



(51) International Patent Classification:

D05B 19/12 (2006.01) G06T 7/00 (2017.01)  
D05B 69/20 (2006.01) G06T 7/13 (2017.01)  
G06N 20/00 (2019.01) G06T 7/181 (2017.01)

(21) International Application Number:

PCT/US2021/062426

(22) International Filing Date:

08 December 2021 (08.12.2021)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

17/363,783 30 June 2021 (30.06.2021) US

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, IT, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK,

(54) Title: SYSTEM AND METHOD FOR DETERMINING JOINDER LOCATIONS FOR ASSEMBLY OF GARMENTS

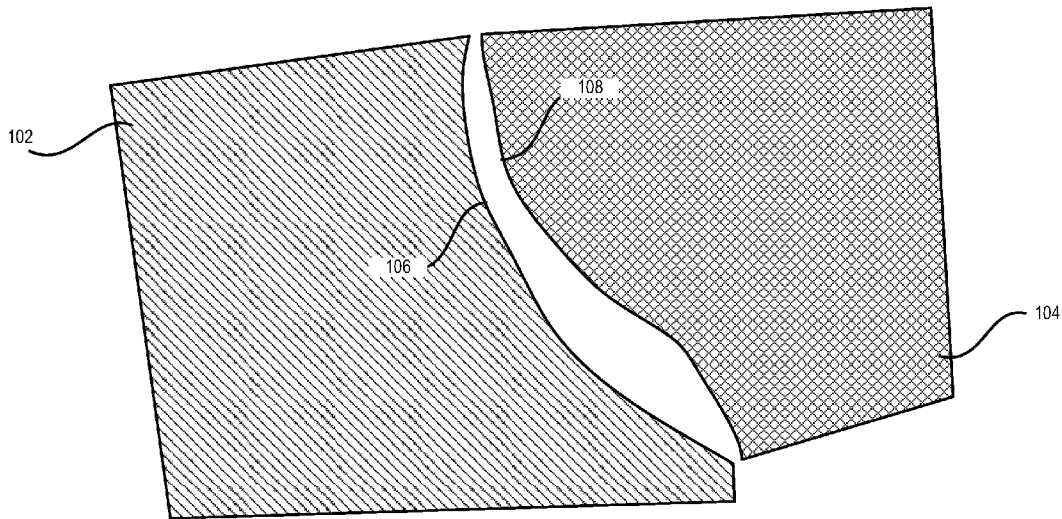


FIG. 1

(57) Abstract: One embodiment can provide a system and method for determining joinder points on to-be-joined fabric pieces. During operation, the system captures an image comprising the to-be-joined fabric pieces; identifies to-be-joined edges, respectively, on the fabric pieces; for each edge, computes a curve that substantially fits the edge; and determines the joinder points on the edge based on the computed curve. Variance of distance between two consecutive joinder points on the edge is within a predetermined value.



EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,  
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,  
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,  
KM, ML, MR, NE, SN, TD, TG).

**Published:**

— *with international search report (Art. 21(3))*

# SYSTEM AND METHOD FOR DETERMINING JOINDER LOCATIONS FOR ASSEMBLY OF GARMENTS

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## BACKGROUND

### 10 Field

[0001] This disclosure is generally related to automation in garment fabrication. More specifically, this disclosure is related to a system and method for determining joiner locations for attaching two pieces of fabric.

### 15 Related Art

[0002] Automation (e.g., the use of robotic systems) has been widely used and is transforming manufacturing in various industries (e.g., the automobile industry). However, even as the global demand for clothing has increased because of increased population, changes in consumer attitude toward fast fashion, and an increase in the average income in many countries, automation in garment manufacturing is still mainly focused on fabric production. The actual assembly of garments, which typically involves sewing operations, is still mostly dependent on skilled manual labor. The cost of sewing can be between 30% and 60% of the total cost of garment fabrication.

[0003] Increasing labor cost has become an important driving force of garment-assembly automation. Relatively simple sewing operations, such as sewing a button or a pocket, can be done by robots. More complicated sewing or fabric attachment operations that involve two fabric pieces having different lengths, contours or curvatures (e.g., attaching sleeves) remain challenging for robots.

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## SUMMARY

[0004] One embodiment can provide a system and method for determining joiner points on to-be-joined fabric pieces. During operation, the system captures an image comprising the to-be-joined fabric pieces; identifies to-be-joined edges, respectively, on the fabric pieces; for each edge, computes a curve that substantially fits the edge; and determines the joiner points on the

edge based on the computed curve. Variance of distance between two consecutive joiner points on the edge is within a predetermined value.

[0005] In a variation on this embodiment, identifying the to-be-joined edges comprises inputting the captured image to a trained machine-learning model.

5 [0006] In a variation on this embodiment, computing a curve that substantially fits the edge comprises computing a spline based on a number of points on the identified edge.

[0007] In a further variation, computing the spline comprises: determining the number of points on the identified edge based on a predetermined spatial sampling rate, and computing the spline that traverses the determined number of points.

10 [0008] In a variation on this embodiment, determining the joiner points comprises computing a total length of the curve and a segment length between adjacent joiner points.

[0009] In a further variation, the joiner points are substantially evenly distributed along the curve, and the segment length is determined based on the total length of the curve and a predetermined number of the joiner points.

15 [0010] In a variation on this embodiment, the system outputs location information of the determined joiner points on each edge, thereby facilitating an automated joining operation on the fabric pieces.

## 20 BRIEF DESCRIPTION OF THE FIGURES

[0011] FIG. 1 illustrates exemplary fabric pieces that are to be made into a T-shirt.

[0012] FIG. 2 illustrates an exemplary block diagram of a computer-vision system for determining joiner points on fabric pieces, according to one embodiment.

25 [0013] FIG. 3A illustrates exemplary fabric pieces with marked edges, according to one embodiment.

[0014] FIG. 3B illustrates exemplary splines computed to fit the edges of the fabric pieces, according to one embodiment.

[0015] FIG. 3C illustrates exemplary splines with an increased number of segments, according to one embodiment.

30 [0016] FIG. 4 illustrates a histogram of the segment lengths for the splines shown in FIG. 3C, according to one embodiment.

[0017] FIG. 5A illustrates exemplary joiner points on edges of fabric pieces, according to one embodiment.

35 [0018] FIG. 5B illustrates a histogram of the joiner segment lengths for the two edges shown in FIG. 5A, according to one embodiment.

[0019] FIG. 6 presents a flowchart illustrating the process for determining joiner points on to-be joined fabric pieces, according to one embodiment.

[0020] FIG. 7 presents a flowchart illustrating the process for determining locations of joiner points along a spline, according to one embodiment.

5 [0021] FIG. 8 illustrates an exemplary computer and communication system for facilitating a computer-vision system, according to one embodiment.

[0022] In the figures, like reference numerals refer to the same figure elements.

## DETAILED DESCRIPTION

10 [0023] The following description is presented to enable any person skilled in the art to make and use the embodiments, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other  
15 embodiments and applications without departing from the spirit and scope of the present disclosure. Thus, the present invention is not limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

### Overview

[0024] Embodiments described herein solve the technical problem of identifying  
20 locations of joiner points (e.g., stitch locations) that can be used in some applications as part of an automated garment fabrication process. When two pieces of fabric are to be joined, a computer-vision system can first identify points located on the to-be-joined edges of the fabric pieces. Based on these identified points, the computer-vision system can compute a spline to match the curve on each edge. Oversampling can optionally be used to achieve a smoother  
25 spline. To generate a joiner pattern with substantially equal spacing between joiner points, the system can divide each spline into the same number of segments. More specifically, the system can compute the total length of each spline and then evenly divide the total length into a predetermined number of segments. The endpoints of each segment on one piece of fabric and the corresponding endpoints on the other piece of fabric can be identified. The joiner points  
30 between the endpoints on one piece of fabric are mapped to the corresponding joiner points on the other piece of fabric, wherein the corresponding two joiner points are to be attached together, thus ensuring the two fabric pieces can be attached evenly, even when the edges of the two pieces of fabric have different contours or lengths. In addition to the evenly spaced stitch pattern, other designs with different segments of different spacing between joiner points can also be  
35 implemented using a similar technique.

### **Computer-Vision System for Automated Sewing**

[0025] FIG. 1 illustrates exemplary fabric pieces that are to be made into a T-shirt. More specifically, left-side fabric piece 102 is the front panel of the T-shirt and right-side fabric piece 5 104 is the sleeve of the T-shirt. FIG. 1 also shows that left-side fabric piece 102 has a curved edge 106 and right-side fabric piece 104 has a curved edge 108. When making the T-shirt, one needs to join (e.g., sew) edge 106 with edge 108. As one can see from FIG. 1, edges 106 and 108 have different curvatures and lengths. This is because the human body is a three-dimensional (3D) structure and the T-shirt is designed to provide a good fit to the 3D human body by joining 10 pieces of fabric that are cut into two-dimensional (2D) patterns.

