensifier, e.g., to avoid operational amplifiers becoming saturated. Disadvantageously, such protection measures only trigger when the output brightness is far above the desired maximum output brightness level, and as such, do not provide a solution to the problem of more limited overshoots in output brightness above the desired maximum output brightness level which nevertheless cause the above-mentioned temporary blindness problems if not otherwise mitigated. The above measures thus apply to surges in scene brightness and corresponding (if not otherwise mitigated) surges in output brightness which are still within the operational envelope of

the image intensifier. In other words, the surge in scene brightness at which the photocathode is switched off would otherwise cause a corresponding surge in output brightness which would not yet saturate operational amplifiers of the image intensifier.

Optionally, the control circuit is configured to determine the scene brightness by at least one of:

- determining the output brightness by measuring an anode current, wherein the anode current is a current of electrons accelerated from an output side of the electron multiplier towards the phosphorous layer, and dividing the output brightness by the luminous gain of the image intensifier;
- measuring a photocathode current, wherein the photocathode current is a current of electrons accelerated from the photocathode towards an input side of the electron multiplier, and dividing the photocathode current by a luminous sensitivity of the photocathode;
- if the photocathode is a gated photocathode, measuring a decline of a gating voltage after a gating pulse, multiplying said measured decline by a capacitance of a cathode gap of the image intensifier, and dividing said multiplication product by a luminous sensitivity of the photocathode;
- determining the output brightness by measuring an operating current of the electron multiplier and subtracting a bias current of the electron multiplier, and dividing the output brightness by the luminous gain of the image intensifier; and
- using a photosensor configured to measure the scene brightness.

There are several ways for the control circuit to determine the scene brightness, either for the purpose of automatic brightness control or for the purpose of detecting a surge in scene brightness or for both purposes. An advantage of measuring the anode current is that the anode current may be one or even several orders of magnitude larger than the photocathode current and therefore its measurement may result in a higher signal-to-noise ratio. An advantage of measuring the photocathode current is that this current is independent of the electron multiplication by the electron multiplier and therefore not subject to potentially unpredictable and/or undesirable side-effects associated with the electron multiplication, such as saturation effects.

Optionally, the control circuit is configured to, after reactivating the photocathode, determine if the output brightness still exceeds the desired maximum output brightness level, and if so:

- deactivate the photocathode and interrupt the automatic brightness control;

- further reduce the luminous gain of the image intensifier in accordance with a second gain reduction parameter; and
- after further reducing the luminous gain, reactivate the photocathode and resume the automatic brightness control.

The reduction in output brightness may be a two-step process in which each time a stepwise reduction in luminous gain is performed. By dividing such a reduction of the luminous gain across two steps, it may on the one hand be avoided that initially a too large reduction is applied by which the output brightness falls far below the desired maximum output brightness level, while on the other hand it may be avoided that a too small reduction is applied by which the process may have to be repeated several times, which in turn may result in interruptions in the operation of the image intensifier.

Optionally, the control circuit is configured to regulate the luminous gain of the image intensifier by at least one of:

- adjusting a duty cycle of an operating voltage which is used to gate the photocathode;
- adjusting an electron multiplication gain of the electron multiplier, for example by adjusting an operating voltage of the electron multiplier.

Optionally, the control circuit is configured to:

- measure the scene brightness periodically;
- deactivate the photocathode for one or more measurement periods.

Optionally, the control circuit is configured to deactivate the photocathode using at least one of:

- a microcontroller or other digital processing unit incorporating control logic which processes a digital representation of the scene brightness;
- a hardware comparator which receives an analogue or other non-digital representation of the scene brightness as input and which outputs a control signal to a circuit supplying a photocathode voltage to the photocathode.

An advantage of using a hardware comparator may be that the latency may be reduced with respect to a digital processing of the scene brightness.

