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Inventor Colin J. Lazauski
 Glenn H. Mitchell
 Thomas N. Fetherston II

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3 METHOD FOR DETERMINING ACOUSTIC IMPACT OF UNDERWATER
4 ACOUSTIC SOURCES ON MARINE ANIMALS

5
6 STATEMENT OF GOVERNMENT INTEREST

7 The invention described herein may be manufactured and used
8 by or for the Government of the United States of America for
9 governmental purposes without the payment of any royalties
10 thereon or therefore.

11
12 BACKGROUND OF THE INVENTION

13 (1) Field of the Invention

14 The present invention relates generally to environmental
15 impacts of acoustic sources, and more particularly to
16 quantitatively determine the acoustic impact of underwater
17 acoustic sources on marine animals in a defined area of any body
18 of water.

19 (2) Description of the Prior Art

20 Prior methods for determining acoustic impact on marine
21 animals have either not quantitatively determined the number of
22 animals effected, or if determining the number effected, have
23 done so in a non-deterministic way. As an example, the Zone of
24 Influence (ZOI) method determines the maximum range, or zone,
25 around the acoustic source at which an animal is influenced under
26 several criteria. The ZOI method establishes zones for such

1 criteria as audibility, responsiveness, masking and hearing loss,
2 discomfort, or injury. Although this method does give the
3 distances at which marine mammals are affected by man-made noise,
4 it does not determine the number of animals affected.

5 One present quantitative method, the Acoustic Integration
6 Model (AIM), is able to count the number of animals influenced.
7 It uses a statistical distribution of animals in depth and
8 location combined with zones of influence. Inherent in the
9 method is a Monte Carlo simulation that moves the animals in
10 depth and location according to assumed behavior. Results are
11 dependent on the average of many Monte Carlo simulation runs and
12 on the accuracy of the input behavioral parameters. Each run of
13 the Monte Carlo simulation provides a different result and can
14 lead to incorrect attributions of the influence of model
15 parameters because of this variance. In addition, running
16 numerous Monte Carlo simulations is time consuming and costly.
17 Further, the AIM method does not include the effects of the
18 podding or herding tendencies of the animals.

20 SUMMARY OF THE INVENTION

21 Accordingly, it is an object of the present invention to
22 provide a method to determine the acoustic impact of underwater
23 acoustic sources on marine animals in a defined area of any body
24 of water.

25 Another object of the present invention is to provide a
26 method to determine the number of marine animals acoustically

1 impacted by underwater acoustic sources in a defined body of
2 water.

3 Still another object of the present invention is to provide
4 a deterministic method for assessing the acoustic impact of
5 underwater acoustic sources on marine animals in a defined area
6 of any body of water.

7 Other objects and advantages of the present invention will
8 become more obvious hereinafter in the specification and
9 drawings.

10 In accordance with the present invention, a method is
11 provided to quantify and predictively estimate acoustic impacts
12 to marine animals within a chosen area. The method begins with
13 information collection, including information on the types of
14 acoustic sources to be modeled, on the animal assemblages in the
15 chosen area, on the environmental characteristics of the area and
16 on the environmental regulations relevant to acoustic impacts in
17 the area. An acoustic model, appropriate for the chosen area and
18 its environmental characteristics, is then selected. As an
19 example, the Comprehensive Acoustic Simulation System/Gaussian
20 RAY Bundle (CASS/GRAB) model for horizontally stratified and
21 range-variant environments would be an appropriate model for the
22 East Coast Shallow Water Training Range (ECSWTR). Given the
23 acoustic source characteristics and environmental characteristics
24 of the chosen area, the acoustic model generates a source
25 footprint of all sources to be located at the site. Depending on
26 the impact criteria governing the area, the acoustic model