[0026] When the T-shirt is to be made manually, a human (e.g., a skilled seamstress) can sew fabric pieces 102 and 104 together. During sewing, the seamstress can line up edges 106 and 108 at their corresponding ends and use his or her real-time visual and haptic feedback to match and stitch the correct points on each edge together. For example, using a sewing machine, 15 they can start from one end and, as they move to the other end, they can straighten and join about one inch of fabric from each side at a time and feed them under the presser foot of the sewing machine to stitch the fabric pieces together. By the time they reach the other end, the two fabric pieces are joined. During sewing, the seamstress can make constant adjustment (e.g., stretching one fabric piece while compressing the other piece) to match the length of the two pieces in order 20 to achieve the desired effect. Such maneuvers can be hard to mimic in an automated setting. More specifically, it is challenging for a robot to locate the correct matching points (also referred to as the joiner points) on the two fabric pieces being joined, because the haptic feedback, real-time visual feedback, and dexterity of robots can be significantly inferior to humans.

[0027] In some embodiments, a computer-vision system can be used to automatically 25 determine the joiner points on two to-be-joined fabric pieces. The corresponding joiner points on the two fabric pieces can function as fixed points to be attached together, while an automated joining process (such as an automated linear sewing process) can be used to join the edges between the joiner points. In this way, it is possible to create an automated joining process to join two fabric pieces with different contours and/or lengths. A garment created using an 30 assembly process that is based on such pre-determined joiner points can have a seam that is fixed or attached together (e.g., “pinched”) at such joiner points, and the part of the seam between two consecutive joiner points may be joined using a conventional fabric-joining method such as sewing. As a result, the mismatch of lengths, contour, shape, stretching, tension or other fabric property between two consecutive joiner points can be tolerated by the fabric- 35 joining method, but does not accumulate along the seam, because such mismatch is reset at each

joinder point. Note that embodiments of the present invention are not limited to any particular fabric-joining method and can apply to various methods, including but not limited to stitching, gluing, and fusing.

5 [0028] FIG. 2 illustrates an exemplary block diagram of a computer-vision system for determining joinder points on fabric pieces, according to one embodiment. Computer-vision system 200 can include a camera module 202, an edge finder 204, a curve-computing module 206, a segmentation module 208, a joinder-point-determination module 210, and an output module 212. During operation, camera module 202 can capture images of fabric pieces placed on a work surface. Depending on the application, the fabric pieces can lie flat on the work  
10 surface, similar to the example shown in FIG. 1, or the fabric pieces can have different orientations. Camera module 202 can include one or more cameras, including but not limited to: a 2D camera and a 3D camera. A 2D camera can capture 2D imaging information (e.g., red green blue (RGB) images). A 3D camera can capture depth information, in addition to the 2D imaging information.

15 [0029] Edge finder 204 can identify the edges of each fabric piece. Various image-processing techniques can be used. For example, using a machine-learning technique (e.g., by training a neural network), edge finder 204 can learn to determine the edge of a fabric piece. Once an edge is determined, edge finder 204 can mark the edge with a number of points along the edge. For example, edge finder 204 can determine that certain pixels in the image of the  
20 fabric pieces correspond to the edge of the fabric piece and can label a subset of the pixels as edge points. The labeling of the edge points can be done using an annotation process. In some embodiments, the system can use light sources with wavelengths outside of the visible light's spectrum for edge detection, to reduce detection noise or for other reasons.

25 [0030] FIG. 3A illustrates exemplary fabric pieces with marked edges, according to one embodiment. In FIG. 3A, the edges points are marked using round dots.

[0031] Note that, because edge finder 204 can only determine whether an image pixel is on the edge or not, without knowing the exact shape of the edge, it is hard to control the distance between two adjacent edge points, which define the shape of the edge. Edge finder 204 can place the edge points randomly along each edge, or place the edge points according to a predetermined  
30 placement rule. Ideally, if the edge points are placed in such a way that they are equally spaced, then these edge points can be used as joinder points. However, without knowing the exact shape of the curve, it is difficult to accomplish such a goal. In one example, the edge points can be placed to achieve equal spacing along a particular axis (e.g., a vertical or horizontal axis). As can be seen from FIG. 3A, the length of each edge segment (i.e., the segment along the edge between  
35 adjacent edge points) is not guaranteed to be a constant. For example, on the edge of the left

fabric piece, the segment between edge points 302 and 304 is significantly longer than the segment between edge points 306 and 308. Moreover, because of the differences in length and curvature between the two edges, the way these edge points are distributed on each edge can be significantly different. If one attempts to sew the two fabric pieces together by joining edge points on the left fabric pieces with edge points on the right fabric piece, the resulting garment will have unevenly joined seams.

[0032] In one embodiment, edge finder 204 can also have object-tracking capabilities. Once the fabric pieces and their edges are identified, they can be tracked in subsequent frames. As a result, the annotated edge points marking the edges can be bound to the edges of the fabric pieces, even after the fabric pieces are moved to a different location in the camera view or when the camera zooms in or out.

[0033] Returning to FIG. 2, based on the edge points identified by edge finder 204, curve-computing module 206 can compute a curve for each edge that fits the shape of the edge. Various curve-fitting or interpolation techniques can be used to compute the curve, including but not limited to: polynomial interpolation, spline interpolation, trigonometric interpolation, etc. In one embodiment, curve-computing module 206 can compute a spline for each edge. Note that a spline is a piecewise polynomial (parametric) curve. Spline interpolation produces smaller errors even with low degree polynomials (e.g., third degree) and can avoid the oscillating problem.

[0034] FIG. 3B illustrates exemplary splines computed to fit the edges of the fabric pieces, according to one embodiment. In FIG. 3B, dashed line 312 indicates a computed spline fitting the edge of the left fabric piece, and dashed line 314 indicates a computed spline fitting the edge of the right fabric piece. In the example shown in FIG. 3B, the number of segments (i.e., polynomial pieces) in each spline is relatively small, and the resulting fitted curve may not be sufficiently smooth. Note that the number of segments may be determined by the number of random edge points identified by edge finder 204. To enhance the smoothness of the fitted curve, the system can increase the number of segments by increasing the number of waypoints (also referred to as knots) that a spline goes through. For example, edge finder 204 can increase the number of points being identified on the detected edge by 10 or even 100 times, or more.

[0035] FIG. 3C illustrates exemplary splines with an increased number of segments, according to one embodiment. In FIG. 3C, the number of waypoints on each spline (e.g., spline 322 or spline 324) is 100 times what is shown in FIG. 3B, resulting in much smoother curves.

[0036] However, increasing the spatial sampling rate or the number of waypoints on each spline does not solve the non-uniformity problem. The lengths of the segments included in each spline can vary significantly. FIG. 4 illustrates a histogram of the segment lengths for the splines shown in FIG. 3C, according to one embodiment. As shown in FIG. 4, there is a wide range of



segment lengths for both splines. In FIG. 4, the length of a segment is expressed using the number of pixels occupied by the segment. The length of the shortest segment can be about 0.016 pixel, whereas the length of the longest segment can be about 0.032 pixel. In other words, the longest segments are about twice the length of the shortest ones. The widely varying segment length means that the knots on the spline cannot be used as joiner points (e.g., fixed stitching locations).

[0037] Returning to FIG. 2, segmentation module 208 can compute the lengths of segments between desired joiner points based on a predetermined joiner or stitch pattern. For example, if equally spaced stitches are desired, the length of each segment on a particular spline can be the same. In this case, to calculate the segment length for a particular spline, segmentation module 208 can compute the total length of the spline and then divide the total length of the spline by a predetermined number of segments. To compute the total length of a spline, segmentation module 208 can use an integration technique to compute the length of each polynomial piece and then add all pieces together. To distinguish the segment between joiner points from the segment between knots/waypoints on the spline, the segment between joiner points is also referred to as a joiner segment.

[0038] Note that, to prevent the joiner points from being overcrowded or too sparse, segmentation module 208 may also adjust the number of joiner points to be made on a particular garment section. When two fabric pieces are to be joined, one needs to consider the lengths of both splines (e.g., splines 322 and 324 in FIG. 3C), because the number of joiner points on each edge will be the same. The joiner segment length for a longer spline would be longer than that of a shorter spline.

[0039] In certain situations, the joiner segments in different sections of a fabric edge can be of different lengths. For example, to achieve a certain drape or fold effect (e.g., in women's dresses), the space between joiner points in one section of an edge may be different from that in another section of the same edge. Based on the specification provided by the garment designer, segmentation module 208 can compute the lengths of all stitch segments along a to-be-sewed edge. In addition to the length and shape of the two fabric pieces, the thickness or weight of the fabric pieces, the material properties of the fabric including how stretchable the fabrics may be, and particular design criteria such as garment draping may be factors used by the segmentation module 208 to determine the appropriate distribution and the number of joiner points appropriate in each situation.

