SUMMARY OF THE DISCLOSED TECHNIQUE

In accordance with one aspect of the disclosed technique, there is thus provided an apparatus for increasing the resolution of a cryogenically cooled and vacuum-sealed infrared imaging detector. The apparatus includes a two-dimensional detector array of photosensitive pixels arranged in a matrix, a masking filter, optics, shifting means, and a processor. The detector array is successively exposed to an image scene, to acquire multiple imaging samples of the scene. The masking filter is disposed between the detector array and the focal plane of the image scene and is maintained at a fixed position with respect to the detector array. The masking filter reduces the region of the pixels collecting incident radiation from the image scene for each of the imaging samples, such that only a portion of each pixel area of the image scene is imaged onto the corresponding pixel of the detector array. The optics are disposed between the masking filter and the focal plane of the image scene, and direct the incident radiation onto the detector array through the masking filter. The shifting means successively shifts the optical path of the image scene relative to the masking filter, by a shifting increment equal to a fraction of the pixel width of the array pixels and corresponding to a fill factor reduction amount, to provide imaging of different sub-pixel regions in each of the imaging samples. The processor reconstructs an

image frame having a resolution greater than the intrinsic resolution of the detector, by a factor defined by the fill factor reduction amount, from the acquired imaging samples. The masking filter may be integrated with the detector array. The masking filter may include configuring the detector array such that the photosensitive region of the pixels of the array is smaller than the potentially maximum photosensitive region of the pixels. The shifting means may shift the optical path of the image scene relative to the masking filter by repositioning the optics with respect to the masking filter and the detector array. The shifting means may alternatively shift the optical path of the image scene relative to the masking filter by repositioning the masking filter and the detector array with respect to the optics. The f-number of the detector optics may be decreased by a factor corresponding to the fill factor reduction amount. The detector may operate within the wavelength range of approximately 1-15 µm. The detector may be a thermal imaging detector.

In accordance with another aspect of the disclosed technique, there is thus provided a method for increasing the resolution of a cryogenically cooled and vacuum-sealed infrared imaging detector that includes a two-dimensional detector array of photosensitive pixels arranged in a matrix. The method includes the procedures of successively exposing the detector array to an image scene to acquire

multiple imaging samples of the scene, and reducing the region of the pixels collecting incident radiation from the image scene for each of the imaging samples, such that only a portion of each pixel area of the image scene is imaged onto the corresponding pixel of the detector array. The method further includes the procedure of successively shifting the optical path of the image scene relative to a masking filter maintained at a fixed position with respect to the detector array, by a shifting increment equal to a fraction of the pixel width of the array pixels and corresponding to a fill factor reduction amount, to provide imaging of different sub-pixel regions in each of the imaging samples. The method further includes the procedure of reconstructing an image frame having a resolution greater than the intrinsic resolution of the detector, by a factor defined by the fill factor reduction amount, from the acquired imaging samples. The method may further include the procedure of decreasing the f-number of the detector optics by a factor corresponding to the fill factor reduction amount.

between detector array 110 and the focal plane 150 of a scene to be imaged by the detector. Detector array 110 is made up of a lattice or matrix pattern of photosensitive pixels arranged in rows and columns (e.g., a 320x240 array, which includes 320 pixels along the array width and 240 pixels along the array height). The pixels in array 110 may be any suitable size or area, where the individual pixel size is generally substantially consistent across all pixels of the array. Fill factor reduction means 120 is operative to selectively reduce the active (i.e., photosensitive) region of the pixels of detector array 110, by masking or blocking a portion of the photosensitive region of the pixels from receiving radiation from the image scene, such that only a portion of the image scene pixel is imaged onto the corresponding detector array pixel. The active region and masked region of the pixels are then progressively shifted during subsequent imaging samples of the scene. In particular, optical element 140 projects an image region 152 of image plane 150 onto masking filter 130, which in turn blocks out a portion of image region 152 from reaching the corresponding pixel 111 of detector array while allowing only the remaining portion 154 of image region 152 to reach pixel 111. Consequently, pixel 111 includes an imaged region 114 that is less than the total area (i.e., potential photosensitive area) of array pixel 111. Masking filter 130 includes a masking region 132 and a non-masking

region 134, such that radiation incident onto masking region 132 (via optical element 140) is prevented from passing through (toward detector array 110), while radiation incident onto non-masking region 134 is passed through. For example, masking region 132 may be embodied by a substantially opaque or non-transmissive portion of filter or a non-transmissive coating disposed at the required portion, whereas non-masking region 134 may be embodied by a substantially transmissive portion of filter 130, such as a window or opening thereat.

