including malignancies, as well as later stage cancers, which can potentially raise survival rates of hard-to-diagnose asymptomatic patients. The disclosed technology can be used by board-certified radiologists to diagnose neoplasms as benign or malignant prior to any surgical biopsy or resection intervention, which may also improve patient survival rate while reducing unnecessary biopsies. The disclosed technology, when integrated with a fine needle biopsy instrument, can be used in medical procedures to confirm noninvasive diagnoses, which can reduce the level of invasiveness of such biopsy procedures. The disclosed technology, when integrated pre-operatively with Computed Tomography (CT) x-ray images and/or intra-operatively with minimally invasive surgical high definition video instrumentation, can fuse CT, optical and ultrasound images, and thereby can further give surgeons added abilities to locate, diagnose, and surgically excise or repair diseased tissue without damaging healthy tissue. The disclosed technology, when integrated with specialized surgical instrumentation, can fuse ultrasound images with other data, and can give surgeons added abilities to locate and manipulate anatomic areas of interest while minimizing unnecessary damage to nearby structures. The disclosed technology can reduce the amount of time for the brachytherapy treatment of malignant neoplasms, for example, by precisely guiding the insertion of sealed radioactive sources and catheters into the proper location. Similarly, the disclosed technology can aid insertion of high-dose, localized pharmaceuticals for treatments of diseases.

[0005a] According to a first aspect, there is provided a method of producing acoustic waveforms in an acoustic imaging device, comprising: synthesizing, in one or more waveform synthesizers, one or more composite waveforms to be transmitted toward a target, wherein a composite waveform is formed of a plurality of individual orthogonal coded waveforms that are mutually orthogonal to each other and correspond to different frequency bands, such that each of the individual orthogonal coded waveforms includes a unique frequency with a corresponding phase; transmitting, from one or more transmitting positions relative to the target, one or more composite acoustic waveforms comprising a plurality of acoustic waveforms, wherein the transmitting includes selecting one or more transducing elements of an array to transduce the plurality of individual orthogonal coded waveforms of the respective one or more composite waveforms into the plurality of corresponding acoustic waveforms of the respective one or more composite acoustic waveforms; and receiving, at one or more receiving positions relative to the target, returned acoustic waveforms that are returned from at least part of the target

corresponding to the transmitted acoustic waveforms, wherein the receiving includes selecting at least some of the transducing elements of the array to receive the returned acoustic waveforms, wherein the transmitting positions and the receiving positions each include one or both of spatial positions of an array of transducer elements relative to the target and beam phase center positions of the array, wherein the transmitted acoustic waveforms and the returned acoustic waveforms produce an enlarged effective aperture of the acoustic imaging device.

[0005b] According to a second aspect, there is provided a synthetic aperture acoustic waveform imaging system, comprising: a waveform generation unit comprising one or more waveform synthesizers coupled to a waveform generator, wherein the waveform generation unit synthesizes a composite waveform comprising a plurality of individual orthogonal coded waveforms corresponding to different frequency bands that are generated by the one or more waveform synthesizers according to waveform information provided by the waveform generator, wherein the individual orthogonal coded waveforms are mutually orthogonal to each other and correspond to different frequency bands, such that each of the individual orthogonal coded waveforms includes a unique frequency with a corresponding phase; a transmit/receive switching unit that switches between a transmit mode and a receive mode; an array of transducer elements in communication with the transmit/receive switching unit to transmit a composite acoustic waveform comprising a plurality of acoustic waveforms from one or more transmitting positions relative to the target, the transmitted acoustic waveforms of the composite acoustic waveform based on the synthesized individual orthogonal coded waveforms of the composite waveform, and to receive at one or more receiving positions relative to the target returned acoustic waveforms corresponding to the plurality of transmitted acoustic waveforms that return from at least part of the target, wherein the transmitted acoustic waveforms and the returned acoustic waveforms produce an enlarged effective aperture of the synthetic aperture acoustic waveform imaging system, and wherein the transmitting positions and the receiving positions each include one or both of spatial positions and beam phase center positions; a multiplexing unit in communication with the array of transducer elements to select one or more transducing elements of an array to transduce the plurality of individual orthogonal coded waveforms into the plurality of corresponding acoustic waveforms, and to select one or more transducing elements of the array to receive the returned acoustic waveforms; an array of analog to digital (A/D) converters to convert the received returned acoustic waveforms that are received by the array of transducer

elements from analog format to digital format, wherein the received returned acoustic waveforms provide information of the target; a controller unit in communication with the waveform generation unit and the array of A/D converters, the controller unit comprising a memory unit to store data and a processing unit coupled to the memory unit to process the information as data; and a user interface unit in communication with the controller unit.

