Metamorphic Manufacturing, or Robotic Blacksmithing – A Vision for a New Technology

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The Third Wave of Digital Manufacturing

Agile and reconfigurable manufacturing has been dominated by two waves of innovation. The first was numerically controlled *subtractive* manufacturing, commonly known as CNC machining. The second was numerically controlled *additive* manufacturing, often called 3-D printing. There is rightly much excitement about these technologies as they have revolutionized how we make things, however, they both have shortcomings.

Machining is a time-consuming process, adding considerable cost to components because only a fraction of the original material is used in the part (the rest is turned to chips) and an expensive machine is tied up for some time to make the part.

Additive manufacturing is in its infancy, but often components are created from powders. This also produces significant waste; secondary operations are usually needed for high performance and the costs of raw materials and equipment usage can be high.

‘Revolutionary’

Machine makes 3-D objects from drawings

By Kathleen Sullivan
American-Statesman Staff

Wedged into the corner of an unused photo lab at the University of Texas is an ungainly machine that can transform a computer drawing into a three-dimensional model at the touch of a button.

Sometime next year, the machine, which was developed by a UT graduate student, will make its way out of the lab and into the commercial arena. It will leave with the blessing of the UT Board of Regents, which Thursday gave an Austin company exclusive licensing rights to the "revolutionary" new technology embodied in the machine.

The licensing pact paves the way for the first transfer of technology from the University of Texas at Austin to a commercial venture.

The company that won the right to market the invention is Nova Automation Corp., whose principal shareholders are an Austin consulting engineer and Nova Graphics International Corp., an Austin-based computer graphics software firm.

The agreement represents a "hard fought" victory for UT's fledgling Center for Technology Development and Transfer, said Meg Wilson, coordinator of the center, which was given life during the last Texas Legislature and got

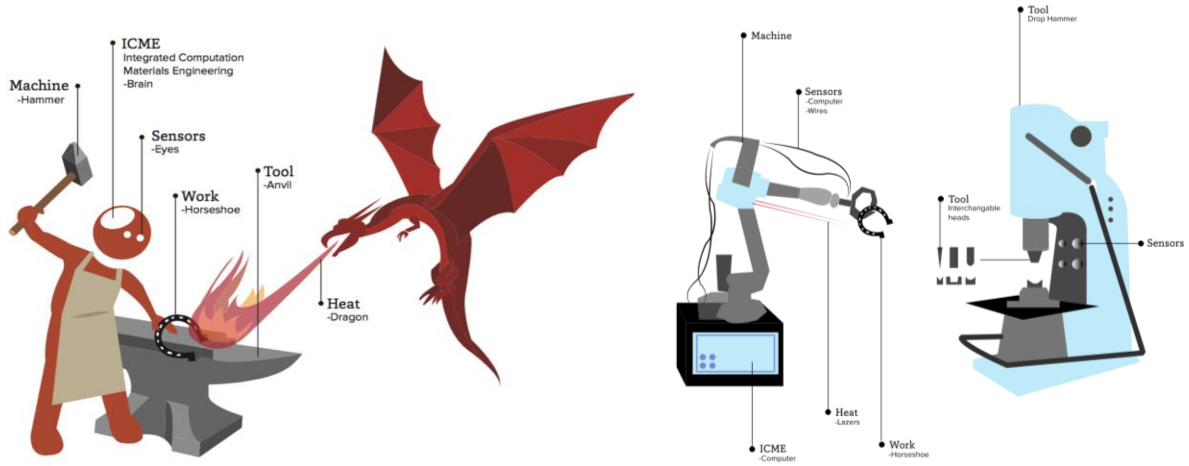
See Inventor, A11

Staff photo by Ralph Barrera

Associate Professor Joe Beaman shows some three-dimensional plastic models made by the 'selective laser centering' device developed by Carl Deckard, left.

The first two waves of digital and reconfigurable manufacturing: Early CNC System - to calculate airfoil coordinates MIT circa 1949 [Marty, 2013] and 1987 news clipping from the Austin American-Statesman newspaper heralding Nova Automation and their "revolutionary" new technology of 3-D printing.

