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Stereolithography Multi-blade Recoating System

Abstract

A three-dimensional (3D) printing system configured to manufacture a three-dimensional (3D) article includes a vessel configured to contain a photocurable resin, a build plate coupled to the vertical movement mechanism, an imaging subsystem configured to selectively image over a build plane that is above the build plate, a coating subsystem including a plurality (N) of coater blades coupled to a horizontal movement mechanism, the N coater blades defining lateral regions therebetween, and a controller. The controller is configured to operate the vertical movement mechanism to position an upper surface of the build plate or the 3D article one layer thickness below the build plane, operate the horizontal movement mechanism to translate the N coater blades over the build plane and to provide a new layer of resin over the upper surface, and operate the imaging subsystem to selectively irradiate the new layer of resin in the lateral regions.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS [0001] This non-provisional patent application claims priority to U.S. Provisional Application Ser. No. 63/552,935, Entitled “Stereolithography Multi-blade Recoating System” by Patrick Dunne et al., filed on Feb. 13, 2024, incorporated herein by reference under the benefit of U.S.C. 119(e).

FIELD OF THE INVENTION
[0002] The present disclosure concerns an apparatus and method for the digital fabrication of three-dimensional (3D) articles by a layer-by-layer selective radiative curing of a photocurable build material. More particularly, the present disclosure concerns a way of reducing a total fabrication time.
BACKGROUND
[0003] 3D printing systems are in wide use for prototyping and manufacturing articles. One type of 3D printing system utilizes a process called stereolithography. A typical stereolithography system utilizes a resin vessel, an imaging system, and a build plate within liquid photocurable resin held by the resin vessel. An article is manufactured in a layer-by-layer manner by selectively imaging and radiatively curing layers of the photocurable resin over the build plate. There is an ongoing desire to improve productivity of 3D printing systems.
SUMMARY
[0004] A first aspect of the disclosure is a three-dimensional (3D) printing system configured to manufacture a three-dimensional (3D) article. The 3D printing system includes a vessel configured to contain a photocurable resin, a build plate coupled to the vertical movement mechanism, an imaging subsystem configured to selectively image over a build plane that is above the build plate, a coating subsystem including a plurality (N) of coater blades coupled to a horizontal movement mechanism, the plurality of coater blades defining lateral regions therebetween, and a controller. The controller is configured to operate the vertical movement mechanism to position an upper surface of the build plate or the 3D article one layer thickness below the build plane, operate the horizontal movement mechanism to translate the N coater blades over the build plane and to provide a new layer of resin over the upper surface, and operate the imaging subsystem to selectively irradiate the new layer of resin in the lateral regions.
[0005] In one implementation, the N coater blades are coupled to a support that moves with the N coater blades in unison during translation. The support can include two end portions that are spaced apart along a lateral X-axis (X), the translation is along a lateral Y-axis (Y) that is orthogonal to X. The N coater blades can extend along X between the two end portions. Motion of the support can be constrained by a linear bearing or by two linear bearings.
[0006] In another implementation, the controller is configured to operate the imaging subsystem concurrently with operating the horizontal movement mechanism.
[0007] In yet another implementation, the N coater blades extend along an oblique angle relative to X and Y. The horizontal movement mechanism can be configured to move the N coater blades along Y during a coating operation.

[0008] In a further embodiment, the N coater blades extend radially outward from a vertical axle. The build plane can have a lateral shape of a whole or partial circle.

Description

BRIEF DESCRIPTION OF THE FIGURES

[0009] FIG. **1** is a schematic illustration of an embodiment of a three-dimensional (3D) printing system for manufacturing or fabricating a 3D article.

[0010] FIG. **2** is an isometric drawing that illustrates certain components of a three-dimensional (3D) printing system for manufacturing or fabricating a 3D article.

[0011] FIG. **3** is an isometric drawing of a coating subsystem in isolation.

[0012] FIG. **4** is an isometric cutaway view of a single coater blade in isolation.

[0013] FIG. **5** is a schematic plan view of a multi-blade embodiment of a coater module positioned over a build plane.