It is noted that any of the components of fill factor reduction means 120 may be fully or partially integrated with the IR imaging detector in accordance with the disclosed technique, or may be separate therefrom. For example, masking filter 130 may be situated within the housing enclosing the IR detector, while optical element 140 may be situated outside of the housing, provided optical element 140 and masking filter function to implement the aforementioned masking operation of the image plane 150 onto the detector array 110.

Reference is now made to Figures 2A, 2B, 2C and 2D. Figure 2A is a perspective view schematic illustration of an initial set of image sub-frames acquired over successive imaging samples with the apparatus of Figure 1. Figure 2B is a perspective view schematic illustration of a subsequent set of image sub-frames acquired over successive imaging

samples with the apparatus of Figure 1. Figure 2C is a perspective view schematic illustration of another subsequent set of image sub-frames acquired over successive imaging samples with the apparatus of Figure 1. Figure 2D is a perspective view schematic illustration of a final set of image sub-frames acquired over successive imaging samples with the apparatus of Figure 1. Detector array 110 is depicted with nine (9) pixels arranged in a three-by-three (3x3) matrix. Masking filter 130 is disposed directly on array 110, and includes nine windows (i.e., non-masking regions 134) situated on a sub-region of each of the detector pixels ($DP_{x,y}$) of detector array 110, while the remaining area of masking filter 130 is made up of masking regions 132. The image plane 150 is similarly divided into nine image pixels ($IP_{x,y}$) arranged in a three-by-three (3x3) matrix (i.e., each image pixel representing the region of image plane 150 that would ordinarily be projected onto a corresponding detector pixel during regular image acquisition).

A first set of sub-frames of image scene 150 is acquired in Fig. 2A. The light (IR radiation) emitted from image scene 150 is directed toward detector array 110 through masking filter 130 via optical element 140 (not shown), such that only the radiation passing through the windows 134 of masking filter 130 reaches detector array 110. In particular, each detector pixel of detector array 110 captures a portion of a corresponding

image pixel of image plane 150. For example, referring to the first imaging sample ("sub-frame 1") in Fig.2A, radiation corresponding to an upper-left corner image pixel ($IP_{1,1}$) is directed toward a detector pixel ($DP_{1,1}$) situated at the upper-left corner of detector array 110. A portion of the radiation (154) passes through the masking filter window and is incident onto the a sub-region 114 of detector pixel $DP_{1,1}$. The rest of the radiation (152) from image pixel $IP_{1,1}$ is blocked by the masking region 132, such that it does not reach detector pixel $DP_{1,1}$. Consequently, detector pixel $DP_{1,1}$ includes an imaged region 114 and a non-imaged region 112. Similarly, the next image pixel ($IP_{1,2}$) in the top row of image plane 150 reaches detector pixel $DP_{1,2}$ after passing through the masking filter window, such that only a portion of image pixel $IP_{1,2}$ is incident onto a sub-region of detector pixel $DP_{1,2}$. Fill factor reduction means 120 is shown implementing an exemplary fill factor reduction of 25% (i.e., "25%FF"), denoting that each imaged region 114 occupies approximately one-quarter of the area of the respective pixel, while each non-imaged region 112 occupies an area of approximately three-quarters of the respective pixel. The remaining pixels ($DP_{x,y}$) of detector array 110 are imaged in an analogous manner during the first imaging sample (sub-frame), resulting in each detector pixel acquiring an imaged region

114 at its upper-left quadrant, while the remainder of the detector pixel is non-imaged.

Following acquisition of the first imaging sample, the portion of each image pixel imaged onto detector array 110 is shifted for the subsequent imaging samples. The shifting increment between each imaging sample is selected in accordance with the fill factor reduction amount, and is generally equal to a fraction of the pixel width (defined as the distance between the midpoint of adjacent pixels of the detector array). In this example, the fill factor reduction amount is 25% (25%FF), and so the shifting increment is also selected to be 25%, or approximately one quarter of the pixel width of the detector pixels. The shifting may be implemented by adjusting the line-of-sight of fill factor reduction means 120 relative to detector array 110 (e.g., by suitable adjustment of masking filter 130 and/or of optical element 140). Referring to the second imaging sample ("sub-frame 2") in Fig.2A, each detector pixel $DP_{x,y}$ receives incident radiation from another portion of image pixel $IP_{x,y}$, such that the imaged region 114 corresponds to an upper-middle quadrant of the corresponding image pixel $IP_{x,y}$ (e.g., the imaged quadrant of "sub-frame 1" being shifted to the right by a quarter of the pixel width, such that the second image quadrant partially overlaps the first image quadrant). Referring to the third imaging sample ("sub-frame 3"), the line-of-sight is

shifted again such that the imaged region 114 of each detector pixel $DP_{x,y}$ corresponds to an upper-right quadrant of the corresponding image pixel $IP_{x,y}$ (e.g., the imaged quadrant of "sub-frame 2" being shifted to the right by a quarter of the pixel width).