Optionally, the control circuit is configured to, when performing the automatic gain control, regulate the luminous gain of the image intensifier using a first desired maximum output brightness level, a first gain value, a second desired maximum output brightness level, and a second gain value, wherein the second gain value is smaller than the first gain value and wherein the second desired maximum output brightness level is higher than the first desired maximum output brightness level,

wherein the control circuit is configured to, with increasing scene brightness starting from a lowest scene brightness:

- use and maintain the first gain value as the luminous gain until reaching the first desired maximum output brightness level;
- after reaching the first desired maximum output brightness level, reduce the luminous gain with respect to the first gain value to maintain the output brightness at the first desired maximum output brightness level until reaching a second gain value;
- after reaching the second gain value, maintain the second gain value until reaching the second desired maximum output brightness level; and
- after reaching the second desired maximum output brightness level, reduce the luminous gain with respect to the second gain value to maintain the output brightness at the second desired maximum output brightness level.

The above measures are based on the following insights. Conventionally, the luminous gain of an image intensifier may be kept constant with increasing scene brightness until the output brightness reaches the desired maximum output brightness (MOB) level. At higher scene brightness level, e.g., above 10mLux, the output brightness may be kept constant at or near the desired maximum output brightness level, e.g., by automatic brightness control. Thereby, two control regimes may be employed: constant gain and constant MOB. In the first, output brightness may linearly increase with scene brightness; in the latter, gain may decrease inversely with scene brightness. Earlier power supply units, limited by simple analogue electronics, facilitated only this basic regulation. Modern, software-controlled auto-gating power supply units allow more advanced regulation. The inventors have recognized that the use of a single maximum output brightness level may be disadvantageous at low and intermediate scene brightness levels, e.g., below 10mLux . The inventors have for example considered a soldier using a night vision device in darkness. In such a situation, it may be undesirable to have the same (relatively high) output brightness as in dawn or dusk. Namely, such a higher output brightness may reduce situational awareness, necessitate a long adjustment to darkness, and create discomfort when using a monocular device. Additionally, light leakage by image intensifier output brightness reflected from the face of the soldier can reveal the soldier's position. As such, at darkness, it may be desirable to maintain a lower output brightness which is more balanced with the environment. The above measures may therefore introduce two different desired maximum output brightness levels, namely a first desired maximum output brightness level for lower scene brightness level and a second, higher, desired maximum output brightness level for higher scene brightness levels.

This has been found to address the aforementioned disadvantages of using a relatively high output brightness in deep darkness. Advantageous, the above measures provide optimized output brightness across a wide range of scene brightness levels and facilitate faster adaptation of the human eye when alternating between or simultaneously using the night vision device and unaided vision.

It is noted that the above measures, as well as thereto related measures, may also be implemented by the control circuit independently of the photocathode emergency deactivation, with the latter term referring to the deactivation of the photocathode, step-wise luminous gain reduction, and photocathode reactivation.

Optionally, the first desired maximum output brightness level is selected in a range where the human eye perceives fine detail in the intensified display of the scene while avoiding overexposure of the human eye which will otherwise result in a temporary loss of sensitivity. For example, the first desired maximum output brightness level may be selected to be within a range of 1.5 to 4 cd/m2.

Optionally, the first gain value is used for scene brightness levels up to 1mLux. For such scene brightnesses, the signal-to-noise ratio of the image intensifier is a dominant factor in the Johnson criteria for Detection, Recognition, and Identification.

Optionally, the second gain value is used for scene brightnesses from 1 to 5mLux. The range from 1 to 5mLux is a range of scene brightness levels where a modulation transfer function (MTF) of the image intensifier is a dominant factor in the Johnson criteria for Detection, Recognition, and Identification.

Optionally, the second desired maximum output brightness level is selected in a range of 6 to 12 cd/m2. The range of 6 to 12 cd/m2 is optimal for the human eye to perceive fine detail in the intensified display of the scene for a range of scene brightness levels where, when the scene is viewed without aid of the image intensifier, minor overexposure to the human eye will not result in a temporary loss of sensitivity.

Optionally, the control circuit is configured to reduce the luminous gain of the image intensifier by reducing an electron multiplication gain of the electron multiplier by adjusting an operating voltage of the electron multiplier, and when the electron multiplication gain reaches a first electron multiplier gain level, reduce the luminous gain of the image intensifier by reducing a duty cycle of an operating voltage which is used to gate the photocathode, and when the duty cycle reaches a first duty cycle value, further reduce the electron multiplication gain below the first electron multiplier gain level, and when the electron multiplication gain reaches a second electron multiplier gain level, further reduce the luminous gain of the image intensifier by further reducing the duty cycle below the first duty cycle value.