[0014] FIG. **6** is a flowchart depicting a method of manufacturing a 3D article.

[0015] FIG. **7**A is a schematic plan view of a multi-blade coater module beginning to translate over a build plane.

[0016] FIG. **7**B is a schematic plan view of a multi-blade coater module at the end of a translation over a build plane.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0017] FIG. **1** is a schematic illustration of an embodiment of a three-dimensional (3D) printing system **2** for manufacturing or fabricating a 3D article **4**. In describing system **2**, mutually orthogonal axes X, Y, and Z will be utilized and otherwise referred to as an X-axis, a Y-axis, and a Z-axis. Axes X and Y are lateral axes that are generally horizontal. The Z-axis is a vertical axis that is generally aligned with a gravitational reference. The term “generally” implies that a direction or magnitude is not necessarily exact but is by design. Thus the term “generally horizontal” means horizontal (perpendicular to a gravitational vector) to within design and manufacturing tolerances. The term “generally aligned” means aligned to within design and manufacturing tolerances.

[0018] 3D printing system **2** includes a resin vessel **6** for containing a photocurable resin **8**. In the illustrated embodiment, photocurable resin **8** includes, inter alia, a monomer, a catalyst, and a filler. The catalyst allows the resin **8** to be hardened and cured with an application of radiation such as blue radiation, violet radiation, or ultraviolet radiation that would typically have a wavelength of less than about 450 nm (nanometers). Photocurable resins for stereolithography systems are known in the art.

[0019] System **2** includes a build plate **10** with an upper surface **12** upon which the 3D article **4** is formed. A build plate support structure **14** supports build plate **10**. A vertical movement mechanism **16** is operable to vertically position the build plate support structure **14** and in doing so vertically position the build plate **10**. In one embodiment, the vertical movement mechanism **16** includes a fixed motor coupled to a lead screw. The build plate support structure **14** includes a threaded bearing that receives the lead screw. As the motor turns the lead screw, the effect is to controllably translate the build plate support structure **14** up or down. In addition, the vertical movement mechanism **16** and the build plate support structure **14** include mutually engaging linear bearings that assure linear motion of the build plate support structure **14** along the vertical axis Z. Various vertical and lateral movement mechanisms are known in the field of stereolithography. All typically include linear bearings for guiding motion but the movement can be based upon a lead screw, a rack and pinion system, a belt and pulley system, or other well-known means of imparting motion.

[0020] System **2** includes a resin level subsystem **18** configured to maintain a resin upper surface **20** at a predetermined vertical position. In the illustrated embodiment, the resin upper surface **20** is generally coincident with a build plane **22**. The resin level subsystem **18** can include a resin level sensor and a weight coupled to a pully system. The weight is partially immersed in the resin **8** such that raising and lowering the weight alters a vertical position of the resin upper surface **20** via volumetric displacement. The resin level sensor outputs a signal indicative of a vertical position of the resin upper surface **20**. The signal is analyzed and the pully system is operated to raise and lower the weight to maintain the resin upper surface **20** to be generally coincident with the build plane **22**.

[0021] An “upper surface” **24** can be defined which is either the upper surface **12** or an upper surface **24** of the 3D article **4** when it is partially formed. Before forming an additional material layer onto the 3D article **4**, the upper surface **24** is positioned at a vertical position that is generally one material layer thickness below the build plane **22**.

[0022] System **2** includes a coating subsystem **26**. After upper surface **24** is positioned one layer thickness below build plane **22**, the coating subsystem **26** is configured to pass over the upper surface and to define a new layer **28** of the resin **8** over the upper surface **24**. Details of the coating subsystem **26** will be discussed infra. The new layer **28** of resin **8** has the resin upper surface **20** that is generally coincident with build plane **22**.