Additional imaging samples are acquired in an analogous manner, covering remaining overlapping portions (e.g., quadrants) of each image pixel, by successively adjusting the line-of-sight systematically over the same shifting increment (e.g., a quarter pixel width) along both the vertical axis and the horizontal axis of the image plane 150, applying a technique called "microscanning", known in the art. For example, referring to the fifth imaging sample ("sub-frame 5") in Fig.2B, the line-of-sight is shifted downwards by the shifting increment with respect to the first imaging sample, such that the imaged region 114 of each detector pixel $DP_{x,y}$ corresponds to an middle-left quadrant of the corresponding image pixel $IP_{x,y}$ (e.g., the imaged quadrant of "sub-frame 1" being shifted downwards by a quarter of the pixel width). The remaining imaging samples ("sub frame 6" through "sub-frame 16") result in additional image pixel portions being acquired (i.e., imaging a respective portion that was not acquired in a previous sub-frame).

The line-of-sight alignment of fill factor reduction means 120 relative to detector array 110 may be successively shifted using any

suitable mechanism or technique, in order to obtain the desired imaged sub-region on the detector pixels for each imaging sample. For example, masking filter 130 and detector array 110 remain in a fixed position, and thus the positions of masking regions 132 and non-masking regions 134 remain stationary, while optical element 140 is successively repositioned for each imaging sample to shift the directional angle at which optical element 140 directs the radiation from image scene 150. Alternatively, masking filter 130 and detector array 110 are jointly repositioned relative to optical element 140 (i.e., where masking filter 130 remains fixed with respect to detector array 110), for adjusting the optical path of image scene 150 for each imaging sample. It is noted that the actual size of the imaged regions on the detector pixels may be varied, such as by adjusting the characteristics of masking filter 130 (e.g., size, amount, and/or relative positions of non-masking regions 134) and/or adjusting the optical characteristics of optical element 140. In some detectors, such as vacuum-sealed detector and/or cryogenically-cooled detectors, it is very difficult to reposition a masking filter relative to the detector array, since the two components should be arranged as close as possible to one another. Consequently, a mechanism for repositioning a movable masking filter would need to be situated within the cryogenic storage dewar (vacuum flask) along with the masking filter and detector array.

This requires such a mechanism to be exceptionally miniature and fast moving, while being capable of operating in cryogenic temperatures. Furthermore, the cryogenic storage dewar would require significant enlargement, as well as an enhanced cooling mechanism to support the additional heating load. Thus, even if the implementation of a movable masking filter is feasible, the aforementioned issues would yield a detector with minimal practical applications due to the resultant high cost, higher power consumption, greater volume, and lower reliability. Therefore, according to an embodiment of the disclosed technique, a stationary masking filter is maintained at a fixed position and orientation relative to the detector array, while the optical path of the image scene is successively adjusted relative to the stationary masking filter between imaging samples.

The different sub-regions of the image pixels $IP_{x,y}$ of image plane 150 may be imaged in any order or permutation. For example, a bottom row of image pixel portions may be imaged first (i.e., the four sub-frames depicted in Fig.2D), followed by a higher row, and so forth; or alternatively, a first column of image pixel portions may be imaged in a first group of sub-frames, followed by an adjacent column, and so forth. Furthermore, the imaged sub-regions may be nonconsecutive within a given sub-frames (e.g., an upper-left quadrant and lower-right quadrant of

the image pixel may be simultaneously acquired in one sub-frame, while an upper-right quadrant and lower-left quadrant of the image pixel are simultaneously acquired in a subsequent sub-frame).

After all the sub-frames are acquired over successive imaging samples, where each individual sub-frame corresponds to a different imaged sub-region of each image pixel of image plane 150, a final image frame is constructed from all of the acquired sub-frames. Namely, all of the imaged sub-regions for each image pixel are processed and combined, in accordance with a suitable image processing scheme. Reference is now made to Figure 3, which is a schematic illustration of a reconstructed image frame, referenced 164, formed from the image sub-frames of Figures 2A, 2B, 2C and 2D, compared with a regular image frame, referenced 162, of the imaging detector. Regular image frame 162 includes a total of 9 pixels (3x3), whereas reconstructed image frame 164 includes a total of 144 sub-pixels (12x12), providing a 16-fold increase in resolution (i.e., increasing the number of pixels by a factor of four along each of the horizontal and vertical axes). In particular, each individual pixel in reconstructed image frame 164 (corresponding to a pixel of image frame 162) is made up of 16 sub-pixels arranged in a 4x4 matrix. Each sub-pixel of reconstructed image frame 164 is formed from a combination of the respective sub-frames in which that sub-pixel was imaged. For

example, sub-pixel 168 of image frame 164 is formed based on sub-frames 1 and 2 (Fig.2A) and sub-frames 5 and 6 (Fig.2B), in which that particular sub-pixel portion of image plane 150 was acquired (in different configurations).