1 expresses the acoustic propagation at the site as Sound Pressure
2 Level (SPL), Sound Exposure Level (SEL), or other energy based
3 criteria consistent with the governing regulations. The marine
4 animal distribution, based on the most current information for
5 marine animal assemblages in the geographic range of the area in
6 question, is then overlaid onto the acoustic propagation at the
7 site. The marine animal distribution is time-weighted to
8 correspond with the proposed acoustic source usage, as well as
9 short term and seasonal marine animal behavior patterns. The
10 total number of impacted marine animals is then calculated.
11 Impacts are calculated by species, source, scenario and season.
12 The calculated number is then rounded upwards to the next whole
13 individual, pod, or group, depending on the animals' behavioral
14 patterns and social structure. The acoustic test procedure,
15 acoustic sources, source locations, or other criteria relevant to
16 the number of marine animals impacted can then be modified to
17 ameliorate the acoustic impacts.

18 19 BRIEF DESCRIPTION OF THE DRAWINGS

20 A more complete understanding of the invention and many of
21 the attendant advantages thereto will be readily appreciated as
22 the same becomes better understood by reference to the following
23 detailed description when considered in conjunction with the
24 accompanying drawings wherein like reference numerals refer to
25 like parts and wherein:

1 FIG. 1 is a flow chart diagram illustrating the method of
2 the present invention;

3 FIG. 2 is a flow chart diagram illustrating the combination
4 of animal, environmental and acoustic data to obtain a
5 quantitative assessment of impacted animals.

6
7 DESCRIPTION OF THE PREFERRED EMBODIMENT

8 Referring now to FIG. 1, there is shown a flow chart
9 illustrating the method 10 for quantitatively estimating acoustic
10 impacts to marine animals. Method, or process 10 incorporates
11 five major modules used in determining the marine animal impacts
12 of acoustic sources. The process 10 begins with information
13 collection at 20. The information is sifted at module 30 for
14 relevance to the particular cases being examined. The
15 information is processed at module 40 to model the acoustic
16 sources and obtain animal population distribution maps. Post
17 processing module 50 obtains the acoustic footprints from module
18 40 and overlays these with the animal distribution maps.
19 Finally, module 60 calculates and tabulates the results as animal
20 takes, or total impacts by species, scenario, source and/or
21 season. In a preferred embodiment, the information from module
22 30 is input to a computer, indicated by dashed line 70, which
23 implements modules 40, 50 and 60. The method may further include
24 a modification decision at 80 whether to change all or part of
25 the information input to module 20, or accept the number of takes
26 as the final impact assessment. Modifications can include

1 changes in site, acoustic source changes, acoustic source
2 locations, test scenario changes, or modifications to other
3 criteria affecting the take calculation.

4 In information collection module 20, method 10 determines
5 the parameters affecting the overall impact scenario. This
6 includes determining the requirements driving the use of acoustic
7 sources in the marine environment, shown in FIG. 1 as acoustic
8 requirements identification 22. As an example, training of Navy
9 sonar technicians requires active sonar detection in an
10 underwater environment, with different training objectives
11 requiring different mixes of acoustic sources, durations,
12 intensities and the like. The acoustic requirements for each
13 training objective would be identified at 22.

14 Environmental data for the chosen site is gathered at 24.
15 This includes bottom profiles, bottom losses, sound velocity
16 profiles and other site-specific data affecting the acoustics and
17 animal behavior at the site. The environmental data is
18 preferably obtained from direct measurements at the site in order
19 to obtain the most up to date and accurate information. The data
20 may be compared with historical records to verify results.

21 The animal population at the site is identified at 26. A
22 complete review of marine animal distribution in the geographic
23 range of the area in question is performed. The review is
24 initially the presence or absence of marine animals within the
25 area that may be affected by acoustic transmissions. This
26 initial list is all inclusive of species for which the analysis

1 must be performed and which could be found in the general area at
2 any time of the year. The necessary information is gathered from
3 all available sources. Relevant papers include those that
4 describe a particular marine animal species, or group of species,
5 spatial and temporal distribution, abundance, habitat use, social
6 behavior, feeding habits and other subject matter related to the
7 ecology of the species or group of species in question.
8 Applicable museum and whaling records are also used in the
9 definition of each species used in the model.

