Development of an Autonomous Vision Sensor-Actuator-Based Circumferential Seam Path Tracker Welding Machine for LPG Cylinders

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Research Article

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Abstract

This paper presents an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine for LPG (Liquefied Petroleum Gas) cylinders. The machine is designed to avoid various hazardous health issues that are found on the workers due to unfavorable working conditions during the welding process because of high temperature, dangerous fumes, and a large amount of luminous flux in the workstation. This machine involves a pneumatic holder to hold the cylindrical workpiece inside a metallic body frame. When the cylindrical workpiece rotates in a pneumatic holder, some amount of deflection arises due to the improper arrangement of fixtures and cylinders. It is not easy to overcome this deflection in fixtures, and due to this, the welding process is not done correctly. The undercut and overcut errors can also be found due to the improper shape of fixtures and cylinders. Therefore, the box setup is designed to cope with this problem, and the box contains an RGB (Red Green Blue) camera, LED (Light Emitting Diode), and ultrasonic sensor. The box is installed in front of the welding torch to capture the image of the seam path of the workpiece. Firstly, the image is created with the help of a LED fitted inside the box. The LED creates the shadow of the jobber joint of the cylindrical workpiece. The camera captures that shadow. After capturing the image of shadow, the centroid of the seam path (represented by shadow) of the cylindrical workpiece is traced. It is sent to the Raspberry Pi microcontroller for further processing. According to the position of the centroid coordinate, the microcontroller sends the control commands to the microstep driver of the stepper motor to follow this centroid coordinate, and the torch is controlled and the welding process is done autonomously. The experimental setup is made, and the autonomous welding process is performed in many cylinders. The successful welding results verify the effectiveness and efficiency of the developed machine.

1. Introduction

Using a visual sensor (RGB camera), a robotic seam tracking system works in real-time tracking mode. The data recording mode acquires the seam before welding. Robotic welding gives good repeatability of welding path trajectories, as robots perform well in the structured environment despite any situation. Robots are programmed to do repetitive work and can perform similar jobs only, and humans can perform welding flexibly on various workpieces. To make robotic welding more flexible, computer vision as an external input source comes into play. Many small and medium-sized enterprises (SMEs) don't use robotic welding, and it's because the contour and programming method of this kind of stuff is time-consuming. Lots of improvement is still required in the programming that enables the firms with economical and high-quality weld in a shorter period. The SolidWorks system is used to model the particular machine, workpiece, tools, and workspace. This model is then rigorously used for robot simulation and path planning of the modeled arrangement. After modeling the whole system, the program has been generated to control the activities of various tools needed to execute the MIG (Metal Inert Gas) welding over the seam of the cylinder. Before the program gets executed, it is usually necessary to perform verification and minute changes to the program [1]. This process is known as program touch-up and is being performed as lead-through or walk-through programming. Program touch-ups are accomplished using calibration points within the robot cell or otherwise by counterbalancing errors with sensors in the real robot. Various strategies work on real-time tracking with the help of 2D laser sensors [2–3], otherwise with the use of arc sensing of functions of welding current or voltage occurring when welding torch is advanced in a wearing pattern [4]. Tactile sensing or force feedback has been used to locate the starting point of the welding seam by determining the contact point in between the welding torch and workpiece [5].

Some other alternatives are also available that focus on the perfect placement of the workpiece before the offline programming of the robotic motions. The actual machine pose can be designated and calibrated to correspond to the SolidWorks model with the help of optical sensors [6–7]. Many approaches focus on computer vision for approximation and reconstruction of the actual workpiece shape size, then automated preparation of the programming for new workpieces [8]. Intensified use of the computer visions will enable the improved range of exposure and determination of the exact location of the orientation of the workpiece to be welded could enhance the efficiency of the welding processes by the offline programmed robots. Then the required level of competence for using robotic welding in the different enterprises will lower-down, and vice-versa will maximize the benefits. The various existing methods or machines and their comparative analysis are listed in Table 1.

Table 1
Various existing methods or machines and their comparative analysis

S. No	Title	Authors	Year	Remark
1	Seam Tracking for Mobile Welding Robot Based on Terminal Sliding Mode	Qiao et al. [9]	2019	Non-smooth seam tracking controller is designed based on the terminal sliding mode to improve the performance of seam tracking
2	Automatic touchup of welding paths using 3D vision	Njaastad and Egeland [10]	2016	The results show small variations in the corrected object pose estimation
3	Efficient weld seam detection for robotic welding based on local image processing	Shi et al. [11]	2009	Detection of the seam done correctly by use of vision sensors and result accomplished
4	Visual measurement and tracking in laser hybrid welding	Fennander et al. [12]	2009	Laser hybrid weld accomplished while tracking and measuring the specimen to be weld
5	Three Dimension Curve Welding Seam Modeling for Seam Tracking	Chen et al. [13]	2008	The orientation model was obtained according to the position model and other edges characteristic points of the seam
6	Population-based uncalibrated visual servoing	Bonkovic et al. [14]	2008	Population servoing has been accomplished with the help of vision sensors
7	Seam Tracking of Intelligent Arc Welding Robot	Daeinabi and Teshnehlab [15]	2006	An algorithm that is presented for vision based Arc welding robots having 6 axes of freedom for seam tracking
8	Visual servoing for constrained planar robots subject to complex friction	Dean-León et al. [16]	2006	While using vision sensors, complex friction is controlled
9	Direct imaging-based seam tracking for welding control	Tuominen and Lipping [17]	2006	Seam tracking has been done using image processing
11	A computational approach to edge detection	Canny [18]	1986	Accurate detection of edges was performed through the computational approach

RGB cameras are available in an extensive range and at a reasonable charge in the present situation. Developing an efficient and valuable computer vision-controlled robotic system remains a tough job to perform while using the 2D pictures that intrinsically only achieve a prediction of the 3D environment. However, the advent of RGB cameras and even more recent preface of the HP RGB cameras 480P 60-

degree wide-angle camera has made 3D data rivulets at video rate broadly obtainable. This camera provides the robot with enabling new methods to take further useful and accurate judgments. Gu et al. [19] designed the laser visual sensor-based autonomous seam welding tracking system and tested it to weld the two plates. However, the method was only implemented for the fixed workpieces. Reference paper [20] presented the image processing method to trace the welding path for plasma welding (PAW). However, only a schematic diagram of the experimental setup was shown, and a physical model of the setup was not found in that work. In paper [21], an image processing-based method was implemented as a non-destructive test to check the welding quality. Zhao et al. [22] developed a laser vision method-based additive weld seam tracking system for a linear welding process. However, during the literature survey, it is found that the cost of a laser vision system is costlier than the RGB camera-based detection system. Light-based weld seam tracking system for a flat workpiece was studied in a study [23]. However, only the tracking system was developed, and real-time experiments with the welding process were not found in their work.

After summarizing the literature review, we have found that most of the automatic seam welding process or machine was developed only to join the flat plat workpieces. Furthermore, it is also observed that the laser vision system is used in their machines, which is costlier than the RGB camera-based machine. Therefore, this paper introduces an autonomous seam tracker welding machine that employs a low-cost RGB camera for seam detection and not through the laser, which is already available in the market at a very high price range [24]. An experimental arrangement has been implemented and executed a series of tests to examine the machine's efficiency. The paper exhibits certain sections of the work methods that have been in the entire development of the present welding machine. The moreover section of this paper manifests the fundamental steps used in computer vision, and the next section explains the implementation of the system. The successive section describes information flow, pose-estimation through SolidWorks, and the RGB camera data. Lastly, the latter segment is a review of the outcomes achieved.

2. A Modern Approach

We all know that change and evolution are the only consistent things in this whole universe. Other than these, the rest of the things are inconsistent. So the idea also needs to be some sort of evolved one. In this paper, we are going ahead with a very different technique of collecting the data and further using it for implementation in the described method. Previously lots of work has been done on automatic welding machines and robots while adopting various methods and techniques. Automatic welding machines are available at an exorbitant price range in this world. For instance, we can say that the price of the laser light-based automatic welding machine for a cylinder is rupees 45 lakhs approximately [24]. This paper is all about making the welding torch autonomous for high-quality welding. Here we are about to know that with lots of ease and perfection in the automatic seam welding machine, within a considerable price range which is four times much lesser than the existing one is this one. All of the various affecting factors are kept in mind that are mandatory for the fabrication and acceptance of the said product.

3. Methodology

A place where the welding process is to happen has a harsh condition. Due to the immobility of the welding machines and the equipment for the welding process, welders find themselves in difficulty, and heat energy is also higher near the welding machine. While performing this type of task, lots of hazardous fumes are released that are harmful to the health. These fumes contain compounds such as complex oxides of iron, manganese, and silicon. Prolonged exposure to these fumes may lead a person to lung problems and various kinds of cancers such as lung, larynx, and urinary tract. Some temporary health issues from certain fumes are dizziness, nausea, fever, eye irritation, etc. The problem statement is arranging the manual gas cylinder welding process into a fully automatic gas cylinder seam tracking and welding machine without using the laser light. So to develop and fabricate a fully autonomous welding machine by using LED and RGB cameras for the mobility of the welding torch has been stated elaborately. The autonomous gas cylinder seamed tracking welding machine focuses on RGB cameras rather than laser light. The automatic welding machine comprises a main welding machine body frame of mild steel sheet, and it also acts as the protective shell for the developed tools and the components. All the various elements of the automatic welding machine are placed inside this frame. It includes a pneumatic holder to hold the cylindrical workpiece and is connected with the motor to provide the desired speed to the cylindrical specimen. It is one-sided fixed, and another side of that is joined to a pneumatic cylinder. Motor speed is configurable and messed with the gearbox. It is a fixture-based type connected with the pneumatic holder to rotate the workpiece. Another pneumatic cylinder fixed on the frame, an RGB camera, and an ultrasonic sensor fix with this pneumatic cylinder to place them in the welding position for the data recording. A control board is attached with the frame to configure and control the machine. Moreover, a slider mounted on the mainframe is attached to the welding torch to provide linear motion. It has 2 DOF (Degree of Freedom) that is in the vertical and horizontal directions.

