ABSTRACT
Currently, wearable computers are bulky and expensive, keeping them out of the mass market. This project will build a wearable computer that helps solve these problems by simultaneously reducing cost, and increasing portability.

INTRODUCTION
The inspiration of this project was to create a new iteration of the wearable computer worn by Professor Thad Starner[1] but based on the BeagleBoard[2] single board computer due to its low cost, small size, and low power requirements.

Recent years have seen a proliferation of single board computers such as the BeagleBoard that are based upon embedded processors. These computers have longer battery life and produce less heat than other types of computers such as small tablet PCs or netbooks, making them able to be used closer to the body and thus allowing new form factors. Also, other types of small computers typically have a screen that would not be used in a wearable of the type we are trying to make, and eliminating that screen significantly reduces the cost of the device.

The BeagleBoard in particular serves as a good platform because it is well supported and has a large user community. The good support comes from the fact that Texas Instruments, the manufacturer of the OMAP chip used in the BeagleBoard, are using the BeagleBoard as a way to popularize the use of their chip in small embedded devices with graphical output.

PREVIOUS / RELATED RESEARCH
Good documentation on construction of wearable computers is a bit sparse. The following projects listed are less than 5 years old and are similar to what we are trying to build.
- MITril is a (mostly) COTS wearable from MIT.[3]
- Kent Lyons’ workshop at iswc05, Stargate Wearable Platform, outlines a system based on a small embedded computer.[4]
- Herbert, by Greg Priest-Dorman, is mostly COTS, but far more expensive than what we are aiming for.[5]
- Thad Starner’s Lizzy is similar to our stated goal, but again, it is expensive.

DESIGN - PRESENT AND FUTURE
Concepts and Early Prototype
This project depends not only on what technology is used, but how the user can actually wear the device. Our primary concerns for wearability included physical characteristics such as size, weight, and heat as well as aesthetic considerations.

Figure 1: Three early concepts.

Multiple possible setups were considered. Figure 1 shows three possibilities: a hip mount, a backpack insert, and a bandoleer style sash. The bandoleer was chosen for several reasons. First, it places key components in easy-to-access places. Second, it can be worn regardless of the other clothes the user is wearing, with or without a backpack. Third, the strap mount across the chest allows the components to be spread out for easy heat dissipation.

For Phase One of the project, it was necessary to make design concessions- most notably, the Beagle Board computer that was at the center of the design could not be procured in time, and the Linutop had to be substituted. Due to the size of the Linutop, the bandoleer-style arrangement would not be realistic, so the prototype wearable was housed in an over-the-shoulder bag that rests at the wearers hip. Although this was not the optimal setup, it was already greatly improved over other wearable precedents in terms of size, weight, and visual obtrusiveness.

Concept development for Phase 2 progressed with the Beagle Board in mind, allowing the bandoleer-style to move forward. Some dimensions were determined at this stage, such as the use of a 1.5 inch wide strap and a 4 inch maximum ideal width for the modules that will enclose the various components. Further work was done on the modules to minimize visual obtrusiveness and still fit all necessary components and connections. Other details of the design were added, such as providing a free USB port routed to the top middle of the front strap, giving the user easy access. The video cable connected to the eyepiece will be routed along the back strap, minimizing extra slack cable and allowing the user to simply drape the eyepiece over his shoulder when not in use. The battery, as the heaviest component, will be mounted at the hip to provide stability.
Two features were developed at this stage and not included in the final prototype. Ridged plastic or foam was going to be used under each component. This would serve to not only prevent any heat buildup from the components but also to allow some airflow to help prevent the wearer from sweating. Also, padding was planned for the strap where it rests on the shoulder in order to reduce discomfort. Both these features, though still worth considering for full-scale production, were not implemented in the final prototype since the weight of the prototype was less than expected.

Please see the addendum page(s) for further illustrations and concept work.

Final Prototype Construction

The final prototype mostly adhered to the concept drawing generated at the end of Project 1. A 1.5 strap was used to mount the components diagonally across the users torso. Custom casings were built for both the BeagleBoard and the USB hub module. These casings were made in SolidWorks and 3D printed out of ABS plastic. Each casing had four parts: a top and bottom enclosure and two brackets to let the casing mount onto the strap. The brackets were built separately of the enclosures so that they could be stitched in place on the strap without interference.

Both the bracket-enclosure joint as well as the seam between the two enclosure halves was a simple pressure-fit joint. These seams held reasonably well by simply making the inner and outer contact surfaces with zero spacing and then orienting the parts so that the striation of the plastic was perpendicular to the joining direction. All these joints could easily be epoxied solid, but we decided not to in order to facilitate modification and demonstration of the inner components.