The presently disclosed measures further provide a night vision device comprising the control circuit and the image intensifier as defined in the present disclosure, the night vision device being for example a head mounted goggle or a weapon sight or a handheld device or an intensified CMOS sensor camera for capturing an output of the image intensifier.

It will be appreciated by those skilled in the art that two or more of the above-mentioned embodiments, implementations, and/or aspects of the invention may be combined in any way deemed useful.

Modifications and variations of any entity described in this specification (e.g., any circuit, device, method, etc.), which correspond to the described modifications, variations, and optional aspects of another one of these entities, may be carried out by a person skilled in the art on the basis of the present description.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter. In the drawings,

Fig. 1 shows an image intensifier in the form of an image intensifier bare vacuum tube without its power supply unit and encapsulation;

Fig. 2 shows a longitudinal section of an encapsulated image intensifier, showing photocathode, an electron multiplier, and a phosphorous layer, as well as a power supply unit which is wrapped around a portion of the image intensifier;

Fig. 3 shows a flowchart of an exemplary operation of a control circuit which is configured to regulate a luminous gain of the image intensifier;

Fig. 4 shows the luminous gain of the image intensifier and the output brightness as a function of scene brightness for an exemplary image intensifier; and

Fig. 5 shows a scheme to reduce the luminous gain of an image intensifier.

It should be noted that items which have the same reference numbers in different figures, have the same structural features and the same functions, or are the same signals. Where the function and/or structure of such an item has been explained, there is no necessity for repeated explanation thereof in the detailed description.

List of reference numerals

The following list of references and abbreviations is provided for facilitating the interpretation of the drawings and shall not be construed as limiting the claims.

100 bare image intensifier vacuum tube

110 input window

120	photocathode layer on inside face of input window
130	electron multiplier
140	phosphorous layer on inside face of output window
150	output window
160	power supply unit
170	control circuit as an element of the power supply unit
200	method of regulating luminous gain of image intensifier
210	automatic brightness control
220	determining scene brightness
230	identifying sudden increase in scene brightness
240	regulating luminous gain of image intensifier
250	deactivating photocathode and interrupting automatic brightness control
260	reducing luminous gain
270	reactivating photocathode and resuming automatic brightness control
300	input illumination axis (lux) (logarithmic)
310	output brightness axis (cd/m2) (logarithmic)
320	luminous gain axis (cd/m2/lux) (linear)
330	output brightness curve (cd/m2)
332, 334	desired maximum output brightness levels
340	luminous gain curve (cd/m2/lux)
342, 344	desired luminous gain values
400	electron multiplication gain (operating voltage)
402-406	electron multiplier gain levels
420	duty cycle for photocathode gating
422, 424	duty cycle values

DETAILED DESCRIPTION OF EMBODIMENTS

Fig. 1 shows an image intensifier in the form of an image intensifier (I2) tube 100. The I2 tube as shown is known per se from the field of night vision devices. Indicated in Fig. 1 is a longitudinal plane LS. **Fig. 2** shows a longitudinal section of the I2 tube 100 along this plane LS. It can be seen that the I2 tube 100 comprises an input window 110 with a photosensitive layer 120 forming a photocathode (henceforth referred to as photocathode 120 or in short cathode), an electron multiplier 130 in the form of a micro channel plate, and a phosphorous layer 140 on top of the glass or fiber-

optic output window 150 acting as an anode (and henceforth also simply referred to as anode). The I2 tube 100 may be part of a direct view system. During operation of such a direct view system, the photocathode 120 creates an electron image from the scene when imaged onto the photocathode by an optical lens (not shown in Fig. 2), the electron multiplier 130 intensifies the electron image via electron multiplication, thereby obtaining a multiplied electron image, and the phosphorous layer 140 converts the multiplied electron image into visible light to obtain the intensified display of the scene.