[0023] System **2** includes an imaging subsystem **30**. Imaging subsystem **30** is configured to scan an energy beam **32** over the build plane **22** to selectively cure and harden the new layer **28** of resin **8** and to form a new material layer of the 3D article **4**. In an illustrative embodiment, imaging subsystem **30** includes a laser that generates a radiation beam **32** that is reflected by a scanner. The scanner scans the radiation beam **32** over the build plane **22**. In an illustrative embodiment, the scanner includes two galvanometer mirrors including an X-mirror and a Y-mirror configured to scan the radiation beam along the X-axis and the Y-axis respectively over the build plane **22**. Imaging subsystems are known in the field of stereolithography.

[0024] In another embodiment, imaging subsystem **30** includes a light source, a reflective micromirror array, and projection optics. The light source illuminates the micromirror array. Individual mirrors in the micromirror array have two states including an ON state and an OFF state. In the ON state, a mirror reflects a pixel of light through the projection optics and to the build plane **22**. In the OFF state, the mirror reflects a pixel of light to a light trap that absorbs the light. In this way, the imaging subsystem **30** selectively illuminates an array of pixels over the build plane **22**. Such imaging subsystems are known as “DLP systems” or digital light processing subsystems and are known in the art of stereolithography.

[0025] Whether the imaging system **30** uses a scanning laser or pixel array, the light for selective curing is selected from a wavelength that is in the blue to ultraviolet range or from about 100 to 500 nanometers. The photocurable resin **8** catalyst is sensitive to the selected wavelength.

[0026] A controller **34** is coupled to the vertical movement mechanism **16**, the resin level subsystem **18**, the coating subsystem **26**, the imaging subsystem **30**, and other portions of system **2**. The controller **34** includes a processor **36** (such as a CPU or central processing unit) coupled to a non-transient information storage device **38** (such as flash memory). Storage device **38** stores software instructions. Controller **34** is configured to operate the portions of system **2** as the processor **36** executes the software instructions stored on the non-transient information storage device **38**. Controller **34** can includes a single unit that is associated with system **2** or it can include a plurality of control units that can be co-located with and or remotely located relative to the illustrated system **2**.

[0027] FIG. **2** is an isometric drawing that illustrates certain components of an embodiment of system **2**. In the illustrated embodiment from a user point of view the axes X, Y, and Z can be described. The lateral X-axis extends from left to right. The lateral Y-axis extends from front to back or from front to rear. The vertical Z-axis extends upward. The illustrated components include the resin vessel **6**, build plate **10**, build plate support structure **14**, vertical movement mechanism **16**, and resin level subsystem **18** (including the weight that is raised and lowered). The vertical movement mechanism **16** includes a motor **15** coupled to a vertical lead screw for providing vertical positioning of the build plate support structure **14** and the build plate **10**. Between the build plate support structure **14** and the vertical movement mechanism **16** are a pair of linear bearings (hidden in this figure) to control linearity of motion along the Z-axis. Not illustrated is the coating subsystem **26** and imaging subsystem **30**.

[0028] FIG. **3** is an isometric drawing of an embodiment of a coating subsystem **26** in isolation. Coating subsystem **26** includes a wiper module **40** or coater module **40** which includes a coater blade **42** that is supported between two end portions **44** which are at opposed ends of the coater blade **42** with respect to the lateral X-axis. While FIG. **3** illustrates a wiper module **40** with a single coater blade **42**, it is to be understood that an illustrative embodiment to be disclosed infra includes a plurality of coater blades **42** mounted to a wiper module or support **40**.

[0029] FIG. **4** is an isometric cutaway view of a single coater blade **42** in isolation. One end of the cutaway view illustrates an internal recess **46** that is at least partially filled with resin **8** to facilitate coating irregular upper surfaces **24** of 3D articles **4**. Coater blade **42** also has a lower edge **48**.

[0030] Referring back to FIG. **3**, coating subsystem **26** includes a pair of linear bearings **50** at opposed ends of the coater module **40** with respect to the X-axis. The end portions **44** are in sliding engagement with and supported by the linear bearings **50**. The end portions **44** slide upon the linear bearings **50** along the Y-axis.

