

# 3D Texture Maps from an Articulated Sensor Camera Mesh

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Figure 1: Left: Input into our system, a chair. Center: An articulated 3D mesh scanner. Right: Our result, a scanned chair.

## Abstract

In this paper we introduce a novel system for hand held 3d scanning. We work towards creating an articulated camera mesh with interwoven sensors to detect physical geometry. By combining many sensors, including bend sensors and accelerometers, to get more information about larger scale physical deformations we can add much information and accuracy to 3D reconstructions based on images. Initial prototypes we have built show that this can work well as a scanning technique for mid-size objects (those bigger than a breadbox but smaller than a car), as the entire object must be transversed similar to a flat bed scanner.

**CR Categories:** K.6.1 [Management of Computing and Information Systems]: Project and People Management—Life Cycle; K.7.m [The Computing Profession]: Miscellaneous—Ethics

**Keywords:** 3D scanning, camera mesh, articulated sensor mesh

## 1 Introduction

Although early 3d scanning techniques required the use of physical touch such as 3D digitizers with articulated arms that had six degrees of freedom, much of the current work in 3D scanning has focused on reconstruction from photographic data. Using a combination of laser and optical scanners one can recreate in objects in 3D with a high level of detail [Levoy et al. 2000]. And other software based optical scanning technologies are becoming more and more robust, where even simple web cameras can be used to reconstruct 3D objects [Pan et al. 2009].

However we believe there are cases where you may not easily be able to see the entire object, but still want to gain a 3d reconstruction of it; there maybe other objects in the way or places where it is hard to gain the right perspective like the inside of a vase.

We wish to create a handheld 3d scanning device that can easily capture hard to reach areas and also be easy to use. By creating

an articulate mesh based scanner we hope to reconstruct the 3D geometry with very little computation and instead depend on physical sensors to gain 3D deformation information.

## 2 Related Work

There has been previous work on creating flexible Camera Arrays for creating panoramas where one can change the field of view by bending the structure [Nomura et al. 2007]. However these systems do not sense the deformation and instead just stitch the photos together. We improve upon these designs by adding sensing of the flexible mesh. This gives us an accurate measure of the current 3d geometry of the mesh, which can be used to reconstruct the object on the computer.

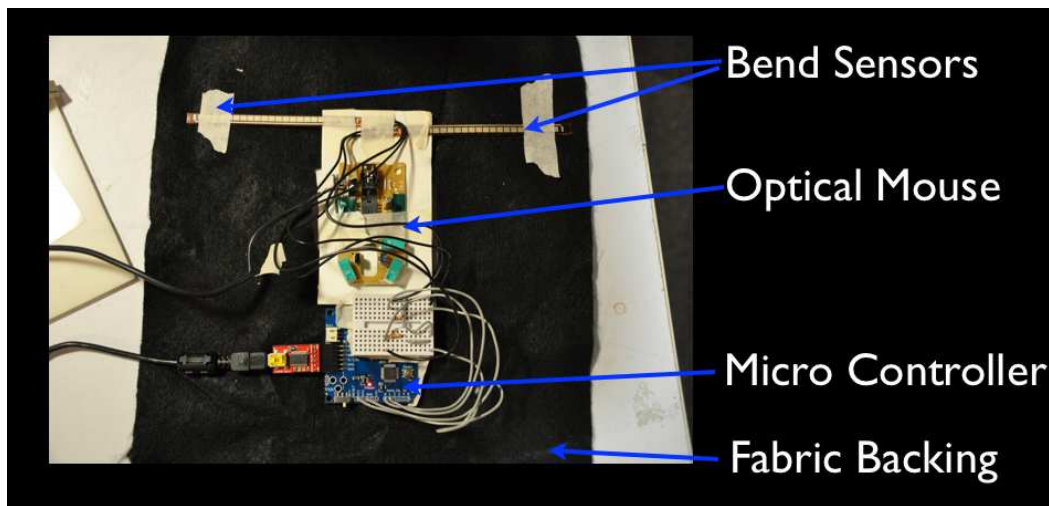
Other flexible sensor meshes have been built such as chainX [Mistree 2008]. But we plan to augment these designs by adding higher resolution image sensing and the ability to sense its motion over an object through optical flow. This is similar the way in which optical sensors have been employed in addition to ultrasonic sensors to be able to reconstruct 3D volumetric renderings of the inside of humans [Buil et al. 2003].

Also we build off of work done by Gelsight which can be used to scan 3d objects with a very high frequency detail captured by use of gel substrate [Johnson and Adelson 2009]. The object could be translated across the surface to scan an entire object, and they also built a hand held scanner that can be translated across the surface. We instead focus on lower frequency detail but at a larger scale.