Reconstructed image frame 164 represents a 16-fold increase in resolution with respect to image frame 162, which is an image frame that would result from regular imaging with detector array 110 (i.e., without application of the disclosed technique). The intrinsic resolution of detector array 110 is represented by a 3x3 pixel density (i.e., 3 rows by 3 columns of pixels = 9 total pixels), as depicted in image frame 162, whereas reconstructed image frame 164 includes 12x12 sub-pixels within the same fixed area of array 110. As a result, the final image frame contains greater image detail (i.e., by a factor of sixteen) as compared to a standard image frame, as each pixel of the reconstructed image frame is made up of sixteen individual sub-pixels which provides four times the detail or information along each axis as would be contained in the corresponding pixel of the standard image frame.

It is appreciated that alternative resolution increase factors (i.e., the amount by which the image resolution is increased) may be obtained by varying the shifting increment between sub-frames, as well as the fill factor reduction amount (i.e., the amount by which the active region of the

CLAIMS

1. An apparatus for increasing the resolution of a cryogenically cooled and vacuum-sealed infrared imaging detector, comprising:

a two-dimensional detector array of photosensitive pixels arranged in a matrix, said detector array successively exposed to an image scene, to acquire multiple imaging samples of said scene;

a masking filter, disposed between said detector array and the focal plane of said image scene and maintained at a fixed position with respect to said detector array, said masking filter operative to reduce the region of said pixels collecting incident radiation from said image scene for each of said imaging samples, such that only a portion of each pixel area of said image scene is imaged onto the corresponding pixel of said detector array;

optics, disposed between said masking filter and the focal plane of said image scene, said optics operative to direct said incident radiation onto said detector array through said masking filter;

shifting means, for successively shifting the optical path of said image scene relative to said masking filter, by a shifting increment equal to a fraction of the pixel width of said array pixels and corresponding to a fill factor reduction amount, to provide imaging of different sub-pixel regions in each of said imaging samples; and

a processor, operative for reconstructing an image frame having a resolution greater than the intrinsic resolution of said detector, by a factor defined by said fill factor reduction amount, from said acquired imaging samples.

2. The apparatus of claim 1, wherein said masking filter is integrated with said detector array.

3. The apparatus of claim 1, wherein said masking filter comprises configuring said detector array such that the photosensitive region of the pixels of said array is smaller than the potentially maximum photosensitive region of said pixels.

4. The apparatus of claim 1, wherein said shifting means shifts the optical path of said image scene relative to said masking filter by repositioning said optics with respect to said masking filter and said detector array.

5. The apparatus of claim 1, wherein said shifting means shifts the optical path of said image scene relative to said masking filter by

repositioning said masking filter and said detector array with respect to said optics.

6. The apparatus of claim 1, wherein the f-number of said optics is decreased by a factor corresponding to said fill factor reduction amount.

7. The apparatus of claim 1, wherein said detector is operative within the wavelength range of 1–15 μm.

8. The apparatus of claim 1, wherein said detector is a thermal imaging detector.

9. A method for increasing the resolution of a cryogenically cooled and vacuum-sealed infrared imaging detector comprising a two-dimensional detector array of photosensitive pixels arranged in a matrix, the method comprising the procedures of:

successively exposing said detector array to an image scene, to acquire multiple imaging samples of said scene;

reducing the region of said pixels collecting incident radiation from said image scene for each of said imaging samples, such that

only a portion of each pixel area of said image scene is imaged onto the corresponding pixel of said detector array;

successively shifting the optical path of said image scene relative to a masking filter maintained at a fixed position with respect to said detector array, by a shifting increment equal to a fraction of the pixel width of said array pixels and corresponding to a fill factor reduction amount, to provide imaging of different sub-pixel regions in each of said imaging samples; and

reconstructing an image frame having a resolution greater than the intrinsic resolution of said detector, by a factor defined by said fill factor reduction amount, from said acquired imaging samples.

10. The method of claim 9, further comprising decreasing the f-number of the detector optics by a factor corresponding to said fill factor reduction amount.