Further, the welding torch is united with the sliders to the mainframe, and the torch is linked with the consumable electrode feeder for continuous electrode supply. An RGB camera connected with the pneumatic cylinder captures the welding path images to locate precisely the welding track. This track is the shadow formed of the circumferential lap joint due to the light source (LED). The LED is placed inside the frame with the pneumatic holder, and an ultrasonic sensor is also mounted. The LED is placed at an angle such that it creates a sharp edge shadow on the other half of the cylinder. That shadow gets tracked through an RGB camera. The ultrasonic sensor gets placed to control the vertical movement of the welding torch. It helps to maintain the exact distance of the welding torch from the specimen as needed for perfect welding. These electrical components are placed inside a heat-resisting box to protect them from high heat and flux. It is attached to that pneumatic holder. The embodiment further includes a welding glass that remains configured to the main body frame. One can observe the welding process while protecting eyes from the harmful radiations emitted. The heart of this welding machine is the microcontroller, and that's Raspberry Pi 4(B) 8GB RAM (Random Access Memory), which processes the captured data and provides required impulses to motor drivers connected with it to rotate the motor to neutralize the errors in the welding path for precise welding. The micro-step driver used is TB6560 it receives the signal from the microcontroller and provides signals to the motor. The motor used is a stepper motor of the type NEMA23 and is connected with the sliders to generate the desired motion to the welding torch.

At first, the LPG cylinder gets a full rotation to record its data. While recording the data, the seam of the cylinder gets displayed on the monitor. After data recording, the camera, ultrasonic sensor, and LED were removed from the said frame to protect them from the heat and flux generated while welding. The recorded data are in the form of coordinates with the exact point of the circumferential seam of the cylinder. Simultaneously the image processing is done on the captured RGB image and then converted into an HSV (High Saturation Value) image. Now filtering the welding area is done by selecting the uppermost and the lowermost value from the converted HSV image and rejecting the rest of the parts in the HSV image. The data collection ends here, and the data gets further stored in the dictionary data type of format, within which stored data is in the form of time and the coordinates of the circumferential seam of the LPG cylinder. So at this point, the process of data storage is also done. The task to be done further in the filtered image is finding the centroid of the area, and only this area generally needs to be welded. So the centroid of the filtered image is found by using the formulas so generated using the coordinates of x and y as **cX** and **cY** as mentioned below: -

cX = (M [“m10”] / M [“m00”])

cY = (M [“m01”] / M [“m00”])

The centroid of the circumferential seam is found from the above-mentioned formula. The centroid finding also gets executed while rotating the cylinder for data recording. A notation of centroid gets displayed on the monitor with a centroid dot over the welding seam. Now the welding operation is planned to be done in that area only. So after data storage gets done, a dialogue box appears on the screen asking whether to execute the welding operation over the recorded data or not. When someone permits to weld the seam of the cylinder, then only the stored data is fed into the stepper motors. With the help of the microstep driver and microcontroller signal is given to the stepper motors to accurately position the welding torch for the welding of the circumferential area of the gas cylinder in a precise way. After the successful execution of the welding process, the program is prepared in a manner such that it sets back the welding torch to the initial position for the next cylinder welding.

4. Advantageous Effects Of The Present Machine

In one embodiment of the present machine, the adaption of the MIG welding operation on the LPG cylinder may lead to the high quality of welding at a much faster rate. Further, the adaptation of the RGB camera in the machine allows the machine to capture the images in the RGB format, thereby enabling better processing for seam tracking and providing better visibility than conventional methods. Furthermore, the LED, RGB camera, and ultrasonic sensor adaption allow the seam welding machine to track the seam path automatically. The present device also shows that the LED and the RGB camera configuration inside the said heat-resisting box provide insulation to the said LED and camera, protecting them from external or internal damage. Moreover, the operational connection of the microcontroller with the said welding torch allows the welding torch to perform MIG welding operation automatically without any lagging. In addition, the autonomous seam welding machine also reduces human interaction, which may reduce the cost of the labor charge and speed up the welding operation. In a nutshell, the autonomous seam welding machine can automatically track welding seam paths for performing MIG welding operations cost-effectively and efficiently.

5. Brief Description About The Developed Autonomous Vision Sensor-actuator-based Circumferential Seam Path Tracker Welding Machine

The section briefly describes the developed autonomous vision sensor-actuator-based circumferential seam path tracker welding machine. We have used SolidWorks software to design the two-dimensional (2D) and three-dimensional (3D) models of the machine. Figures 1–9 illustrate the various 2D and 3D views of the machine. Table 2 reveals the part number and name of the various components of a machine. The present work relates to a welding machine. More specifically, it shows an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine (1000) capable of tracking a seam path of the cylindrical workpiece (101) for performing MIG welding operations in an automated way. In an embodiment of the present machine, the cylindrical workpiece (101) is an LPG cylinder. However, it should be emphasized that the present work is not limited to welding operation in the LPG cylinder (101). The inventive aspects, along with various components and engineering involved, will now be explained with reference to Figs. 1–9 herein.

Referring to Fig. 1, the autonomous seam welding machine (1000) includes a machine body frame (103). The machine body frame (103) is the outermost part of the machine (1000), which protects the machine (1000) from any external damage. In the machine, the said machine frame (103) is placed on a table (100) for providing support to the said machine (1000). The said welding machine (1000) further includes a mount (104) adapted to hold the said cylindrical workpiece (101). In an exemplary embodiment of the machine, the said mount is a pneumatic holder (104), which is configured inside the said machine frame (103). The said pneumatic holder (104) is adapted to hold the said LPG cylinder (101) (refer to Figs. 2–4). As the name suggests, the said pneumatic holder (104) is operated by pressurized air or gas, preferably pressurized inert gases.

In one embodiment of the present machine, the said pneumatic holder (104) is adapted to rotate the said LPG cylinder (101) for carrying a welding operation in the whole of the cylinder (101). In a machine, the said pneumatic holders (104) are configured inside holes provided on both sides of the machine frame (103) (refer to Fig. 1). In the embodiment of a machine, this configuration of the said holder (104) with the said frame (103) is merely an example and may be configured in a different way also. Further, referring to Fig. 2–7, the said seam welding machine (1000) further includes a box (107) configured inside the machine frame (103). The said box (107) has an opening face towards the cylinder (101). The box (107) is made up of metal, and particularly, the said box is made up of about 3 mm layer of stainless-steel sheet.

Referring to Figs. 5–7, the said autonomous seam welding machine (1000) further includes a light source (102), specifically a LED (102) which is configured to an inner side of the said box (107) (refer to Fig. 6). The said LED (102) is configured in such a manner so as to create a shadow of a circumferential lap joint of the said LPG cylinder (101) by projecting a light on the said LPG cylinder (101). More specifically, the LED (102) projects sharp cut-off light around a welding point to create a dark shadow of the circumferential lap joint of the said LPG cylinder (101). The said autonomous seam welding machine (1000) further includes an RGB camera (108) which is also configured inside the said box (107). The said RGB camera (108) is adapted to capture the images of the shadow of the circumferential lap joint of the said LPG gas cylinder (101) created by the said LED (102) (see Figs. 5–7).

The LED (102) and the RGB camera (108) are configured inside the said box (107) for insulation, thereby protecting the said LED (102) and the said RGB camera (108) from any damage (refer to Fig. 7). The box (107) includes an insulation layer. Preferably, the said box (107) is coated with the said glass wool so that the said box (107) resists the high amount of heat generated during the MIG welding operation. More particularly, the said box (107) is coated with about a 10 mm layer of glass wool. More specifically, the said LED (102) and camera (108) are configured inside the box (107) for protection against a welding flux and heat generated around the said box (107) during the MIG welding operation. In another embodiment of a machine, the box (107) may also protect the LED (102) and the camera (108) from any other damage. Referring to Fig. 4, the said welding machine (1000) further includes a microcontroller (112). The said microcontroller has an operational connection with the said RGB camera (108). The said microcontroller is adapted to process the images of the circumferential lap joint of the said cylinder (101) in an RGB format for tracking the seam path of the gas cylinder (101) accurately.

The microcontroller (112) is adapted to process the RGB images of the circumferential lap joint of the said gas cylinder (101) by passing the said images through different filters for detecting the said seam path of the said cylinder (101) accurately and thereby tracking the seam path of the gas cylinder (101) accordingly. In one embodiment of the present machine, more particularly, the said RGB images of the circumferential lap joint of the cylinder (101) are passed through filters to smooth the noise of the images, thereafter an extracted data is converted into the welding seam path, and thereby realizing the real-time tracking of the seam.

Again, referring to Figs. 5–7, the said autonomous seam welding machine (1000) further includes an ultrasonic sensor (110) which is configured to an extended part of the said box (107). The said ultrasonic sensor (110) is adapted to generate a signal based on a position of a welding torch (106) with respect to the welding point. The received signal is sent to the said microcontroller (112) for processing the said signal to monitor a clearance between the said welding torch (106) and the welding point.

In a machine, the said welding torch (106) is configured to the extended part of the box (107) through a hole (refer to Fig. 4). The said welding torch (106) carries out the MIG welding operation by following the tracked welding seam path of the said gas cylinder (101).

Again, referring to Fig. 4, the said microcontroller (112) is operatively connected to the welding torch (106) for controlling the movement of the said welding torch (106) for performing welding operation in an automated way and accurate manner. More particularly, the said microcontroller (112) has an operational connection with the said welding torch (106) via a stepper motor (109). In the embodiment of the machine, the said stepper motor (109) is configured to the said torch (106). More particularly, the said motor (109) controls the movement of the welding torch (106) by a slider (105) after receiving instructions from the said microcontroller (112). In a machine, the said instructions are based on the tracking of the welding seam path or the position of the welding torch (106) with respect to the said welding point, or the like instructions.

Further coming back to the slider (105), the said slider (105) is mechanically connected to the said welding torch (106) via a sliding mechanism, and the said slider (105) has an operational connection with the said motor (109). The slider (105) slides the said welding torch (106) in upward, downward, right, and left direction according to the welding point of the seam path of the cylinder (101) (refer Figs. 1–9). In one embodiment of the present machine, the machine (1000) has a transparent welding glass (111) which is installed at the machine frame (103). The said welding glass (111) is adapted for a worker to monitor the welding operation.

The working of the autonomous seam welding machine (1000) is explained below.

