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(54) **PLATFORM FOR DISTRIBUTED LANDCOVER FEATURE DATA REVIEW**

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G06T 7/11	(2017.01)
G06T 7/50	(2017.01)
G06T 7/62	(2017.01)
G06V 20/10	(2022.01)
G06V 20/13	(2022.01)
G06V 20/17	(2022.01)

(52) **U.S. Cl.**

CPC ***G06V 10/44*** (2022.01); ***G06T 7/11*** (2017.01); ***G06T 7/50*** (2017.01); ***G06T 7/62*** (2017.01); ***G06V 20/10*** (2022.01); ***G06V 20/13*** (2022.01); ***G06V 20/17*** (2022.01); *G06T 2207/20081* (2013.01); *G06T 2207/30181* (2013.01); *G06T 2207/30188* (2013.01); *G06V 20/176* (2022.01); *G06V 20/182* (2022.01); *G06V 20/188* (2022.01)

(58) **Field of Classification Search**

CPC G06T 7/11; G06T 7/50; G06T 7/62; G06T 2207/20081; G06T 2207/30181; G06T 2207/30188; G06V 10/44; G06V 20/10; G06V 20/13; G06V 20/17; G06V 20/176; G06V 20/182; G06V 20/188

See application file for complete search history.

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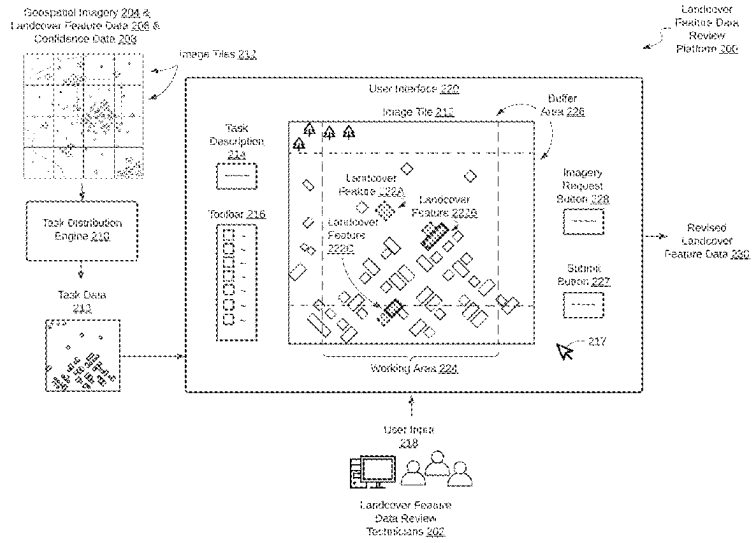
(57) **ABSTRACT**

Methods and systems for extracting and reviewing landcover feature data are provided. An example method involves accessing geospatial imagery covering a geographic area and landcover feature data extracted from the geospatial imagery, subdividing the geospatial imagery into a grid of image tiles, assigning landcover feature data review technicians to review the image tiles and associated landcover feature data through a landcover feature data review platform, and receiving revised landcover feature data that modifies the landcover feature data.

11 Claims, 7 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 63/598,396, filed on Nov. 13, 2023, provisional application No. 63/515,671, filed on Jul. 26, 2023.

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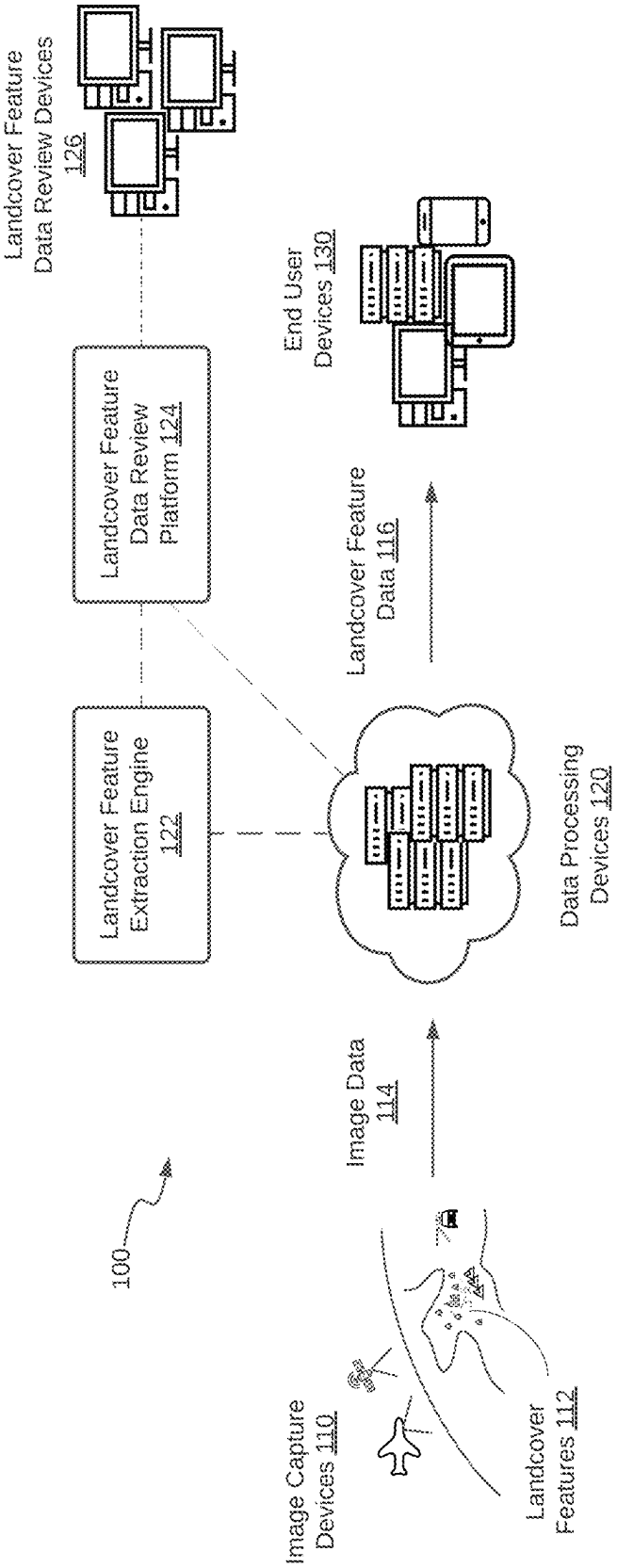
Landcover Feature Data Review Devices 126
End User Devices 130
Landcover Feature Data Review Platform 124
Landcover Feature Data 116
Landcover Feature Extraction Engine 122
Data Processing Devices 120
100
Image Data 114
Image Capture Devices 110
Landcover Features 112

FIG. 1

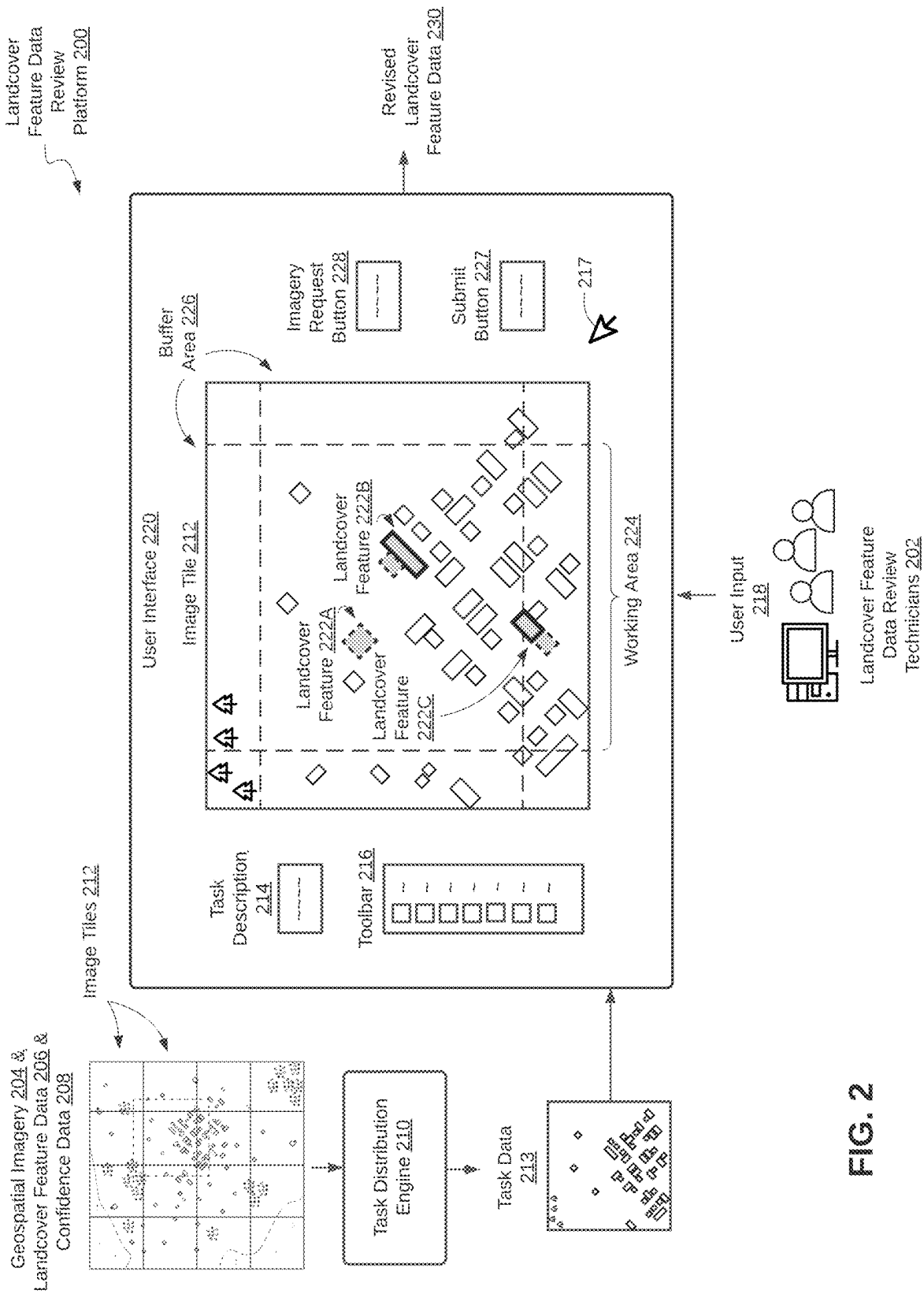
Landcover Feature Data Review Platform 200
Revised Landcover Feature Data 230
User Interface 220
Image Tile 212
Buffer Area 226
Imagery Request Button 228
Submit Button 227
217
Landcover Feature 222A
Landcover Feature 222B
Landcover Feature 222C
Working Area 224
Task Description 214
Toolbar 216
Image Tiles 212
User Input 218
Landcover Feature Data Review Technicians 202
Geospatial Imagery 204 & Landcover Feature Data 206 & Confidence Data 208
Task Distribution Engine 210
Task Data 213