10 Finally, governing environmental regulations at the site are
11 identified at 28. Relevant regulations, treaties and laws,
12 inclusive of state, federal and international requirements, must
13 be examined for application to determine acoustic impacts.
14 Examples of relevant regulations include the Marine Mammal
15 Protection Act and the Endangered Species Act.

16 The second module, or sifting module 30, analyzes the data
17 gathered at module 20 and determines the specific requirements
18 for the impact scenario being analyzed. The specific acoustic
19 sources impacting the marine environment are identified at 32.
20 The acoustic source identification process compares the
21 requirements identified at 22 with known acoustic source
22 specifications, choosing the acoustic source, or sources, best
23 matching those requirements. Complete description of equipment
24 or sources to be used during a test or exercise must be
25 considered. Relevant information is found in the system
26 description of projector or impulsive sources. Source levels,

1 wave characteristics, directivity, and other information
2 particular to the source are examples of data used in comparing
3 requirements to equipment specifications. Scenarios (how the
4 source is used in time and space) for use of the equipment in the
5 area must be detailed for accuracy of model outputs.

6 Based on the environmental data obtained at 24, an acoustic
7 model is chosen at 34. As with acoustic source identification
8 32, the acoustic analysis tool best modeling the environment is
9 chosen. For example, in a shallow water, horizontally stratified
10 environment having varying bottom depths and sediment types, the
11 well-known Comprehensive Acoustic Simulation System/Gaussian RAY
12 Bundle (CASS/GRAB) model provides adequate results.

13 Based on the animal population data of 26 and the
14 environmental data of 24, animal abundance figures for the site
15 are determined at 36. The biological data is sorted to include
16 those animals that utilize the specific habitat found at the site
17 during any time of the year. In order to be used in the model,
18 an estimate of local abundance must be assessed. The estimate
19 must then be distributed throughout the area in varying
20 'densities' that coincide with habitat use. The estimate is
21 obtained from available surveys and analyses of marine animal
22 populations, such as those of the National Marine Fisheries
23 Service. Seasonal variations are considered when such data are
24 available, with impacts analyzed by season rather than over a
25 full year. When no seasonal data is available, the abundance
26 levels are considered constant throughout the year. Habitat

1 preference also affects animal abundance. Generally, if the area
2 under study consists of an optimum habitat for a species,
3 population abundance is maximized within that habitat. For less
4 than optimum habitat areas, allowances are made for excursions
5 from optimum habitat areas by distributing a percentage of the
6 local population both inshore and seaward from the optimum
7 habitat area. As with other data, the percentage used is based
8 on surveys, sightings, etc. that provide a ratio of out-of-
9 habitat sightings to habitat sightings. Where no out-of-habitat
10 data exists, a conservative estimate of 10% can be used.
11 Finally, social group size of each species is considered. Marine
12 mammals exhibit grouping and social behavior that can vary by
13 season or geographic location. A statistical mode from a data
14 set and range, taken from marine mammal characterization reports
15 in the literature, are used to characterize groupings. As an
16 example, small group size is a common characteristic of all
17 baleen whales and all large whales. The average number of
18 individuals reported per sighting was three, with a mode of 1 and
19 a range of 1 to 65. The data further indicates that more than
20 50% of sightings were that of a single individual. Thus, for
21 this group of animals, a single individual is chosen as a
22 representative group, or pod size.