[0040] Once the length of each joiner segment is computed, joiner-point-determination module 210 can then locate the joiner points on each edge. This can be done in an iterative manner. In one embodiment, joiner-point-determination module 210 can start from one end of a

spline to determine one joiner point at a time until it reaches the other end of the spline. For example, the starting end of a spline can be the first waypoint on the spline, and joiner-point-determination module 210 can compute the length of the polynomial piece between this waypoint and the next waypoint (e.g., using an integration technique). Joiner-point-determination module 5 210 can then compare this computed length with the previously determined joiner segment length. If the length of the current polynomial piece is less than the joiner segment length, joiner-point-determination module 210 can move to the next waypoint and adds the length of the next polynomial piece to the length of the current polynomial piece. This process repeats itself until the total length of polynomial pieces traversed by joiner-point-determination module 10 210 is at least equal to the predetermined joiner segment length. Joiner-point-determination module 210 can then identify the current waypoint as the first joiner point. Starting from the first joiner point, joiner-point-determination module 210 can repeat the above process until it finds a second joiner point (i.e., until the total length of polynomial pieces between the first and second joiner points is equal to or just over the predetermined joiner segment length). This 15 process is repeated until the other end of the spline is reached. Because the two splines are different (e.g., the two edges can have different curvatures and lengths), joiner-point-determination module 210 generally can separately determine the joiner points on each spline.

**[0041]** FIG. 5A illustrates exemplary joiner points on edges of fabric pieces, according to one embodiment. Note that the number of joiner points shown in FIG. 5A is much smaller 20 than those used in the actual cases in order to provide a better visual illustration. Moreover, to demonstrate the corresponding relationship between the joiner points on the two edges, FIG. 5A also shows the hypothetical threads binding each pair of joiner points. For example, a thread can connect a joiner point 502 on the edge of the left fabric piece to a corresponding joiner point 504 on the edge of the right fabric piece. In some embodiments, the determined joiner 25 points can also be labeled using an annotation tool. Like the previously mentioned waypoints shown in FIG. 3A, the determined joiner points can be tracked such that they can be correctly identified even when the fabric pieces are moved around in the camera view or when the camera zooms in or out.

**[0042]** In the example shown in FIG. 5A, the joiner points are substantially equally 30 spaced, meaning that the joiner segments on each edge have approximately the same length. FIG. 5B illustrates a histogram of the joiner segment lengths for the two edges shown in FIG. 5A, according to one embodiment. As shown in FIG. 5B, the lengths of the joiner segments vary between 0.99 and 1.02 pixels. There is only approximately 3% variation in the joiner segment length, compared with the 100% variation shown in FIG. 4. The level of variation of the 35 joiner segment length can depend on the spatial sampling rate along the curve. A higher spatial

sampling rate can result in a more uniform joiner segment length. In one embodiment, the spatial sampling rate can be selected such that the variance of the length of the joiner segment (i.e., the distance between two consecutive joiner points) can be no more than a predetermined threshold value.

5           **[0043]** Returning to FIG. 2, once the joiner points on each edge are identified, output module 212 can output the locations (e.g., the pixel coordinates) of the joiner points. Such location information can be used by a robotic control module. The robotic control module can, for example, use this location information to control the feeding of the fabric to an automated sewing system to ensure that a sewing machine attaches the fabric pieces at the determined  
10 locations of the joiner points. If other bonding mechanisms are used, such as adhesion, the robotic control module can use the joiner point location information to control the application of adhesives and pressure.

**[0044]** FIG. 6 presents a flowchart illustrating the process for determining joiner points on to-be joined fabric pieces, according to one embodiment. During operation, a computer-  
15 vision system captures one or more images of the to-be-joined fabric pieces (operation 602). The images can be still images or video images. Moreover, the images can include 2D or 3D images.

**[0045]** From the captured images, the computer-vision system can identify the to-be-joined edges on the fabric pieces (operation 604) and determine a number of points on each identified edge (operation 606). Various computer-vision techniques can be used to identify the  
20 edges. In one embodiment, a previously trained machine-learning model can be used to identify the edges. The captured image can be fed to the trained model, which can subsequently output the identified edges of the fabric pieces.

**[0046]** The edge points can be determined according to a predetermined rule. The number of edge points can be determined based on the desired resolution. In general, the number  
25 of edge points can be significantly larger (e.g., ten times or more) than the number of joiner points.

**[0047]** Based on the determined edge points, a curve-fitting operation can be performed to obtain a curve that fits the shape of each edge (operation 608). In some embodiments, a spline-interpolation technique can be used to compute a spline for each edge. The computed  
30 spline can pass all the edge points on the edge. The order of polynomial used in the spline interpolation can be adjusted depending on the resolution requirement. Using higher order polynomials can reduce the amount of fitting errors but may incur a higher computation overhead.

**[0048]** Once the fitted curve is obtained, the system can compute the length of the joiner  
35 segment, i.e., the distance between adjacent joiner points (operation 610). In some

embodiments, the joiner points are to be equally spaced on each edge. Hence, computing such a length can involve dividing the total length of the fitted curve by a predetermined number of joiner segments. The total length of a spline can be computed by calculating (e.g., using integration) the length of each polynomial piece and computing a sum over all polynomial pieces on the spline. In some cases, on a particular edge, the joiner segment lengths may be different in different sections, depending on the desired effect.

[0049] The system can then determine, based on the length of each joiner segment, the location of each joiner point (operation 612). In some embodiments, the system may traverse the polynomial pieces on a spline, one at a time, in order to determine the locations of the joiner points such that the length of each joiner segment is set according to the previously determined length value. This operation is performed for both to-be-joined edges. The system then outputs the determined locations of the joiner points on each edge (operation 614). The location information of the joiner points can be used to guide a robotic system (e.g., a sewing robot) to place stitches (or adhesives) based on the joiner points to join the two fabric pieces together and to achieve the desired joining effect. Note that the computer-vision system can also have object- or feature-tracking capabilities, and the determined locations of the joiner points can be associated with physical locations on the fabric pieces. Therefore, even when the robotic system uses a different computer-vision system with a different viewing angle or field of view, the locations of the joiner points can remain mapped to the corresponding pixel coordinates used by the computer vision of the robotic system, thereby guiding the robotic system to perform the joining operations.

[0050] FIG. 7 presents a flowchart illustrating the process for determining locations of joiner points along a spline, according to one embodiment. During operation, the system obtains the lengths of individual joiner segments along the edge (operation 702).

[0051] The system subsequently selects a starting point on the spline (operation 704). At the beginning, the starting point is an end point of the spline. From the starting point, the system computes the length of an adjacent polynomial piece (operation 706) and determines whether an accumulated length value of the current joiner segment reaches or surpasses the previously determined length value of the joiner segment (operation 708). If not, the system computes the length of a next, adjacent polynomial piece on the spline (operation 710) and adds the length of this polynomial piece to the accumulated length (operation 712), and repeats the comparison process (operation 708). Otherwise, the system determines that the distal end point of this polynomial piece is the location of a joiner point (operation 714) and further determines whether the other end of the spline has been reached (operation 716).

[0052] If the other end of the spline is reached, the operation is completed. Otherwise,

the system assigns the most recently determined location of the joiner point as the starting point (operation 718) and repeats the process by computing the length of the next adjacent polynomial piece (operation 706). The operations shown in FIG. 7 can work in the scenario where the number of polynomial pieces on the spline is significantly larger than the number of stitches. In situations where the number of polynomial pieces on the spline is comparable or less than the number of joiner points, the system can increase the spatial sampling rate to compute a spline with a greater number of polynomial pieces.

**[0053]** FIG. 8 illustrates an exemplary computer system for facilitating a computer-vision system, according to one embodiment. In FIG. 8, computer system 800 can include a processor 802, a memory 804, and a storage device 806. Furthermore, computer system 800 can be coupled to peripheral input/output (I/O) user devices 810, e.g., a display device 812, a keyboard 814, a pointing device 816, and a camera 818. Storage device 806 can store an operating system 808, a computer-vision system 820, and data 840.

**[0054]** Computer-vision system 820 can include instructions, which when executed by computer system 800, can cause computer system 800 or processor 802 to perform methods and/or processes described in this disclosure. Specifically, computer-vision system 820 can include instructions for causing camera 818 to capture images (image-capturing module 822), instructions for determining edges on fabric pieces (edge-determination module 824), instructions for tracking objects in the images (object-tracking module 826), instructions for computing curves that fit the to-be-joined edges (curve-fitting module 828), instructions for determining lengths of individual joiner segments (joiner segment-length-determination module 830), instructions for determining locations of joiner points on the edges (joiner-points-determination module (832), and instructions for outputting the determined joiner-point locations (output module 834). Data 840 can optionally include the designed join patterns 842.

**[0055]** In some embodiments, the various modules in computer-vision system 820, such as modules 822-834 can be partially or entirely implemented in hardware and can be part of processor 802. Further, in some embodiments, the system may not include a separate processor and memory.