FIG. 2

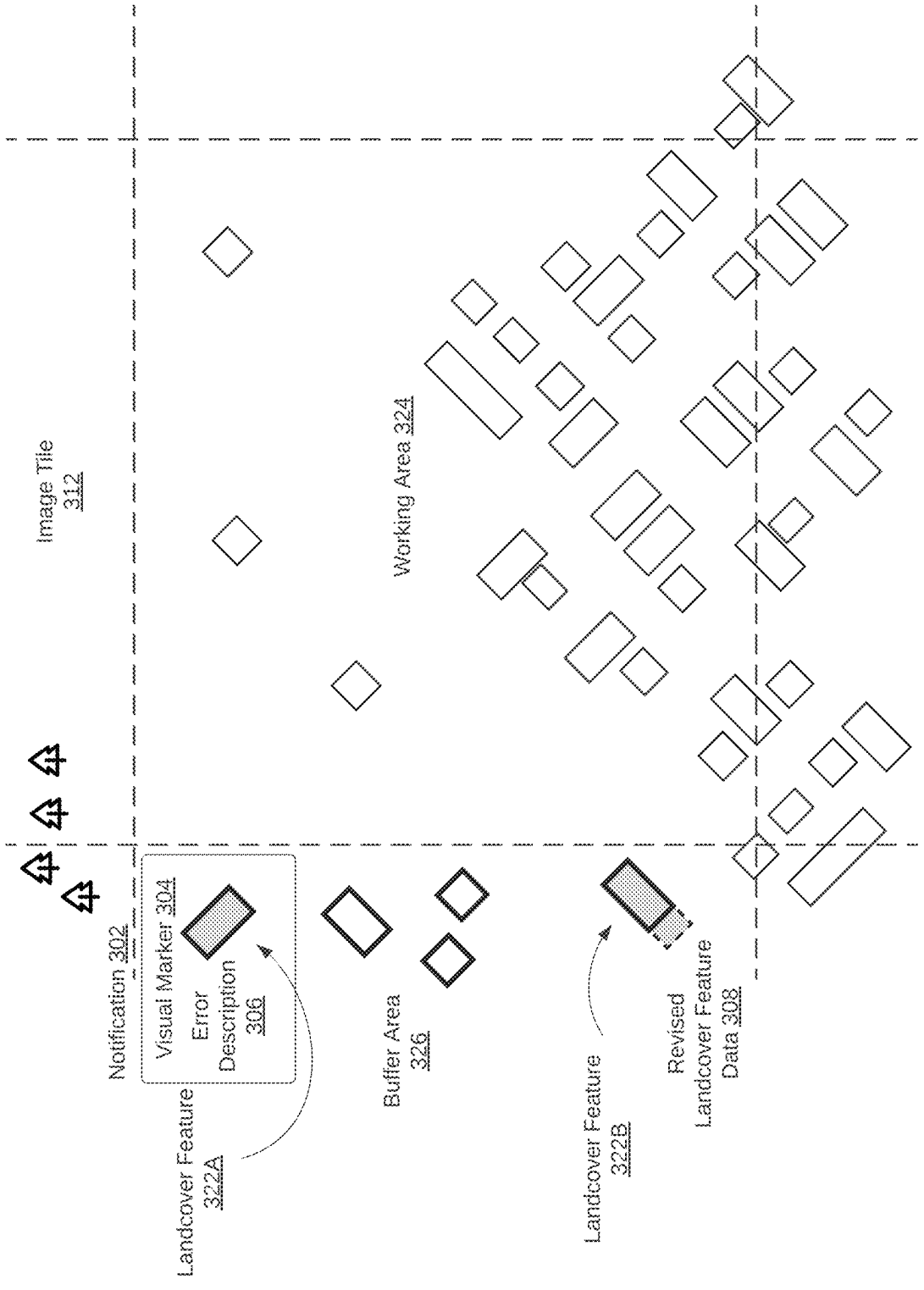
Image Tile
312
Working Area 324
Notification 302
Visual Marker 304
Error
Description
306
Landcover Feature
322A
Buffer Area
326
Landcover Feature
322B
Revised
Landcover Feature
Data 308

FIG. 3

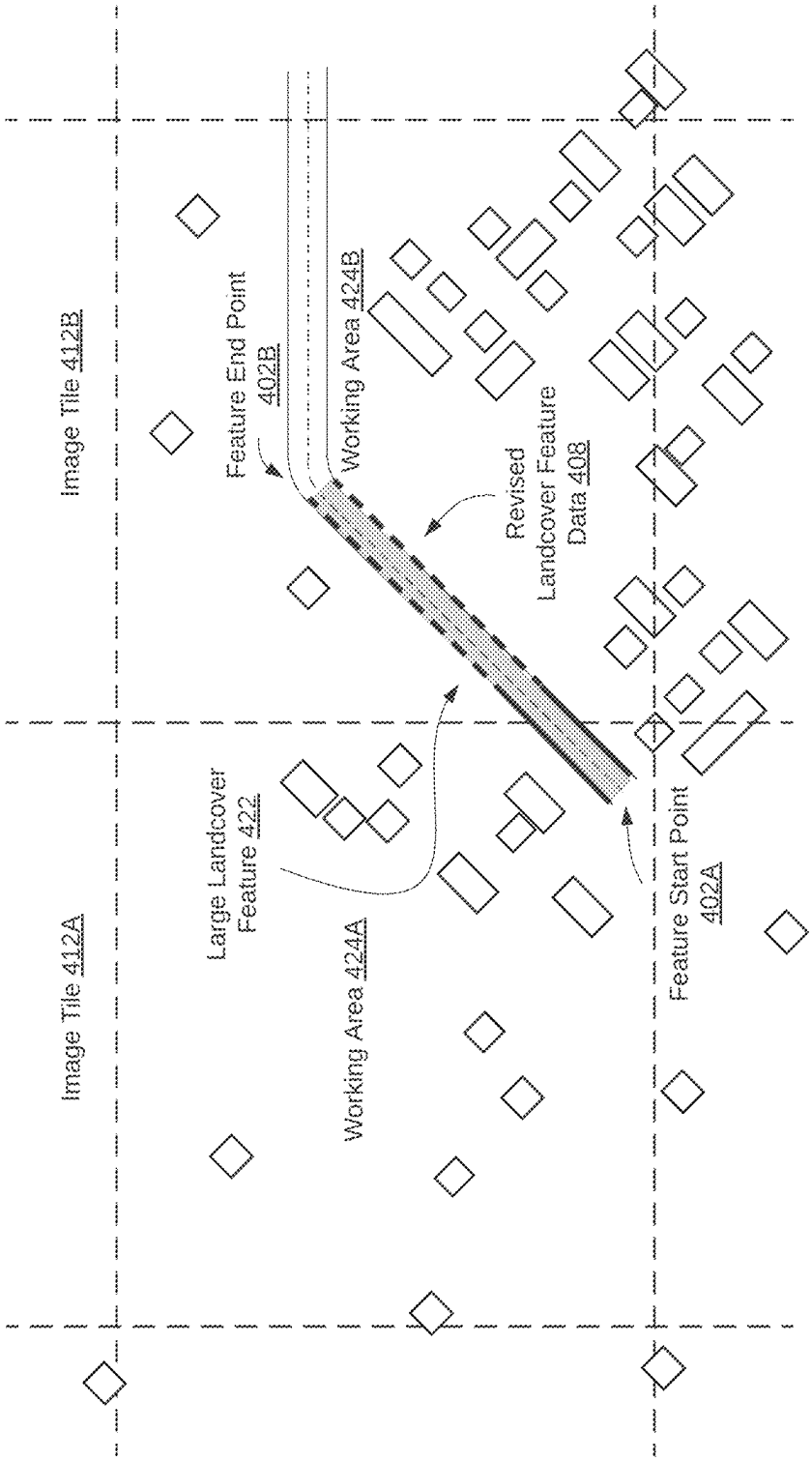
Image Tile 412B
Feature End Point 402B
Working Area 424B
Revised Landcover Feature Data 408
Large Landcover Feature 422
Working Area 424A
Image Tile 412A
Feature Start Point 402A