23 The animal population data of 26 in combination with the
24 environmental compliance requirements of 28 generate the acoustic
25 harassment criteria at 38. Complete review of criteria for
26 measuring acoustic harassment is determined using a combination

1 of the laws, previous precedents for acoustic harassment criteria
2 and available scientific publications relating to acoustic
3 effects on marine animals. Types of criteria can be expressed as
4 Sound Pressure Level (SPL), sound intensity level, or an energy
5 based criteria such as Sound Exposure Level (SEL), energy flux
6 density level, or energy source level. The decision to use any
7 criteria is based upon availability of scientific information and
8 how appropriate the choice is when considering the type of sound
9 source - impulsive, broadband, tonal, pulsed, or continuous in
10 time and frequency.

11 In processing module 40, the acoustic source identification
12 of 32 and the acoustic model identification of 34 provide the
13 necessary input data for acoustic modeling at 42. Acoustic
14 modeling module 42 provides results for each separate acoustic
15 region encompassed by the site, e.g., a continental shelf region,
16 a shelf break region and a region sloping down to deep ocean
17 depths.

18 Module 40 also processes the animal abundance data of 36 to
19 obtain animal distribution maps at 44. These maps determine the
20 number of marine animals, which may be influenced by the acoustic
21 sources in the proposed area. The animal abundance data of 36
22 are transcribed onto the range area maps to obtain animal
23 distribution maps of the site. Seasonal variations and
24 distribution with water depth are represented.

25 Post processing module 50 receives the results of acoustic
26 modeling 42 and combines these results with the acoustic

1 harassment criteria of 38 to obtain a source footprint at 52,
2 which corresponds to acoustic harassment levels at the site. The
3 acoustic modeling of 42 provides the propagation loss results for
4 the site, indicating how the acoustic energy from a source
5 decreases with distance from the source. Essentially, the
6 harassment criteria of 38 limits the range of the acoustic source
7 to those areas surrounding the source where the acoustic energy
8 exceeds the developed criteria. For each source-modeling region,
9 the maximum harassment range is determined in eight separate
10 directions, i.e., at 45° increments about the source. Connecting
11 the maximum ranges for a set of all angles results in a
12 propagation rosette about the source for that region. Where
13 appropriate for the environmental aspects of the site, symmetry
14 is used to reduce the number of directional calculations. The
15 animal distribution maps of 44 and the source footprint of 52 are
16 overlaid at 54, with the result being processed at take
17 calculation module 60 to obtain the final number of animals
18 takes, or animals impacted by the acoustic sources in accordance
19 with the environmental compliance criteria applicable to the
20 site.

21 Referring now to FIG. 2 there is shown a flow chart
22 illustrating post processing module 50 and calculation module 60
23 in greater detail. For most acoustic test scenarios, the
24 acoustic source is allowed, or required, to maneuver over the
25 test site. Method 10 can consider up to a total of six paths
26 covering the test site. As an example, a typical rectangular

1 site may include a continental shelf region, a shelf break and a
2 region sloping down to deep ocean depths. Six paths are
3 necessary to adequately cover such a site: three parallel to the
4 shelf break (on the shelf, at the break and along the slope), one
5 perpendicular to the shelf break, and two diagonal paths. For
6 other sites with a single topography, e.g., those having only a
7 continental shelf portion, only one to three paths may be
8 necessary to describe the acoustic propagation throughout the
9 site, i.e., a diagonal, along the shelf, or across the shelf.
10 Where a stationary source is to be used, the path would consist
11 of a single point at the source location. The appropriate paths
12 are chosen at 102.

13 Site location corresponding the position on the path or
14 track is calculated at 104. For each location, the acoustic
15 source rosette corresponding to that location is chosen at 106
16 from input 108 of module 40 and harassment criteria 38. The site
17 area covered by the rosette is stored at 110. The source
18 position is incremented at 112 and a check is made at 114 to see
19 if all track positions have been included. If not, module 52
20 returns to 104 to calculate the next source location. If all
21 tracks are complete, the acoustic footprint consisting of all the
22 stored site area coverages is input to overlay module 54. Each
23 animal species for which harassment criteria is available has a
24 representative distribution by depth as shown by the animal
25 distribution maps of 44. Overlay module 54 creates a data file

1 of bathymetric data and animal distribution maps input 116 and
2 corresponding acoustic footprints from 52.

