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[54] **VISION GUIDED AUTOMATIC ROBOTIC PATH TEACHING METHOD**

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[51] **Int. Cl.**[6] **G05B 19/41**

[52] **U.S. Cl.** **318/568.15**; 318/568.16; 318/568.13

[58] **Field of Search** 364/474.03, 474.02, 364/474.024, 474.31, 474.05, 474.37, 191; 395/93, 94, 80–99; 901/3, 47; 219/125; 318/576, 577, 568.13, 568.14

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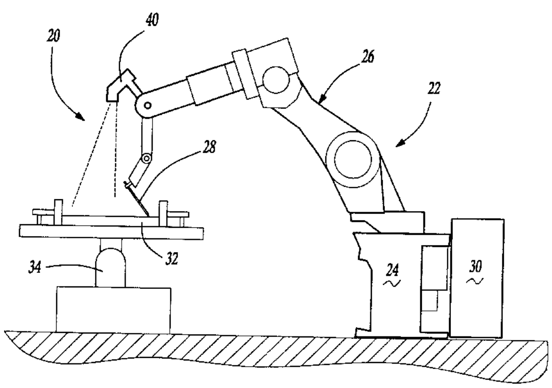
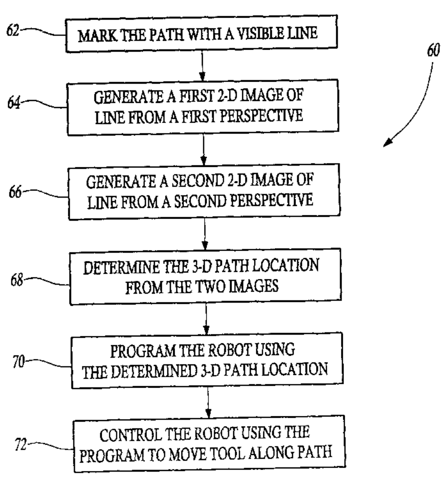
Assistant Examiner—Rita Leykin
Attorney, Agent, or Firm—Howard & Howard

[57] **ABSTRACT**

A method of controlling a robot system **(20)** includes using a camera **(40)** to generate a first, two-dimensional image of a marking **(42)** on a workpiece **(32)**. A second, two-dimensional image of the marking **(42)** is generated from a second perspective. The two images are then used to generate a three-dimensional location of the marking in real space relative to the robot **(22)**. Since the visible marking **(42)** corresponds to a desired path **(48)**, the three-dimensional location information is used to automatically program the robot **(22)** to follow the desired path.