**[0056]** In general, the disclosed embodiments provide a computer-vision system that can be used to facilitate automated garment fabrication. More specifically, the computer-vision system can be used to guide the operations of a robotic system when joining two pieces of fabric by determining locations of joiner points on edges of the fabric pieces. The computer-vision system can include one or more cameras capable of capturing images of the fabric pieces. Based on the captured image, the computer-vision system can identify to-be-joined edges and compute a curve (e.g., a spline) for each edge. The computer-vision system can then determine the total

length of the edge as well as the length of any joiner segment along the edge, thus facilitating the determination of joiner points based on a predetermined joining pattern. The determined joiner points can be used to guide the robotic system to join the two fabric pieces together by applying stitches or adhesives at the joiner points, thus achieving the desired joining pattern.

5           **[0057]** The methods and processes described in the detailed description section can be embodied as code and/or data, which can be stored in a computer-readable storage medium. When a computer system reads and executes the code and/or data stored on the computer-readable storage medium, the computer system performs the methods and processes embodied as data structures and code and stored within the computer-readable storage medium.

10           **[0058]** Furthermore, the methods and processes described above can be included in hardware modules or apparatus. The hardware modules or apparatus can include, but are not limited to, application-specific integrated circuit (ASIC) chips, field-programmable gate arrays (FPGAs), dedicated or shared processors that execute a particular software module or a piece of code at a particular time, and other programmable-logic devices now known or later developed.

15           When the hardware modules or apparatus are activated, they perform the methods and processes included within them.

**[0059]** The foregoing descriptions of embodiments of the present invention have been presented for purposes of illustration and description only. They are not intended to be exhaustive or to limit the present invention to the forms disclosed. Accordingly, many  
20           modifications and variations will be apparent to practitioners skilled in the art. Additionally, the above disclosure is not intended to limit the present invention. The scope of the present invention is defined by the appended claims.

**What Is Claimed Is:**

1. A computer-executed method for determining joiner points on to-be-joined fabric pieces, comprising:
  - 5 capturing, by a computer-vision system, an image comprising the to-be-joined fabric pieces;
  - identifying to-be-joined edges, respectively, on the fabric pieces;
  - for each edge, computing a curve that substantially fits the edge; and
  - determining the joiner points on each edge based on the computed curve, wherein
  - 10 variance of distance between two consecutive joiner points on the edge is within a predetermined value.
2. The method of claim 1, wherein identifying the to-be-joined edges comprises inputting the captured image to a trained machine-learning model.
3. The method of claim 1, wherein computing a curve that substantially fits the edge
- 15 comprises computing a spline based on a number of points on the identified edge.
4. The method of claim 3, wherein computing the spline comprises:
  - determining the number of points on the identified edge based on a predetermined spatial sampling rate; and
  - computing the spline that traverses the determined number of points.
- 20 5. The method of claim 1, wherein determining the joiner points comprises computing a total length of the curve and a segment length between adjacent joiner points.
6. The method of claim 4, wherein the joiner points are substantially evenly distributed along the curve, and wherein the segment length is determined based on the total length of the curve and a predetermined number of the joiner points.
- 25 7. The method of claim 1, further comprising outputting location information of the determined joiner points on each edge, thereby facilitating an automated joining operation of the fabric pieces.

8. A garment manufacturing system, comprising:  
a fabric cutting module to produce to-be-joined fabric pieces;  
a camera to capture an image comprising the to-be-joined fabric pieces;  
an edge-identifying module to identify to-be-joined edges, respectively, on the fabric  
5 pieces;  
a curve-fitting module to compute, for each edge, a curve that substantially fits the edge;  
a joiner-point-determination module to determine joiner points on each edge based on  
the computed curve, wherein variance of distance between two consecutive joiner points on the  
edge is within a predetermined value; and  
10 a fabric-joining module to join the to-be-joined fabric pieces by attaching the  
corresponding joiner points along the respective edges of the to-be-joined fabric pieces.
9. The garment manufacturing system of claim 8, wherein the edge-identifying  
module is configured to input the captured image to a trained machine-learning model to identify  
the to-be-joined edges.
- 15 10. The garment manufacturing system of claim 8, wherein the curve-fitting module is  
configured to compute a spline based on a number of points on an identified edge.
11. The garment manufacturing system of claim 8, wherein computing the spline  
comprises:  
determining the number of points on the identified edge based on a predetermined spatial  
20 sampling rate; and  
computing the spline that traverses the determined number of points.
12. The garment manufacturing system of claim 8, wherein, while determining the  
joiner points, the joiner-point-determination module is configured to compute a total length of  
the curve and a segment length between adjacent joiner points.
- 25 13. The garment manufacturing system of claim 11, wherein the joiner points are  
substantially evenly distributed along the curve, and wherein the segment length is determined  
based on the total length of the curve and a predetermined number of the joiner points.
14. The garment manufacturing system of claim 8, further comprising an output



module configured to output location information of the determined joiner points on each edge, thereby facilitating an automated joining operation of the fabric pieces.

15. A non-transitory computer-readable storage medium storing instructions that when executed by a computer cause the computer to perform a method for determining joiner  
5 points on to-be-joined fabric pieces, the method comprising:  
capturing an image comprising the to-be-joined fabric pieces;  
identifying to-be-joined edges, respectively, on the fabric pieces; for each edge,  
computing a curve that substantially fits the edge; and  
determining the joiner points on each edge based on the computed curve, wherein  
10 variance of distance between two consecutive joiner points on the edge is within a  
predetermined value.

16. The computer-readable storage medium of claim 15, wherein identifying the to-be-joined edges comprises inputting the captured image to a trained machine-learning model.

17. The computer-readable storage medium of claim 15, wherein computing a curve  
15 that substantially fits the edge comprises computing a spline based on a number of points on the identified edge.

18. The computer-readable storage medium of claim 17, wherein computing the spline comprises:  
determining the number of points on the identified edge based on a predetermined spatial  
20 sampling rate; and  
computing the spline that traverses the determined number of points.

19. The computer-readable storage medium of claim 15, wherein determining the joiner points comprises computing a total length of the curve and a segment length between adjacent joiner points.

20. The computer-readable storage medium of claim 18, wherein the joiner points  
25 are substantially evenly distributed along the curve, and wherein the segment length is determined based on the total length of the curve and a predetermined number of the joiner points.

21. A piece of garment, produced by:

- capturing an image comprising two to-be-joined fabric pieces;
  - identifying to-be-joined edges, respectively, on the fabric pieces;
  - for each edge, computing a curve that substantially fits the edge;
  - determining joiner points on each edge based on the computed curve, wherein variance
- 5 of distance between two consecutive joiner points on the edge is within a predetermined value;
- and
- joining the to-be-joined fabric pieces by attaching the corresponding joiner points along the respective edges of the to-be-joined fabric pieces.