It is noted that in order to reduce the complexity of the drawings, Fig. 2 does not explicitly show the photon propagation and emissions nor the electron currents since said aspects are known per se from the field of night vision devices. Moreover, it will be appreciated that Figs. 1 and 2 may not necessarily be drawn to scale.

Fig. 2 further shows a power supply unit 160 for the image intensifier. Such power supply units are known per se. In the example of Fig. 2, the power supply unit is in the shape of a hollow cylinder which is wrapped around a portion of the I2 tube 100. It is noted that the power supply unit 160 was not shown in Fig. 1. The power supply unit 160 may be connected to one or more batteries placed in a battery holder of the direct view system and may be arranged for providing the different operating voltages required to operate the direct view device. For example, the power supply unit 160 may provide operating voltages for the photocathode 120 and the electron multiplier 130.

Fig. 2 further shows a control circuit 170 for regulating a luminous gain of the image intensifier. The control circuit 170 may be implemented as an electronic circuit which is comprised in, and may also be powered by, the power supply unit 160. However, this is not a limitation, in that the control circuit 170 may also be differently implemented, for example outside of the power supply unit 160. In general, the control circuit 170 may comprise one or more electronic circuits. The one or more electronic circuits may comprise, or be, one or more microprocessors which execute appropriate software stored in a corresponding memory, e.g., a volatile memory such as RAM or a non-volatile memory such as Flash (not shown). Alternatively, the control circuit 170 may be, wholly or partially, implemented in programmable logic, such as, e.g., a field-programmable gate array (FPGA), as a dedicated hardware circuit, e.g., an Application Specific Integrated Circuit (ASIC), or by any other suitable electronic means.

Fig. 3 illustrates a method 200 of regulating a luminous gain of an image intensifier, such as the image intensifier of Figs. 1-2. The method 200 may, but does not need to, correspond to an operation of the control circuit 170 of Fig. 2. The method 200 may comprise performing automatic brightness control 210 in respect of the image intensifier. The automatic brightness control 210 may be a control mode of the control

circuit. The automatic brightness control 210 may comprise determining 220 a scene brightness, the scene brightness being a brightness of the scene that is imaged onto the image intensifier, and regulating 240 a luminous gain of the image intensifier to maintain an output brightness at or below a desired maximum output brightness level. It will be appreciated that while Fig. 3 shows the determining step 220 and the regulating step 240 as separate steps which are sequentially and repeatedly performed, both steps may also be performed simultaneously or in any other manner. It is further noted that automatic brightness control using the determining steps 220 and regulating steps 240 as described in this paragraph is known per se.

Fig. 3 illustrates further steps of the method 200, namely a step of determining 230 when a sudden increase in the scene brightness occurs. Here, 'sudden' increase may be defined as at least a doubling of the scene brightness within less than 10 milliseconds. The sudden increase may be determined in various ways, but may generally result in the output brightness of the image intensifier exceeding the desired maximum output brightness level unless such a rise in output brightness is otherwise mitigated. The determining step 230 may be performed in-between the determining step 220 and the regulating step 240, but may also be performed in any other manner, for example simultaneously with one of said steps. It is further noted that the determining steps 220 and 230 are shown in Fig. 3 as being part of the automatic brightness control 210 but may also be separate steps. If it is determined that there is a sudden increase in the scene brightness which causes the output brightness to exceed the desired maximum output brightness level, for example by a certain margin or reaching a preset level above the desired maximum output brightness level, the method 200 may proceed to step 250 in which the photocathode is deactivated and the automatic brightness control is interrupted. In a subsequent step 260, the luminous gain of the image intensifier may be reduced in accordance with a first gain reduction parameter. After reducing the luminous gain, in a subsequent step 270, the photocathode may be reactivated and automatic brightness control may be resumed.