Firstly, the LED (102), which is isolated inside the box (107), projects the light on the workpiece (101), which is mounted on the pneumatic holder (104) to create the shadow of the circumferential lap joint of the said workpiece. Thereafter, the RGB camera (108), which is also configured inside the box (107), captures the images and transfers the said images to the microcontroller (112). The isolation of said LED (102) and camera (108) inside the box (108) provides insulation. Accordingly, the said microcontroller (112) processes the said images in RGB format for automatically tracking the real-time welding seam path of the said workpiece (101). After that, the microcontroller (112) transfers the signal based on the seam tracking to the said welding torch (106) via the stepper motor for performing the welding operation by following the seam path. At the same time, the ultrasonic sensor (110) generates a signal based on the position of the welding torch with respect to the welding point and transfers the said signal to the microcontroller (112). After that, the microcontroller (112) processes the said signal and repeatedly monitor the clearance between the welding torch (106) and the welding point, and based on that, the welding torch (106) slides in up, down, left, or right direction via the said slider (105) and the said motor (109) for performing welding operation in an automated way.

Table 2
Part number and name of the various components of an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine

Part Number	Part Name
1000	Autonomous seam welding machine
100	Table
101	LPG cylinder
102	Light Source (LED)
103	Machine Body Frame
104	Pneumatic Holder
105	Slider
106	Welding Torch
107	Heat Resisting Box
108	RGB Camera
109	Stepper Motor
110	Ultrasonic Sensor
111	Welding Glass
112	Microcontroller
113	Pneumatic cylinder

6. Experimental Study

This section briefly discusses the electronic components of an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine. We also describe the working principle of various electronic components used in welding machines. Figure 10 shows the control block diagram of an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine. The specifications of various used electronic components of an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine are listed in Table 3. As we can see in the figure, the RGB camera is connected with the microcontroller, which captures the image of the seam path (jobber's joint) of the workpiece and delivers this capturing image to the microcontroller (Raspberry Pi 4B 8GB). Then the received image data is further converted into the required format, which is needed for the centroid coordinate calculation. An ultrasonic sensor connected to the microcontroller senses the vertical distance between the workpiece and the welding torch. Moreover, the sensor continuously sends data to the microcontroller to keep the welding torch accurately. As shown in the diagram, Raspberry Pi is the microcontroller that connects several electronic components for data transfer and processing. The sensing device sends data to the microcontroller and is processed and passed to the microstep drivers (TB6560). The microstep drivers are connected with the microcontroller, and the stepper motors deliver the data. After receiving the signals from the microcontroller, the driver amplifies that signal data to the stepper motors. After getting the desired control command, the stepper motors provide the required amount of rotation to the sliders mounted over the welding torch. The SMPS is connected to the microstep drivers in the circuit diagram to give the 12Volt DC voltage supply for its functioning. The microcontroller is also connected to the computer for displaying live data recording. The computer is used to give specific commands to the microcontroller for performing welding procedures over the workpiece, and we can also monitor the whole process through this computer.

In the first step of experimentation, we install a camera in the tracking system for real-time tracking of the welding path. We use an LED light to make a shadow between the jobber's joint for the experimentation. Here the camera and led are kept inside the insulation box to protect the electronic parts from heat and light. The camera captures the image of the jobber joint and shadow. Then, it sends to the microcontroller for further processing. In the microcontroller, the different filter processes are applied in the received image, and according to our requirement, the desired image is selected. Then in the next step, we calculate the centroid coordinate of the shadow and add offset to place the torch at the right position with the help of drivers. We apply one more filter to avoid unwanted coordinates. A filter is applied to arrange the coordinates in a proper curve, and unwanted data can be removed so the torch can move on a smooth path. Figure 11 reveals the tracking image of the seam path, and it is displayed in three windows: grey, mask, and frame. Only the frame window is kept for further processing, and the rest of the windows are removed. Figure 12 shows the data recording and location of the centroid coordinate of the seam. The welding area has been located from the seam, and it also displays the recorded data in the dialogue box. After getting the centroid coordinate of the seam, the coordinate data is sent to the microcontroller and is processed and passed to the microstep drivers. The microstep drivers are connected with the microcontroller, and the stepper motors receive the data. After receiving the signals from the microcontroller, the driver amplifies that signal data to the stepper motors. After getting the desired control command, the stepper motors give the required amount of rotation to the sliders mounted over the welding torch, and the autonomous welding process is performed. Figure 13 represents the snapshot of the physical model of the developed autonomous vision sensor-actuator-based circumferential seam path tracker welding machine. The machine contains all the necessary components for welding, such as a welding torch, pneumatic cylinder, pneumatic holder, slider, welding glass, heat-resisting box, ultrasonic sensor, LED light, stepper motor, microstep driver, microcontroller, and RGB camera. Figure 14 illustrates the snapshot of the sliders mechanism connected with the stepper motors to control the motion of the welding torch autonomously. These sliders are mounted on the machine's mainframe, and a stepper motor is also connected with each slider to provide linear motion to the torch to perform proper welding on the specimen. Figure 15 shows the snapshot of the specimen (LPG cylinder) before the welding process, and the two halves of the cylinder are placed in between the pneumatic holder, which provides enough pressure to the cylindrical halves to stay connected while welding and is given a full rotation. Figure 11 illustrates the snapshot of tracking of seam path and gets displayed in three windows that are named as gray, mask, and frame. This process is done before welding, and the full rotation is given to the specimen to record the desired data from the specimen. We can hide the rest of the windows and only concentrate over the frame window to watch the data recording. Figure 12 represents a snapshot of the data recording and also locates the centroid of the seam. This process is simultaneously done with the data recording, image processing, and centroid pointing. Then, we find the welding area from the seam, and the recorded data is displayed in the shell dialogue box. This data is further fed to the stepper motor with the help of the driver to adjust the welding torch for the welding process. Figure 16 reveals the real-time snapshot of the autonomous circumference welding process of the LPG cylinder. All the data is recorded into the microcontroller then the required signal is fed to the microstep driver. Then the recorded data is amplified and passed to the stepper motors to control the motion of the welding torch through the sliders. Figure 17 shows the snapshot of the final specimen after autonomous seam tracking and welding. All the processes are carried out autonomously only permission is given to the system to perform the welding over the LPG cylinder. Once the welding process is done, the welding torch is programmed so that it acquires the original position for the next specimen welding process. As the autonomous welding process is done once, it will perform the same task again and again without being tired. The machine of the present experimentation facilitates raising productivity and minimizing operational costs by removing errors and manual intervention. The whole cost of the developed machine is approximately 5 Lakhs.

After conducting all the welding processes in the cylinder, the high-pressure bursting test (which is basically done by cylinder manufacturer industries) is performed to verify the effectiveness and efficiency of the welding joints (obtained through our developed machine). Figure 18 shows the snapshots of the welding blast test results of the cylinder in very high-pressure air. As we can see, the cylinder is burst in a longitudinal direction, which verifies the effectiveness of the obtained circumferential jogger joints.

Table 3
Specifications of various used electronic components of an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine

Name	Specifications
Microcontroller	Raspberry Pi 4B 8GB
Switch	On-Off Switch
Motor	NEMA23 Stepper motor
Motor Driver	TB6560 microstep driver
SMPS (Switch Mode Power Supply)	12Volt and 12Amp
Camera	HP RGB camera 480P / 30 FPS (Frame Per Second)
Sensors	Ultrasonic Sensor (HC-SR04), Distance Measuring Range: 2 cm to 400 cm
Jumper Wire	Male and Female Jumper Wires

7. Conclusion And Future Work

This paper concludes with an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine for LPG cylinders. The machine is successfully designed and experimented with avoiding various hazardous health issues that are found on the workers due to unfavorable working conditions during the welding process because of high temperature, dangerous fumes, and a large amount of luminous flux in the workstation. It is not easy to overcome the deflection in fixtures so that we can conclude this in a real-time autonomous compensation of the error, and due to this, the welding quality is enhanced. The undercut and overcut errors were also compensated perfectly. The process was successfully completed in a few steps. Firstly, the image was created with the help of a LED fitted inside the box. The LED created the shadow of the jobber joint of the cylindrical workpiece. The camera captured the shadow of the joint. After capturing the image of shadow, the centroid of the seam path (represented by shadow) of the cylindrical workpiece was traced. It was sent to the Raspberry Pi microcontroller for further processing. According to the position of the centroid coordinate, the microcontroller sent the control commands to the microstep driver of the stepper motor to follow this centroid coordinate, and the torch was controlled autonomously, and the welding process was done. The successful welding test result verifies the effectiveness and efficiency of the developed machine. Future work can include an IMU (Inertial Measurement Unit) sensor to detect the deflection in fixtures so that the accuracy of the welding process can be more enhanced. Moreover, instead of vision sensor arrangements, the pin-type encoder system can be connected with the welding torch to trace the centroid coordinate of the jobber joint.

Declarations

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Code availability

For image processing, the code was written in the Python language and implemented in the Raspberry Pi microcontroller. This code is used to produce the results in this article can be obtained upon request from the corresponding authors.

Availability of data and materials

All data and materials used to produce the results in this article can be obtained upon request from the corresponding authors.

Ethical approval

The authors declare that there is no ethical issue applied to this article. Consent to participate The authors declare that all authors have read and approved to submit this manuscript to IJAMT.

Consent to publish

The authors declare that all authors agree to sign the transfer of copyright for the publisher to publish this article upon on acceptance.

Competing interests

The authors declare that there is no conflict of interest.