3 Calculation module 60 receives the data file from module 54
4 and first calculates the footprint area for each bathymetric
5 interval at the site for each track, or path, at 118. Each track
6 or path is calculated separately as the source is moving through
7 the site at separate time intervals, thus each track is
8 separately capable of affecting the animal population and
9 overlapping areas of the tracks need to be counted for each
10 track. The bathymetric footprint area is then multiplied, at
11 120, by the animal density in each bathymetric interval to obtain
12 the number of takes for each depth interval, i.e., the footprint
13 area is multiplied by the total number of mammals in the depth
14 interval (from the distribution map input 116) and divided by the
15 total map area. The takes for each track and bathymetric
16 interval are added together at 122 to obtain the total takes. It
17 is noted that the total takes is rounded upwards to conform to
18 the pod or group size of the marine animal being considered, as
19 described previously.

20 The invention thus been described is a method for
21 determining the acoustic impact of underwater acoustic sources on
22 marine animals in a defined area of any body of water. The
23 method includes assembling data about the environmental and
24 acoustic characteristics of the site, about the acoustic sources
25 to be used at the site, about marine animals known to inhabit the
26 area and about marine animal acoustic harassment criteria

1 pertinent to the site. Based on the above, acoustic modeling is
2 performed and the areas within the site having acoustic energy
3 levels above the harassment criteria are identified. These
4 source footprints are overlaid with animal distribution maps to
5 obtain the total number of takes, or animals impacted by the
6 acoustic sources. The method overcomes the shortcomings of
7 previous impact assessment methods. In comparison to the ZOI
8 method, the method of the present invention provides a
9 quantitative assessment of the number of animals impacted.

10 Unlike the random behavior simulation of the AIM method, the
11 method of the current invention determines the number of animals
12 within the site using the best available animal population data.

13 Although the present invention has been described relative
14 to a specific embodiment thereof, it is not so limited. As an
15 example, computer 70 may encompass module 30 (indicated by dashed
16 line 70a) such that the data gathered at module 20 is input to
17 computer 70a as data files. The sifting process of module 30 can
18 then be implemented within computer 70a, or the data files may be
19 displayed for sifting by an operator.

20 Thus, it will be understood that many additional changes in
21 the details, materials, steps and arrangement of parts, which
22 have been herein described and illustrated in order to explain
23 the nature of the invention, may be made by those skilled in the
24 art within the principle and scope of the invention.

1 Attorney Docket No. 82361

2

3 METHOD FOR DETERMINING ACOUSTIC IMPACT OF UNDERWATER

4 ACOUSTIC SOURCES ON MARINE ANIMALS

5

6 ABSTRACT OF THE DISCLOSURE

7 A method is provided to estimate acoustic impacts to marine
8 animals within a chosen area. The method begins with data
9 collection on types of acoustic sources to be modeled, animal
10 assemblages in the chosen area, environmental characteristics of
11 the area and on relevant environmental regulations. An acoustic
12 model, appropriate for the chosen area and its environmental
13 characteristics, is then selected and generates a source
14 footprint of all sources to be located at the site. The marine
15 animal distribution is then overlaid onto the acoustic
16 propagation at the site. The marine animal distribution is time-
17 weighted to correspond with the proposed acoustic source usage,
18 as well as short term and seasonal marine animal behavior
19 patterns. The total number of impacted marine animals is then
20 calculated. Impacts are calculated by species, source, scenario
21 and season. The calculated number is then rounded upwards to the
22 next whole individual, pod, or group, depending on the animals'
23 behavior patterns.