Imagine if a machine can act like a blacksmith does, squeezing and bending metal into shape, and doing this at temperatures and with deformation that actually improve the materials properties. We refer to this as *metamorphic* manufacturing and believe it will take its place alongside existing digital maniufacturing: additive and subtractive manufacturing.



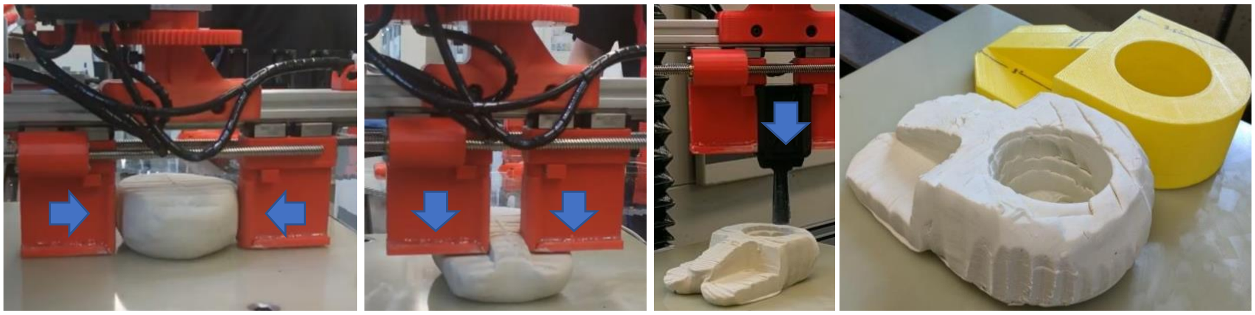
The past and future of metamorphic manufacturing

Benefits of Metamorphic Manufacturing

Blacksmiths have demonstrated that with skill and ingenuity a huge range of components (armor, swords, art) can be produced, and they can develop remarkable properties in the process, such as samurai blades with very hard sharp edges and tough interiors. However, human blacksmiths cannot be relied upon to make parts with high dimensional precision or highly reproducible properties, but with advances in machines (servo-controlled presses, precision robotics, precision optical non-contact metrology) it is possible to mimic the attributes of a blacksmith, but with dramatically improved dimensional control, reproducibility and monitoring of the process path to assure quality, allowing high performance components to be used in safety-critical applications. There can be immense cost and time savings replacing closed-die forgings with robotically blacksmithed parts, particularly if they are assured to have high properties and performance.

An example of a plastic shaping process

The first LIFT prize challenged students to develop systems that could create shapes from computer controlled deformation systems that they created (see: roboticblacksmithing.com). Oil-based clay (plasticine) was used as the workpiece material because it is relatively easy to deform and has been used for decades to represent hot metal in physical models. The winning team (Team Honey Badger, from The Ohio State University) developed a system that created both a simple bracket and horse-shoe with a single reprogrammable system that adds rotatable squeezers to a CNC machining mill. This can be adapted to metals with high force actuators.



Frame grabs from a video of the Honey Badger system (video at https://www.youtube.com/watch?v=QflVRXLwsAw). From left to right showing basic shaping of the billet using multiple inward motions of the pincers, •Downward motion of separated platens to create the septum, • Incremental piercing using an auto-changed tool to create the central hole, • Comparing the numerically shaped plasticine to the target shape. The same system has been reprogrammed to create a horseshoe shape from the same size and shape plasticine block.

The Path Ahead

The full vison of metamorphic manufacturing integrates shaping, working and heat treatment to optimize properties and shape and local properties and recording of shape and temperature to allow assured reproduction of critical process elements. This leverages recent technical developments, but requires significant integration and advanced control systems.

There are many *machines* that can be used including hammers, displacement controlled presses, rollers, etc. Because deformation is provided in small increments, only modest forces are needed. *Optical* monitoring and *Control* systems are required to measure the current shape of the component and temperature field and strains can be estimated by computation. Correction routines can adjust shape the way a blacksmith would. Significant *integration* and an advanced closed-loop *control* system will be required to create advanced parts using this type of incremental deformation.

In order for this approach to truly thrive, it will need to be adopted to where validation and verification protocols exist so that components made in this way can be certified for safety-critical use, for example in aircraft. The rewards that can drive this are large. This approach promises high-quality, rapidly produced parts that have low environmental footprint, can have low-cost and are produced locally.