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Figures

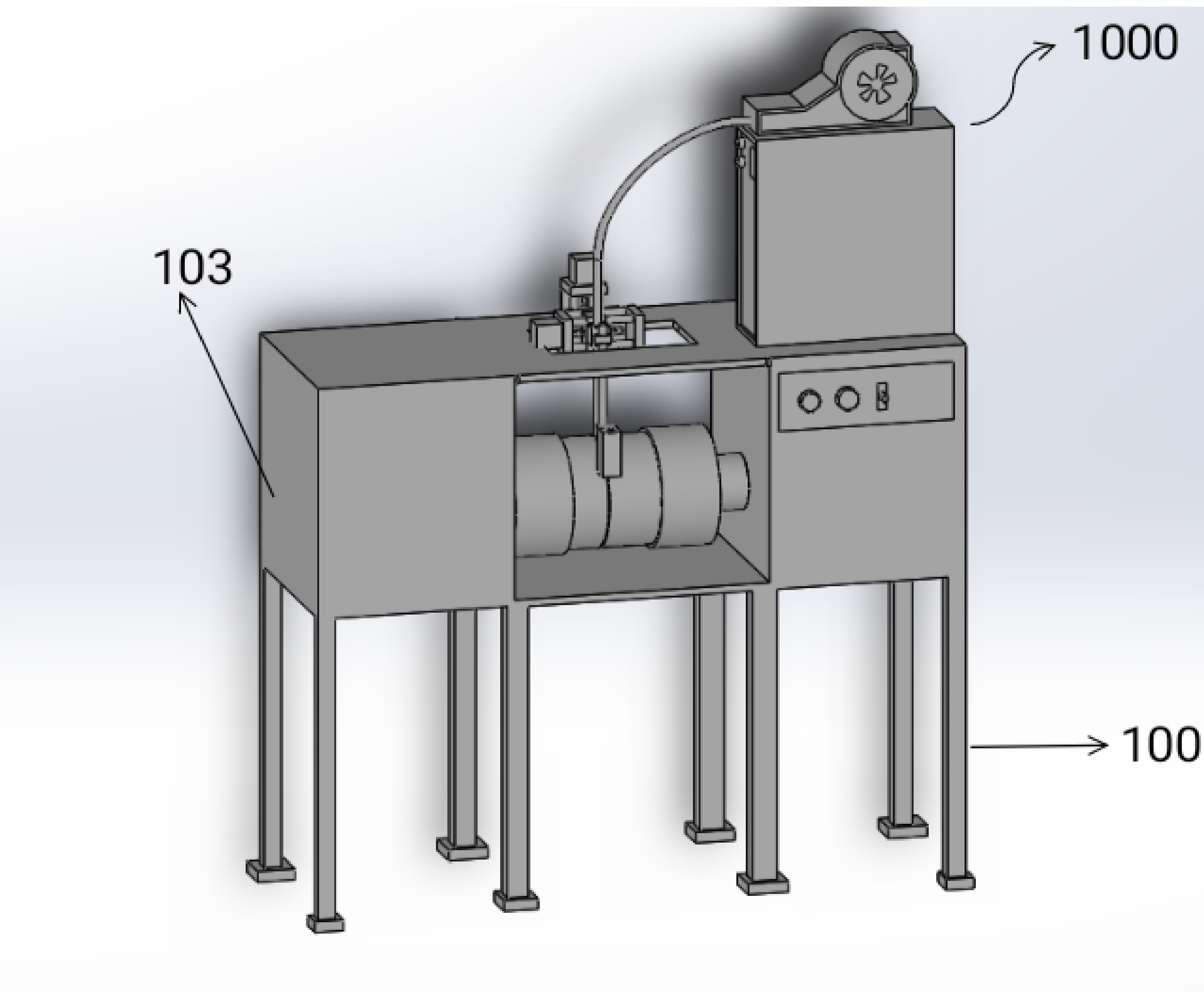

Figure 1

Isometric view of an autonomous seam path tracker welding machine

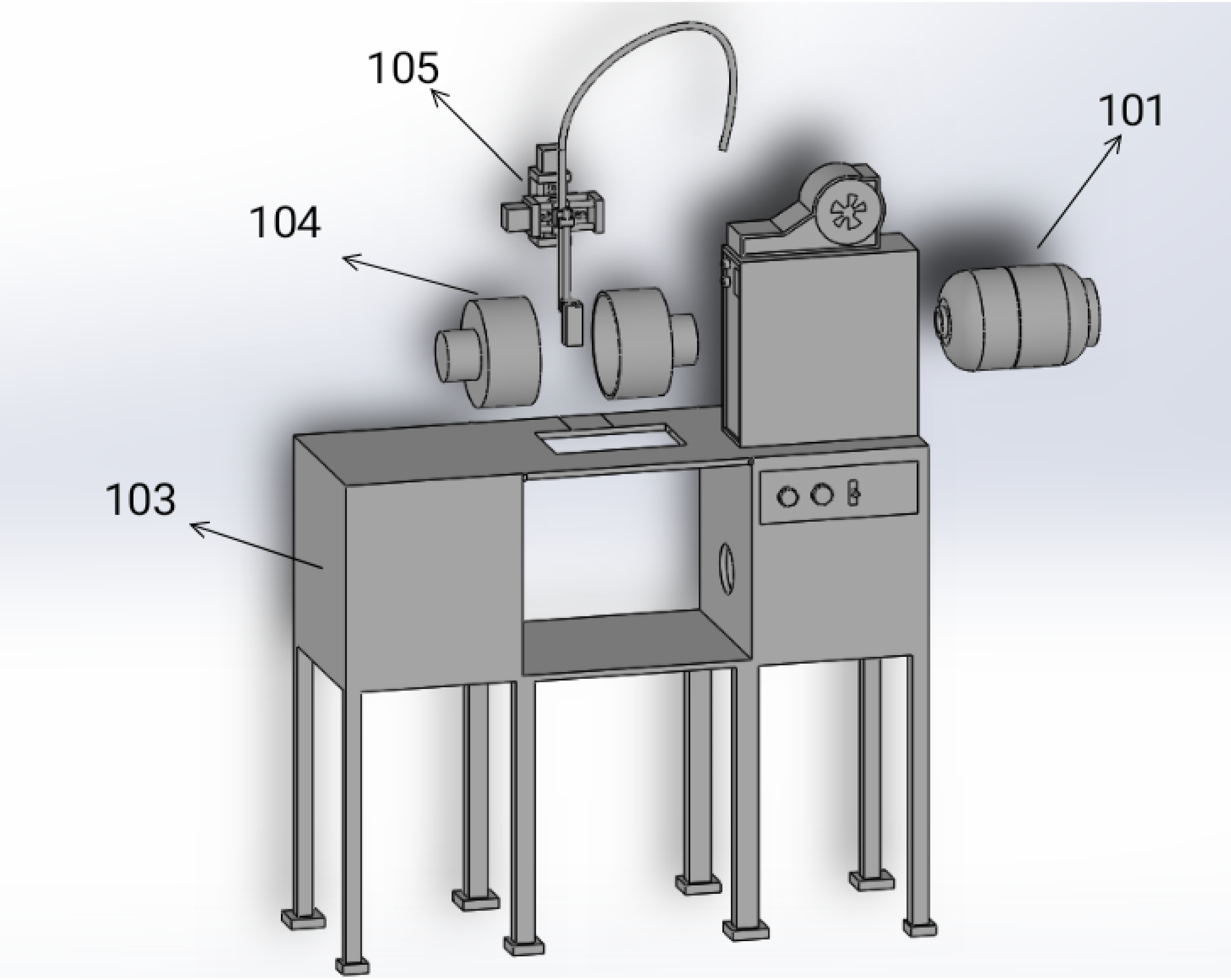

Figure 2

Perspective view of an autonomous seam path tracker welding machine

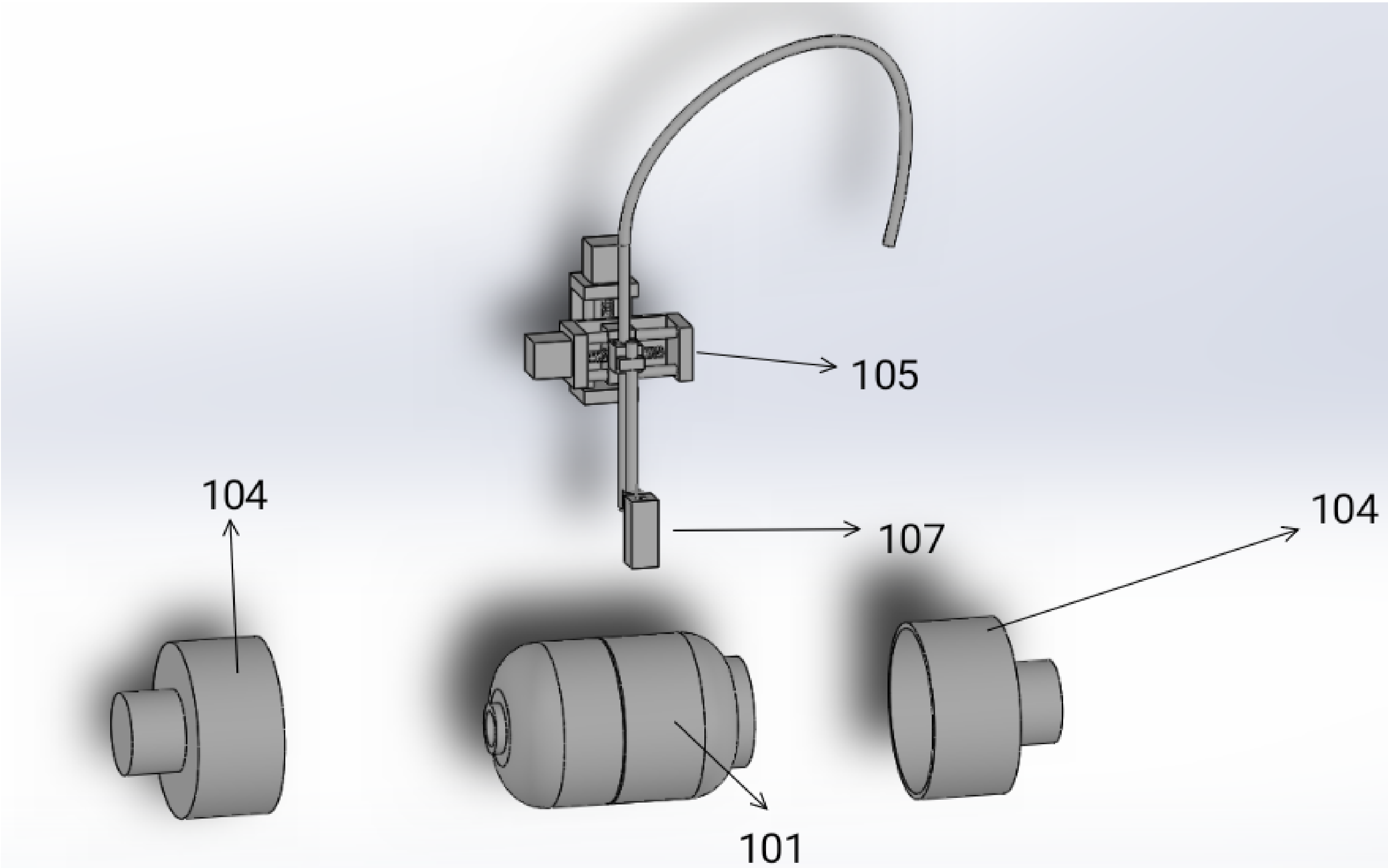

Figure 3

Exploded view of the components of an autonomous seam path tracker welding machine