FIG. 4

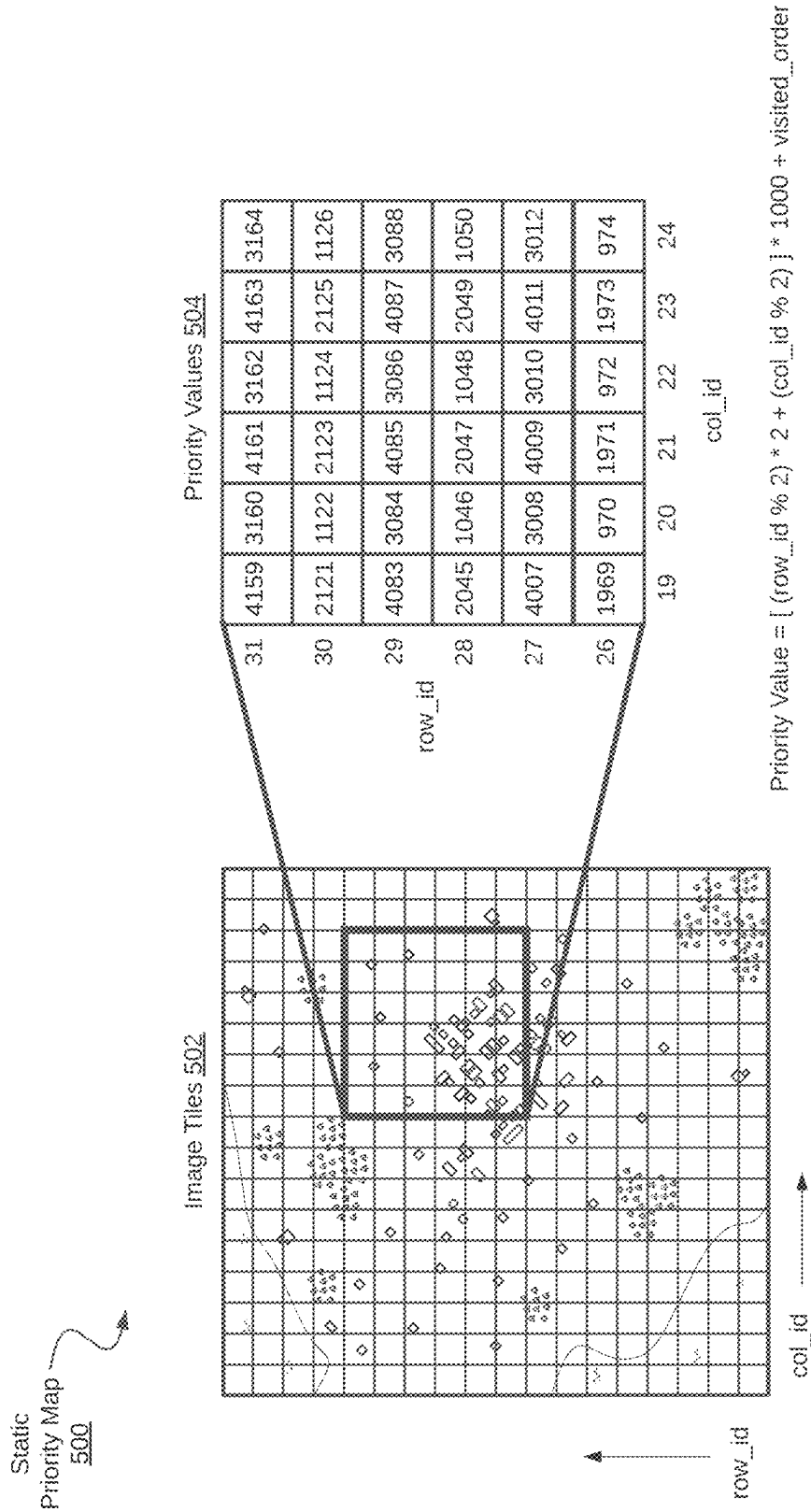
Static
Priority Map
500
Image Tiles 502
Priority Values 504
row_id
col_id
Priority Value = [(row_id % 2) * 2 + (col_id % 2)] * 1000 + visited_order
31 4159 3160 4161 3162 4163 3164
30 2121 1122 2123 1124 2125 1126
29 4083 3084 4085 3086 4087 3088
28 2045 1046 2047 1048 2049 1050
27 4007 3008 4009 3010 4011 3012
26 1969 970 1971 972 1973 974
19 20 21 22 23 24
row_id
col_id

FIG. 5

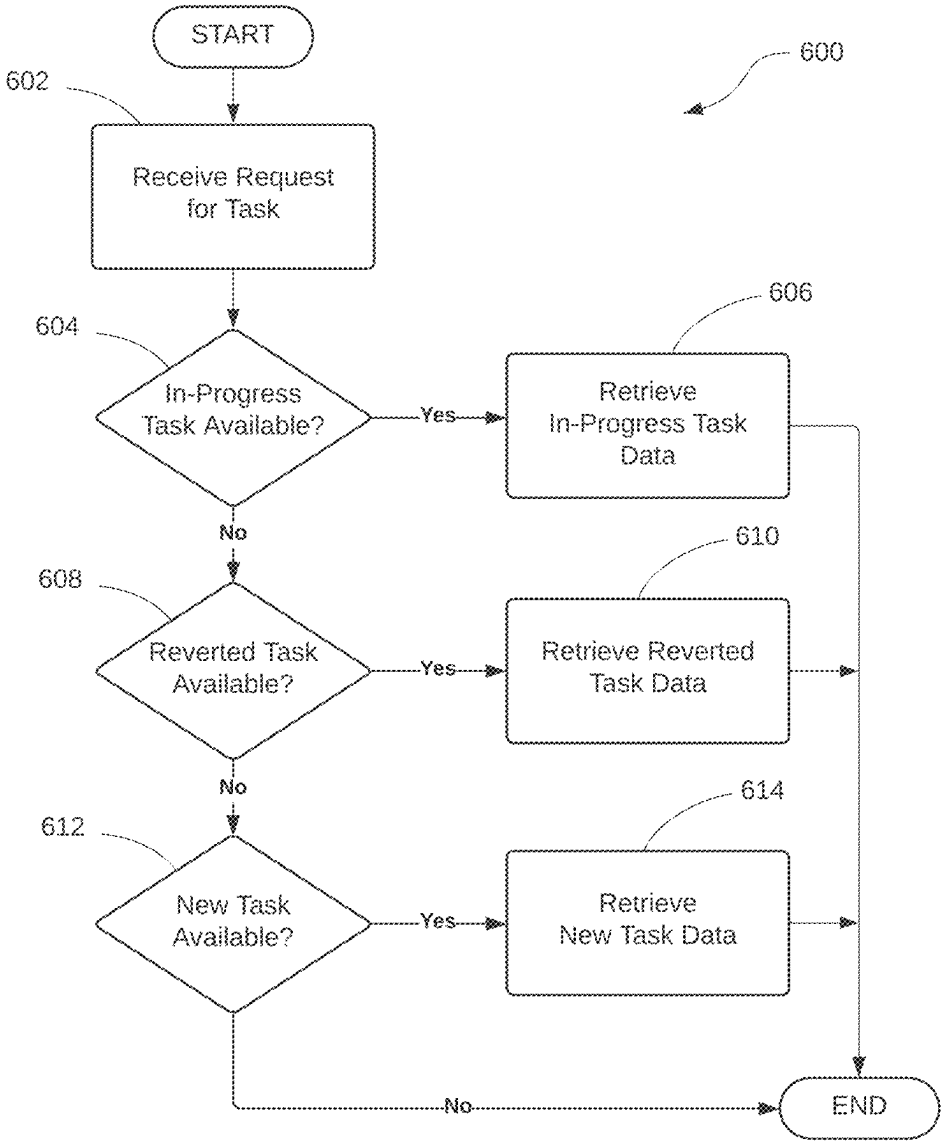
START
600
602
Receive Request for Task
604
In-Progress Task Available?
Yes
606
Retrieve In-Progress Task Data
No
608
Reverted Task Available?
Yes
610
Retrieve Reverted Task Data
No
612
New Task Available?
Yes
614
Retrieve New Task Data
No
END

