



## Automated Recognition of 3D Features in GPIR Images

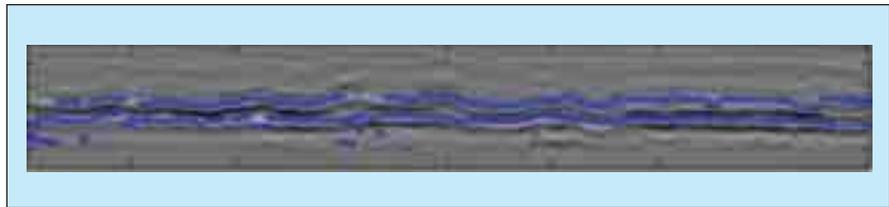
Enhanced images emphasizing features of interest are prepared for scrutiny by human analysts.

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A method of automated recognition of three-dimensional (3D) features in images generated by ground-penetrating imaging radar (GPIR) is undergoing development. GPIR 3D images can be analyzed to detect and identify such subsurface features as pipes and other utility conduits. Until now, much of the analysis of GPIR images has been performed manually by expert operators who must visually identify and track each feature. The present method is intended to satisfy a need for more efficient and accurate analysis by means of algorithms that can automatically identify and track subsurface features, with minimal supervision by human operators.

In this method, data from multiple sources (for example, data on different features extracted by different algorithms) are fused together for identifying subsurface objects. The algorithms of this method can be classified in several different ways. In one classification, the algorithms fall into three classes: (1) image-processing algorithms, (2) feature-extraction algorithms, and (3) a multiaxis data-fusion/pattern-recognition algorithm that includes a combination of machine-learning, pattern-recognition, and object-linking algorithms.

The image-processing class includes preprocessing algorithms for reducing



Features Representing Two Pipes were generated by applying a feature-extraction algorithm to data from a GPIR scan of 110th Street in New York City. This synthetic image contains the detection marks overlaid on GPIR data from a mid-depth horizontal slice viewed from overhead. The gaps and undulations are minimized in subsequent processing by a multiaxis data-fusion/pattern-recognition algorithm.

noise and enhancing target features for pattern recognition. The feature-extraction algorithms operate on preprocessed data to extract such specific features in images as two-dimensional (2D) slices of a pipe. Then the multiaxis data-fusion/pattern-recognition algorithm identifies, classifies, and reconstructs 3D objects from the extracted features. In this process, multiple 2D features extracted by use of different algorithms and representing views along different directions are used to identify and reconstruct 3D objects. In object linking, which is an essential part of this process, features identified in successive 2D slices and located within a threshold radius of identical features in adjacent slices are linked in a directed-graph data structure. Relative to past approaches, this multiaxis approach offers the advantages of more re-

liable detections, better discrimination of objects, and provision of redundant information, which can be helpful in filling gaps in feature recognition by one of the component algorithms.

The image-processing class also includes postprocessing algorithms that enhance identified features to prepare them for further scrutiny by human analysts (see figure). Enhancement of images as a postprocessing step is a significant departure from traditional practice, in which enhancement of images is a preprocessing step.

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*The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40698.*

## Algorithm Plans Collision-Free Path for Robotic Manipulator

This algorithm is designed to make minimal demands upon computational resources.

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An algorithm has been developed to enable a computer aboard a robot to autonomously plan the path of the manipulator arm of the robot to avoid collisions between the arm and any obstacle, which could be another part of the robot or an external object in the vicinity of the robot. In simplified terms, the algorithm generates trial path segments and tests each segment for potential collisions in an iterative process that ends when a se-

quence of collision-free segments reaches from the starting point to the destination. The main advantage of this algorithm, relative to prior such algorithms, is computational efficiency: the algorithm is designed to make minimal demands upon the limited computational resources available aboard a robot.

This path-planning algorithm utilizes a modified version of the collision-detection method described in "Improved

Collision-Detection Method for Robotic Manipulator" (NPO-30356), *NASA Tech Briefs*, Vol. 27, No. 3 (June 2003), page 72. The method involves utilization of mathematical models of the robot constructed prior to operation and similar models of external objects constructed automatically from sensory data acquired during operation. This method incorporates a previously developed method, known in the art as the method of ori-