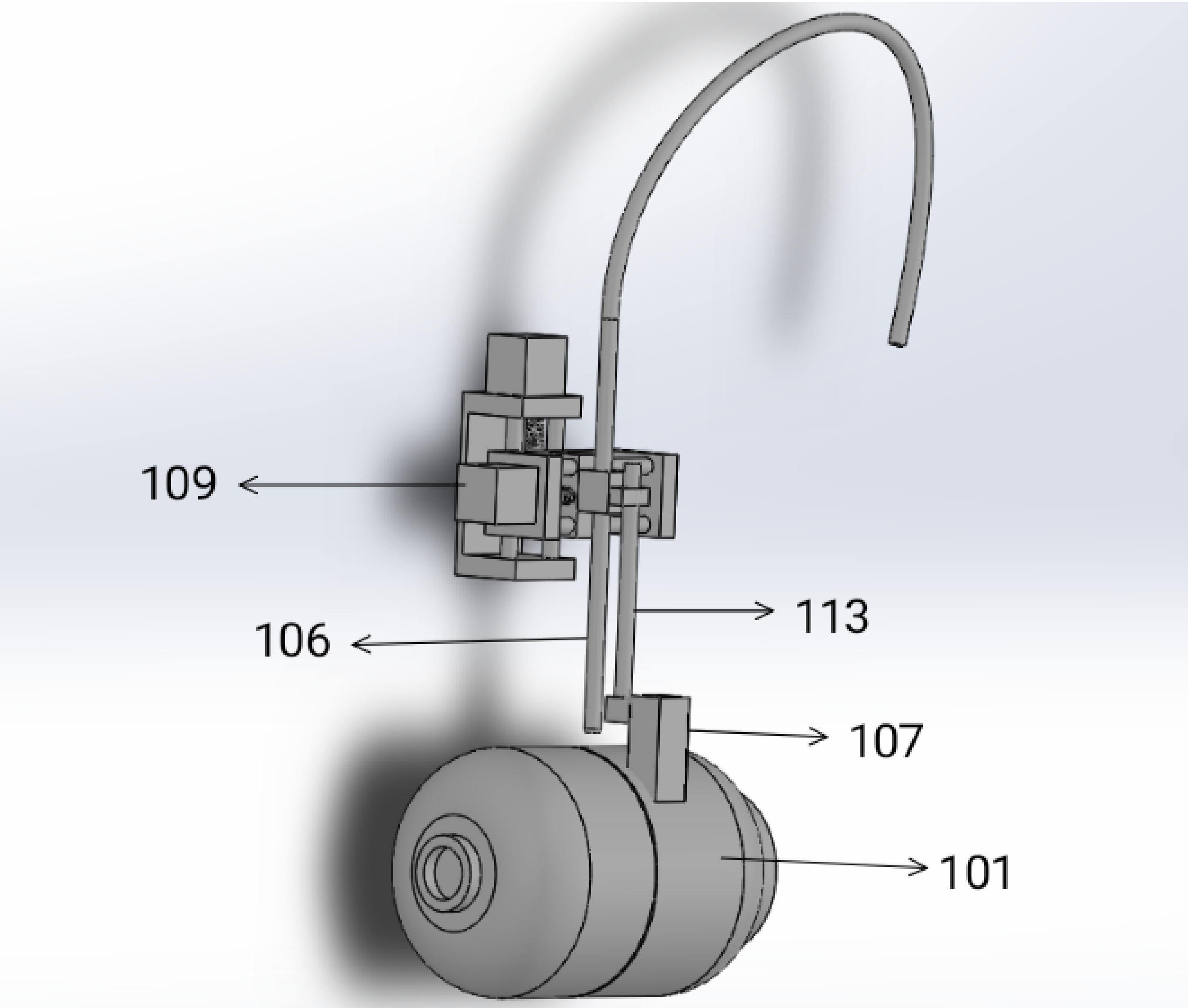

Figure 4

Perspective view of the components of an autonomous seam path tracker welding machine

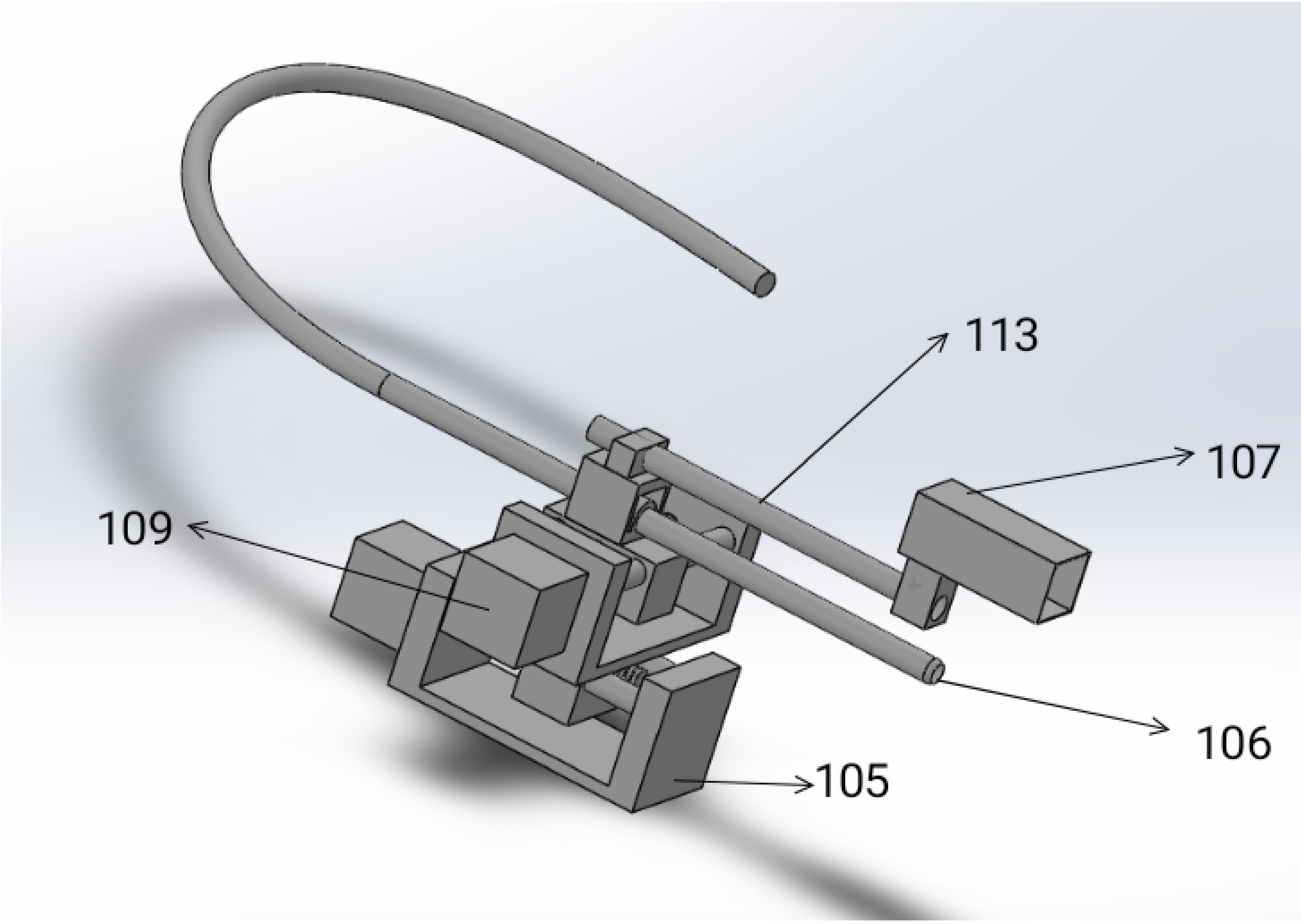

Figure 5

Perspective view of an RGB camera connected with a heat resisting box along with the various components of an autonomous seam path tracker welding machine