SUMMARY OF THE DISCLOSED TECHNIQUE

In accordance with one aspect of the disclosed technique, there is thus provided an apparatus for increasing the resolution of a cryogenically cooled and vacuum-sealed infrared imaging detector. The apparatus includes a two-dimensional detector array of photosensitive pixels arranged in a matrix, a masking filter, an optical element, shifting means, and a processor. The detector array is operative within the wavelength range of 1–15 μm and is successively exposed to an image scene, to acquire multiple imaging samples of the scene. The masking filter is disposed between the detector array and the image scene and is maintained at a fixed position with respect to the detector array. The masking filter masks part of the active region of the pixels within the wavelength range of 1–15 μm by a fill factor reduction amount, for each of the imaging samples, such that only a portion of each pixel area of the image scene is imaged onto the corresponding masked pixel of the detector array. The optics are disposed between the masking filter and the image scene, and direct the incident radiation onto the detector array through the masking filter. The shifting means successively shifts the optical path of the image scene relative to the masking filter and the detector array between each of the imaging samples, by a shifting increment corresponding to the fill factor reduction amount, to provide imaging of different sub-pixel regions in each of the imaging samples. The processor reconstructs an image frame from the acquired imaging samples, the reconstructed image frame having a resolution greater than the intrinsic resolution of the detector, by a factor defined by the

fill factor reduction amount. The masking filter may be a coating disposed on the detector array. The masking filter may include configuring the detector array such that the photosensitive region of the pixels of the array is smaller than the potentially maximum photosensitive region of the pixels. The shifting means may shift the optical path of the image scene relative to the masking filter by repositioning the optics with respect to the masking filter and the detector array. The shifting means may alternatively shift the optical path of the image scene relative to the masking filter and the detector array by jointly repositioning the masking filter and the detector array with respect to the optics. The f-number of the detector optics may be selected in accordance with to the fill factor reduction amount to provide a selected sensitivity of the detector. The selected sensitivity of the detector may correspond to the sensitivity of a non-fill factor reduced detector. The detector may be a thermal imaging detector.

In accordance with another aspect of the disclosed technique, there is thus provided a method for increasing the resolution of a cryogenically cooled and vacuum-sealed infrared imaging detector that includes a two-dimensional detector array of photosensitive pixels arranged in a matrix, the detector array operative within the wavelength range of 1–15 μm. The method includes the procedures of successively exposing the detector array to an image scene to acquire multiple imaging samples of the scene, and masking part of the active region of the pixels within the wavelength range of 1–15 μm by a fill factor reduction amount, for each of the imaging samples, via

a masking filter disposed within the cryogenic storage dewar and maintained at a fixed position with respect to the detector array, such that only a portion of each pixel area of the image scene is imaged onto the corresponding masked pixel of the detector array. The method further includes the procedure of successively shifting the optical path of the image scene relative to the masking filter and the detector array between each of the imaging samples, , by a shifting increment corresponding to the fill factor reduction amount, to provide imaging of different sub-pixel regions in each of the imaging samples. The method further includes the procedure of reconstructing an image frame from the acquired imaging samples, the reconstructed image frame having a resolution greater than the intrinsic resolution of the detector, by a factor defined by the fill factor reduction amount. The method may further include the procedure of selecting the f-number of the detector optics in accordance with the fill factor reduction amount to provide a selected sensitivity of the detector. The selected sensitivity of the detector may correspond to the sensitivity of a non-fill factor reduced detector.

between detector array 110 and the scene 150 to be imaged by the detector. Detector array 110 is made up of a lattice or matrix pattern of photosensitive pixels arranged in rows and columns (e.g., a 320x240 array, which includes 320 pixels along the array width and 240 pixels along the array height). The pixels in array 110 may be any suitable size or area, where the individual pixel size is generally substantially consistent across all pixels of the array. Fill factor reduction means 120 is operative to selectively reduce the active (i.e., photosensitive) region of the pixels of detector array 110, by masking or blocking a portion of the photosensitive region of the pixels from receiving radiation from the image scene, such that only a portion of the image scene pixel is imaged onto the corresponding detector array pixel. The active region and masked region of the pixels are then progressively shifted during subsequent imaging samples of the scene. In particular, optical element 140 projects an image region 152 of image scene 150 onto masking filter 130, which in turn blocks out a portion of image region 152 from reaching the corresponding pixel 111 of detector array while allowing only the remaining portion 154 of image region 152 to reach pixel 111. Consequently, pixel 111 includes an imaged region 114 that is less than the total area (i.e., potential photosensitive area) of array pixel 111. Masking filter 130 includes a masking region 132 and a non-masking

region 134, such that radiation incident onto masking region 132 (via optical element 140) is prevented from passing through (toward detector array 110), while radiation incident onto non-masking region 134 is passed through. For example, masking region 132 may be embodied by a substantially opaque or non-transmissive portion of filter or a non-transmissive coating disposed at the required portion, whereas non-masking region 134 may be embodied by a substantially transmissive portion of filter 130, such as a window or opening thereat.

It is noted that any of the components of fill factor reduction means 120 may be fully or partially integrated with the IR imaging detector in accordance with the disclosed technique, or may be separate therefrom. For example, masking filter 130 may be situated within the housing enclosing the IR detector, while optical element 140 may be situated outside of the housing, provided optical element 140 and masking filter function to implement the aforementioned masking operation of the image scene 150 onto the detector array 110.