## 3 Articulated Meshes as 3D Scanners

Our goal in this project was to create an articulated mesh of sensors that could know what shape it was currently deformed to, be able to sense the color and texture under every node, and send this information back to the computer to reconstruct the 3D geometry. You could imagine wrapping an object in a "blanket" of sensors that would deform to the objects geometry and in one pass you would have a 3D model of that object on your computer. But this scenario requires many many sensors and very small sensors as well. 3D

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**Figure 2:** *The initial prototype and a description of its essential parts.*

laser scanners can easily get sub millimeter accuracy, so to get that type of resolution you would need millions of sensors that were also sub millimeter.

But instead of creating an entire mesh that could be wrapped around an object you could instead create only a small portion of that mesh and move it around the entire object. In away it would be like cleaning the object, you want to move this sensor cloth around the object and cover every square inch.

The advantages to an articulated sensor mesh as a 3D scanner are that it is small and can get to regions that other methods cannot because of space constraints. Traditional optical and laser based scanners need to be at least a foot away to see the entire object. As opposed to articulated 6DOF arms and many laser scanners, the object does not need to remain stationary. It requires much less computation than reconstructing a 3D model from a set of still images. And in the end it could be folded up and put in your pocket.

## 4 Implementation

We set out to build a larger model of a mesh scanner with off the shelf parts because our goal of creating an articulated mesh sensor no thicker than a sheet of cloth may currently be technically challenging. We use standard usb web cameras for image input and a number of sensors to be able to reconstruct the 3D geometry. The goal is to use bend sensors to approximate the curvature at a give point on the object, then move the sensor to a different point on the object, measure the distance traveled on the surface of the object using optical flow, and measure the new curvature at the new point. We could then reconstruct the geometry by starting at the point then rotating to the curvature at that point, translating the distance measured and repeating.

### 4.1 First Prototype

We began building our first prototype to evaluate the possibility of using bend sensors to accurately measure the angle of curvature at a given point on an object, and using a camera for both texture map data and optical flow. We also tested different substrates for connecting all of the nodes together. We used an Arduino microcontroller to send the sensor data back to the computer which ran a custom program created in Processing with OpenGL.

Our basic setup consisted of one main node containing the camera, microcontroller, and optical mouse, and two child nodes with nothing but cardboard. The nodes were connected by bend sensors and could be bent more than 90 degrees in either direction. The nodes were arranged linearly, and attached to a common substrate to prevent them from disconnecting and to make the entire system easier to hold.



**Figure 3:** *Results from the initial prototype. A human arm being scanned.*

#### 4.1.1 Mouse as position Sensor

We attempted to use optical flow to get a measure of distance in X and Y directions the mesh traveled over the object, however due to lighting conditions and motion blur we were unable to get reliable results from software based optical flow. Instead we opted to use an optical mouse as a relative position sensor. Optical mice run optical flow in hardware, which offloads a great deal of processing from our software. Our optical mouse had a resolution of 400dpi. We used the library ProControl to get raw relative data from the mouse as opposed to cursor locations.

As a result of this decision to use a mouse as sensor our mesh scanner had to stay very close to the object being scanned, because the focal length of most optical mice is very short. This ended up creating problems when the sensor was moved but not close enough to the object, resulting in gaps in the data.

### 4.1.2 Evaluation of Mesh Substrates

Because our mesh scanner had to be placed on, conform to, and translate over the objects it was scanning it was important that the substrate that the mesh scanner was supported by had to move smoothly over the object. We tried a number of different materials and many of them would get caught on kinks in the object, or create too much friction. There was also a trade off between ease of deformation and flimsiness of the entire structure.

The first material we tried was felt which provided a strong enough support for all of the sensors but easily got caught on a variety of objects, creating problems in ease of use. Next we tried thin sheets of acrylic plastic, however these sheets were too sturdy and did not deform easily enough, also the edges and corners of the material would get caught easily. We found a thinner plastic worked well but was unable to support the weight of all the nodes.

Our final solution was to use a two sheets of thin plastic, with a foam inner sheet to provide structural support.