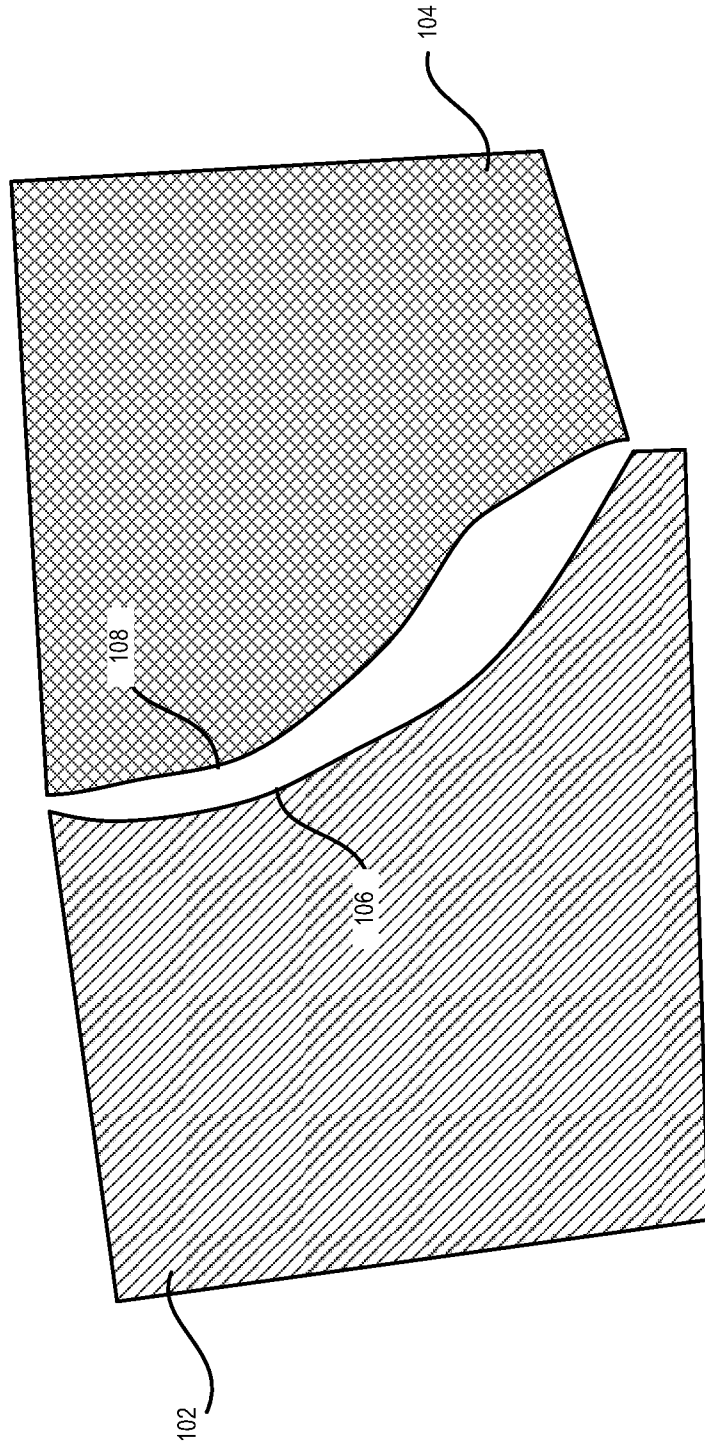
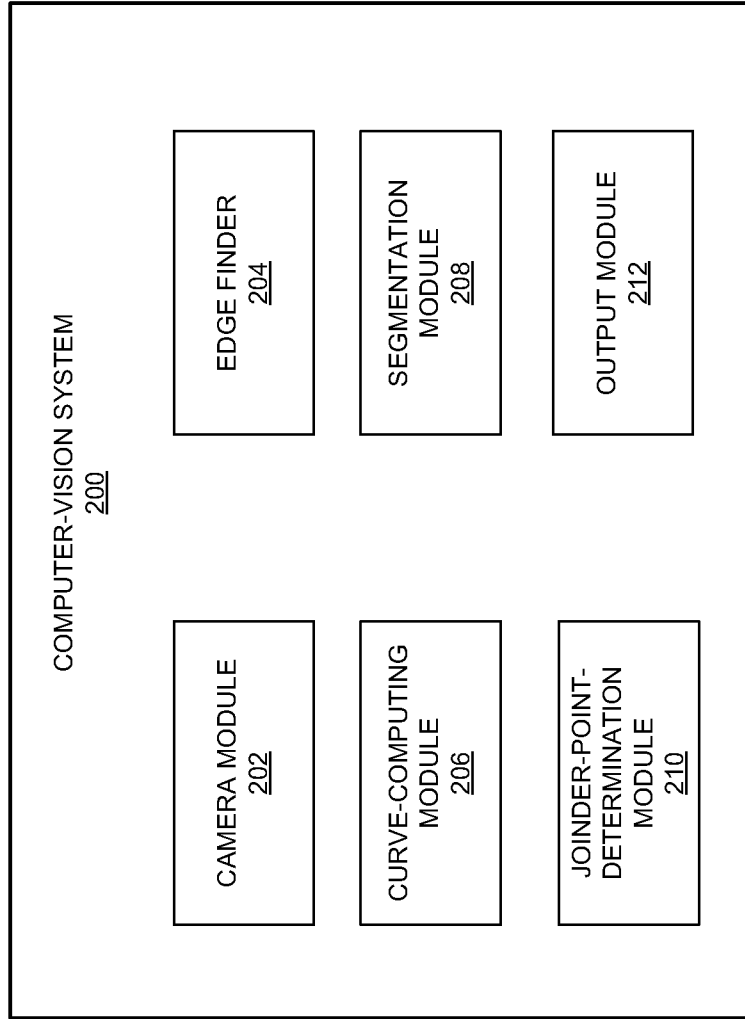