22 Claims, 2 Drawing Sheets





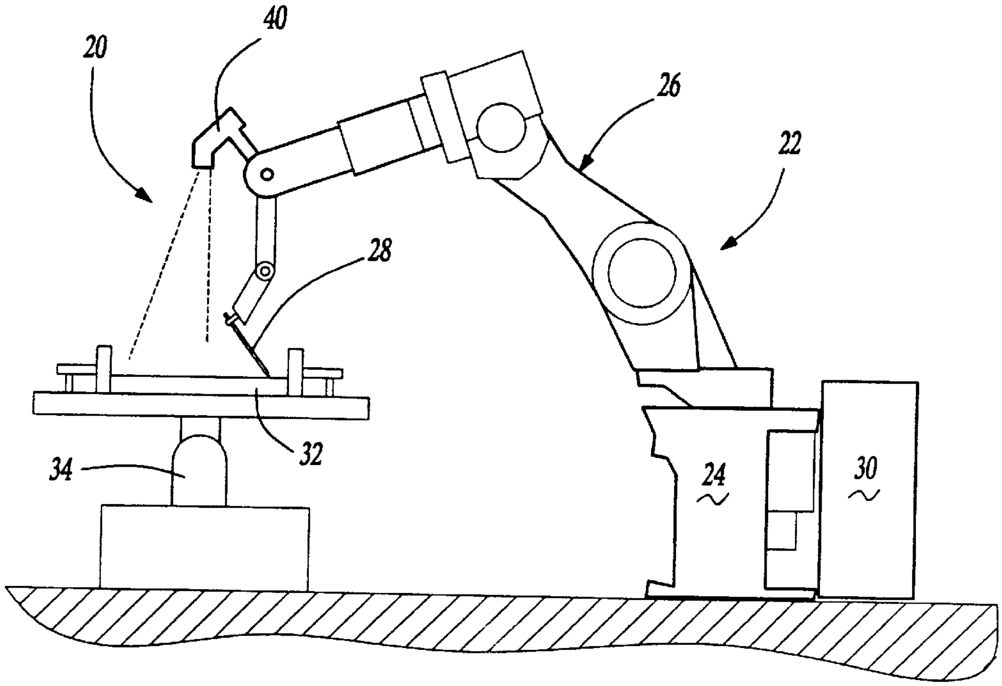


Fig-1

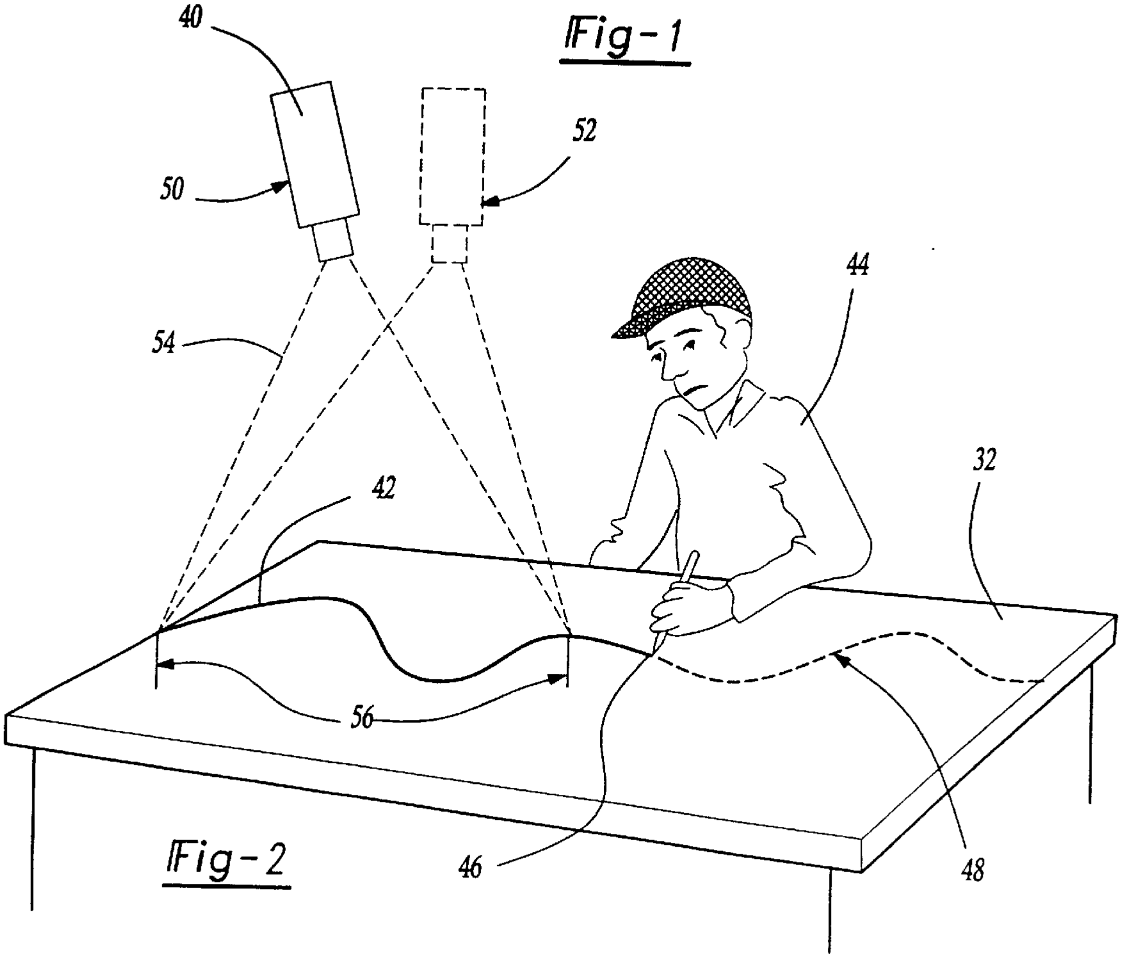


Fig-2

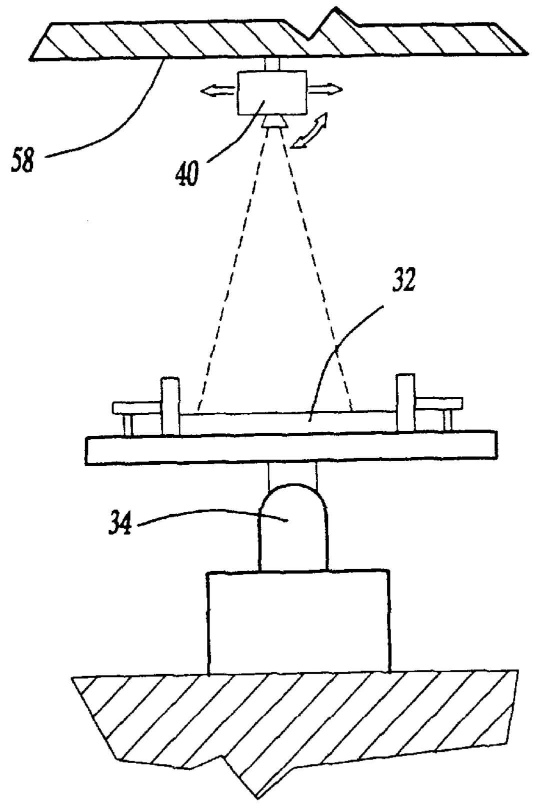

58
40
32
34

Fig-3

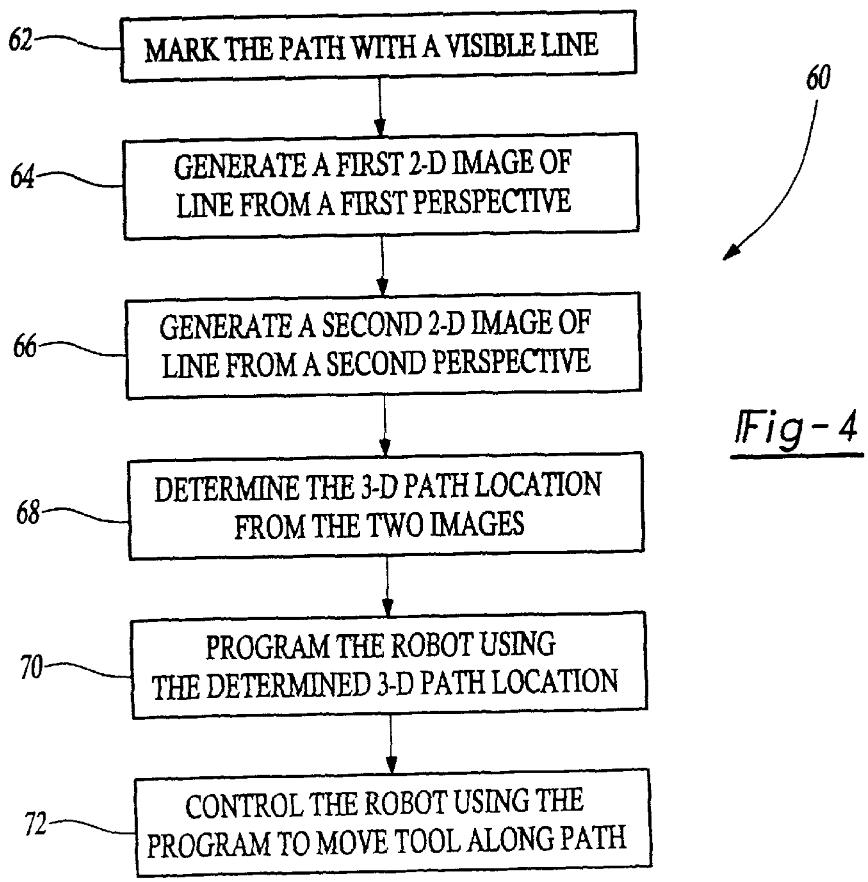

62
MARK THE PATH WITH A VISIBLE LINE
64
GENERATE A FIRST 2-D IMAGE OF LINE FROM A FIRST PERSPECTIVE
66
GENERATE A SECOND 2-D IMAGE OF LINE FROM A SECOND PERSPECTIVE
68
DETERMINE THE 3-D PATH LOCATION FROM THE TWO IMAGES
70
PROGRAM THE ROBOT USING THE DETERMINED 3-D PATH LOCATION
72
CONTROL THE ROBOT USING THE PROGRAM TO MOVE TOOL ALONG PATH
60

Fig-4

VISION GUIDED AUTOMATIC ROBOTIC PATH TEACHING METHOD

BACKGROUND OF THE INVENTION

This invention generally relates to a method for programming a robot to follow a desired path. More particularly, this invention relates to a method of programming a robot to move a tool along a desired path using visual information to complete the programming process.

Industrial robots are increasingly being used for a wider variety of applications. In most instances, it is necessary to "teach" the robot the path along which the robot must move to complete the desired operation. For example, in a welding application, the robot must be programmed to move into a number of successive orientations that will effectively move the welding torch along the seam on the workpiece.