FIG. 6

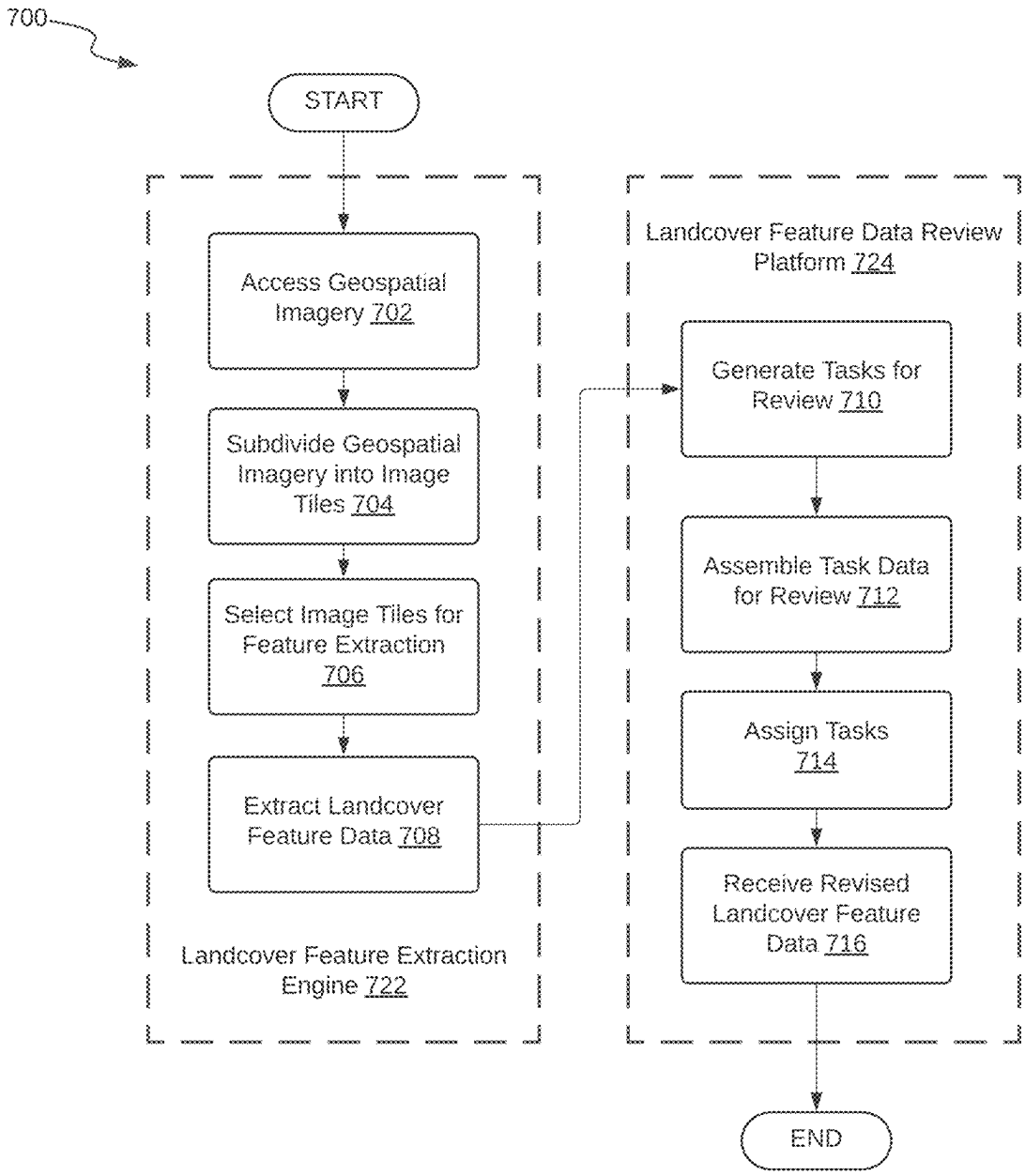
700
START
Access Geospatial Imagery 702
Subdivide Geospatial Imagery into Image Tiles 704
Select Image Tiles for Feature Extraction 706
Extract Landcover Feature Data 708
Landcover Feature Extraction Engine 722
Landcover Feature Data Review Platform 724
Generate Tasks for Review 710
Assemble Task Data for Review 712
Assign Tasks 714
Receive Revised Landcover Feature Data 716
END

FIG. 7

PLATFORM FOR DISTRIBUTED LANDCOVER FEATURE DATA REVIEW

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit under 35 U.S.C. § 120 as a continuation of U.S. patent application Ser. No. 18/437,477, filed Feb. 9, 2024, which claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional App. 63/515,671, filed Jul. 26, 2023, and U.S. Provisional App. 63/598,396, filed Nov. 13, 2023. The contents of each of the aforementioned applications are incorporated herein by reference in their entirety.

BACKGROUND

Landcover feature extraction has become increasingly important for a variety of applications, including urban planning, agriculture, and environmental monitoring. Landcover feature data can be extracted through manual means (e.g., by manual user annotation of geospatial imagery), or through automated means (e.g., by a machine learning model trained to extract such features directly from imagery). Whether extracted manually or through automated means, the scale of such an operation typically necessitates a quality control process in which the extracted data is reviewed for errors by human technicians and corrected where appropriate.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an example system for extracting and reviewing landcover feature data.

FIG. **2** is a schematic diagram of an example landcover feature data review platform for reviewing landcover feature data extracted from imagery.

FIG. **3** illustrates an example use case of a landcover feature data review platform in which a landcover feature data review technician assigned to review an image tile makes a revision regarding landcover feature data that belongs to an adjacent image tile.

FIG. **4** illustrates an example use case of a landcover feature data review platform in which a landcover feature data review technician makes a revision to a landcover feature that spans two adjacent image tiles.

FIG. **5** is an illustration of an example static priority map that sets out a predetermined sequence in which a grid of image tiles containing landcover feature data extracted from imagery covering a geographic area can be assigned to landcover feature data review technicians for review.

FIG. **6** is a flowchart illustrating an example method for assigning landcover feature data review technicians to image tiles in a distributed landcover feature data review platform.

FIG. **7** is a flowchart of an example method for extracting and reviewing landcover feature data that involves extracting landcover feature data from imagery using a machine learning model and revising the extracted landcover feature data using a distributed landcover feature data review platform.

DETAILED DESCRIPTION

As mentioned above, an automated landcover feature extraction process should be followed by a quality control step in which the data extracted by the automated process is reviewed for errors by human technicians and corrected where appropriate. This kind of quality control process can present challenges at scale in cases where there are large swathes of geospatial imagery covering a wide area of interest and several layers of feature types to review.

Since the process for reviewing geospatial data at large scales can be time-consuming, areas of interest are often broken down into smaller work areas (i.e., image tiles) which are distributed among teams of data reviewers. However, a common problem with this approach is that landcover features cannot always be contained within individual image tiles. Indeed, if an area of interest were simply divided into a grid of non-overlapping image tiles, it would be exceedingly common for a landcover feature to land on the border between two adjacent image tiles. As a result, if two or more landcover feature data reviewers are assigned to work on adjacent image tiles simultaneously, conflicts can arise in the area bordering the adjacent image tiles. These problems not only complicate the distribution of data review tasks, but can also lead to inconsistencies and/or duplication of work among data reviewers, thereby slowing processing times and potentially decreasing accuracy.

As will be seen below, the present disclosure provides a system in which data review tasks are distributed among data review technicians in a manner that minimizes conflicts. Further, a platform is provided in which data review technicians are empowered to cooperate with one another at the boundaries between adjacent image tiles through the use of various annotation tools that transform what was once a source of conflict into an opportunity to further refine data accuracy. This kind of distributed data review platform may be particularly useful when integrated into a machine learning extraction process, as the human-revised data can provide a source of ongoing source of training data to support continual fine-tuning of the machine learning model.

FIG. **1** is a schematic diagram of an example system **100** for extracting and reviewing landcover feature data.

The system **100** includes one or more image capture devices **110** to capture image data **114** of an area of interest containing one or more landcover features **112**. A landcover feature **112** that is depicted in the image data **114** may include a built feature such as a building, road, bridge, pavement, or a natural feature such as trees, grassland, water, or area of bare land.

An image capture device **110** may include any suitable sensor (e.g., camera) onboard an aircraft, satellite, drone, or other device capable of capturing imagery of an area of interest from a generally overhead point of view (i.e., geospatial imagery). An image capture device **110** may also include any suitable sensor (e.g., camera) onboard a motor vehicle (e.g., street view car), unmanned aerial vehicle (e.g., drone), or personal device (e.g., smart phone), that is capable of capturing imagery of a landcover feature from a more oblique perspective at a ground or near-ground level.

The image data **114** comprises the raw image data captured by such image capture devices **110** along with any relevant metadata, including camera parameters (e.g., interior camera parameters and exterior camera parameters), geospatial position information (e.g., latitude and longitude position), or other relevant metadata that may be provided. The image data **114** may contain several batches of imagery covering the same area, from different points of view, which may have been captured on the same dates, or on different dates.

