Claims

1. A method of imaging comprising:

receiving a first signal from one or more array elements of a first type in a mixed transducer array;

receiving a second signal from one or more array elements of a second type in the mixed transducer array, wherein at least one of the first type and the second type is an optical sensor;

generating a first image from the first signal and a second image from the second signal; and

combining the first image and the second image to generate a compound image.

2. The method of claim 1, wherein the first type and the second type are optical resonators with different characteristics.

~~3. The method of claim 2, wherein the first type is a high Q optical resonator and the second type is a low Q optical resonator.~~

~~4. The method of claim 2, wherein the first type is a tunable optical resonator operated as a high Q optical resonator and the second type is a tunable optical resonator operated as a low Q optical resonator.~~

~~5. The method of claim 1, wherein the first type is a non-optical transducer and the second type is an optical sensor.~~

~~6. The method of claim 5, wherein the non-optical transducer is a piezoelectric transducer, a single crystal material transducer, a piezoelectric micromachined ultrasound transducer (PMUT), or a capacitive micromachined ultrasonic transducer (CMUT).~~

~~7~~3. The method of claim 1~~5~~, wherein the second type is a broad bandwidth optical sensor, and wherein the method further comprises receiving a third signal from one or more array elements of a third type, wherein the third type is an ultra-sensitive optical sensor.

~~8. The method of claim 7, comprising filtering the first signal, the second signal, and/or the third signal using one or more filters.~~

~~9. The method of claim 8, wherein the one or more filters comprise a harmonic band-pass filter.~~

~~10. The method of claim 1, wherein combining the first and second images comprises determining an average of the first image and the second image.~~

~~11. The method of claim 10, wherein combining the first and second images comprises determining an arithmetic or geometric average of the first image and the second image.~~

~~12~~4. The method of claim 1~~0~~, wherein combining the first and second images comprises determining a weighted average of the first image and the second image.

~~13~~5. The method of claim 4~~12~~, further comprising determining one or more compounding coefficients for the first and second images and combining the first and second images based on the one or more compounding coefficients.

~~14~~6. The method of claim 5~~13~~, wherein determining one or more compounding coefficients for the first and second images comprises:

transforming the first and second images to first and second transform domain images using at least one transformation operator;

determining one or more transform domain compounding coefficients for the first and second transform domain images; and

inverse transforming the one or more transform domain compounding coefficients to determine the one or more compounding coefficients for the first and second images.

~~15~~7. The method of claim 6~~14~~, wherein determining one or more transform domain compounding coefficients for the first and second transform domain images comprises applying one or more coefficient compounding rules to the first and second transform domain images.

~~16. The method of claim 14, wherein the at least one transformation operator comprises a Fourier Transform, a Discrete Wavelet Transform (DWT), a Discrete Cosine Transform (DCT), or a Wave Atom Transform.~~

~~17~~8. The method of claim 5~~13~~, wherein determining one or more compounding coefficients for the first and second images comprises:

determining a first image quality factor map for the first image and a second image quality factor map for the second image; and

determining a first compounding coefficient for the first image based on the first image quality factor map, and a second compounding coefficient for the second image based on the second image quality factor map.

~~18~~9. The method of claim 5~~13~~, wherein determining one or more compounding coefficients for the first and second images comprises determining a local entropy of each pixel in the first image and in the second image, and determining one or more compounding coefficients based on the determined local entropies.

~~19~~10. The method of claim 5~~13~~, wherein determining one or more compounding coefficients for the first and second images comprises applying a linear filter to each of the first and second images.

~~20. The method of claim 19, wherein the linear filter comprises a Difference of Gaussian filter.~~

~~21~~11. The method of claim 5~~13~~, wherein determining one or more compounding coefficients for the first and second images comprises determining one or more compounding coefficients as a function of imaging depth.

~~22~~12. The method of claim 4~~12~~, wherein determining a weighted average of the first image and the second image comprises applying a saturation mask that reduces weight of at least a portion of the first image and/or second image that has exceeded a predetermined saturation threshold.