Both housings were made slightly larger than was necessary in order to accommodate variances in the way the wires fit inside. The ends of the housings were both made fully open, rather than with individual holes as in the original drawings, for the same reason. Also, the housing for the BeagleBoard was made with cooling vents on the underside of the housing that extend to the housings edge. Passthrough buttons were built into the top enclosure to provide access to the USER and RESET buttons on the board itself. The USB hub module was modified from the original design, with two user-accessible ports now available on the leading edge of the enclosure rather than one sewn into the strap. Although not implemented in the prototype, a headphone jack slot is also built into the casing, alongside the two USB ports.

Two components were not given plastic casings as originally intended: the battery and the display control module. The display was not available in time and thus was not included. The battery housing was given a fabric enclosure for simplicities sake. Since the battery housing is where the two strap ends are connected, a sturdy plate was 3D printed out of ABS plastic and stitched to the back of the battery housing. This plate has two loops which the strap ends are anchored to.

For the purposes of good body fit, the strap was made with a great deal of available adjustment length. The adjustment buckle was positioned on the chest above the topmost module, in easy reach while wearing the device, while the excess strap tucks neatly under the wearable. The strap is also specially angled–the anchors for the strap on the battery housing, as well as the way the ends are sewn into loops, angle the strap so that it lays flat against the body.

It is important to note that although this design has made significant strides towards our goal, a mass-produced design would be even better. Much of the bulk of the existing casings is a result of using hacked together hardware, and more specialized internal components would result in a much slimmer design. This would also address an issue that was raised about women wearing the design, since the components extend so far up the chest. Even with a conservative estimate of shrinking the overall size of the components by two-thirds,
this will no longer be an issue.

**HARDWARE**

The BeagleBoard is an OMAP3530 platform designed specifically to address the Open Source Community. It measures only 3.0” by 3.1”. The OMAP3530 Processor features an ARM Cortex-A8 core with 256KB L2 cache running at up to 600MHz, a graphics accelerator, and a TMS320C64x+ DSP. The BeagleBoard has 256MB of NAND memory and 128MB MDDR SDRAM. No other memory devices are on the BeagleBoard. It is possible however, that additional memory can be added to BeagleBoard by installing a NAND based device in the SD/MMC slot or use the USB OTG port and a powered USB hub to drive a USB Thumb drive or hard drive. Support for this is dependent upon driver support in the OS.

We installed Linux on an SD card according to the instructions from http://elinux.org/BeagleBoardBeginners, but we used gparted, a gui partitioning utility, instead of fdisk and mkfs because we had trouble with mkfs not being able to see the partitions that fdisk had created.

The Beagle Board draws a maximum of 2 Amps at 5 Volts. This is with all of the peripherals running and the processor fully loaded. It draws closer to 1.5 amps in normal usage. A voltage converter was used in conjunction with a Sony NP-F950 camcorder battery which has a capacity of 5500 mAh at 7.2 V for 39.6 Wh, which gives a usage time of about 5 hours.

The serial interface to the board was made by taking the wires from pins 2, 3, and 5 from a serial cable and connecting them to pins 2, 3, and 5 of the beagleboard serial interface. None of the other wires should be connected to ground or anything else. We had the problem of wires 2 and 3 being swapped, so if trying to use minicom with the beagle board doesn’t work (i.e. you get nothing when trying to use it), then try swapping them.

For connecting to the USB OTG port of the BeagleBoard, the micro USB interface needs to a micro-A plug, so if the cable is being made from a micro-B cable, it will not work because one of the pins (4) needs to be connected to ground whereas in the micro-B cable it is connected to nothing. Look for a little ‘a’ or ‘b’ on the plug. If you have the appropriate micro-A end, then soldering like colors of cable together, along with connecting the sheathings, should work.

The display is half of a Myvu Crystal that is plugged into the BeagleBoard S-Video port. It has a VGA resolution, and a battery life of about 4 hours, but it can be charged through a USB port while it is being used, so it can be used as long as the computer can be used.

**CONCLUSION**

This project has successfully created a prototype of a wearable computer based upon the BeagleBoard single board computer. The small size of the Beagle Board allows a form factors not possible with larger computers. By keeping the cost under $1000 we hope that we have allowed others to cheaply reproduce what we have done. Hopefully this will create further interest and experimentation with wearable computers.

The size and cost of a wearable computer like the one we have described could be reduced further by integrating things like the USB hub, eyepiece control box, and the voltage converter into the same board as the computer. This, along with using bluetooth or some other radio system for the Twiddler will make for a wearable computer that may see widespread acceptance.

**REFERENCES**

1. http://www.cc.gatech.edu/~thad/