Reference is now made to Figures 2A, 2B, 2C and 2D. Figure 2A is a perspective view schematic illustration of an initial set of image sub-frames acquired over successive imaging samples with the apparatus of Figure 1. Figure 2B is a perspective view schematic illustration of a subsequent set of image sub-frames acquired over successive imaging

samples with the apparatus of Figure 1. Figure 2C is a perspective view schematic illustration of another subsequent set of image sub-frames acquired over successive imaging samples with the apparatus of Figure 1. Figure 2D is a perspective view schematic illustration of a final set of image sub-frames acquired over successive imaging samples with the apparatus of Figure 1. Detector array 110 is depicted with nine (9) pixels arranged in a three-by-three (3x3) matrix. Masking filter 130 is disposed directly on array 110, and includes nine windows (i.e., non-masking regions 134) situated on a sub-region of each of the detector pixels ($DP_{x,y}$) of detector array 110, while the remaining area of masking filter 130 is made up of masking regions 132. The image scene 150 is similarly divided into nine image pixels ($IP_{x,y}$) arranged in a three-by-three (3x3) matrix (i.e., each image pixel representing the region of image scene 150 that would ordinarily be projected onto a corresponding detector pixel during regular image acquisition).

A first set of sub-frames of image scene 150 is acquired in Fig. 2A. The light (IR radiation) emitted from image scene 150 is directed toward detector array 110 through masking filter 130 via optical element 140 (not shown), such that only the radiation passing through the windows 134 of masking filter 130 reaches detector array 110. In particular, each detector pixel of detector array 110 captures a portion of a corresponding

image pixel of image scene 150. For example, referring to the first imaging sample ("sub-frame 1") in Fig.2A, radiation corresponding to an upper-left corner image pixel ($IP_{1,1}$) is directed toward a detector pixel ($DP_{1,1}$) situated at the upper-left corner of detector array 110. A portion of the radiation (154) passes through the masking filter window and is incident onto the a sub-region 114 of detector pixel $DP_{1,1}$. The rest of the radiation (152) from image pixel $IP_{1,1}$ is blocked by the masking region 132, such that it does not reach detector pixel $DP_{1,1}$. Consequently, detector pixel $DP_{1,1}$ includes an imaged region 114 and a non-imaged region 112. Similarly, the next image pixel ($IP_{1,2}$) in the top row of image scene 150 reaches detector pixel $DP_{1,2}$ after passing through the masking filter window, such that only a portion of image pixel $IP_{1,2}$ is incident onto a sub-region of detector pixel $DP_{1,2}$. Fill factor reduction means 120 is shown implementing an exemplary fill factor reduction of 25% (i.e., "25%FF"), denoting that each imaged region 114 occupies approximately one-quarter of the area of the respective pixel, while each non-imaged region 112 occupies an area of approximately three-quarters of the respective pixel. The remaining pixels ($DP_{x,y}$) of detector array 110 are imaged in an analogous manner during the first imaging sample (sub-frame), resulting in each detector pixel acquiring an imaged region

114 at its upper-left quadrant, while the remainder of the detector pixel is non-imaged.

Following acquisition of the first imaging sample, the portion of each image pixel imaged onto detector array 110 is shifted for the subsequent imaging samples. The shifting increment between each imaging sample is selected in accordance with the fill factor reduction amount, and is generally equal to a fraction of the pixel width (defined as the distance between the midpoint of adjacent pixels of the detector array). In this example, the fill factor reduction amount is 25% (25%FF), and so the shifting increment is also selected to be 25%, or approximately one quarter of the pixel width of the detector pixels. The shifting may be implemented by adjusting the line-of-sight of fill factor reduction means 120 relative to detector array 110 (e.g., by suitable adjustment of masking filter 130 and/or of optical element 140). Referring to the second imaging sample ("sub-frame 2") in Fig.2A, each detector pixel $DP_{x,y}$ receives incident radiation from another portion of image pixel $IP_{x,y}$, such that the imaged region 114 corresponds to an upper-middle quadrant of the corresponding image pixel $IP_{x,y}$ (e.g., the imaged quadrant of "sub-frame 1" being shifted to the right by a quarter of the pixel width, such that the second image quadrant partially overlaps the first image quadrant). Referring to the third imaging sample ("sub-frame 3"), the line-of-sight is

shifted again such that the imaged region 114 of each detector pixel $DP_{x,y}$ corresponds to an upper-right quadrant of the corresponding image pixel $IP_{x,y}$ (e.g., the imaged quadrant of “sub-frame 2” being shifted to the right by a quarter of the pixel width).