[0031] Two belts **52** are individually supported by pulleys **54** at opposed ends of the coater module **40**. The belts **52** are attached to the end portions **44** at the opposed ends of the coater module **40**. A motor **56** is coupled to two of the pulleys **54**. Rotation of the pulleys **54** by motor **56** causes movement of the belt and translation of the coater module **40** along the Y-axis in sliding engagement and support by the linear bearings **50**. The combination of the motor **56**, pulleys **54**, belts **52**, and other possible components can be referred to as a “lateral movement mechanism” **58** for transporting coater module **40** along the Y-axis.

[0032] A set of four vertical actuators **60** support and vertically position the linear bearings **50**. The vertical actuators **60** are individually coupled between a vertical support **62** (FIG. **5**) and one of the linear bearings **50**. The linear bearings **50** individually are supported by a front vertical actuator **60** and a rear vertical actuator **60** which enables a height and angular tilt of each linear bearing **50** to be adjusted. In one embodiment, the vertical actuators **60** individually include a motorized lead screw that turns and thereby raises or lowers a nut that is attached to one end portion of one of the linear bearings **50**. The set of four vertical actuators **60** and other associated components can be referred to as a “vertical actuator system” **61**.

[0033] In the discussion that follows, it is to be understood that the coater module **40** can include end portions **44** that extend along Y and support a plurality of coater blades **42** that extend along X and are arranged along Y. FIG. **5** is a schematic plan view depicting a multi-blade embodiment of the coater module **40** positioned over build plane **22**. Coater module **40** includes two end portions **44** coupled by the plurality of coater blades **42**. The end portions **44** are individually coupled to linear bearings **50**. It is to be understood that the embodiment of FIG. **5** can be similar in certain respects to the embodiment of FIGS. **3** and **4** except for including a plurality of coater blades **42**.

[0034] Coater blades **42** can be modified relative to the coater blade **42** illustrated in FIG. **4**. For example, one coater blade can have a hollow circular cross-section with an internal recess **46** having a generally circular cross-section. Other generally rectangular, triangular, and variable shaped embodiments are possible.

[0035] The coater module **40** defines lateral regions **70** between pairs of coater blades **42**. In the illustrated embodiment, the lateral regions **70** are generally rectangular in shape and allow radiation from the imaging subsystem **30** to reach the build plane **22** between the coater blades **42**. The coater module **40** including the end portions **44** and coater blades **42** is configured to move as one unit along Y. Thus, during a fabrication or manufacturing process, the plurality of coater blades **42** move in unison.

[0036] FIG. **6** is a flowchart depicting a method **100** of manufacturing a 3D article using the embodiment of FIG. **5**. Generally speaking, method **100** is performed by controller **34** as the processor **36** executes software instructions stored on non-transient or non-volatile information storage **38**.

[0037] According to **102**, the coating subsystem **26** is calibrated. This can include leveling and height calibration of the lower edges **48** of the coater blades **42** relative to the build plane **22**. According to **104**, the vertical movement mechanism **16** is operated to position the upper surface of build platform **10** or later the 3D article **4** one layer thickness below the build plane **22**.

[0038] According to **106**, the plurality of coater blades **42** are positioned at a start position as illustrated in FIG. **5**. According to **108**, the lateral movement mechanism **58** is operated to begin translating or scanning the coater module **40** along Y as illustrated in FIG. **7**A. As scanning occurs, a plurality of leveled wakes **72** are formed behind the coating blades **42** and within the lateral regions **70**.

[0039] According to **110**—concurrent with translation of the coater blades **42**, the imaging subsystem **30** selectively irradiates the build plane **22** within the leveled wakes **72**. FIG. **7**B illustrates the state at which the coating blades **42** are fully translated along Y. During this translation, the imaging subsystem **30** has fully imaged the build plane **22**. Steps **104-110** can be repeated until the 3D article **4** is fully fabricated.

[0040] The coater module **40** is described as including coater blades **42** extending along X and translating along Y. In a first alternative embodiment, the coater blades **42** can extend along an axis that is oblique relative to X and Y (but still lateral or horizontal). Various geometries of the coater blades **42** are possible such as arcuate, zig-zag, or irregular as desired.