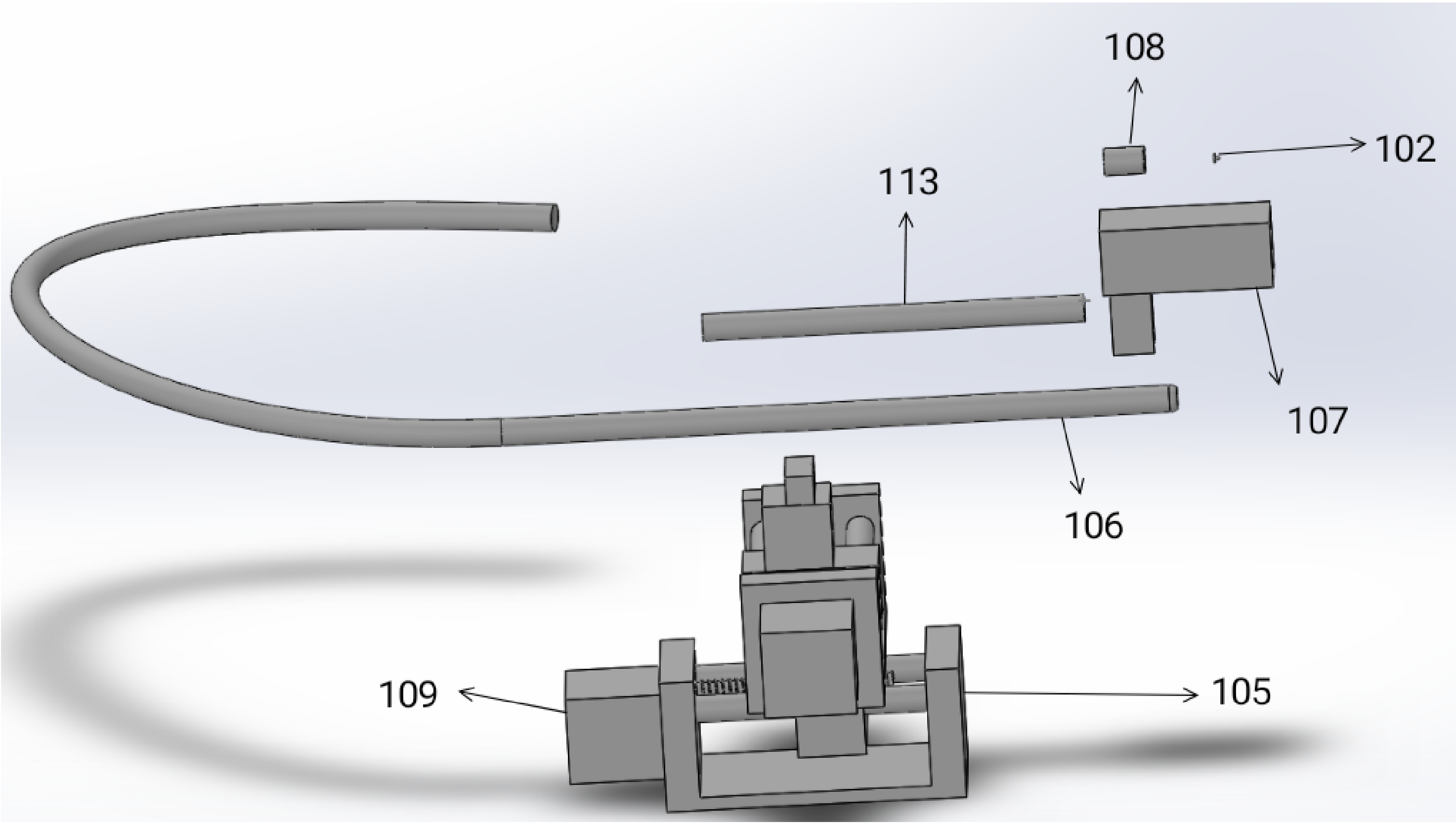

Figure 6

Side view of the RGB camera attached with the heat resisting box of an autonomous seam path tracker welding machine

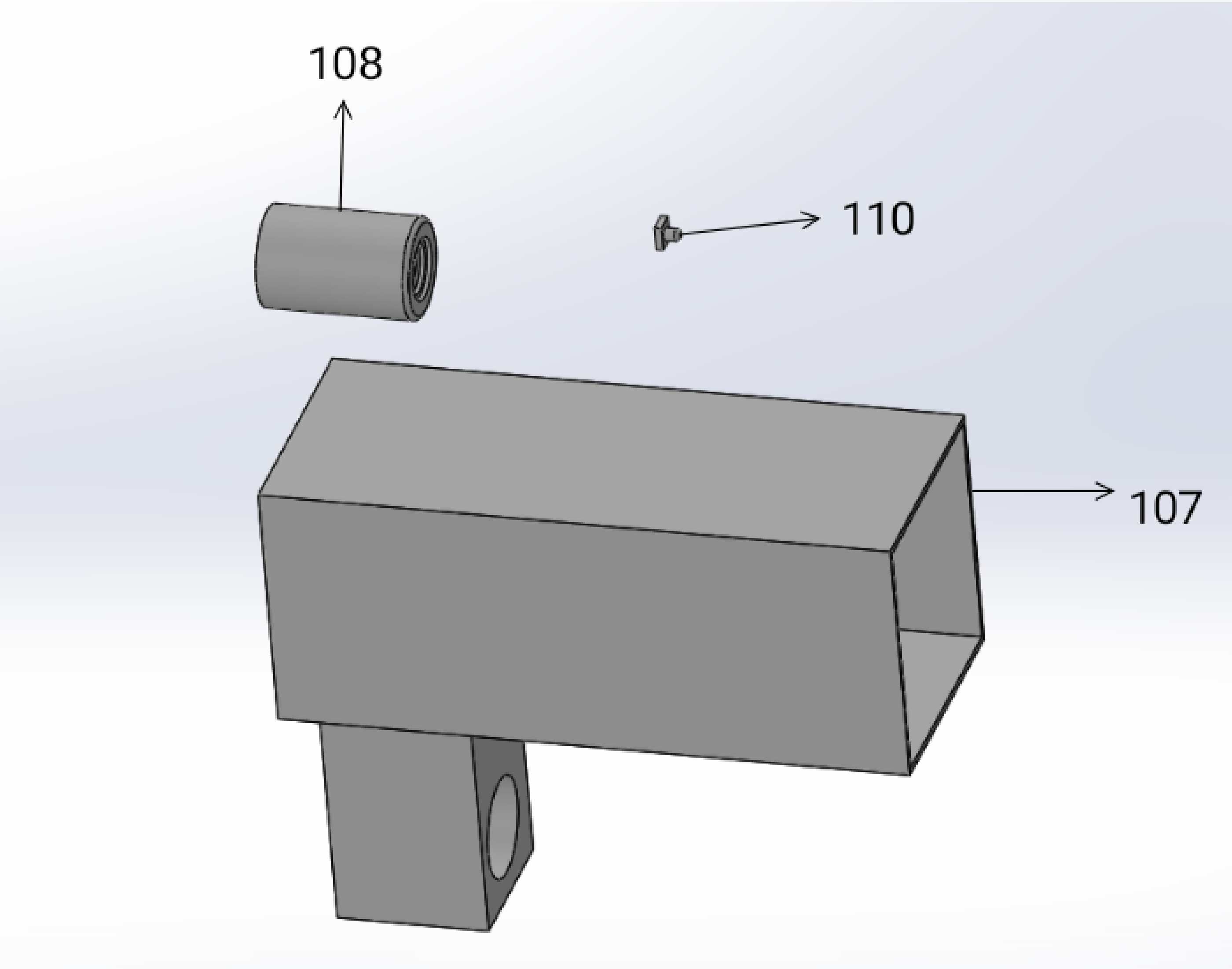

Figure 7

Perspective view of the RGB camera attached with the heat resisting box and the ultrasonic sensor of an autonomous seam path tracker welding machine

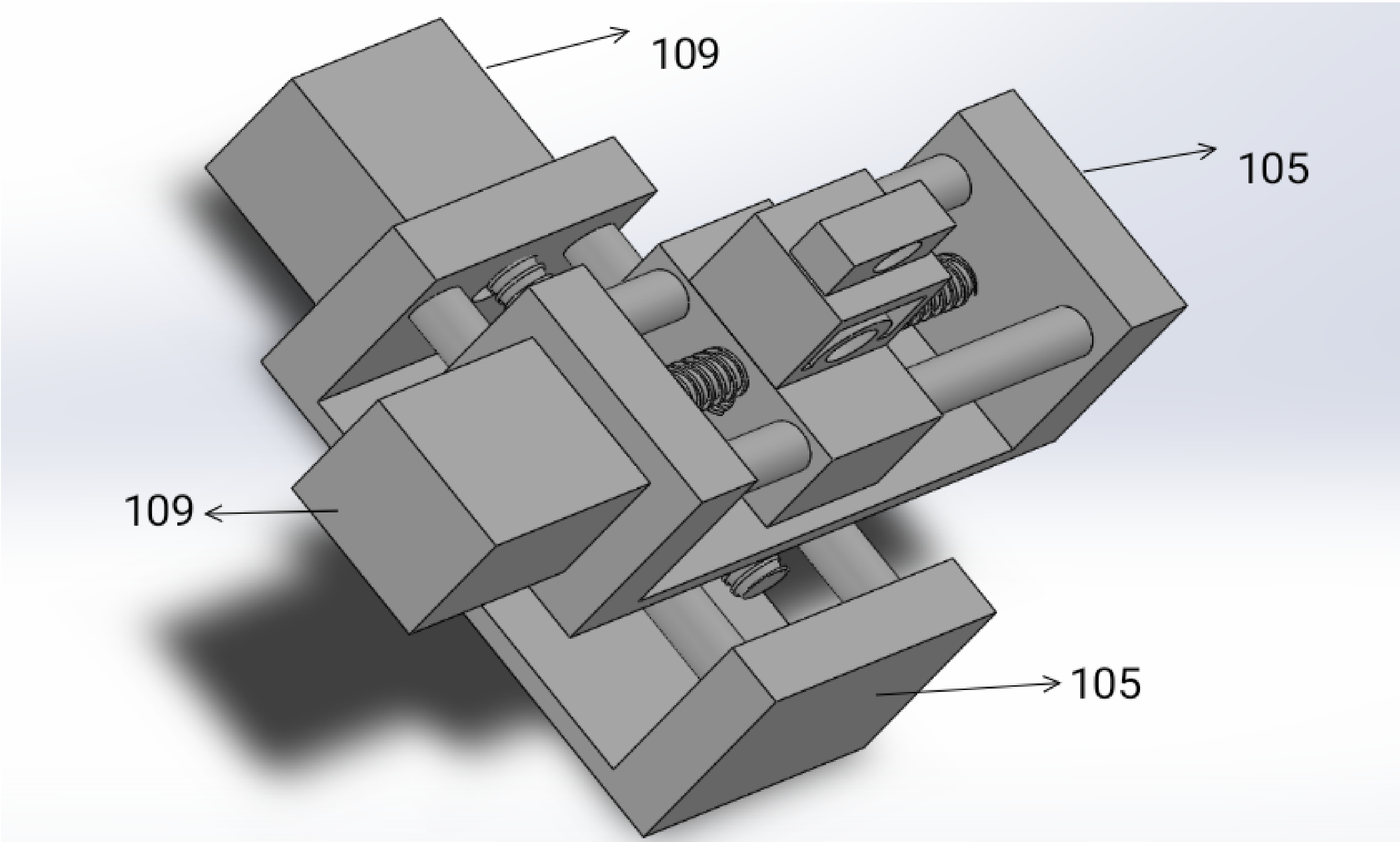

Figure 8

Perspective view of the slider mechanism and stepper motors of an autonomous seam path tracker welding machine