The system **100** further includes one or more data processing devices **120** to process the image data **114** to produce landcover feature data **116** as described herein. The data processing devices **120** include one or more computing

devices, such as virtual machines or servers in a cloud computing environment comprising one or more processors for executing computing instructions. In addition to processing capabilities, the data processing devices **120** include one or more communication interfaces to receive/obtain/access the image data **114** and to output/transmit landcover feature data **116** through one or more computing networks and/or telecommunications networks such as the internet. Such computing devices further include memory (i.e., non-transitory machine-readable storage media) to store programming instructions that embody the functionality described herein.

The data processing devices **120** are configured to run (i.e., store, host or access) a landcover feature extraction engine **122**. The landcover feature extraction engine **122** cooperates with a landcover feature data review platform **124** as described herein. The landcover feature extraction engine **122** and the landcover feature data review platform **124** are represented here as distinct functional units. However, this arrangement is shown for illustrative purposes only, and it is to be understood that any of the functionality described herein may be accomplished by any combination of programs, software modules, or other sets of non-transitory machine-readable instructions.

In some cases, the landcover feature data review platform **124** may be hosted by the data processing devices **120** in a manner remotely accessible by landcover feature data review devices **126** (e.g., through the internet). In other cases, parts of the landcover feature data review platform **124** may be locally executable directly at landcover feature data review devices **126** and parts of the landcover feature data review platform **124** may be hosted remotely.

In any case, the landcover feature data review devices **126** include one or more computing devices configured to run (i.e., store, host or access) the landcover feature data review platform **124**. The landcover feature data review devices **126** therefore may include one or more user input devices (e.g., keyboard, mouse, touchscreen) to receive user input into the landcover feature data review platform **124** and a display device to allow a user to view a user interface provided by the landcover feature data review platform **124**.

The landcover feature data **116** may be generally understood to include any data representation of landcover features. For example, the landcover feature data **116** may be in a raster format in which the pixels of an image are labelled as belonging to a particular landcover feature type. As another example, the landcover feature data **116** may be in a vector format in which the shape and size of landcover features are captured in combinations of points, lines, and/or polygons, and associated constraints, georeferenced to the imagery. In many such cases, a landcover feature may be represented by a polygon that indicates the size and shape of the landcover feature (e.g., a polygon representing a building footprint). In some examples, the vector data may also contain annotation operation data that indicates the order in which a sequence of annotation operations were performed to generate the vector data. In the vector data format, the landcover features may be represented in a two-dimensional space (e.g., XY plane) corresponding to approximately the ground plane (generally suitable for two-dimensional landcover features such as roads and terrain types). In other cases, the landcover features may be represented in a three-dimensional reconstructed space (i.e., XYZ space), in which some or all of the landcover features are modeled in three dimensions (e.g., 3D buildings).

In operation, the landcover feature extraction engine **122** accesses the image data **114** and extracts the landcover feature data **116** from the image data **114**. Feature extraction may be performed according to any suitable process depending on the type of features desired and the imagery available. The landcover feature extraction engine **122** may also perform various pre-processing steps such as camera calibration (e.g., bundle adjustment). One of the image pre-processing steps may involve subdividing the area of interest covered by the image data **114** into smaller areas (i.e., image tiles) for ease of distribution among a team of data review technicians, as described in greater detail with respect to FIG. **2**, below.

In some cases, the feature extraction may involve a machine learning process. For example, landcover features that can be extracted from single imagery, including two-dimensional features such as building footprint polygons, can be extracted from imagery using the machine learning process described in U.S. patent application Ser. No. 17/731,769, entitled MACHINE LEARNING FOR VECTOR MAP GENERATION, filed Apr. 28, 2022, the entirety of which is hereby incorporated by reference. As another example, landcover features that can be extracted from multiview imagery, including three-dimensional features such as 3D buildings, can be extracted from multiview imagery using the machine learning process described in U.S. patent application Ser. No. 18/319,553, entitled VECTOR DATA PROJECTION AND FEATURE MATCHING TO DETERMINE THREE-DIMENSIONAL STRUCTURE, filed May 18, 2023, the entirety of which is hereby incorporated by reference. In cases where the image data **114** is divided into smaller image tiles, these machine learning extraction processes may be applied to individual image tiles and their results may be combined to form a set of landcover features extracted from the larger area of interest.

In some cases, the feature extraction process may be preceded by an initial filtering step in which it is determined which areas of the area of interest should be subject to feature extraction in the first place. For example, in cases where the image data **114** is divided into smaller image tiles, a machine learning model may be applied to a set of image tiles covering the area of interest to determine a likelihood and/or presence of features to be extracted. Image tiles in which there are likely to be no features for extraction can be excluded from the feature extraction process to save on further processing times and resources.

Following the initial extraction by the landcover feature extraction engine **122**, a subset of the landcover feature data **116** may be forwarded to the landcover feature data review platform **124** for review and/or correction where appropriate. In cases where the image data **114** is divided into smaller image tiles, each image tile may be associated with the landcover feature data **116** generated from that image tile (as described in greater detail below with respect to FIG. **2**, below), forming a package of data comprising the set of landcover feature data **116** and the associated image data **114** for the image tile.

In some cases, selecting which of the landcover feature data **116** (i.e., which image tiles) to be forwarded for review may involve determining parts of the landcover feature data **116** that are most likely to contain errors, and therefore, are most likely to benefit from human revision. In some cases, this determination may involve an evaluation of confidence data associated with the extracted landcover feature data **116**, as described in greater detail with respect to FIG. **2**, below.

Once forwarded to the landcover feature data review platform **124**, the landcover feature data **116** may be bundled into "tasks" to be reviewed by landcover feature data review

technicians operating landcover feature data review devices **126**. Through the landcover feature data review platform **124**, these landcover feature data review technicians can be instructed to review the landcover feature data **116** against the image data **114** to identify and resolve errors or inaccuracies. The refined landcover feature data **116** may be shared back to the data processing devices **120** and combined into a final product deliverable to an end user.

Following the generation (and refinement) of the landcover feature data **116**, the data processing devices **120** may provide such landcover feature data **116** to one or more end user devices **130**. An end user device **130** may include one or more computing devices configured to run (i.e., store, host or access) one or more software programs to display, process, or otherwise use the landcover feature data **116** (e.g., a GIS viewer, CAD software). In some examples, an end user device **130** may include a display device and user interface and may allow a user to view and manipulate the landcover feature data **116**. The end user devices **130** may use the landcover feature data **116** for any suitable application, such as to display models of the landcover features **112** through a viewer, or for other purposes.

In cases where a machine learning process is used to initially extract the landcover feature data **116**, the refined landcover feature data **116** obtained from the landcover feature data review platform **124** may be further leveraged to retrain the machine learning model used in the process. Thus, the accuracy of the landcover feature extraction engine **122** may be continually improved.

FIG. **2** is a schematic diagram of an example of a landcover feature data review platform **200**, which may be understood to be a non-limiting example of the landcover feature data review platform **124** of FIG. **1**.

As an overview, the landcover feature data review platform **200** includes a task distribution engine **210** which assigns "tasks" to be carried out by landcover feature data review technicians **202**, and includes a user interface **220** through which the landcover feature data review technicians **202** can review and revise landcover feature data **206** associated with the assigned tasks.

Beginning with the task distribution engine **210**, the task distribution engine **210** accesses geospatial imagery **204**, landcover feature data **206**, and confidence data **208**, and uses this data to assemble "tasks" for distribution to landcover feature data review technicians **202**. As described in FIG. **1**, this data may have been derived from an automated process performed by the landcover feature extraction engine **122** of FIG. **1**. Also as mentioned in FIG. **1**, this data is divided according to a set of image tiles **212**, in which each image tile **212** is associated a set of geospatial imagery **204** and a set of landcover feature data **206** extracted from that geospatial imagery **204**. As described below, the image tiles **212** can also be further associated with associated confidence data **208**.

The task distribution engine **210** then determines, for each image tile **212**, whether the image tile **212** should be subject to review. The task distribution engine **210** makes this determination for each image tile **212** with reference to the associated confidence data **208**.

The confidence data **208** indicates a degree of confidence that one or more of the landcover features in the image tile **212** are accurately represented in the landcover feature data **206**. The confidence data **208** may be represented on a feature-by-feature basis or on a tile-by-tile basis. In either case, the confidence data **208** may be inherent to the extraction of the landcover feature data **206** (e.g., a probability or certainty value associated with a machine learning extraction) or may be an additional data layer added by a separate analytical step (e.g., based on heuristics). For example, the confidence data **208** may be in the form of a probability value associated with the machine learning output for each extracted landcover feature. As another example, the confidence data **208** may be in the form of an overall confidence score for each image tile **212**.