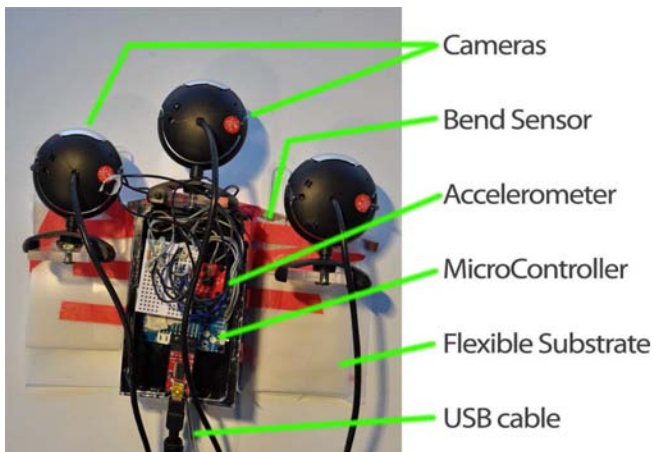


Figure 4: The final prototype with 3 articulated cameras.

## 4.2 Final Physical Prototype

Building on what we had learned from the first prototype we set out to create a 3 camera mesh array. In our final prototype in addition to the bend sensors we also included an accelerometer for absolute orientation information. We use one accelerometer in the main node and then sense the relative positions of the other node based on the bend sensors, this solution ends up being cheaper than using an accelerometer at every node. The accelerometer helps in situations where you change angles very quickly, for example the transition between the seat and the back of a chair. However the accelerometer does not give accurate rotation information when it is not changing its orientation relative to the direction of gravity; this it is important for the object being scanned to remain a constant orientation with respect to the direction of gravity as well.

We sample every inch the entire mesh moves in any direction. this length was chosen because more frequent sampling led to larger missing data areas due to the mouse sensor not being close enough to the object.

We also addressed the fact that our bend sensors only gave us very accurate results when being bent in one direction. We still wanted to be able to easily sense convex and concave structures. We choose to make our system reversible, so that the bend sensors were always

bending the same direction, so we added the ability to turn the cameras around and added a second mouse on the other side. We also sought to have a more robust prototype, so we built a laser-cut structure around the electronics and attached this to the substrate as well.



Figure 5: The underside of the scanner. Here the optical mouse is visible along with the bend sensors.



Figure 6: The final prototype in action. Note that the cameras can bend to conform to the shape of the object being scanned.

### 4.2.1 Cameras

From our first prototype it became clear that we needed web cameras that had macro lenses. We also wanted to add a local light source so that the scanning would be able to operate even in the dark but also to get rid of the shadow cast by the camera onto the surface. We were able to find off the shelf cameras that met our need. However we still placed the cameras 1.5 inches from the surface in order to scan a larger area at once. Due to the size of our sensor nodes we needed to get a larger area of sensing, because we could not get very accurate results of the contour information.



### 4.3 Software Reconstruction

We used OpenGL and Processing to create 3D models from the data sets. The algorithm starts at the first data point and works out. This can be a problem because much of the data we base our reconstruction on is relative. Therefore if there is even a little bit of noise in the system, or some value is sensed wrong our reconstruction will get worse and worse.

We mapped each image taken on to a plane in 3d oriented according to the sensor data. In the future we would like to add some feature based image stitching or use viewfinder alignment to better stitch the images together [Adams et al. 2008].

## 5 Results

With our prototype mesh array 3D scanner we were able to scan a variety of objects. As you can see in figure 7 we are able to capture the basic shape of a complex object at a medium size scale along with color and texture information. We are also able to capture hard to reach geometry such as the inside of a trash can or behind a filing cabinet (figures 8 and 9). The system is also fairly portable.

However there are still many problems with our system. Currently the resolution for the geometry is low at about one polygon per inch. This could be improved by creating smaller sensors or sampling more frequently. Problems arose in our system with sampling at smaller distances due to problems correctly measure x and y translation using optical mice over non planar surfaces. We also have problems with color calibration and color accuracy across cameras and lighting conditions. The LED lighting used by the cameras also casts a specific pattern on the textures, however this could be removed in software. Motion blur from moving the scanner too quickly also brings up issues of scalability and cost.



**Figure 7:** Our scanner currently works best on large, curvy objects, like this chair.

## 6 Future Work

We would like to continue this work by creating smaller nodes and using the cameras for optical flow based position information. By increasing the number of nodes we could also cut down on the time required to scan an entire object - this could be a big win over other scanning technologies. There is also the possibility of combining this project with gelSight, which would provide higher frequency details and our system could provide lower frequency, gross 3D shape information.



**Figure 8:** The inside of a trashcan being scanned. Our scanner can easily fit in hard to reach places.



**Figure 9:** Our system can scan hard to reach places, such as behind filing cabinets.

## 7 Conclusion

This paper presented a novel system for capturing 3D texture maps and 3D geometry using a sensed articulated camera array. Our contributions include augmenting flexible camera arrays with sensors, using both absolute and relative sensors for more realistic reconstruction, using cheap 2d relative position sensors to be able to time multiplex the sensing area.

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