The sudden increase in the scene brightness may be determined in various ways. For example, the output brightness of the image intensifier may be determined by measuring the anode current. As is known per se, the anode current may be defined as the current of electrons accelerated from the output side of the electron multiplier towards the phosphorous layer. The measured anode current may be divided by the luminous gain of the image intensifier to obtain an estimate of the scene brightness. In another example, the photocathode current may be measured. As is known per se, the photocathode current may be defined as the current of electrons accelerated from the

photocathode towards the input side of the electron multiplier. The photocathode current may be divided by a luminous sensitivity of the photocathode to obtain the estimate of the scene brightness. In another example, the photocathode may be a gated photocathode. In such an example, the decline of the gating voltage of the gated photocathode after a gating pulse may be measured. The measured decline of the gating voltage may be multiplied by a capacitance of a cathode gap of the image intensifier, and the result of the multiplication may be divided by a luminous sensitivity of the photocathode to obtain the estimate of the scene brightness. In yet another example, the operating current of the electron multiplier may be measured, a bias current of the electron multiplier may be subtracted from said measurement, and the result may be divided by the luminous gain of the image intensifier to obtain the estimate of the scene brightness. In yet another example, a photosensor may be used to directly measure the scene brightness. It will be appreciated that two or more of the aforementioned ways to determine the sudden increase in the scene brightness may be combined, for example to increase reliability or accuracy of the measurement.

In some examples, the control circuit may be configured to, after reactivating the photocathode, determine if the output brightness still exceeds the desired maximum output brightness level, for example by a certain margin, and if so, repeat the steps 250-270 of Fig. 3 but using a second gain reduction parameter in step 260. The gain reduction may thus be a two-step process in which, when the initial gain reduction by way of steps 250-270 does not sufficiently reduce the output brightness, the process exemplified by steps 250-270 may be repeated using the second gain reduction parameter. The second gain reduction parameter may be the same, larger than, or smaller than the first gain reduction parameter. The second gain reduction parameter may be chosen so that it is unlikely that the output brightness still exceeds the desired maximum output brightness level by any substantial margin.

In some examples, the control circuit may be configured to measure the scene brightness periodically, for example *N*-times per second, and deactivate the photocathode for one or more measurement periods. In a specific example, the control circuit may measure the electrical current flow to the anode. This current may be proportional to the amount of light output by the image intensifier, e.g., the output brightness. If the output brightness exceeds a preset level, e.g., 3x the desired maximum output brightness level, the photocathode may be instantaneously switched off, ceasing all light amplification and turning the image intensifier output off for the duration of one measurement cycle. The anode current may be measured at for example 500kHz. If a most recent sample value exceeds the preset level, the

photocathode may be immediately switched off. In such an example, the worst-case response time may thus be 2µs which may be sufficiently fast to suppress a severe light flash. Alternatively, instead of sampling and processing a digital representation of the anode current, a hardware comparator may be used. The hardware comparator may receive an analogue or other non-digital representation of the scene brightness as input and output a control signal to a circuit supplying a photocathode voltage to the photocathode. The hardware comparator, which may be part of a microcontroller or a dedicated IC, may be set to a preset level. When using such a hardware comparator, the response time to a surge in scene brightness may be reduced to nearly zero.

Fig. 4 shows the luminous gain of the image intensifier and the output brightness as a function of input window light exposure which may be directly proportional to scene brightness for an exemplary image intensifier. More specifically, Fig. 4 shows along the horizontal axis the input illumination 300 of the image intensifier (in lux), which input illumination may elsewhere also be referred to as scene brightness. Moreover, a luminous gain function 340 is shown which represents the luminous gain (in cd/m2/lux) used by the control circuit as a function of input illumination 300, with the scale for the luminous gain function 340 depicted on the righthand vertical axis 320. The resulting output brightness 330 is shown (in cd/m2), with the scale for the output brightness 330 depicted on the lefthand vertical axis 310.

The luminous gain function 340 may be explained as follows. The control circuit may be configured to, in the automatic gain control mode, regulate the luminous gain of the image intensifier using a first desired maximum output brightness level 332, a first gain value 342, a second desired maximum output brightness level 334, and a second gain value 344. Typically, the second gain value 344 is smaller than the first gain value 342 and the second desired maximum output brightness level 334 is higher than the first desired maximum output brightness level 332. More specifically, the control circuit may be configured to, with increasing scene brightness starting from a lowest or at least relatively low scene brightness, use and maintain the first gain value 342 as the luminous gain until the output brightness reaches the first desired maximum output brightness level 332. After reaching the first desired maximum output brightness level, the luminous gain may be reduced with respect to the first gain value 342 to maintain the output brightness at the first desired maximum output brightness level 332 until reaching a second gain value 344. After reaching the second gain value 344, the second gain value 344 may be maintained until the output brightness reaches the second desired maximum output brightness level 334. After reaching the second desired maximum output brightness level 334, the luminous gain may be reduced with

respect to the second gain value 344 to maintain the output brightness at the second desired maximum output brightness level 334. The above thus describes characteristics of the luminous gain function 340 for increasing scene brightness levels.