~~23. The method of claim 1, wherein the optical sensor is a WGM optical resonator.~~

~~24. The method of claim 1, wherein the optical sensor is a microbubble optical resonator, a photonic integrated circuit (PIC) optical resonator, a microsphere resonator, a microtoroid resonator, a microring resonator, a microbottle resonator, a microcylinder resonator, or a microdisk optical resonator.~~

~~25. The method of claim 1, wherein one or more non-optical transducers in the mixed transducer array transmit acoustic signals at a fundamental frequency *f*, and~~

~~the one or more array elements of the first type, the second type, or both the first type and second type, are configured to produce one or more optical responses upon receiving harmonic or subharmonic acoustic echoes corresponding to the transmitted acoustic signals, wherein the one or more array elements of the second type have a bandwidth ranging from at least *f/M* to *Nf*, where *M* and *N* are integers greater than 1.~~

~~26. The method of claim 1, wherein the one or more non-optical transducers transmit acoustic signals at a first fundamental frequency *f1* and a second fundamental frequency *f2*.~~

~~27. The method of claim 26, wherein one or more array elements of the second type are configured to produce one or more optical responses upon receiving acoustic echoes that correspond to a frequency of one or more linear combinations *nf1 + mf2*, wherein *n* and *m* are integers such that *nf1 + mf2* is a positive number.~~

~~28~~13. The method of claim 1, wherein at least one of the first image and the second image is a harmonic image.

~~29~~14. The method of claim 13~~28~~, wherein the harmonic image is a sub-harmonic image or a super-harmonic image.

~~30~~15. An apparatus for imaging a target comprising:

a mixed transducer array comprising:

one or more array elements of a first type configured to receive a first signal;

one or more array elements of a second type configured to receive a second signal, wherein at least one of the first type and the second type is an optical sensor; and

one or more processors configured to:

generate a first image from the first signal and a second image from the second signal; and

combine the first image and the second image to generate a compound image.

~~31~~16. The apparatus of claim 15~~30~~, wherein the first type and the second type are optical resonators with different characteristics.

~~32. The apparatus of claim 31, wherein the first type is a high Q optical resonator and the second type is a low Q optical resonator.~~

~~33. The apparatus of claim 31, wherein the first type is a tunable optical resonator operated as a high Q optical resonator and the second type is a tunable optical resonator operated as a low Q optical resonator.~~

~~34~~17. The apparatus of claim 15~~30~~, wherein the first type is a non-optical transducer and the second type is an optical sensor.

~~35~~18. The apparatus of claim 17~~34~~, wherein the non-optical transducer is a piezoelectric transducer, a single crystal material transducer, a piezoelectric micromachined ultrasound transducer (PMUT), or a capacitive micromachined ultrasonic transducer (CMUT).

~~36~~19. The apparatus of claim 17~~34~~, wherein the second type is a broad bandwidth optical sensor, and wherein the mixed transducer array further comprises one or more array elements of a third type configured to receive a third signal, wherein the third type is an ultra-sensitive optical sensor.

~~37~~20. The apparatus of claim 19~~36~~, wherein the one or more processors are configured to filter the first signal, the second signal, and/or the third signal using one or more filters.

~~38~~21. The apparatus of claim 20~~37~~, wherein the one or more filters comprise a harmonic band-pass filter.