Programming or teaching a robot a desired path conventionally has been carried out manually. An operator interacts with the robot controller and manually causes the robot to move into the necessary orientations for placing the tool into the necessary positions along the desired path. Each of the positions is then programmed into the robot controller, which later repeats the programmed path. The process is typically time-consuming, difficult and often not accurate enough to yield satisfactory results at the end of the robot operation. Further, the conventional practice includes the drawback of having the operator within the robot work space during the teaching operation, which introduces the possibility for an undesirable collision between the robot and the operator.

Several systems have been proposed that include a robot vision system for controlling robot operation. None, however, have used the vision system to teach or program the robot to follow the program path. For example, U.S. Pat. Nos. 4,616,121; 4,965,499; and 5,572,103 each include a vision system associated with an industrial robot that provides visual information for making corrections to a preprogrammed path during robot operation. Such systems have been proposed for accommodating deviations between an actual desired path and a preprogrammed path that the robot is following. In each of these systems, however, it is necessary to preprogram the robot in the conventional manner.

There is a need to simplify and improve current robot path teaching methods. For example, it is desirable to eliminate the need for the operator to be within the robot work envelope during the path training procedure. Additionally, it is desirable to improve efficiency in teaching a robot path by reducing the amount of time required.

This invention addresses the needs described above while avoiding the shortcomings and drawbacks of the prior art. This invention provides a method of automatically teaching a robot path using visually acquired information regarding the desired path.

SUMMARY OF THE INVENTION

In general terms, this invention is a method of controlling a robot by automatically programming the robot to follow a desired path using a robot vision system to acquire data regarding the desired path and programming the robot based upon the acquired visual data.

The method of this invention includes several basic steps. First, a workpiece is marked with a visible marking indicating at least a portion of the desired path. A first, two-dimensional image of the line is generated by a vision

system that observes the line from a first perspective. A second, two-dimensional image of the line is generated by the vision system from a second perspective. A three-dimensional location of the path relative to the robot is then generated using the first and second images of the line that was marked on the workpiece. The three-dimensional location of the path is then used to program the robot so that it moves a tool along the desired path.