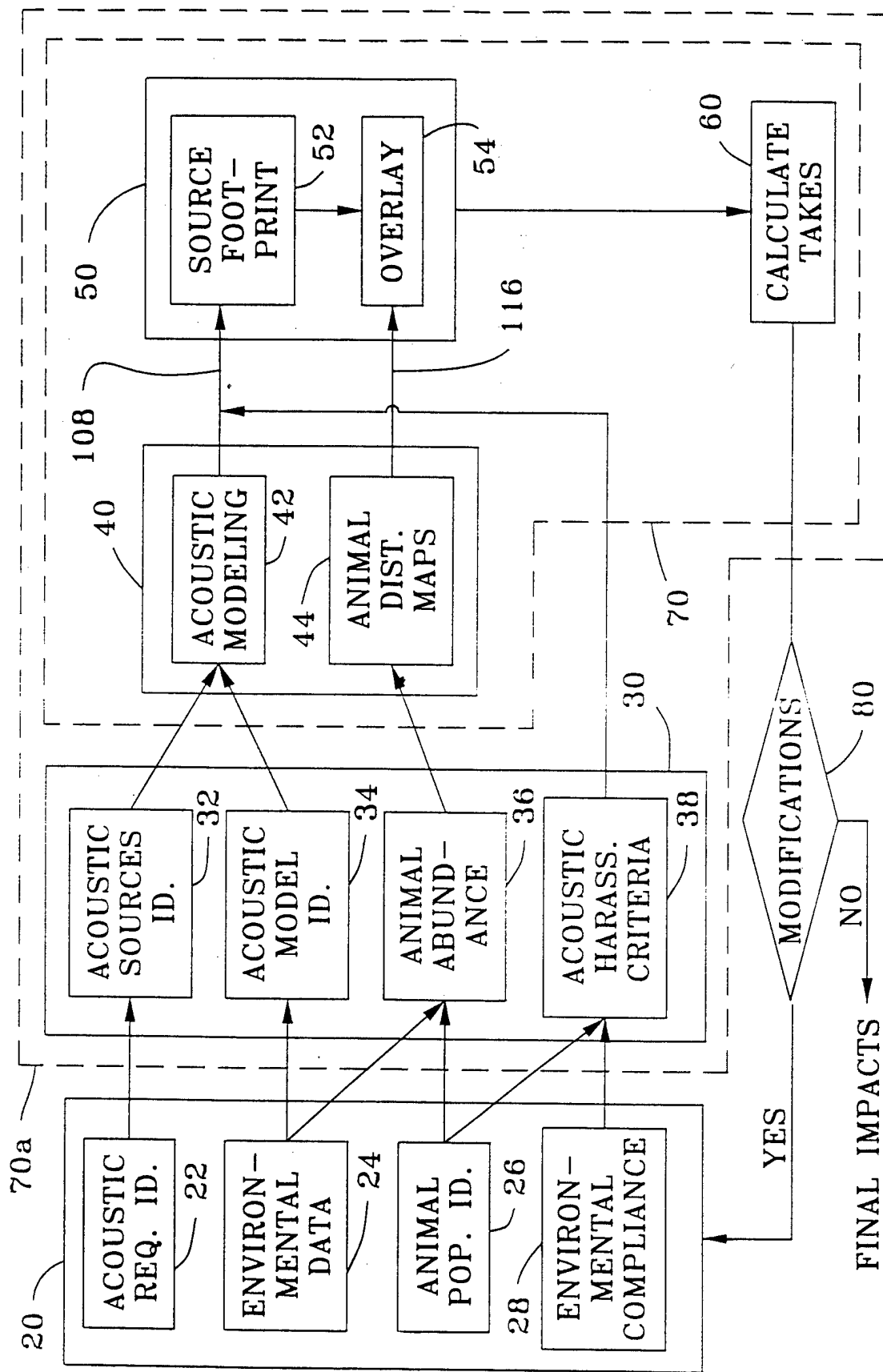


FIG. 1