The first desired maximum output brightness level 332 may be selected in a range where the human eye perceives fine detail in the intensified display of the scene while avoiding overexposure of the human eye which will otherwise result in a temporary loss of sensitivity. For example, the first desired maximum output brightness level 332 may be selected to be within a range of 1.5 to 4 cd/m2. The second desired maximum output brightness level 334 may be selected in a range optimal for the human eye to perceive fine detail in the intensified display of the scene for a range of scene brightnesses where, when the scene is viewed without aid of the image intensifier, minor overexposure to the human eye will not result in a temporary loss of sensitivity. For example, the second desired maximum output brightness level 334 may be selected to be within a range of 6 to 12 cd/m2. The first gain value 342 may be used for a range of scene brightness levels up to 1mLux where the signal-to-noise ratio of the image intensifier is a dominant factor in the Johnson criteria for Detection, Recognition, and Identification. The second gain value 344 may be used for a range of scene brightness levels from 1 to 5mLux where a modulation transfer function (MTF) of the image intensifier is a dominant factor in the Johnson criteria for Detection, Recognition, and Identification.

In some examples, the control circuit may be configured to regulate the luminous gain of the image intensifier by adjusting a duty cycle of an operating voltage which is used to gate the photocathode. Additionally, or alternatively, the control circuit may be configured to regulate the luminous gain of the image intensifier by adjusting an electron multiplication gain of the electron multiplier. For example, the control circuit may adjust the electron multiplication gain by adjusting an operating voltage of the electron multiplier, for example by controlling or steering the power supply unit.

In some examples, the control circuit may be configured to reduce the luminous gain of the image intensifier using a scheme which involves alternatingly adjusting an electron multiplication gain of the electron multiplier and a duty cycle of the photocathode. **Fig. 5** illustrates such a scheme, showing the electron multiplication gain along the horizontal axis 400 and the duty cycle of the photocathode along the vertical axis 420. The electron multiplication gain may be adjusted by adjusting an operating voltage of the electron multiplier. As such, the horizontal axis 400 may also be interpreted as referring to the operating voltage of the electron multiplier. In accordance with said scheme, the control circuit may be configured to reduce the

luminous gain of the image intensifier by initially, e.g., from an initial luminous gain which may be characterized by an initial electron multiplication gain 402 and an initial duty cycle 422, reducing the electron multiplication gain of the electron multiplier, for example through the aforementioned reduction in operating voltage. When the electron multiplication gain then reaches a first electron multiplier gain level 404, the control circuit may reduce the luminous gain of the image intensifier further by reducing a duty cycle of the operating voltage which is used to gate the photocathode. When the duty cycle then reaches a first duty cycle value 424, the control circuit may reduce the electron multiplication gain further below the first electron multiplier gain level 404. When the electron multiplication gain then reaches a second electron multiplier gain level 406, the control circuit may reduce the luminous gain of the image intensifier further by further reducing the duty cycle below the first duty cycle value 424.

It is noted that any of the methods described in this specification, for example in any of the claims, may be implemented as a computer implemented method, e.g., using a (micro)processor, as dedicated hardware, or as a combination of both. Corresponding instructions, e.g., executable code, may be stored on a computer-readable medium e.g., in the form of a series of machine-readable physical marks and/or as a series of elements having different electrical, e.g., magnetic, or optical properties or values. The executable code may be stored in a transitory or non-transitory manner. Examples of computer-readable mediums include memory devices, optical storage devices, integrated circuits, servers, etc.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims.