The various features and advantages of this invention will become apparent to those skilled in the art from the following detailed description of the currently preferred embodiment. The drawings that accompany the detailed description can be briefly described as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagrammatic illustration of a robot system designed according to this invention.

FIG. **2** is a diagrammatic illustration of a portion of the method of this invention.

FIG. **3** is a diagrammatic illustration of another embodiment designed according to this invention.

FIG. **4** is a flow chart diagram summarizing the method of this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** diagrammatically illustrates a robot system **20** including a robot **22** that includes a robot base **24** and a moveable arm **26** supported on the base **24**. One end of the arm **26** supports a tool **28** that is used to perform a desired operation. For example, the tool **28** could be a welding torch or an applicator for applying a sealant.

A controller **30** controls the movement of the robot arm **26** so that a desired operation is performed on a workpiece **32**. The workpiece **32** is diagrammatically illustrated on a conventional support **34** within the robot work envelope.

A vision system includes a camera **40** that is supported on the robot arm **26** in the embodiment of FIG. **1**. The camera **40** preferably is a digital camera that is capable of viewing the workpiece **32** and collecting data representing an image of what is observed by the camera **40**. The camera **40** is in communication with the controller **30** so that the image information obtained by the camera **40** can be processed as described below. A variety of digital cameras are commercially available and those skilled in the art will be able to choose one to satisfy the needs of a particular situation.

FIG. **2** illustrates selected portions of the embodiment of FIG. **1**. The workpiece **32** has a visible line **42** that is being manually marked by an operator **44** using a marker **46**. The marker **46** can be any instrument for marking a visible line on the appropriate surface of the workpiece **32** such as a paintbrush or felt tip marking pen, for example. The line **42** provides a visible marking or indication of the desired path **48** on the workpiece **32**. For purposes of illustration, the path **48** corresponds to a line where sealant should be applied to the surface of the workpiece **32**.

Although an operator **44** is shown manually placing the line **42** onto the workpiece **32** in FIG. **2**, the line **42** can be accomplished in a variety of ways. For example, a laser beam can be used to project a line along the surface of the workpiece **32** in a position that corresponds to the desired path. Alternatively, the workpiece **32** may include a contour that corresponds to the desired path. By selectively illuminating the workpiece **32**, the contour can serve as the visible indication of the desired path **48**. Moreover, a variety of visible markings including line segments, arrows or a series of other visible symbols can be used. A solid continuous line is only one example of a visible marking that is useful with this invention.

In one example, the line **42** is marked using a fluorescent substance. The workpiece **32** is then illuminated using ultraviolet light to cause the fluorescent material to fluoresce visible light that is detectable by the camera **40**. Since the ultraviolet light will not be sensed by the camera **40**, only the marked line will appear bright in the image obtained by the camera **40**.

In all embodiments, it is most desirable to provide a line **42** using a material or illuminating strategy that provides a high contrast so that the line **42** is clearly discernible to the camera **40**.

After the operator **44** completes the line **42** to correspond to the entire path **48**, the operator can exit the robot work envelope. Then the camera **40** is used to obtain two-dimensional images of the line **42**. In the embodiment of FIG. **2**, the camera **40** is illustrated in a first position **50** where it obtains an image of the line **42** from a first perspective. The camera **40** is later moved into another position (illustrated in phantom at **52**) to obtain a second image of the line **42** from a second perspective.

In the illustrated embodiment, the camera **40** has a field of vision **54**. The field of vision **54** is not large enough for the camera **40** to observe the entire line **42** all at one time. Therefore, the camera **40** obtains an image of a segment **56** from the first perspective in the first position **50**. The camera **40** is then moved to obtain a second image of the same segment **56** from a second perspective. In the preferred embodiment, the camera **40** is moved to successively obtain image information regarding adjacent segments of the line **42** until the entire line has been imaged from two perspectives.

Each image obtained by the camera **40** is a two-dimensional representation of the line **42**. The camera **40** preferably is digital and collects digital information representing the line **42** in two dimensions. The two-dimensional information from each perspective is then used to determine a three-dimensional location of the path **48** relative to the robot base **24**.

