allow a lower frame rate for image capture and therefore generates less image data. A profile of the cooling of the consolidated powder layer is used to infer the build quality of each level. However, by monitoring the cooling characteristics of the solidified powder, there is already an inherent delay in feedback control to the laser.

[0007] Any reference herein to a patent document or other matter which is given as prior art is not to be taken as an admission that that document or matter was known or that the information it contains was part of the common general knowledge as at the priority date of any of the claims.

Summary of the Invention

[0008] One aspect of the present invention provides an additive manufacturing system for fabricating 3D objects from successive layers of material, the additive manufacturing system comprising:

an energy projection assembly for inputting energy into a specified area within the layer to consolidate the material;

a plurality of image sensors, each of the image sensors having a corresponding field of view covering at least part of the layer of material, such that each of the fields of view at least partially overlap with the field of view of at least one other of the image sensors; and,

an image processor to capture image data from each of the image sensors; wherein during use;

the image processor controls exposure times for each of the image sensors and combines the image data from the image sensors to provide a single, spatially resolved image of the energy being input throughout the specified area for each layer of material respectively for comparison against threshold data values to locate potential consolidation defects in the specified area.

[0009] Throughout the description and claims of the specification, the word "comprise" and variations of the word, such as "comprising" and "comprises", is not intended to exclude other additives, components, integers or steps.

[0010] The additive manufacturing system according to embodiments of the present invention uses relatively long exposure times to capture a single image of the area being melted or sintered in that layer of powder. The overlapping image data from each of the relevant image sensors is combined to generate a single, spatially resolved image of the energy input at all points within the specified area. The pixel data from this single image is compared to a reference image and differences exceeding a predetermined variance are identified as potential defects in that layer of material. Each layer or 'slice' of the 3D object has a corresponding reference image and the single image generated from the image sensors is compared to the reference image for that slice.

[0011] Locating potential defects from a single image rather than a large set of images captured at high frame rates dramatically reduces the amount of data processing. This in turn reduces processing times such that real time feedback control of the fabrication process requires far

less processing power. As discussed further below, multiple image sensors allow a scalable system with much higher image resolution than otherwise possible.

[0012] Capturing the consolidation of the material as the energy is input provides a more accurate indication of potential defects. In contrast, some known techniques (for example US 2013/314504 discussed above) capture the infrared emissions from the cooling material to infer the build quality of the part. This can involve exposure times of up to five seconds in order to provide adequate image contrast needed for processing. The long exposure times used in embodiments of the present invention may also capture some image data immediately after consolidation. However, the relatively long exposure time is not for the purposes of creating image contrast but rather for data compression. Each pixel of the captured image has a luminosity value indicative of the visible radiation emitted during the energy input at that point. The overlapping fields of view ensure that the entire specified area is covered, but the control processor can switch between relevant image sensors to keep the exposure times short enough that background noise does not have a significant effect on the data captured. The control processor may simply divide up the specified area equally between each of the relevant image sensors or use some other technique for switching between sensors which takes into account the laser's raster pattern.

[0013] The use of multiple cameras allows increased image resolution of the image without resorting to expensive image sensors with large sensor arrays. The system is scalable in the sense that adding more image sensors extends the field of view. Furthermore, overlapping image data of the same sub-region, from different image sensors, is also useful for noise calibration. In contrast, single camera systems would need to use a wide angle lens, and/or a more elevated position to extend field of view. However, there are restrictions on the space surrounding powder bed fusion machines and wide angle lenses, or 'fish-eye' lenses, introduce detrimental image distortions and lower resolution.

[0014] The data captured by each image sensor is a spatially resolved image of the energy input in part of the specified area. When merged with the image data from the other image sensors, a single image with a relatively small amount of spatially resolved image data is indicative of the energy input across the whole area of interest within that layer of material. The comparison between this single image and a reference image requires little processing power and allows real-time feedback control of the laser or electron beam. Smaller data volumes are more easily stored, or used to develop a 3D defect map of the component.

[0015] There is also disclosed a method of fabricating a three dimensional object by additive manufacturing, the method comprising the steps of:

providing a layer of material in an unconsolidated form in a build chamber;

consolidating the material in a specified area of the layer using an energy projection assembly;

capturing a plurality of images of the specified area using a plurality of image sensors, each of the image sensors having a corresponding field of view covering at least part of the layer of material, and at least partially overlapping with the field of view of at least one other of the image sensors;

setting exposure times for image capture such that image data from the image sensors collectively provides a single, spatially resolved image of the specified area as energy is input to the material by the energy projection assembly; and,

comparing the image data from the single, spatially resolved image against threshold data values to locate potential consolidation defects in the specified area.

[0016] Preferably, the exposure times are staggered and at least partially overlapping with each other. Preferably, the energy projection assembly has at least one scanning laser head configured to scan a laser beam across the layer of material in the work bed in a reciprocating raster pattern, the control processor being configured to confine the raster pattern to the area of interest for that layer. However, embodiments of the invention may also be used in a stereo lithography system, digital light projection system, or a masked energy source projection system in which the entire area of interest is simultaneously exposed to an energy beam of corresponding shape.

[0017] In some embodiments of the invention, the image data from the single, spatially resolved image is resolved into scan vectors with associated intensity values corresponding to individual laser tracks followed the laser scan head. Assessing the energy input level along each scan track detects defects while also providing more process information than a straight forward comparison of the image data to reference data.

[0018] In a particularly preferred form, the material is a powdered metal. In other forms, the material is a powdered polymer, ceramic or liquid polymer.

[0019] Preferably the image sensors are CCD (charge-coupled device) arrays, CMOS (complementary metal oxide semi-conductor) arrays, or sCMOS (scientific-CMOS) arrays.

[0020] Preferably, the image processor is configured to selectively activate and deactivate the image sensors when the point of energy input is within areas of overlap between the corresponding fields of view.

[0021] Optionally, the energy projection assembly is configured deactivate between successive layers for a predetermined deactivation period, and the image processor is configured to activate and deactivate the image sensors to capture the single spatially resolved image within a capture period that is less than half the predetermined deactivation period such that the image processor is able to detect the end of the energy input process for each of the successive layers.

[0022] In some embodiments, the additive manufacturing system further comprises a build chamber for housing a build platform to support the layer of material, the build chamber having one or more viewing windows for observing the build process wherein the image sensors are mounted outside the build chamber and view the build platform through one or more of the viewing windows.

[0023] Optionally, the image sensors are positioned to view the layer of material on the build platform at an angle inclined to the normal of the layer, and the image processor is configured to manipulate the image data from each of the image sensors to correct for perspective. This is well suited to retro-fitting the system to existing PBF equipment where the image sensors will need to 'see' through the viewing window(s) on the side of the build chamber.