~~39. The apparatus of claim 30, wherein the one or more processors are configured to combine the first and second images at least in part by determining an average of the first image and the second image.~~

~~40. The apparatus of claim 39, wherein the one or more processors are configured to combine the first and second images at least in part by determining an arithmetic or geometric average of the first image and the second image.~~

~~41. The apparatus of claim 39, wherein the one or more processors are configured to combine the first and second images at least in part by determining a weighted average of the first image and the second image.~~

~~42. The apparatus of claim 41, wherein the one or more processors are configured to determine one or more compounding coefficients for the first and second images and combine the first and second images based on the one or more compounding coefficients.~~

~~43. The apparatus of claim 42, wherein the one or more processors are configured to determine one or more compounding coefficients for the first and second images at least in part by:~~

~~transforming the first and second images to first and second transform domain images using at least one transformation operator;~~

~~determining one or more transform domain compounding coefficients for the first and second transform domain images; and~~

~~inverse transforming the one or more transform domain compounding coefficients to determine the one or more compounding coefficients for the first and second images.~~

~~44. The apparatus of claim 43, wherein the one or more processors are configured to determine one or more transform domain compounding coefficients for the first and second transform domain images at least in part by applying one or more coefficient compounding rules to the first and second transform domain images.~~

~~45. The apparatus of claim 43, wherein the at least one transformation operator comprises a Fourier Transform, a Discrete Wavelet Transform (DWT), a Discrete Cosine Transform (DCT), or a Wave Atom Transform.~~

~~46. The apparatus of claim 42, wherein the one or more processors are configured to determine one or more compounding coefficients for the first and second images at least in part by:~~

~~determining a first image quality factor map for the first image and a second image quality factor map for the second image; and~~

~~determining a first compounding coefficient for the first image based on the first image quality factor map, and a second compounding coefficient for the second image based on the second image quality factor map.~~

~~47. The apparatus of claim 42, wherein the one or more processors are configured to determine one or more compounding coefficients for the first and second images at least in part by determining a local entropy of each pixel in the first image and in the second image, and determining one or more compounding coefficients based on the determined local entropies.~~

~~48. The apparatus of claim 42, wherein the one or more processors are configured to determine one or more compounding coefficients for the first and second images at least in part by applying a linear filter to each of the first and second images.~~

~~49. The apparatus of claim 48, wherein the linear filter comprises a Difference of Gaussian filter.~~

~~50. The apparatus of claim 42, wherein the one or more processors are configured to determine one or more compounding coefficients for the first and second images at least in part by determining one or more compounding coefficients as a function of imaging depth.~~

~~51. The apparatus of claim 41, wherein the one or more processors are configured to determine a weighted average of the first image and the second image at least in part by applying a saturation mask that reduces weight of at least a portion of the first image and/or second image that has exceeded a predetermined saturation threshold.~~

~~52. The apparatus of claim 30, wherein the optical sensor is a WGM optical resonator~~

~~53. The apparatus of claim 30, wherein the optical sensor is a microbubble optical resonator, a photonic integrated circuit (PIC) optical resonator, a microsphere resonator, a~~

~~microtoroid resonator, a microring resonator, a microbottle resonator, a microcylinder resonator, or a microdisk optical resonator.~~

~~54. The apparatus of claim 30, wherein one or more non-optical transducers in the mixed transducer array transmit acoustic signals at a fundamental frequency *f*, and~~

~~the one or more array elements of the first type, the second type, or both the first type and the second type are configured to produce one or more optical responses upon receiving harmonic or subharmonic acoustic echoes corresponding to the transmitted acoustic signal, wherein the one or more array elements of the second type have a bandwidth ranging from at least *f/M* to *Nf*, where *M* and *N* are integers greater than 1.~~

~~55. The apparatus of claim 30, wherein the one or more non-optical transducers transmit acoustic signals at a first fundamental frequency *f1* and a second fundamental frequency *f2*.~~

~~56. The apparatus of claim 55, wherein one or more array elements of the second type are configured to produce one or more optical responses upon receiving acoustic echoes that correspond to a frequency of one or more linear combinations *nf1 + mf2*, wherein *n* and *m* are integers such that *nf1 + mf2* is a positive number.~~

~~57. The apparatus of claim 30, wherein at least one of the first image and the second image is a harmonic image.~~

~~58. The apparatus of claim 57, wherein the harmonic image is a sub-harmonic image or a super-harmonic image.~~