The camera **40** is calibrated so that the image information obtained through the camera has a known relationship to the robot base **24** in real space. Conventional stereo techniques are used to convert the two-dimensional image data from two different perspectives to determine the three-dimensional location of the path on the workpiece **32**. The three-dimensional location information is then used to automatically program the robot **22** so that the robot arm **26** moves in a pattern that will move the tool **28** along the desired path **48** as required for a particular operation.

In the embodiment of FIG. **1**, the camera **40** is mounted on the robot arm **26**. Therefore, moving the camera **40** into a variety of positions to obtain images of the line **42** from different perspectives preferably is accomplished by moving the robot arm **26**. This can be done manually by an operator without requiring the operator to be present within the robot work envelope or automatically if the robot is programmed accordingly. It is important to note that at least two images from two different perspectives for the entire line **42** are obtained to generate the three-dimensional representation of the path **48** in real space. In some applications, it may be desirable to obtain three or more different images from different perspectives and then use all of them for determining the three-dimensional location of the path **48**.

Alternative embodiments include obtaining the three-dimensional information by techniques that differ from extracting the three-dimensional information from stereo images. A variety of known techniques can provide three-dimensional information including imaging scanned laser dots or lines, moiré interferometry, and time of flight laser systems (which are sometimes referred to as LADAR or LIDAR). These techniques are examples that can be used in a system designed according to this invention. It is within the scope of this invention to utilize such a three-dimensional information gathering technique in conjunction with a two-dimensional image that provides the location of the marking **42** on the workpiece.

In some embodiments, it is useful to utilize raised or indented markings on a surface as the marking **42**. In such embodiments, the location of the desired path preferably is obtained from three-dimensional data, which can be gathered through any of the techniques mentioned in the previous paragraph, and does not rely upon obtaining any two-dimensional images.

FIG. **3** diagrammatically illustrates an alternative embodiment to that shown in FIG. **1**. Only selected components are shown in FIG. **3** for simplicity. The camera **40** is not mounted on the robot **22** but, instead, is supported on a rail **58** that is positioned near the robot work envelope. The camera **40** is moveable along the rail **58** as shown by the arrows in FIG. **3**. The camera **40** can be moved linearly or pivoted relative to the rail **58** so that the camera **40** can obtain more than one image from more than one perspective of the line **42** marked on the workpiece **32**.

Another alternative would be to mount more than one camera in fixed positions, respectively, to observe the line **42**. Each camera is used for obtaining a separate image from a different perspective. The two-dimensional image information then is used to generate the three-dimensional location as described above.

FIG. **4** summarizes the method of this invention in flow chart form. The flow chart **60** includes several basic steps that preferably are sequentially completed to program the robot to follow a desired path. The first step at **62** is to mark the desired path by placing a visible line on the workpiece. As discussed above, the visible line can be accomplished in a variety of ways. Then at **64** a first, two-dimensional image of the line is generated from a first perspective. The first image is generated by obtaining a visible representation of the line using a camera and then processing the set of data available from the camera that describes the image obtained. At **66** a second, two-dimensional image of the line, observed from a second perspective, is generated.

Both two-dimensional images are then used at **68** to generate a three-dimensional path location. Conventional stereo techniques, as understood by those skilled in the art, preferably are used to convert the information from the images into a three-dimensional set of data representing the location of the desired path relative to a robot reference frame, which typically is associated with the base **24**. The three-dimensional data is then used by programming module to program the robot at **70** so that the robot controller **30** will be able to control the robot arm **26** so that it moves the tool **28** along the desired path. In this manner, the programming or teaching of the path is accomplished automatically. The need for manually teaching a robot to move along a desired path is eliminated by this invention. Lastly, at **72** the controller **30** controls the robot using the program, which is based upon the determined three-dimensional information, and the robot moves the tool **28** along the desired path **48**.

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