An image tile **212** may be determined to be subject to review based on this confidence data **208** in a number of ways. For example, an image tile **212** may be determined to be subject for review if the confidence data **208** falls below a predetermined threshold. For example, an image tile **212** may be selected for review if the probability value associated with the machine learning output for any landcover feature belonging to that image tile **212** falls below a threshold value. As another example, an overall number of "low confidence" features may be determined for each image tile **212**, and an image tile **212** will only be selected for review if the image tile **212** contains a certain number of "low confidence" features (e.g., greater than 3).

With the set of image tiles **212** selected for review, the task distribution engine **210** then proceeds to assemble the appropriate data into task data **213** intended for distribution to landcover feature data review technicians **202**. Each set of task data **213** contains the appropriate subset of the landcover feature data **206** and the appropriate subset of geospatial imagery **204** that belongs to the image tile **212**.

With the task data **213** prepared, the task distribution engine **210** then proceeds to assign individual landcover feature data review technicians **202** to individual sets of task data **213**, or, in other words, assigns individual landcover feature data review technicians **202** to review individual image tiles **212**. A comprehensive method for assigning landcover feature data review technicians **202** to image tiles **212** is provided later in this disclosure in the description of FIG. **6**. At this stage, however, it is sufficient to acknowledge that image tiles **212** are assigned to landcover feature data review technicians **202** in accordance with some predetermined algorithm that aims to minimize conflicts caused by landcover feature data review technicians **202** working on adjacent image tiles **212**. A landcover feature data review technician **202** who is assigned task data **213** then accesses the appropriate task data **213** through the user interface **220**.

The user interface **220** provides a viewport for viewing the assigned image tile **212** including the geospatial imagery **204** and associated landcover feature data **206**. The user interface **220** can also provide a task description **214** to inform the landcover feature data review technician **202** as to the general nature of the assigned task (e.g., "review building footprint layer"). The user interface **220** can also provide a toolbar **216** through which the landcover feature data review technician **202** may access various tools for revising the landcover feature data **206**. However, it should be noted that these user interface elements are shown for illustrative purposes only, and it is to be understood that the task instructions and the available tools may be accessed through other means (e.g., some tools may be accessed by inputting the requisite keyboard and/or mouse strokes).

It should also be noted at this stage that the image tile **212** may be divided into a working area **224** and a surrounding buffer area **226** which serve different purposes.

A working area **224** of an image tile **212** is the area which contains" the landcover feature data **206** associated with the image tile **212** that is meant to be reviewed by the landcover feature data review technician **202**, whereas the buffer area is an additional space that overlaps with the working areas **224** of other adjacent image tiles **212** and provides addi-

tional visual context, and working space, to the landcover feature data review technician **202**. The size and/or shape of these areas may vary depending on the imagery available and the data review task at hand. For example, a typical working area **224** may comprise a square-shaped area measuring about 1 km×1 km, whereas the buffer area **226** adds an additional 0.2 km in each direction leading to a total area of 1.2 km×1.2 km for the image tile **212**.

The buffer area **226** of an image tile **212** is particularly useful in that it provides additional working space for the landcover feature data review technician **202** for cases where a landcover feature that belongs to an image tile **212** falls on the edge of the working area **224**. Moreover, this buffer area **226** can also be populated with the landcover feature data **206** of adjacent image tiles **212** which provide even further context when several features are being extracted nearby one another.

In some cases, the buffer area **226** may only be populated with the landcover feature data **206** of an adjacent image tile after that adjacent image tile **212** has been reviewed by a landcover feature data review technician **202**. This is so that a landcover feature data review technician **202** can comment on and/or edit the worked performed by another landcover feature data review technician **202** without interfering with the workflow for that landcover feature data review technician **202**.

It should be noted at this stage that these working areas **224** and buffer areas **226** for the image tiles **212** may have been determined at the imagery pre-processing and/or initial feature extraction stage by the landcover feature extraction engine **122**. Indeed, the machine learning model for extracting landcover features from image tiles **212** may have operated within these working areas **224** (i.e., extracting features from working areas **224** but provided the additional context of the surrounding buffer areas **226**).

Further, it should be noted that landcover feature data **206** may be assigned to one image tile **212** or another based on whether the landcover features land within the working area **224** of an image tile **212** as opposed to its buffer area **226**. However, this process of assigning landcover features to image tiles **212** may not always be as simple as assigning landcover features that fall within the boundaries of a working area **224** of an image tile **212** to that image tile **212**. Indeed, as mentioned above, in many cases, some landcover features are likely to fall on the boundary between the working areas **224** of image tiles **212** and therefore may not be "contained" within the working area **224** of any single image tile **212**. Thus, the task distribution engine **210** may assign landcover features to image tiles **212** in accordance with some predetermined algorithm that accounts for such occurrences. For example, for smaller landcover features such as buildings, the features that intersect the bottom and/or right sides of a working area **224** of an image tile **212** may be associated with that image tile **212**, whereas the features that intersect the top and/or left sides of the working area **224** of the image tile **212** may be associated with the adjacent image tile. For larger landcover features such as roads, the features may simply be cut off at the task boundary, with each piece of the feature being assigned to one or the other image tile.

Returning to the function of the user interface **220**, as a general approach, the landcover feature data review technician **202** reviews the landcover feature data **206** provided with the image tile **212** against the associated geospatial imagery **204** and provides user input **218** to make any revisions as appropriate using the available tools. The landcover feature data review technician **202** may annotate the imagery to capture new landcover features that were missed by the initial extraction, and/or edit existing landcover feature data **206** that may have been captured incorrectly. In some cases, the task of the landcover feature data review technician **202** may be instructed to review the entire set of landcover feature data **206** associated with the assigned image tile **212**. In other cases, the task may be to address only certain features that have been flagged for review (e.g., based on the associated confidence data **208** falling below a threshold), and in those cases, the user interface **220** may draw the attention of the landcover feature data review technician **202** to the landcover features at issue (e.g., by visually highlighting the problematic data elements in some manner).

In any case, a few illustrative scenarios in which a landcover feature data review technician **202** revises the landcover feature data **206** will be described here. As a first example, it can be seen that the image tile **212** contains landcover feature **222**A, which indicates a building that appears to have been missed by the automated extraction process by which the landcover feature data **206** was initially generated. In this case, the landcover feature data review technician **202** would access the appropriate tools to generate a new data element representing the missed feature. For example, the landcover feature data review technician **202** may use the mouse cursor **217** to access the appropriate "draw building" tool selected from the toolbar **216** and may proceed to outline the rooftop polygon of the missing building.

As another example, it can be seen that the image tile **212** also contains landcover feature **222**B, which indicates a building which was incorrectly captured by the automated extraction process by which the landcover feature data **206** was generated. In this case, the landcover feature data review technician **202** would access the appropriate tools to modify the data element representing the erroneously extracted feature (e.g., by extending the rooftop polygon to capture the full building rooftop).

As another example, it can be seen that the image tile **212** also contains landcover feature **222**C, which indicates a building which spans the border between the working area **224** and the buffer area **226**. The landcover feature **222**C may have been missed or incorrectly extracted in some manner that the landcover feature data review technician **202** may remedy as described above. As described above, in doing so, the technician **202** has full access to both working area **224** and the buffer area **226** to make the necessary correction.

The user interface **220** may include additional user interface elements that facilitate workflow, such as a "submit" button **227** that the landcover feature data review technician **202** may engage to indicate that review of the assigned image tile **212** is complete, and a "imagery request" button **228** that the landcover feature data review technician **202** may engage to request additional imagery outside of the image tile **212** that may be necessary to complete particular data review task (described in greater detail with reference to FIG. **4**). Further, the landcover feature data review platform **200** may provide functionality for running a topology error detection algorithm on the landcover feature data **206**. Such a topology error detection algorithm may include any algorithm suitable for identifying common topological errors in vector data (e.g., no invalid geometries). The topology error detection algorithm may be executed at will, or may be triggered automatically when a technician presses the "submit" button **227**. In some cases, the landcover feature data review platform **200** may restrict the revised

landcover feature data **230** from being submitted (or accepted) until the topological error detection algorithm is passed.

Further, the landcover feature data review platform **200** may provide functionality for checking, before a landcover feature data review technician **202** submits the image tile **212** as being complete, whether any landcover feature data for an adjacent image tile has recently been reviewed since the time the landcover feature data review technician **202** began working on the image tile **212**. In such a case, the landcover feature data review technician **202** may be provided with the option to download and view the recently reviewed landcover feature data (which may then be populated in the buffer area **226**), thereby providing the landcover feature data review technician **202** with the chance to make further revisions to the landcover feature data **206** for the image tile **212** before submitting.

In sum, the landcover feature data review platform **200** provides an effective means for a distributed group of landcover feature data review technicians **202** to review and revise a large set of landcover feature data **206**. The resulting revised landcover feature data **230** may be used to substitute, or supplement, at least a portion of the initially extracted landcover feature data **206**. The revised landcover feature data **230** may also be used to further train a machine learning model that may have been used in the initial extraction of the landcover feature data **206**, thereby providing a means for continuously improving the accuracy of the extracted data.