Additional imaging samples are acquired in an analogous manner, covering remaining overlapping portions (e.g., quadrants) of each image pixel, by successively adjusting the line-of-sight systematically over the same shifting increment (e.g., a quarter pixel width) along both the vertical axis and the horizontal axis of the image scene 150, applying a technique called “microscanning”, known in the art. For example, referring to the fifth imaging sample (“sub-frame 5”) in Fig.2B, the line-of-sight is shifted downwards by the shifting increment with respect to the first imaging sample, such that the imaged region 114 of each detector pixel $DP_{x,y}$ corresponds to an middle-left quadrant of the corresponding image pixel $IP_{x,y}$ (e.g., the imaged quadrant of “sub-frame 1” being shifted downwards by a quarter of the pixel width). The remaining imaging samples (“sub frame 6” through “sub-frame 16”) result in additional image pixel portions being acquired (i.e., imaging a respective portion that was not acquired in a previous sub-frame).

The line-of-sight alignment of fill factor reduction means 120 relative to detector array 110 may be successively shifted using any

suitable mechanism or technique, in order to obtain the desired imaged sub-region on the detector pixels for each imaging sample. For example, masking filter 130 and detector array 110 remain in a fixed position, and thus the positions of masking regions 132 and non-masking regions 134 remain stationary, while optical element 140 is successively repositioned for each imaging sample to shift the directional angle at which optical element 140 directs the radiation from image scene 150. Alternatively, masking filter 130 and detector array 110 are jointly repositioned relative to optical element 140 (i.e., where masking filter 130 remains fixed with respect to detector array 110), for adjusting the optical path of image scene 150 for each imaging sample. It is noted that the actual size of the imaged regions on the detector pixels may be varied, such as by adjusting the characteristics of masking filter 130 (e.g., size, amount, and/or relative positions of non-masking regions 134) and/or adjusting the optical characteristics of optical element 140. In some detectors, such as vacuum-sealed detector and/or cryogenically-cooled detectors, it is very difficult to reposition a masking filter relative to the detector array, since the two components should be arranged as close as possible to one another. Consequently, a mechanism for repositioning a movable masking filter would need to be situated within the cryogenic storage dewar (vacuum flask) along with the masking filter and detector array.

This requires such a mechanism to be exceptionally miniature and fast moving, while being capable of operating in cryogenic temperatures. Furthermore, the cryogenic storage dewar would require significant enlargement, as well as an enhanced cooling mechanism to support the additional heating load. Thus, even if the implementation of a movable masking filter is feasible, the aforementioned issues would yield a detector with minimal practical applications due to the resultant high cost, higher power consumption, greater volume, and lower reliability. Therefore, according to an embodiment of the disclosed technique, a stationary masking filter is maintained at a fixed position and orientation relative to the detector array, while the optical path of the image scene is successively adjusted relative to the stationary masking filter between imaging samples.

The different sub-regions of the image pixels $IP_{x,y}$ of image scene 150 may be imaged in any order or permutation. For example, a bottom row of image pixel portions may be imaged first (i.e., the four sub-frames depicted in Fig.2D), followed by a higher row, and so forth; or alternatively, a first column of image pixel portions may be imaged in a first group of sub-frames, followed by an adjacent column, and so forth. Furthermore, the imaged sub-regions may be nonconsecutive within a given sub-frames (e.g., an upper-left quadrant and lower-right quadrant of

the image pixel may be simultaneously acquired in one sub-frame, while an upper-right quadrant and lower-left quadrant of the image pixel are simultaneously acquired in a subsequent sub-frame).

After all the sub-frames are acquired over successive imaging samples, where each individual sub-frame corresponds to a different imaged sub-region of each image pixel of image scene 150, a final image frame is constructed from all of the acquired sub-frames. Namely, all of the imaged sub-regions for each image pixel are processed and combined, in accordance with a suitable image processing scheme. Reference is now made to Figure 3, which is a schematic illustration of a reconstructed image frame, referenced 164, formed from the image sub-frames of Figures 2A, 2B, 2C and 2D, compared with a regular image frame, referenced 162, of the imaging detector. Regular image frame 162 includes a total of 9 pixels (3x3), whereas reconstructed image frame 164 includes a total of 144 sub-pixels (12x12), providing a 16-fold increase in resolution (i.e., increasing the number of pixels by a factor of four along each of the horizontal and vertical axes). In particular, each individual pixel in reconstructed image frame 164 (corresponding to a pixel of image frame 162) is made up of 16 sub-pixels arranged in a 4x4 matrix. Each sub-pixel of reconstructed image frame 164 is formed from a combination of the respective sub-frames in which that sub-pixel was imaged. For

example, sub-pixel 168 of image frame 164 is formed based on sub-frames 1 and 2 (Fig.2A) and sub-frames 5 and 6 (Fig.2B), in which that particular sub-pixel portion of image scene 150 was acquired (in different configurations).