In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. Use of the verb "comprise" and its conjugations does not exclude the presence of elements or stages other than those stated in a claim. The article "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. Expressions such as “at least one of” when preceding a list or group of elements represent a selection of all or of any subset of elements from the list or group. For example, the expression, “at least one of A, B, and C” should be understood as including only A, only B, only C, both A and B, both A and C, both B and C, or all of A, B, and C. The invention may be implemented by means of hardware comprising several distinct elements, and by means of a suitably programmed computer. In the device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. The mere fact that certain measures are recited in

mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

CLAIMS

Claim 1. A control circuit (170) for regulating a luminous gain of an image intensifier (100), wherein the image intensifier is configured to obtain an intensified representation of a scene, wherein the image intensifier comprises:

- a photocathode (120) for creating an electron image from a scene that is imaged onto the photocathode;
- an electron multiplier (130) for intensifying the electron image via electron multiplication, thereby obtaining a multiplied electron image;
- an anode comprising a phosphorous layer (140) for converting the multiplied electron image into a visible light image to obtain the intensified representation of the scene;

wherein the control circuit is configured to perform automatic brightness control by regulating (240) a luminous gain of the image intensifier to maintain an output brightness at or below a desired maximum output brightness level;

wherein the control circuit (170) is further configured to:

- determine (220) a scene brightness, the scene brightness being a brightness of the scene that is imaged onto the image intensifier;
- and when a sudden increase in the scene brightness, the sudden increase being at least a doubling of the scene brightness within less than 10 milliseconds, causes the output brightness to exceed the desired maximum output brightness level:
  - deactivate (250) the photocathode and interrupt the automatic brightness control;
  - reduce (260) the luminous gain of the image intensifier in accordance with a first gain reduction parameter; and
  - after reducing the luminous gain, reactivate (270) the photocathode and resume the automatic brightness control.

Claim 2. The control circuit (170) according to claim 1, wherein the control circuit is configured to determine the scene brightness by at least one of:

- determining the output brightness by measuring an anode current, wherein the anode current is a current of electrons accelerated from an output side of the electron multiplier (130) towards the phosphorous layer (140), and dividing the output brightness by the luminous gain of the image intensifier;

- measuring a photocathode current, wherein the photocathode current is a current of electrons accelerated from the photocathode (120) towards an input side of the electron multiplier (130), and dividing the photocathode current by a luminous sensitivity of the photocathode;
- if the photocathode (120) is a gated photocathode, measuring a decline of a gating voltage after a gating pulse, multiplying said measured decline by a capacitance of a cathode gap of the image intensifier, and dividing said multiplication product by a luminous sensitivity of the photocathode;
- determining the output brightness by measuring an operating current of the electron multiplier (130) and subtracting a bias current of the electron multiplier, and dividing the output brightness by the luminous gain of the image intensifier; and
- using a photosensor configured to measure the scene brightness.

Claim 3. The control circuit (170) according to claim 1 or 2, wherein the control circuit is configured to, after reactivating the photocathode (120), determine if the output brightness still exceeds the desired maximum output brightness level, and if so:

- deactivate the photocathode and interrupt the automatic brightness control;
- further reduce the luminous gain of the image intensifier in accordance with a second gain reduction parameter; and
- after further reducing the luminous gain, reactivate the photocathode and resume the automatic brightness control.

Claim 4. The control circuit (170) according to any one of claims 1 to 3, wherein the control circuit is configured to regulate the luminous gain of the image intensifier by at least one of:

- adjusting a duty cycle (420) of an operating voltage which is used to gate the photocathode;
- adjusting an electron multiplication gain (400) of the electron multiplier, for example by adjusting an operating voltage of the electron multiplier.

Claim 5. The control circuit (170) according to any one of claims 1 to 4, wherein the control circuit is configured to:

- measure the scene brightness periodically;
- deactivate the photocathode (120) for one or more measurement periods.

Claim 6. The control circuit (170) according to any one of claims 1 to 5, wherein the control circuit is configured to deactivate the photocathode using at least one of:

- a microcontroller or other digital processing unit incorporating control logic which processes a digital representation of the scene brightness;
- a hardware comparator which receives an analogue or other non-digital representation of the scene brightness as input and which outputs a control signal to a circuit supplying a photocathode voltage to the photocathode (120).