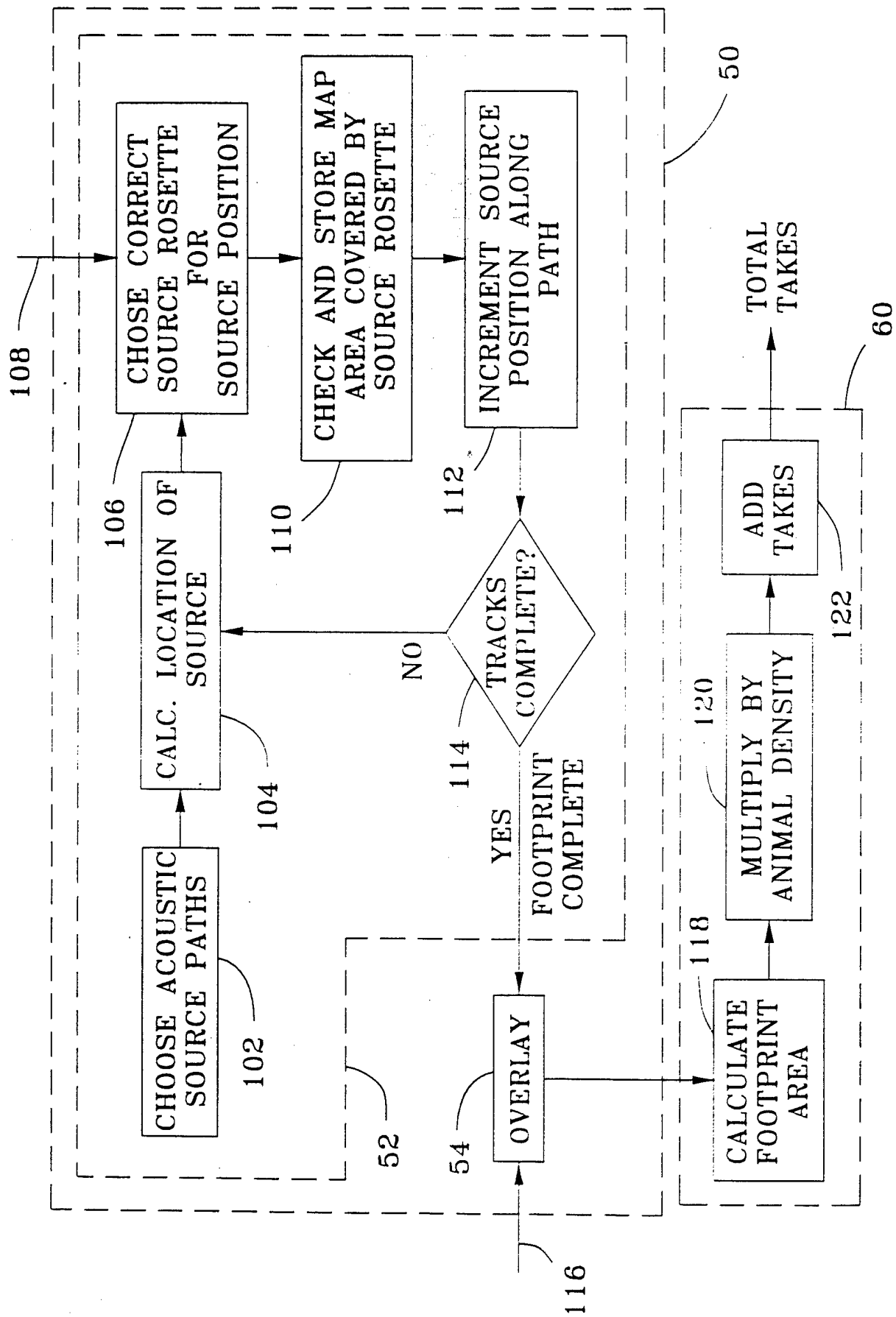


FIG. 2