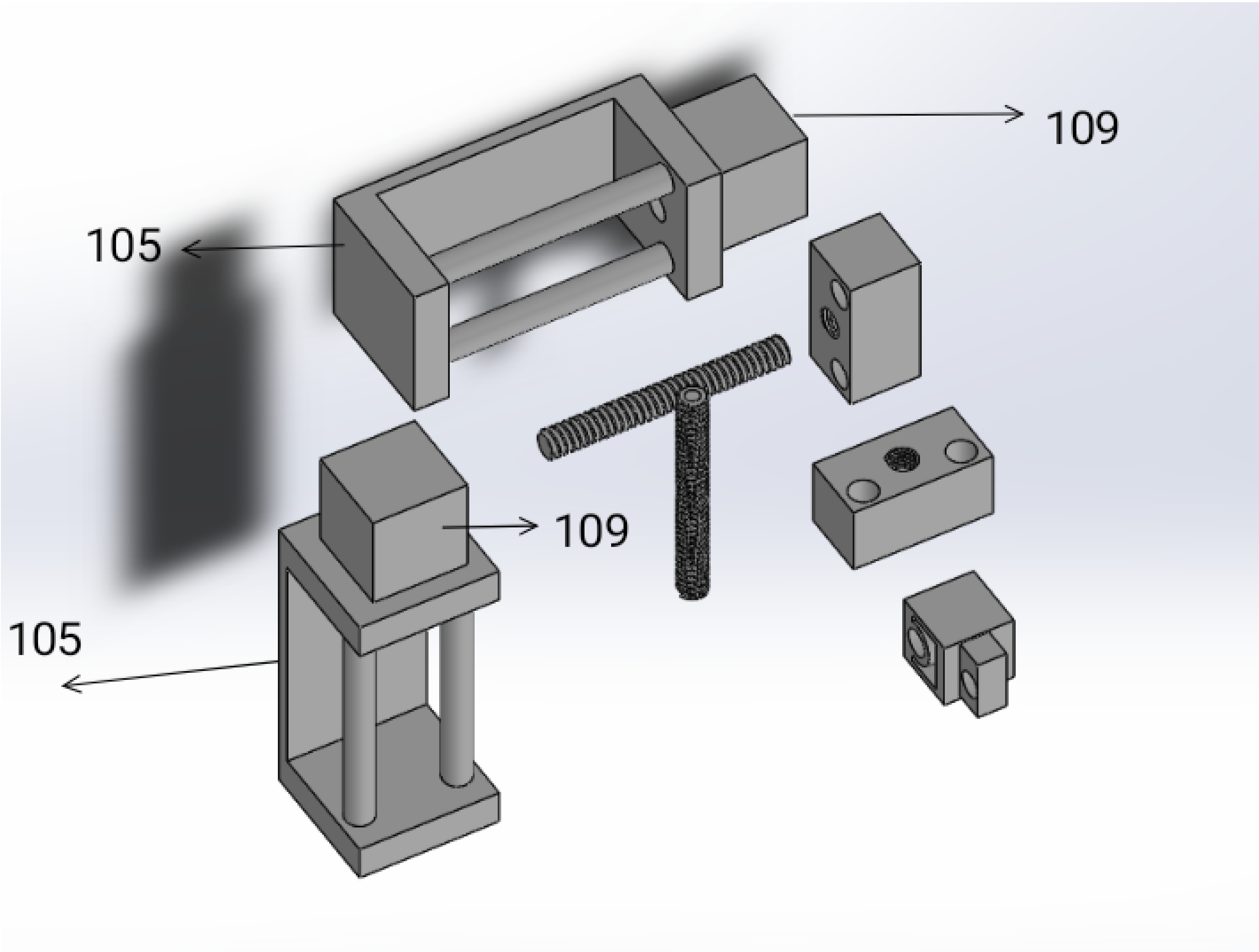

Figure 9

Dismantled view of the slider mechanism and the stepper motors of an autonomous seam path tracker welding machine

Figure 10

Control block diagram of an autonomous vision sensor-actuator-based circumferential seam path tracker welding machine

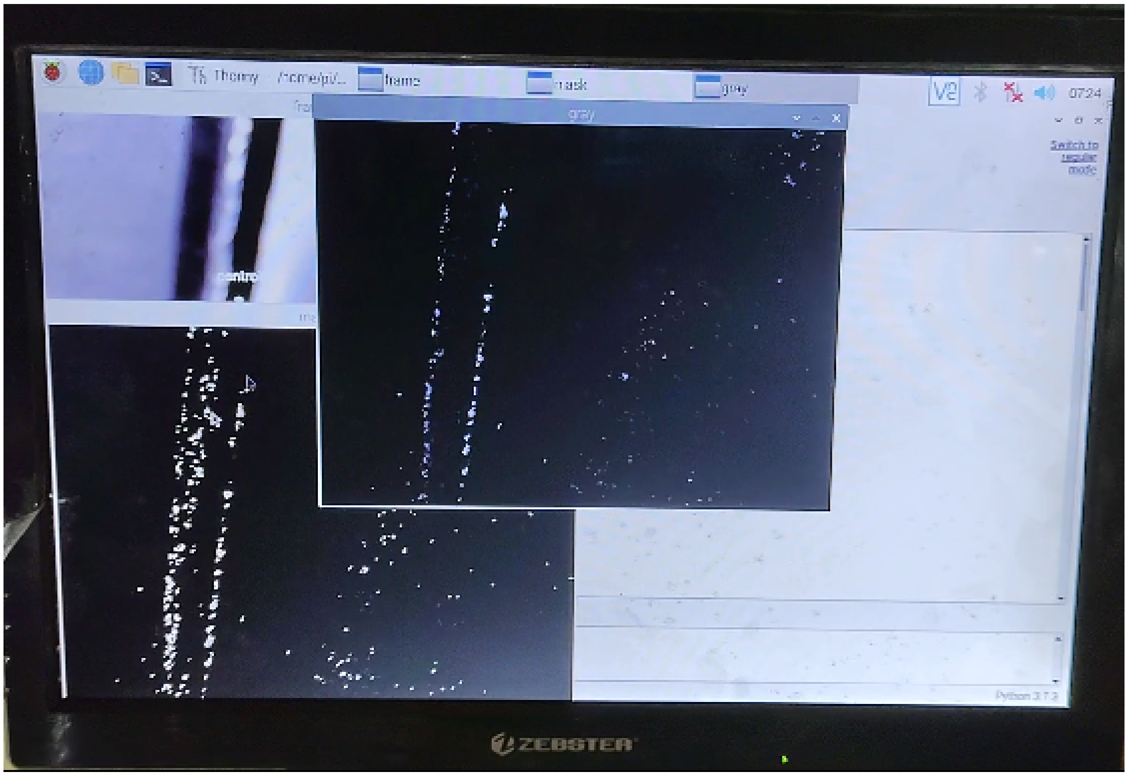

Figure 11

Snapshot of tracking image of seam path in three separate windows that are grey, mask and frame

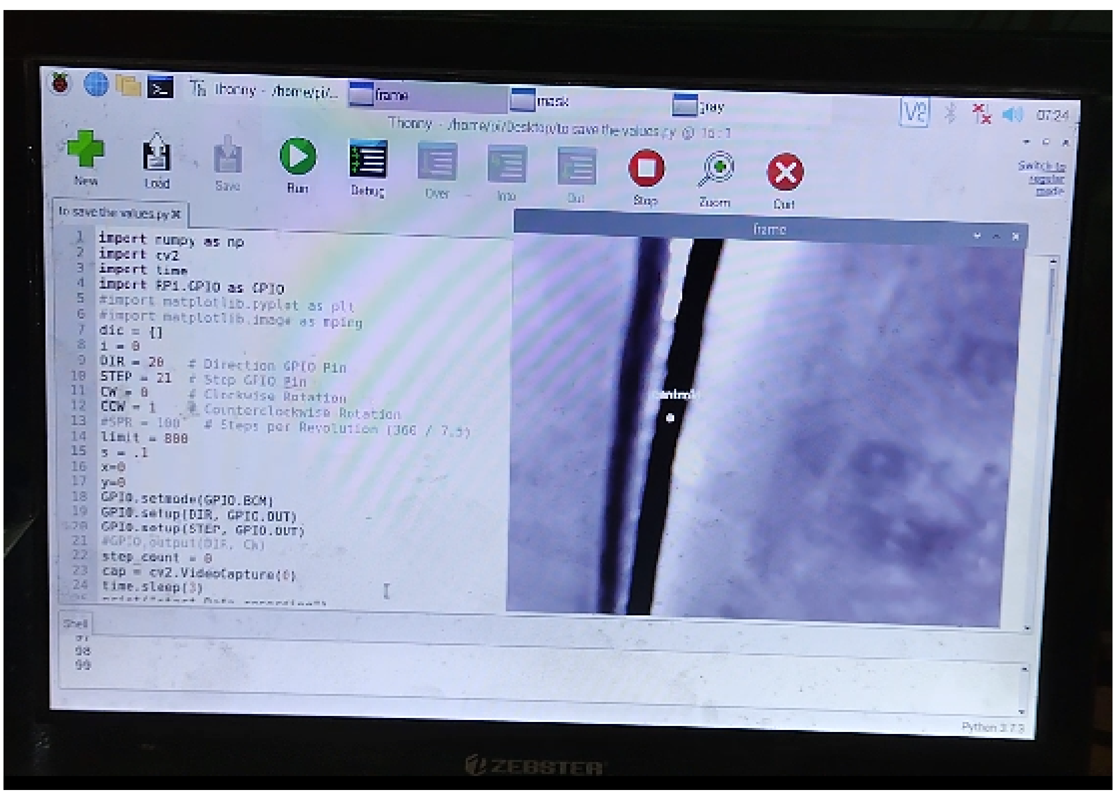

Figure 12

Snapshot of the data recording with the location of the centroid of the seam

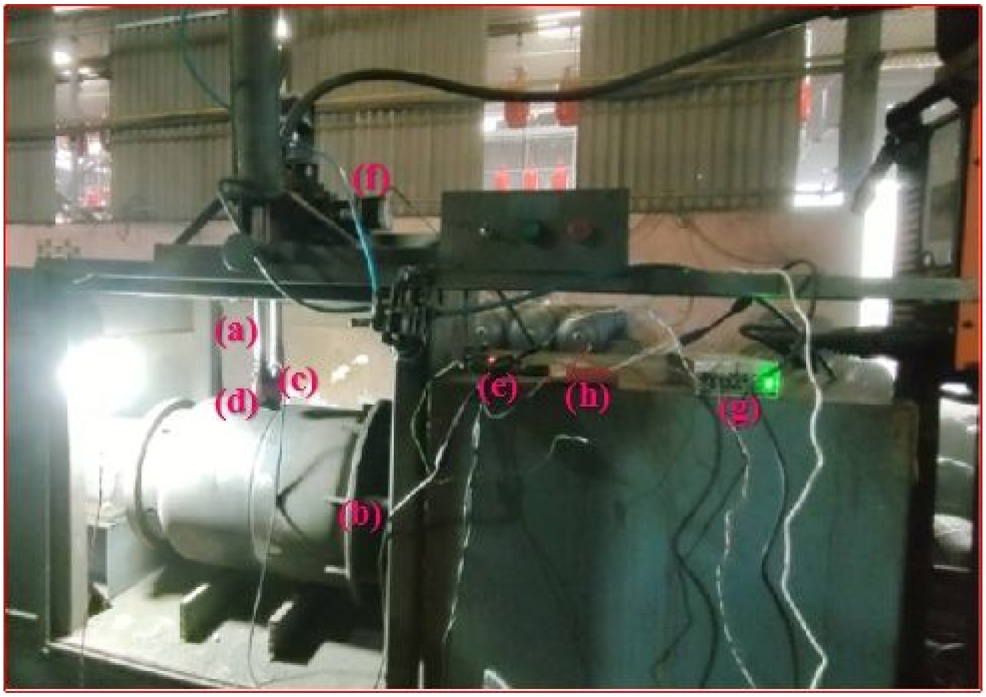

Figure 13

Snapshot of the physical model of the developed autonomous vision sensor-actuator-based circumferential seam path tracker welding machine