FIG. 1



**FIG. 2**

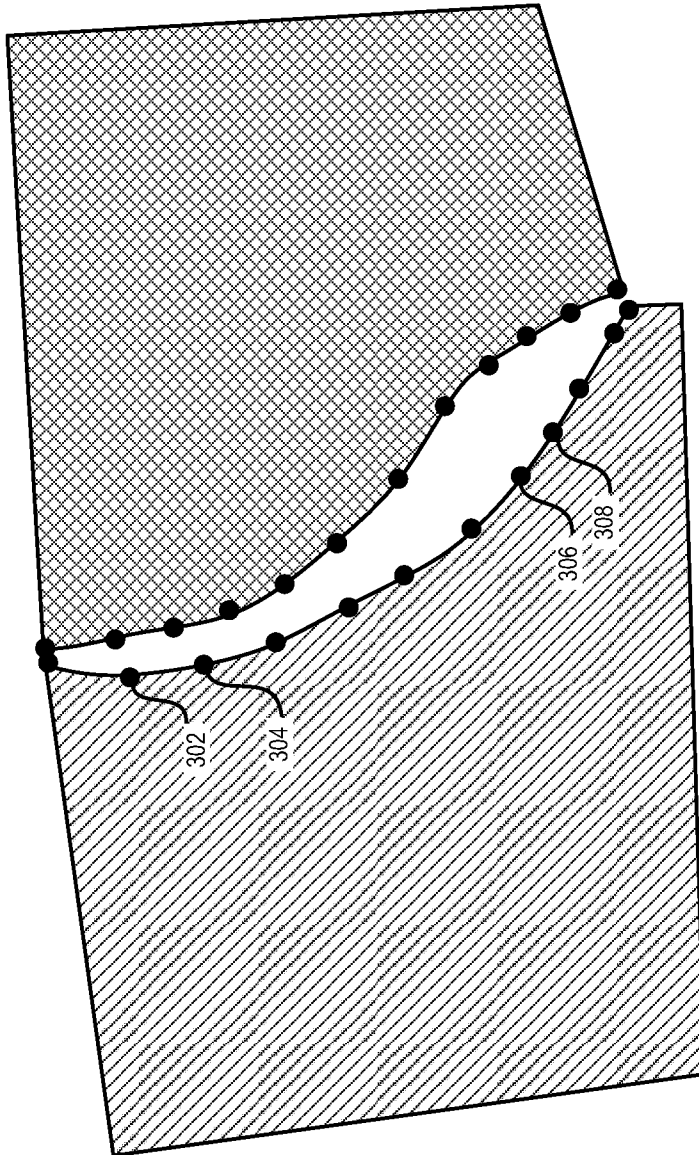


FIG. 3A

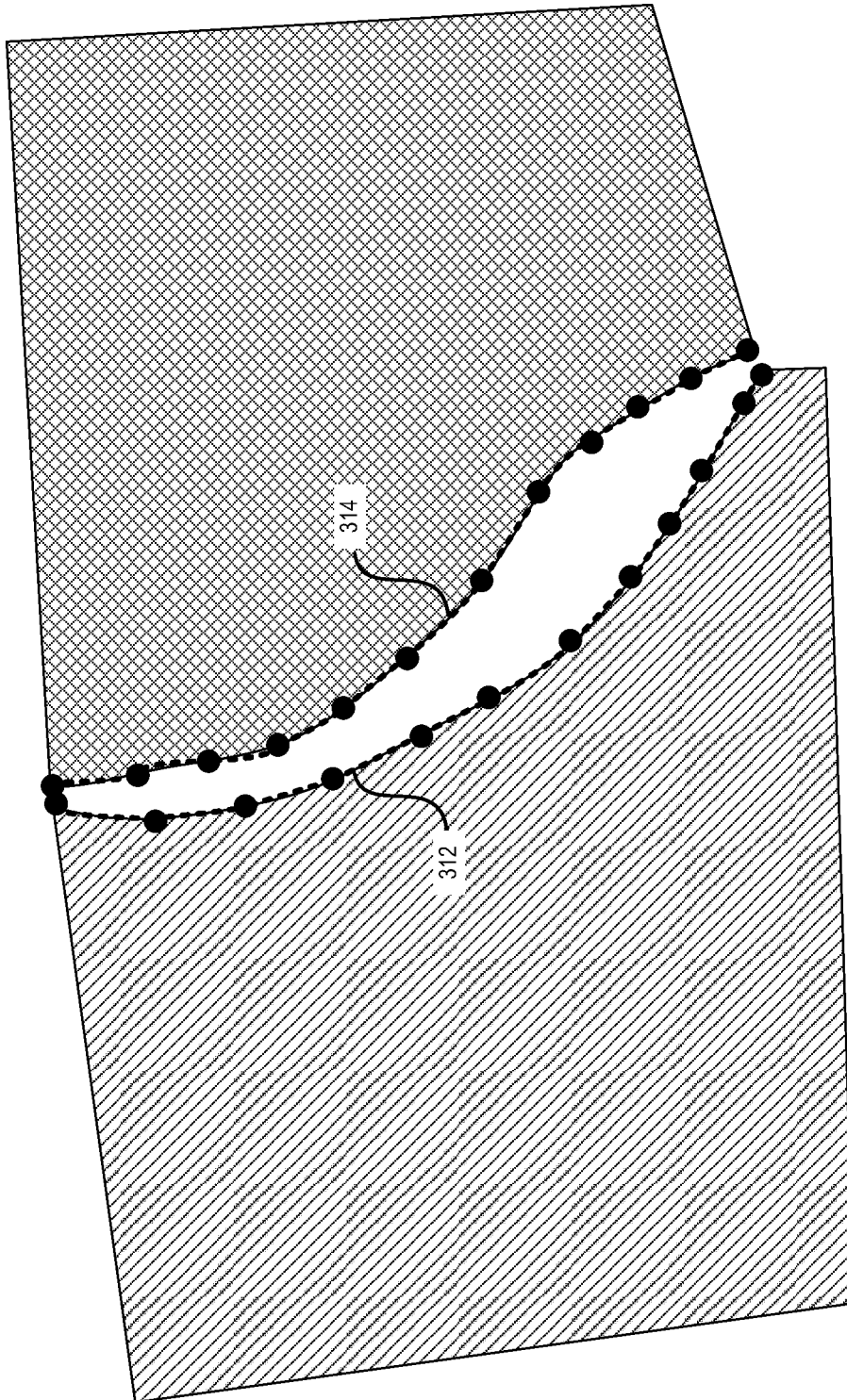


FIG. 3B

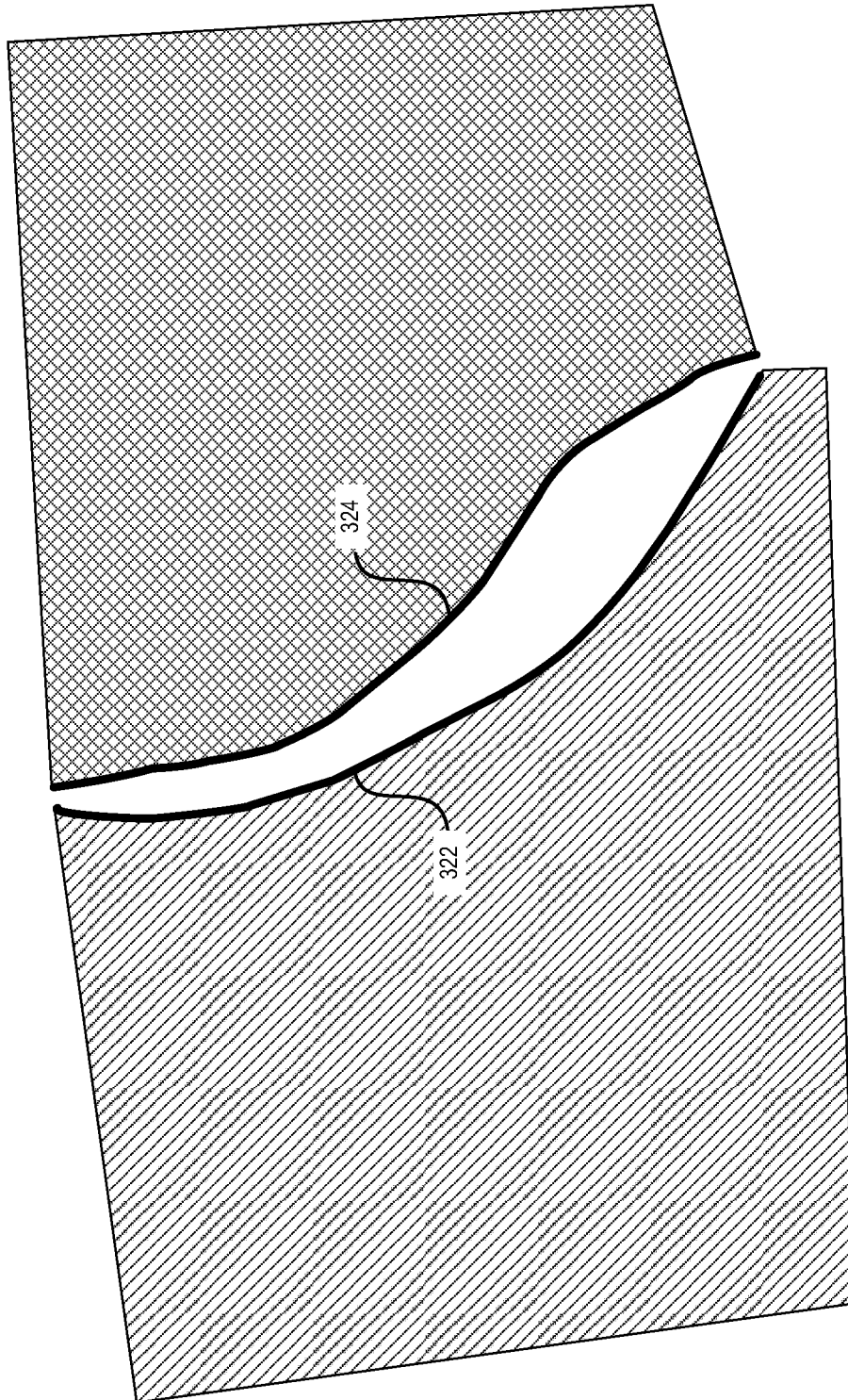
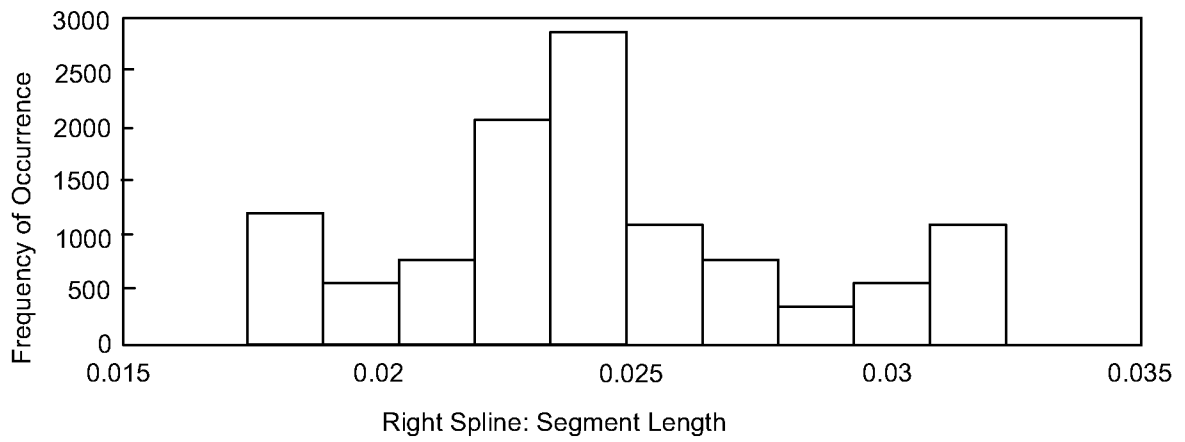
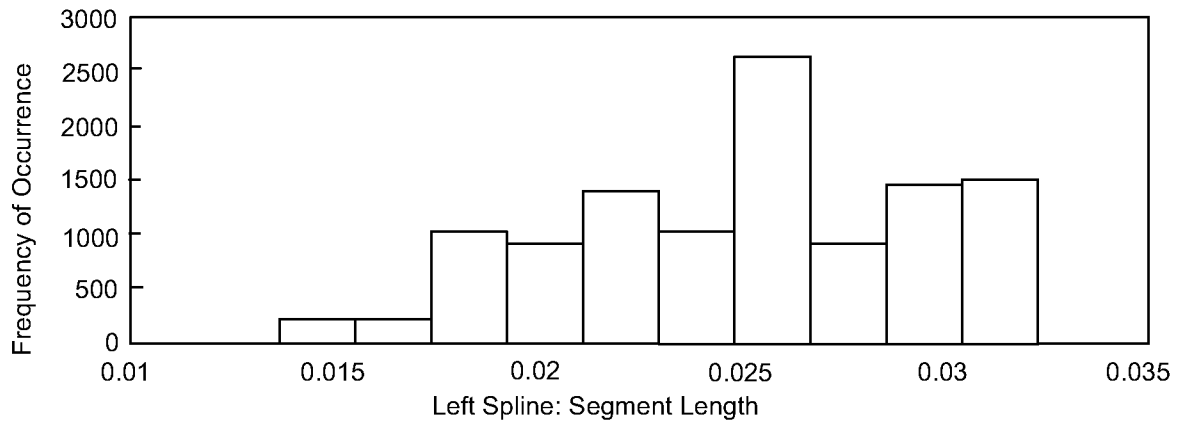