Claim 7. The control circuit (170) according to any one of claims 1 to 6, wherein the control circuit is configured to, when performing the automatic gain control, regulate the luminous gain of the image intensifier using a first desired maximum output brightness level, a first gain value, a second desired maximum output brightness level, and a second gain value, wherein the second gain value is smaller than the first gain value and wherein the second desired maximum output brightness level is higher than the first desired maximum output brightness level, wherein the control circuit is configured to, with increasing scene brightness starting from a lowest scene brightness:

- use and maintain the first gain value (342) as the luminous gain until reaching the first desired maximum output brightness level (332);
- after reaching the first desired maximum output brightness level, reduce the luminous gain with respect to the first gain value to maintain the output brightness at the first desired maximum output brightness level until reaching a second gain value (344);
- after reaching the second gain value, maintain the second gain value until reaching the second desired maximum output brightness level (334); and
- after reaching the second desired maximum output brightness level, reduce the luminous gain with respect to the second gain value to maintain the output brightness at the second desired maximum output brightness level.

Claim 8. The control circuit (170) according to claim 7, wherein the first desired maximum output brightness level (332) is selected in a range where the human eye perceives fine detail in the intensified display of the scene while avoiding overexposure of the human eye which will otherwise result in a temporary loss of sensitivity.

Claim 9. The control circuit (170) according to claim 7 or 8, wherein the first desired maximum output brightness level (332) is selected to be within a range of 1.5 to 4 cd/m2.

Claim 10. The control circuit (170) according to any one of claims 7 to 9, wherein the first gain value (342) is used for scene brightness levels up to 1mLux.

Claim 11. The control circuit (170) according to any one of claims 7 to 10, wherein the second gain value (344) is used for scene brightnesses from 1 to 5mLux.

Claim 12. The control circuit (170) according to any one of claims 7 to 11, wherein the second desired maximum output brightness level (334) is selected to be within a range of 6 to 12 cd/m2.

Claim 13. The control circuit (170) according to any one of claims 7 to 12, wherein the control circuit is configured to reduce the luminous gain of the image intensifier by reducing an electron multiplication gain of the electron multiplier by adjusting an operating voltage of the electron multiplier, and when the electron multiplication gain reaches a first electron multiplier gain level (404), reduce the luminous gain of the image intensifier by reducing a duty cycle of an operating voltage which is used to gate the photocathode, and when the duty cycle reaches a first duty cycle value (424), further reduce the electron multiplication gain below the first electron multiplier gain level, and when the electron multiplication gain reaches a second electron multiplier gain level (406), further reduce the luminous gain of the image intensifier by further reducing the duty cycle below the first duty cycle value.

Claim 14. A night vision device comprising the control circuit (170) and the image intensifier (100) as defined in any one of claims 1 to 13, the night vision device being for example a head mounted goggle or a weapon sight or a handheld device or an intensified CMOS sensor camera for capturing an output of the image intensifier.

Claim 15. A method (200) of regulating a luminous gain of an image intensifier, wherein the image intensifier is configured to obtain an intensified representation of a scene, wherein the image intensifier comprises:

- a photocathode for creating an electron image from a scene that is imaged onto the photocathode;

- an electron multiplier for intensifying the electron image via electron multiplication, thereby obtaining a multiplied electron image;
- an anode comprising a phosphorous layer for converting the multiplied electron image into a visible light image to obtain the intensified representation of the scene;

wherein the method comprises performing automatic brightness control (210) by regulating (240) a luminous gain of the image intensifier to maintain an output brightness at or below a desired maximum output brightness level;

wherein the method further comprises:

- determining (220) a scene brightness, the scene brightness being a brightness of the scene that is imaged onto the image intensifier;
- and when a sudden increase in the scene brightness, the sudden increase being at least a doubling of the scene brightness within less than 10 milliseconds, causes the output brightness to exceed the desired maximum output brightness level:
  - deactivating (250) the photocathode and interrupting the automatic brightness control;
  - reducing (260) the luminous gain of the image intensifier in accordance with a first gain reduction parameter; and
  - after reducing the luminous gain, reactivating (270) the photocathode and resuming the automatic brightness control.