Note: a-Welding torch, b-Pneumatic cylinder holder, c-Heat-resisting box, d-RGB camera, e-Raspberry Pi microcontroller, f-Stepper motor, g-SMPS, h-Microstep driver

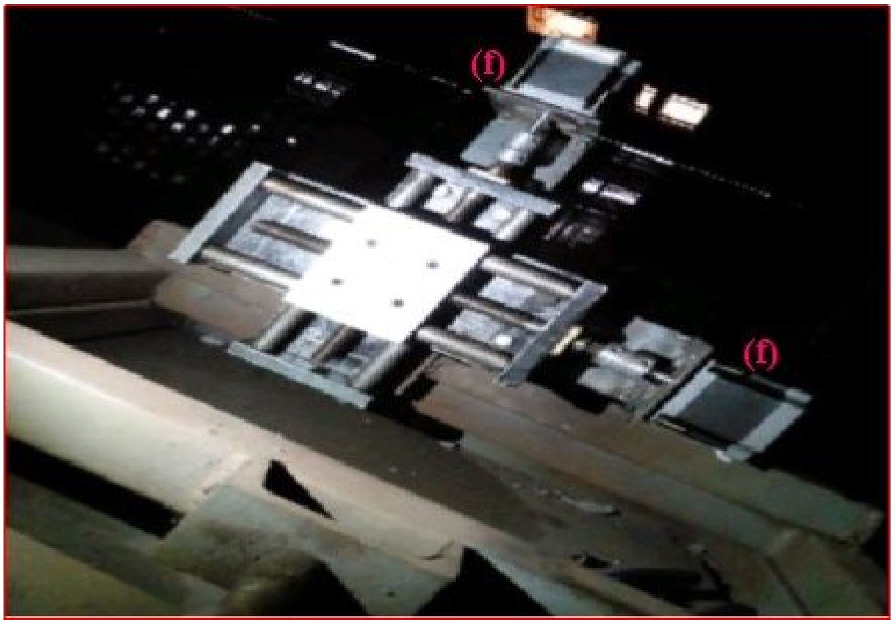

Figure 14

Snapshot of the sliders mechanism connected with stepper motors to control the motion of the welding torch

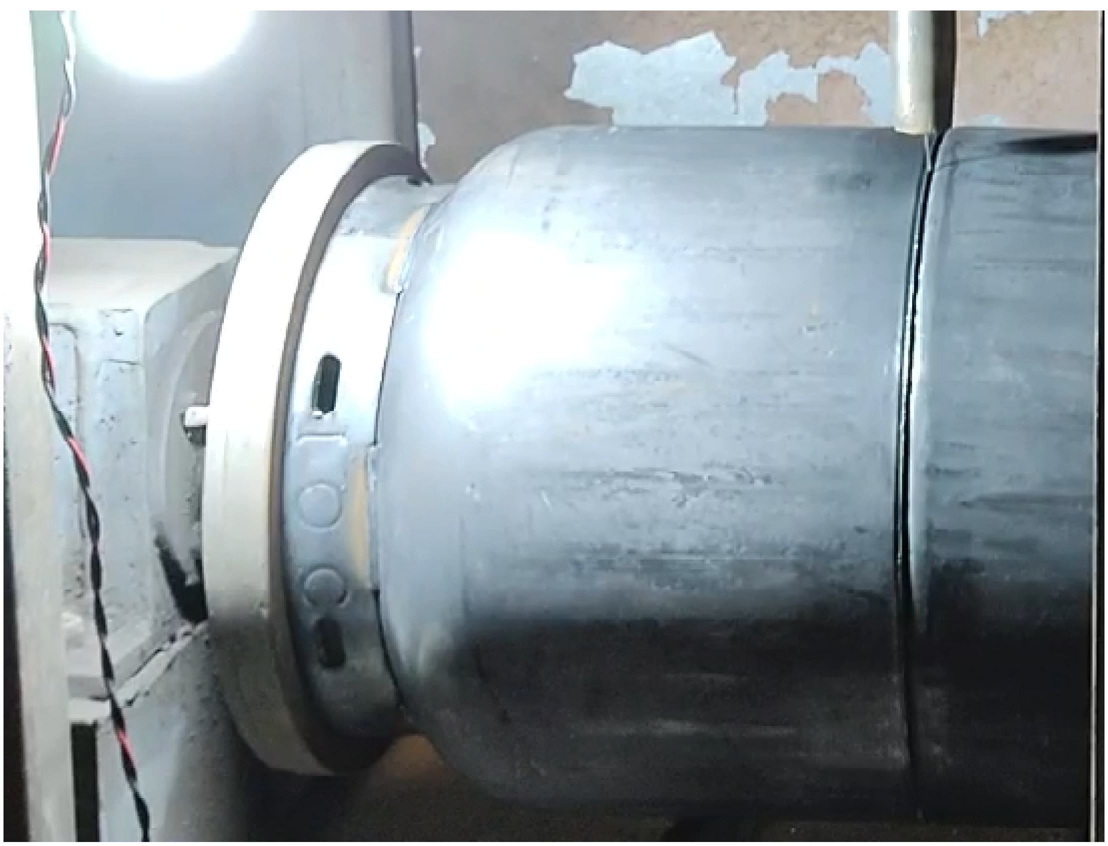

Figure 15

Snapshot of the specimen (LPG cylinder) before welding process

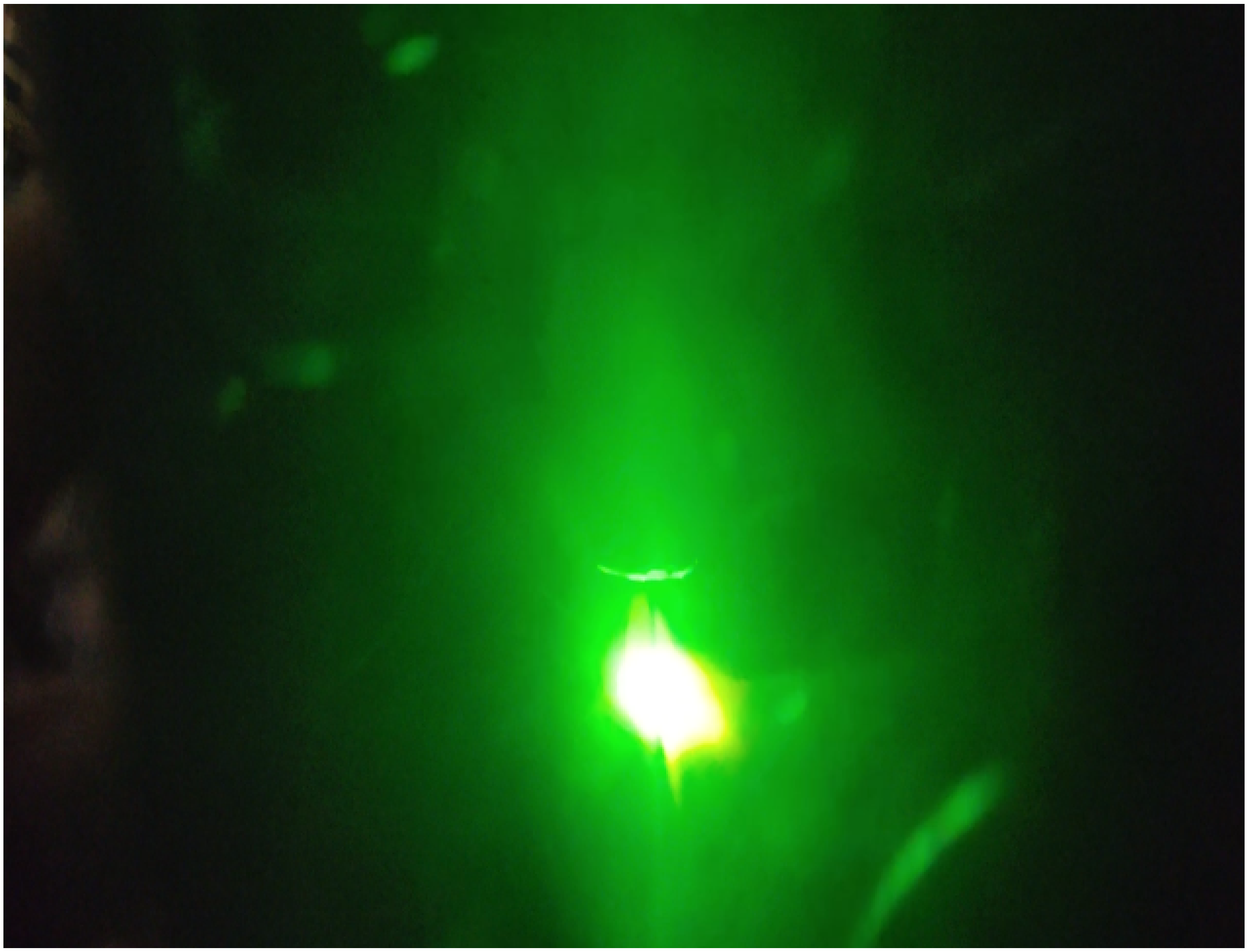

Figure 16

Real-time snapshot of the autonomous circumference welding process of the LPG cylinder

Figure 17

Snapshot of the final specimen after autonomous seam tracking and welding

Figure 18

Snapshots of the welding blast test results