FIG. 3C



**FIG. 4**



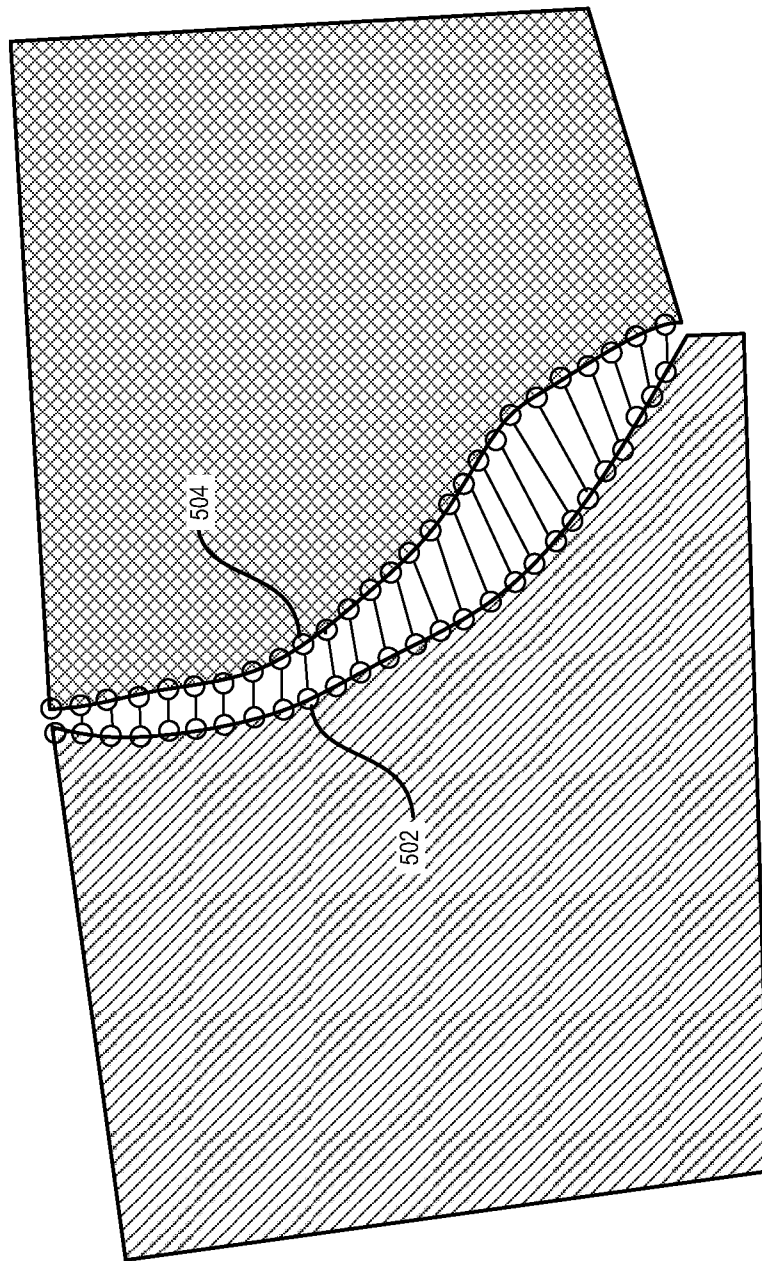
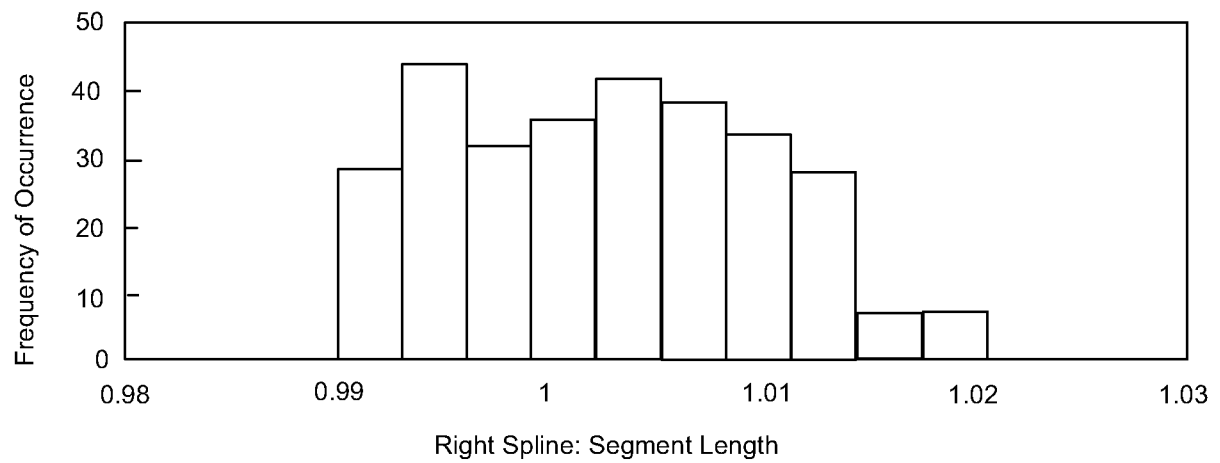
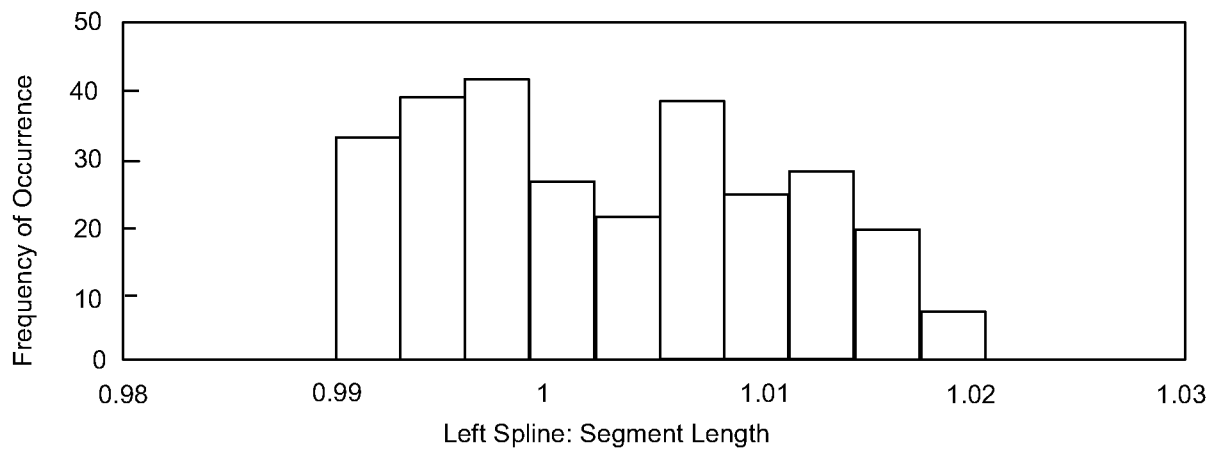
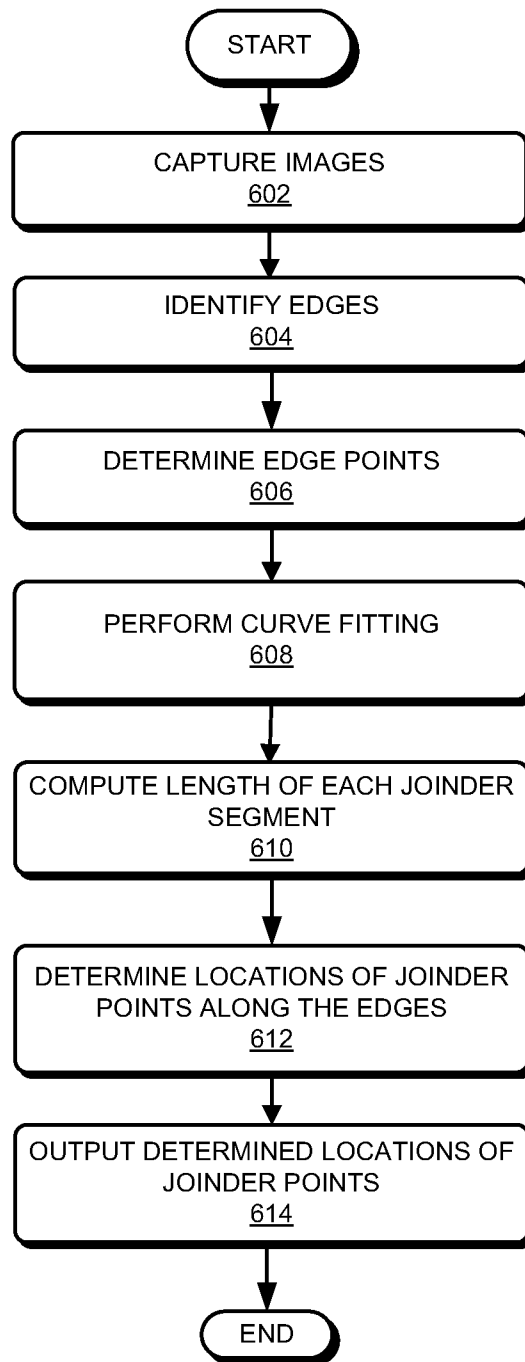