Reconstructed image frame 164 represents a 16-fold increase in resolution with respect to image frame 162, which is an image frame that would result from regular imaging with detector array 110 (i.e., without application of the disclosed technique). The intrinsic resolution of detector array 110 is represented by a 3x3 pixel density (i.e., 3 rows by 3 columns of pixels = 9 total pixels), as depicted in image frame 162, whereas reconstructed image frame 164 includes 12x12 sub-pixels within the same fixed area of array 110. As a result, the final image frame contains greater image detail (i.e., by a factor of sixteen) as compared to a standard image frame, as each pixel of the reconstructed image frame is made up of sixteen individual sub-pixels which provides four times the detail or information along each axis as would be contained in the corresponding pixel of the standard image frame.

It is appreciated that alternative resolution increase factors (i.e., the amount by which the image resolution is increased) may be obtained by varying the shifting increment between sub-frames, as well as the fill factor reduction amount (i.e., the amount by which the active region of the

CLAIMS

1. An apparatus for increasing the resolution of a cryogenically cooled and vacuum-sealed infrared imaging detector, comprising:

a two-dimensional infrared detector array of photosensitive pixels arranged in a matrix, the detector array operative within the wavelength range of 1–15 μm, the detector array configured to be successively exposed to an image scene, to acquire multiple imaging samples of the scene;

a masking filter, disposed between the detector array and the image scene and maintained at a fixed position with respect to the detector array, the masking filter configured to mask part of the active region of the pixels within the wavelength range of 1-15 μm by a fill factor reduction amount, for each of the imaging samples, such that only a portion of each pixel area of the image scene is imaged onto the corresponding masked pixel of the detector array;

optics, disposed between the masking filter and the image scene, the optics configured to direct the incident radiation onto the detector array through the masking filter;

shifting means, for successively shifting the optical path of the image scene relative to the masking filter and the detector array between each of the imaging samples, by a shifting increment corresponding to the fill factor reduction amount, to provide imaging of different sub-pixel regions in each of the imaging samples; and

a processor, configured to reconstruct an image frame from the acquired imaging samples, the reconstructed image frame having a resolution greater than the intrinsic resolution of the detector by a factor defined by the fill factor reduction amount.

2. An apparatus according to Claim 1, in which the masking filter comprises a coating disposed on the detector array.

3. An apparatus according to Claim 1, in which the masking filter comprises configuring the detector array such that the photosensitive region of the pixels of the array is smaller than the potentially maximum photosensitive region of the pixels.

4. An apparatus according to Claim 1, in which the shifting means is configured to shift the optical path of the image scene relative to the masking filter and the detector array by repositioning the optics with respect to the masking filter and the detector array.

5. An apparatus according to Claim 1, in which the shifting means is configured to shift the optical path of the image scene relative to the masking filter and the detector array by jointly repositioning the masking filter and the detector array with respect to the optics.

6. An apparatus according to Claim 1, in which the f-number of the detector optics is selected in accordance with the fill factor reduction amount to provide a selected sensitivity of the detector.

7. An apparatus according to Claim 6, in which the selected sensitivity of the detector corresponds to the sensitivity of a non-fill factor reduced detector.

8. An apparatus according to Claim 1, in which the detector is a thermal imaging detector.

9. A method for increasing the resolution of a cryogenically cooled and vacuum-sealed infrared imaging detector comprising a two-dimensional infrared detector array of photosensitive pixels arranged in a matrix, the detector array operative within the wavelength range of 1–15 μm, the method comprising the procedures of:

successively exposing the detector array to an image scene, to acquire multiple imaging samples of the scene;

masking part of the active region of the pixels within the wavelength range of 1-15 μm by a fill factor reduction amount for each of the imaging samples, via a masking filter maintained at a fixed position with respect to the detector array, such that only a portion of each pixel area of the image scene is imaged onto the corresponding masked pixel of the detector array;

successively shifting the optical path of the image scene relative to the masking filter and the detector array between each of the imaging samples, , by a shifting increment corresponding to the fill factor reduction amount, to provide imaging of different sub-pixel regions in each of the imaging samples; and

reconstructing an image frame from the acquired imaging samples, the reconstructed image frame having a resolution greater than the intrinsic resolution of the detector by a factor defined by the fill factor reduction amount.

10. A method according to Claim 9, further comprising the procedure of selecting the f-number of the detector optics in accordance with the fill factor reduction amount to provide a selected sensitivity of the detector.

11. A method according to Claim 10, in which the selected sensitivity of the detector corresponds to the sensitivity of a non-fill factor reduced detector.