[0041] In a second alternative embodiment, the coater blades **42** extend radially from a vertical axle parallel to Z. The coater blades **42** are angularly rotated about the vertical axis. The build plane **22** can have a circular geometry with the vertical axis at the center. The circular geometry can be a full circle or a partial circle such as a half circle, quarter circle, or some fraction of a circle.

[0042] The specific embodiments and applications thereof described above are for illustrative purposes only and do not preclude modifications and variations encompassed by the scope of the following claims.

Claims

1. A three-dimensional (3D) printing system configured to manufacture a three-dimensional (3D) article comprising: a vessel configured to contain a photocurable resin; a build plate coupled to the vertical movement mechanism; an imaging subsystem configured to selectively image over a build plane that is above the build plate; a coating subsystem including a plurality (N) of coater blades coupled to a horizontal movement mechanism, the N coater blades defining lateral regions therebetween; a controller configured to operate the imaging subsystem and the coating subsystem to form a plurality of layers to fabricate the 3D article, for individual layers the controller is configured to: operate the vertical movement mechanism to position an upper surface of the build plate or the 3D article one layer thickness below the build plane; operate the horizontal movement mechanism to translate the N coater blades over the build plane and to provide a new layer of resin over the upper surface; and operate the imaging subsystem to selectively irradiate the new layer of resin in leveled wakes within the lateral regions.

2. The 3D printing system of claim 1 wherein the N coater blades are coupled to a support that moves with the N coater blades in unison during translation.

3. The 3D printing system of claim 2 wherein the support includes two end portions that are spaced apart along a lateral X-axis (X), the translation is along a lateral Y-axis (Y) that is orthogonal to X.

4. The 3D printing system of claim 3 wherein the N coater blades extend along X between the two end portions.

5. The 3D printing system of claim 2 wherein motion of the support is constrained by a linear

bearing.
6. The 3D printing system of claim 2 wherein motion of the support is constrained by two linear bearings.
7. The 3D printing system of claim 1 wherein the controller is configured to operate the imaging subsystem concurrently with operating the horizontal movement mechanism.
8. The 3D printing system of claim 1 wherein the N coater blades extend along an oblique angle relative to X and Y.
9. The 3D printing system of claim 1 wherein the N coater blades extend radially outward from a vertical axle.
10. The 3D printing system of claim 9 wherein the build plane has a lateral shape of a whole or partial circle.
11. A method of manufacturing a 3D article using a three dimensional printing system including a vessel configured to contain a photocurable resin, a build plate coupled to the vertical movement mechanism, an imaging subsystem configured to selectively image over a build plane that is above the build plate, and a coating subsystem including a plurality (N) of coater blades coupled to a horizontal movement mechanism, the N coater blades defining lateral regions therebetween, the method including: operating the vertical movement mechanism to position an upper surface of the build plate or the 3D article one layer thickness below the build plane; operating the horizontal movement mechanism to translate the N coater blades over the build plane and to provide a new layer of resin over the upper surface; and operating the imaging subsystem to selectively irradiate the new layer of resin in leveled wakes within the lateral regions.
12. The method of claim 11 wherein the N coater blades are coupled to a support that moves with the N coater blades in unison during translation.
13. The method of claim 12 wherein the support includes two end portions that are spaced apart along a lateral X-axis (X), the translation is along a lateral Y-axis (Y) that is orthogonal to X.
14. The method of claim 13 wherein the N coater blades extend along X between the two end portions.
15. The method of claim 12 wherein the support is constrained by a linear bearing.
16. The method of claim 12 wherein the support is constrained by two linear bearings.
17. The method of claim 11 wherein the controller is configured to operate the imaging subsystem concurrently with operating the horizontal movement mechanism.
18. The method of claim 11 wherein the N coater blades extend along an oblique angle relative to X and Y.
19. The method of claim 11 wherein the N coater blades extend outward from a vertical axle.
20. The method of claim 19 the build plane has a lateral shape of a whole or partial circle.