As mentioned above, there are use cases for a landcover feature data review platform in which a landcover feature data review technician makes a revision to a landcover feature that belongs to an adjacent image tile. This scenario is illustrated in FIG. **3**, where a landcover feature data review technician, who is assigned to an image tile **312**, comprising a working area **324** and buffer area **326**, interacts with landcover feature data located in the buffer area **326**, which belongs to an adjacent image tile. This landcover feature data in the adjacent image tile may have been previously reviewed by another landcover feature data review technician who may have missed the errors.

As one example interaction, it can be seen that the buffer area **326** of the image tile **312** contains a landcover feature **322**A that was missed or erroneously captured by both the automated extraction process and the assigned technician. In this case, the technician assigned to the image tile **312** may choose to address the error by generating a notification **302** regarding the error. The notification **302** may comprise a visual marker **304**, such as a window, box, or other marker placed in the vicinity of the landcover feature **322**A that identifies the landcover feature **322**A that is the subject of the notification **302**. The notification **302** may also comprise an error description **306**, which may include a text description, categorization of error type, or other description of the nature of the error. The notification **302** may be associated with the landcover feature data for the landcover feature **322**A (e.g., appended as metadata) and stored by the landcover feature data review platform for viewing by the technician who is assigned to the adjacent image tile or a supervising technician. The creation of the notification **302** may cause the creation of another task (i.e., a "ticket") to be addressed in the workflow of the supervising technician or other technician. Thus, using these available tools, although the technician assigned to the image tile **312** may not have been specifically instructed to comment on the landcover feature **322**A (which may have been assigned to a different technician), the technician is provided the opportunity to collaborate in the overall data review effort by identifying an error made in an adjacent image tile.

As another example interaction, it can be seen that the buffer area **326** of the image tile **312** contains yet another a landcover feature **322**B that was missed or erroneously captured by both the automated extraction process and the assigned technician. In this case, the landcover feature data review technician may choose to directly revise the data element representing the erroneously extracted feature (e.g., by extending the rooftop polygon to capture the full building rooftop), and in doing so, generate revised landcover feature data **308**. However, since the landcover feature **322**B belongs to an adjacent image tile assigned to a different landcover feature data review technician, the landcover feature data review platform may register the revised landcover feature data **308** according to a separate process in which a notification is generated for the assigned technician, or to a supervising technician, to review the revised landcover feature data **308**, before the amendment is accepted. In this case, the landcover feature data review platform provides another opportunity for groups of landcover feature data review technicians to collaborate toward improving the accuracy of landcover feature data.

As mentioned above, there are use cases for a landcover feature data review platform in which a landcover feature data review technician makes a revision to a landcover feature that spans two adjacent image tiles. This scenario is illustrated in FIG. **4**, in which a landcover feature data review technician assigned to an image tile **412**A makes a revision to a landcover feature **422** that spans from the image tile **412**A into an adjacent image tile **412**B. Further, although the buffer areas of the image tiles **412**A, **412**B are not shown (to reduce visual clutter), it is to be understood that the landcover feature **422** (in this case, a road segment) crosses over from the working area **424**A of the image tile **412**A into the working area **424**B of an adjacent image tile **412**B.

Suppose the error to be corrected is that the landcover feature **422**, as originally extracted, does not completely extend from the feature start point **402**A, which indicates the start of the road segment, to the feature end point **402**B, which indicates the end of the road segment (i.e., the next bend in the road). In this case, if the technician assigned to the image tile **412**A were required to ensure that the landcover feature **422** fully extends from the feature start point **402**A to the feature end point **402**B, which would normally not be accessible to the technician, then the technician may request the imagery corresponding to the adjacent image tile **412**B (e.g., using the "imagery request button **228**" of FIG. **2**) in order to complete the revision.

Upon receiving a request for additional imagery for the adjacent image tile **412**B, the landcover feature data review platform may obtain the appropriate imagery, and distribute the appropriate imagery to the requesting technician. In some cases, the landcover feature data associated with the adjacent image tile **412**B may also be obtained, which may assist the technician in completing the revision of the landcover feature **422** in its surrounding context (e.g., with visual cues of nearby buildings and/or other landcover features). In any case, the technician may revise the landcover feature **422**, and in doing so, generate revised landcover feature data **408**. Thus, the landcover feature data review platform provides an opportunity for a landcover feature data review technician to share in the available imagery, including imagery to which the landcover feature data review technician may not have been originally assigned, in order to properly capture a landcover feature that spans multiple adjacent image tiles.

Turning now to methods for assigning landcover feature data review technicians to review landcover feature data, in the above description, reference is made to the need to make such assignments in a manner that minimizes the change for conflict to emerge during the data review process. In particular, it may be advantageous for a method for assigning landcover feature data review technicians to review landcover feature data to minimize the likelihood that any two data reviewers will be assigned to work on adjacent image tiles simultaneously. This may be achieved, at least in part, by following a predetermined sequence dictated by a static priority map, in which each image tile is assigned a priority value that is non-consecutive with each adjacent image tile, and landcover feature data reviewers are assigned to image tiles based on the priority values of these image tiles (e.g., in ascending or descending order). An example of such a static priority map is provided in FIG. **5**, in which a static priority map **500** comprises a grid of image tiles **502** in which each image tile **502** is assigned a priority value **504** that is non-consecutive with the priority value **504** assigned to each adjacent image tile **502**. In this setup, it is unlikely that any two data reviewers will be assigned to work on adjacent image tiles simultaneously.

In the static priority map **500**, the priority values **504** are generated based on the row and column positions of the image tiles **502**. As can be seen in FIG. **5**, each image tile **502** is labeled with its row position (i.e., "row_id") and column position (i.e., "col_id"). In this particular example, for each image tile **502**, its priority value **504** is calculated based on the following Equation 1:

$$PV=[(row_id\ \%2)*2+(col_id\ \%2)]*1000+visited_order \quad (1)$$

wherein PV refers to the priority value **504** of an image tile **502**, "row_id" refers to the row position of the image tile **502**, "col_id" refers to the column position of the image tile **502**, the operator "%" refers to the modulo operation, and "visited_order" is an incrementor. It should be noted that the parameters used in Equation 1 may be varied with experimentation. For example, the equation "PV=[(row_id % 2)*2+(col_id % 2)]*1,000,000+visited_order" may work similarly well. The important feature of Equation 1 is that it provides a mapping for each image tile **502** to a unique priority value **504** in which the priority value **504** for each image tile **502** is non-consecutive with each adjacent image tile **502**. Preferably, the priority value **504** of each image tile **502** is far apart from the priority value **504** of each adjacent image tile **502**, so that it is likely that there will be many more image tiles **502** assigned for data review before any two adjacent image tiles **502** are assigned for review. This is achieved in FIG. **5**, in which the image tile **502** at row 27 column 20 is assigned the priority value **504** of "3008" whereas the adjacent image tiles **502** are assigned the priority values **504** of "4007", "1046", "4009", and "970".

This "static" approach for assigning landcover feature data review technicians to image tiles based on a static priority map may be complemented by a "dynamic" component that takes into consideration the progress being made toward reviewing the set of image tiles. This dynamic component is captured in FIG. **6**, which illustrates an example method **600** for assigning landcover feature data review technicians according to a static priority map as well as additional workflow considerations. Indeed, the method **600** may be understood to be one example method for how the landcover feature data review platform **200** may assign image tiles to landcover feature data review technicians.

At step **602**, a request for a task (i.e., image tile) is received by the landcover feature data review platform. Depending on the architecture of the landcover feature data review platform, the request for a task may take several forms. For example, if the landcover feature data review platform is a web platform accessible by technicians remotely, the request may be made by a user logging into the system and requesting a task for work. If the landcover feature data review platform includes locally executable software, the request may be in the form of a transmission made from the a landcover feature data review technician's machine to a central task distribution server.

At step **604**, it is determined whether an in-progress task is available for the technician who made the request. An in-progress task refers to an unfinished task that the technician may be returning to the system to complete. In-progress tasks may be "locked" to other technicians so that no other technician can be assigned the same task. If an in-progress task is available, then at step **606**, the landcover data review platform retrieves the appropriate data for the in-progress task (e.g., imagery and landcover feature data) and distributes and/or makes available the data to the requesting technician.

It should be noted at this stage that various data protection controls can be implemented by the landcover data review platform to prevent unauthorized access to imagery, landcover feature data, or other data, for unintended or unauthorized purposes. For example, if the landcover feature data review platform includes locally executable software, the software may be limited to downloading the data for a single image tile at a time. Some exceptions may apply. For example, the software may allow the technician to download a small number of tasks to reduce time spent waiting for tasks to download. As another example, a technician may be permitted to download additional imagery when the technician makes a request for additional imagery (e.g., as discussed in FIG. **4**).

Returning to the method **600**, if it is determined that there is no in-progress task available for the requesting technician, then at step **608** it is determined whether a reverted task is available for the requesting technician. A reverted task refers to a task that was previously completed by the requesting technician but which requires additional work from the requesting technician. For example, a reverted task may refer to a task that was reviewed by a supervising technician who made one or more comments that are to be addressed by the requesting technician (e.g., including, for example, one or more comments and/or revisions made by a technician assigned to an adjacent image tile, as described in FIG. **3**). If a reverted task is available, then at step **610**, the landcover data review platform retrieves the appropriate data for the in-progress task (e.g., imagery and landcover feature data) and distributes and/or makes available the data to the requesting technician.