FIG. 5A



**FIG. 5B**



**FIG. 6**

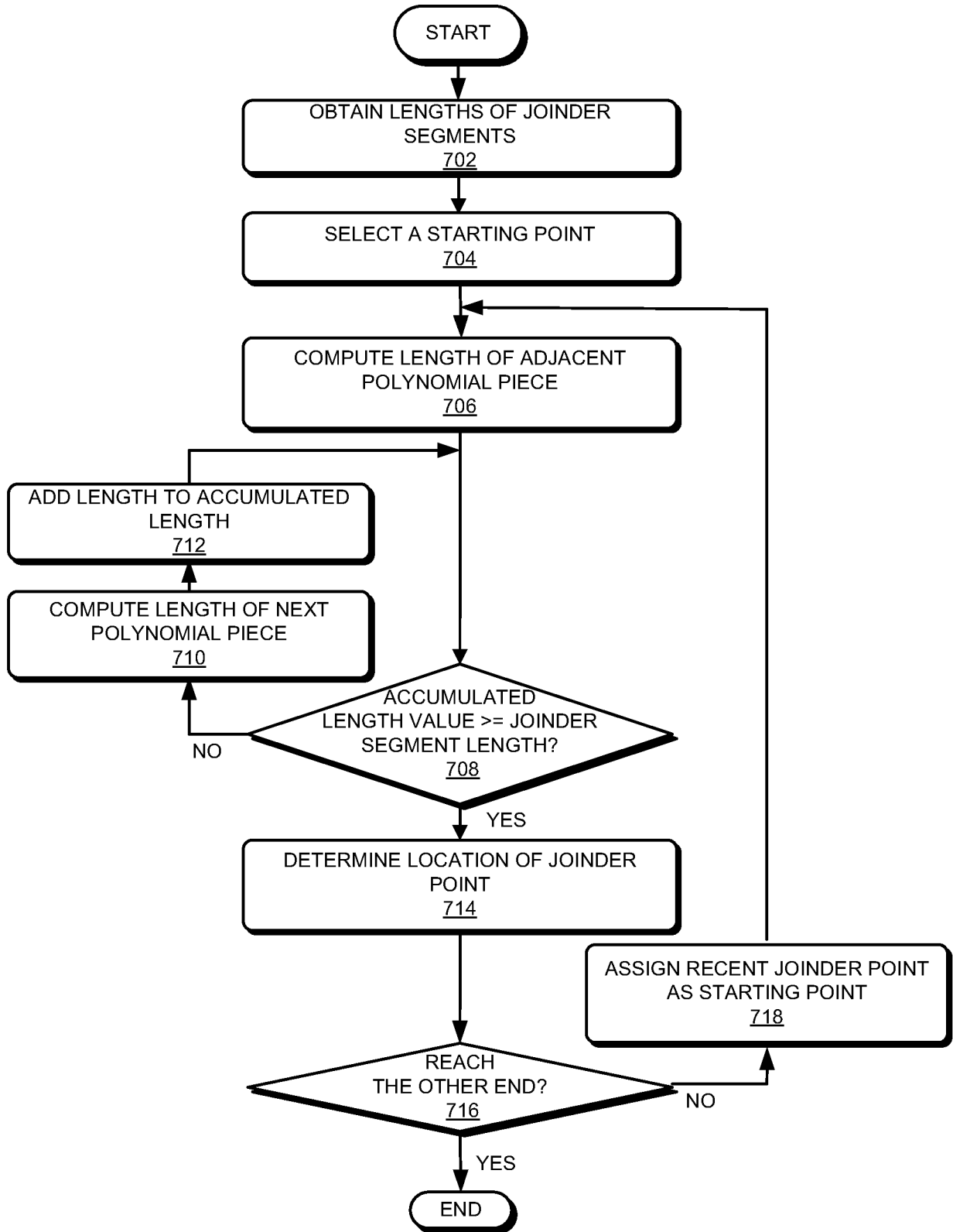


FIG. 7

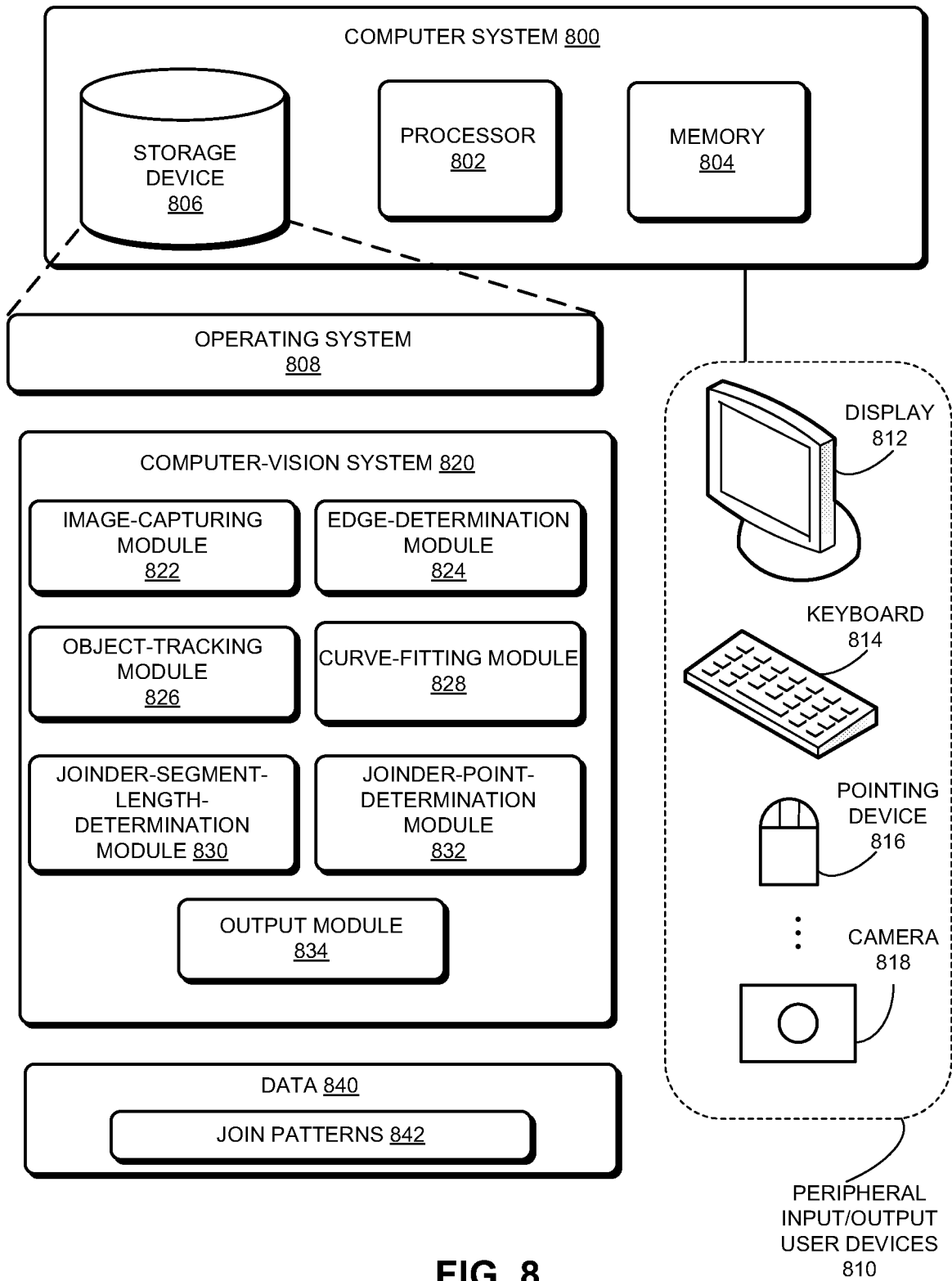


FIG. 8

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US2021/062426

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>		
IPC: D05B 19/12, 69/20; G06N 20/00; G06T 7/00, 7/13, 7/181 CPC: D05B 19/12, 69/20; G06N 20/00; G06T 7/00, 7/13, 7/181		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b>		
Minimum documentation searched (classification system followed by classification symbols) CPC: D05B 19/12, 69/20; G06N 20/00; G06T 7/13, 7/0004, 7/181, 2207/30124		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) US-PGPUB; USPAT; USOCR; FPRS; EPO; JPO; DERWENT; IBM_TDB ( 3 and ((identf\$3 detect\$3) near2 (edges boundaries contour edge))		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6,154,884 (DEHNER) 05 December 2000 (05.12.2000) , entire document.	1-21
A	US 6,854,146 B2 (STOYLES ET AL.) 15 February 2005 (15.02.2005) , entire document.	1-21
A	US 8,955,447 B1 (MIKSCH) 17 February 2015 (17.02.2015) , entire document.	1-21
A	US 2019/0257015 A1 (HARNETT) 22 August 2019 (22.08.2019) , entire document.	1-21
A	US 5,730,075 (MORIGUCHI) 24 March 1998 (24.03.1998) , entire document.	1-21
A	US 2018/0146717 A1 (BALLONE ET AL.) 31 May 2018 (31.05.2018) , entire document.	1-21
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
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Date of the actual completion of the international search <b>06 January 2022 (06.01.2022)</b>		Date of mailing of the international search report <b>11 January 2022 (11.01.2022)</b>
Name and mailing address of the ISA/US <b>COMMISSIONER FOR PATENTS MAIL STOP PCT, ATTN: ISA/US P.O. BOX 1450 ALEXANDRIA, VA 22313-1450, UNITED STATES OF AMERICA</b> Facsimile No. (571)273-8300		Authorized officer <b>HARRY KIM</b> Telephone No. 571-272-4300