[0005c] According to a third aspect, there is provided a method of creating an image from an acoustic waveform, comprising: combining a plurality of coded waveforms corresponding to different frequency bands to produce a composite waveform comprising individual orthogonal wave signals at the different frequency bands, wherein the coded waveforms include a unique frequency with a corresponding phase and amplitude; producing an acoustic wave using the composite waveform for transmission toward a target from a first spatial position relative to the target, wherein the acoustic wave includes individual acoustic wave signals corresponding to the coded waveforms of the composite waveform; transmitting the acoustic wave to the target, wherein the individual acoustic wave signals vary in orientation with respect to each other so that the target receives the individual acoustic wave signals with different waveform orientations over an imaging period; receiving returned acoustic signals from at least part of the target after the transmitted acoustic wave is sent to the target; repeating the combining step, the producing step, and the transmitting step from at least a second position relative to the target, wherein the combining, producing, and transmitting steps are repeated for plurality of positions to form a synthetic aperture; converting the received returned acoustic signals from the plurality of positions into corresponding digital composite waveforms each comprising information of the target; and processing the received composite waveforms to produce an image of at least part of the target.

[0005d] According to a fourth aspect, there is provided a method of creating an image from an acoustic waveform, comprising: combining a plurality of coded waveforms corresponding to different frequency bands to produce a composite waveform comprising individual orthogonal wave signals at the different frequency bands, wherein the coded waveforms include a unique frequency with a corresponding phase and amplitude; producing an acoustic wave formed of individual acoustic wave signals corresponding to the coded waveforms of the composite waveform for transmission toward a target; transmitting the acoustic wave to the target, wherein the individual acoustic wave signals are transmitted from a first set of beam

phase center positions at one or more spatial positions relative to the target, and wherein the individual acoustic wave signals vary in orientation with respect to each other so that the target receives the individual acoustic wave signals with different waveform orientations over an imaging period; receiving returned acoustic signals from at least part of the target after the transmitted acoustic wave is sent to the target; repeating the combining step, the producing step, and the transmitting step from at least a second set of beam phase center positions relative to the target at the one or more spatial positions relative to the target, thereby forming a synthetic aperture; converting the received returned acoustic signals into corresponding digital composite waveforms each comprising information of the target; and processing the received composite waveforms to produce an image of at least part of the target.

[0005e] According to a fifth aspect, there is provided a synthetic aperture acoustic waveform imaging system, comprising: a waveform generation unit comprising one or more waveform synthesizers coupled to a waveform generator, wherein the waveform generation unit synthesizes a composite waveform comprising a plurality of individual orthogonal coded waveforms corresponding to different frequency bands that are generated by the one or more waveform synthesizers according to waveform information provided by the waveform generator, wherein the individual orthogonal coded waveforms are mutually orthogonal to each other and correspond to different frequency bands, such that each of the individual orthogonal coded waveforms includes a unique frequency with a corresponding phase; a transmitter array of transducer elements in communication with the waveform generation unit to transmit a composite acoustic waveform comprising a plurality of acoustic waveforms from one or more transmitting positions relative to the target, the transmitted acoustic waveforms of the composite acoustic waveform based on the synthesized individual orthogonal coded waveforms of the composite waveform, wherein the transmitting positions include one or both of spatial positions of the transmitter array and beam phase center positions of the transducer elements of the transmitter array; a receiver array of transducer elements in communication with the waveform generation unit to receive at one or more receiving positions relative to the target returned acoustic waveforms corresponding to the transmitted acoustic waveforms that return from at least part of the target, wherein the transmitted acoustic waveforms and received acoustic waveforms produce an enlarged effective aperture of the synthetic aperture acoustic waveform imaging system, and wherein the transmitting positions and the receiving positions each include

one or both of spatial positions and beam phase center positions; a first multiplexing unit and a second multiplexing unit in communication with the transmitter array and receiver array, respectively, to select one or more of the transducing elements of the transmitter array to transduce the plurality of individual orthogonal coded waveforms into the plurality of corresponding acoustic waveforms, and to select one or more transducing elements of the receiver array to receive the returned acoustic waveforms; an array of analog to digital (A/D) converters to convert the received returned acoustic waveforms that are received by the receiver array of transducer elements from analog format to digital format, wherein the received returned acoustic waveforms provide information of the target; a controller unit in communication with the waveform generation unit and the array of A/D converters, the controller unit comprising a memory unit to store data and a processing unit coupled to the memory unit to process the information as data; and a user interface unit in communication with the controller unit.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1A shows a diagram of an ultrasound beam generated by a transducer array that forms a real aperture beam in ultrasound imaging.

[0007] FIG. 1B shows a diagram of an ultrasound beam generated by a transducer array whose phase center is in successive positions to form a synthetic aperture beam in ultrasound imaging.

[0008] FIGS. 1C and 1D show diagrams of exemplary composite ultrasound transmit and/or receive beams generated by a transducer array that forms a synthetic aperture beam from multiple transmitting and/or receiving positions.

[0009] FIG. 1E shows a diagram of an exemplary transducer array for generating a composite ultrasound beam of the disclosed technology.

[0010] FIG. 2A shows a block diagram of an exemplary synthetic aperture ultrasound system