If it is determined that there are no reverted tasks available for the requesting technician, then at step **612** it is determined whether there is a new task available to the requesting technician. A new task refers to a task that has not yet been assigned to any data review technician. Selection of a new task data may be made with reference to a static priority map (e.g., as described in FIG. **5**). If a new task is available, then at step **614**, the landcover data review platform retrieves a new set of task data and distributes and/or makes available the data to the requesting technician.

The method **600** therefore provides a method for assigning landcover feature data review technicians according to a static priority map as well as additional workflow consid-

erations. Variations to the method **600** are contemplated, including additional workflow considerations that account for landcover feature data review technicians being assigned to work in one or more teams and/or one or more groups in a hierarchical structure, who may share work among one another according to a set of rules. In some cases, for example, reverted tasks of any team member may be made available to any other team member, thereby further encouraging collaboration among team members. Further, there may be other forms of the method **600** in which different data review technicians occupy different roles in the data review process (e.g., different data review technicians may be assigned to different task types and/or feature types). Moreover, there may be other forms of the method **600** for supervising technicians who are assigned tasks for reviewing work completed by lower-level technicians, for whom the task assignment process may involve a similar prioritization of in-progress tasks, new tasks for review, and reverted tasks for review.

The methods described herein are summarized in FIG. **7**, which provides a method **700** for extracting and reviewing landcover feature data that involves a machine learning model and distributed landcover feature data review platform.

Beginning at the extraction stage, at step **702**, a landcover feature extraction engine **722** (e.g., the landcover feature extraction engine **122** of FIG. **1**) accesses geospatial imagery covering an area of interest. At step **704**, the landcover feature extraction engine **722** subdivides the geospatial imagery into a more workable set of smaller image tiles. At step **706**, the landcover feature extraction engine **722** filters through and selects a subset of the image tiles for feature extraction, based on, for example, a likelihood that the selected image tiles contain the desired feature to be extracted. At step **708**, the landcover feature extraction engine **722** extracts landcover feature data from the selected image tiles, by, for example, applying a machine learning model to extract the desired features.

Turning to the data review stage, at step **710**, a landcover feature data review platform **724** (e.g., the landcover feature data review platform **124** of FIG. **1**) generates a set of tasks for review, corresponding to, for example, each image tile for which there is a likelihood that the image tile contains erroneous landcover feature data. At step **712**, the landcover feature data review platform **724** assembles task data for each task, comprising the imagery for the image tile and the corresponding landcover feature data extracted from that image tile. At step **714**, the landcover feature data review platform **724** assigns the assembled tasks to landcover feature data review technicians, who use the landcover feature data review platform **724** to generate revised landcover feature data with improved accuracy. At step **716** the landcover feature data review platform **724** receives the revised landcover feature data, which can be used directly in a final product and/or used to further train a machine learning model.

Therefore, it should be seen from the present disclosure that systems and methods for extracting and reviewing landcover feature data can be provided in which the risk of conflicts among data reviewers can be minimized, collaboration among data reviewers can be leveraged, and the improved data quality can be used to train a machine learning model as part of a continuous quality improvement process. Although these systems and methods are illustrated in the above figures by way of non-limiting examples, it is emphasized that variations to these examples in which the benefits of the teachings described herein can still be achieved are contemplated.

For instance, although the described examples refer to the use of geospatial imagery as a data source for the extraction of landcover feature data, it is contemplated that other forms of imagery equally be used for the extraction of landcover features (e.g., ground-level imagery of a building). Further, it is contemplated that other feature types aside from landcover features can be extracted from imagery as well (e.g., objects in a visual scene can be extracted from smartphone imagery). Thus, for example, a process that involves using street-view imagery for semantic feature extraction may equally benefit from a quality control process in which the street-view imagery is divided into image tiles which are distributed among of data reviewers who are instructed to review and revise the extracted feature data in a manner similar to the manner described above.

Further, although the imagery used in image tiles may often by the same imagery from which the landcover feature data was extracted, it is contemplated that in some cases, landcover feature data may be compared against different imagery, provided that the imagery covers the same area (e.g., but perhaps captured at a different time or date). In some cases, it may be preferred that the alternative imagery set is properly aligned with the landcover feature data so as to resolve any misalignment issues, allowing the data review technicians to focus on feature extraction issues. In other cases, however, another advantage of the quality control processes described herein is that they may capture and address such misalignment issues.

Moreover, although the data review process described herein may be particularly useful for aiding in quality control and/or retraining of a machine learning model, it is contemplated that the quality control systems and processes described above may equally be applicable to use cases in which landcover feature data is extracted from imagery in a more conventional (i.e., non-machine learning process), including human-extraction processes, in which the initially extracted data could still benefit from a quality control step.

Finally, it should be recognized that features and aspects of the various examples provided above can be combined into further examples that also fall within the scope of the present disclosure. The scope of the claims should not be limited by the above examples but should be given the broadest interpretation consistent with the description as a whole.

The invention claimed is:

1. A method comprising:

accessing geospatial imagery covering an area of interest and a corresponding set of landcover feature data that was extracted by a machine learning model with reference to the geospatial imagery covering the area of interest, wherein the area of interest is divided the area of interest into a grid of image tiles;

determining confidence data associated with each subset of landcover feature data within each image tile that reflects a level of confidence that the landcover feature data within the image tile was correctly extracted by the machine learning model;

generating and assigning tasks for team members of a team of landcover feature data review technicians to review the image tiles in which the landcover feature data is of low confidence;

providing functionality for the team members to view the geospatial imagery and landcover feature data within

an assigned image tile and to make corrections to the landcover feature data with reference to the geospatial imagery; and

receiving one or more corrections to the landcover feature data from systems operated by the landcover feature data review technicians.

2. The method of claim **1**, wherein assigning the tasks comprises:

determining a unique priority value to be assigned to each image tile covering the area of interest, wherein the unique priority values are determined such that the priority value for each image tile is non-consecutive with each adjacent image tile; and

assigning tasks to team members based on an increasing or decreasing sequence through the priority values.

3. The method of claim **1**, further comprising:

providing functionality for the team members to review the corrections made by other team members and to generate tasks for team members to review previously reviewed image tiles.

4. The method of claim **1**, wherein each image tile comprises a working area and a surrounding buffer area, wherein the surrounding buffer area overlaps with the working areas of adjacent image tiles, and wherein the method further comprises:

providing functionality for the team members to generate a notification for a team member assigned to an adjacent image tile regarding an error, or correction, to landcover feature data within the buffer area.

5. The method of claim **1**, further comprising:

providing functionality for the team members to make corrections to elements of landcover feature data that span across two adjacent image tiles.

6. The method of claim **1**, further comprising:

fine-tuning the machine learning model based on the one or more modifications to the landcover feature data and the associated geospatial imagery.

7. The method of claim **1**, further comprising:

providing an online landcover feature data review platform with functionality to generate and assign the tasks to the team members, with functionality for the team members to make the corrections to the landcover feature data, and with functionality to receive the corrections to the landcover feature data.

8. The method of claim **1**, further comprising:

merging the one or more corrections to the landcover feature data with the landcover feature data.

9. The method of claim **1**, wherein the landcover feature data comprises vector data, and wherein the one or more corrections to the landcover feature data comprises a correction to the geometry of a polygon within the landcover feature data.

10. A system comprising one or more computing devices configured to:

access geospatial imagery covering an area of interest and a corresponding set of landcover feature data that was extracted by a machine learning model with reference to the geospatial imagery covering the area of interest, wherein the area of interest is divided the area of interest into a grid of image tiles;

determine confidence data associated with each subset of landcover feature data within each image tile that reflects a level of confidence that the landcover feature data within the image tile was correctly extracted by the machine learning model;

generate and assign tasks for team members of a team of landcover feature data review technicians to review the image tiles in which the landcover feature data is of low confidence;

provide functionality for the team members to view the geospatial imagery and landcover feature data within an assigned image tile and to make corrections to the landcover feature data with reference to the geospatial imagery; and

receive one or more corrections to the landcover feature data from systems operated by the landcover feature data review technicians.

11. At least one non-transitory machine-readable storage medium comprising instructions that when executed cause one or more processors to:

access geospatial imagery covering an area of interest and a corresponding set of landcover feature data that was extracted by a machine learning model with reference to the geospatial imagery covering the area of interest, wherein the area of interest is divided the area of interest into a grid of image tiles;

determine confidence data associated with each subset of landcover feature data within each image tile that reflects a level of confidence that the landcover feature data within the image tile was correctly extracted by the machine learning model;

generate and assign tasks for team members of a team of landcover feature data review technicians to review the image tiles in which the landcover feature data is of low confidence;

provide functionality for the team members to view the geospatial imagery and landcover feature data within an assigned image tile and to make corrections to the landcover feature data with reference to the geospatial imagery; and

receive one or more corrections to the landcover feature data from systems operated by the landcover feature data review technicians.

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