# Workplane-Orientation–Sensing Techniques for Tablet PCs

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## ABSTRACT
Many mobile applications could benefit from having more fine-grained awareness of user-to-device orientation than is possible with traditional landscape and portrait modes. In contrast to approaches that measure absolute orientation of a device in world coordinates, we argue for the need to measure *workplane orientation*: the angle of rotation, relative to the user, around the axis perpendicular to the user's work surface. We present two complementary methods to determine workplane orientation for a hand-held writing surface: one using computer vision techniques and another based on stylus-pose.

**Categories and Subject Descriptors:** H.5.2 [**User Interfaces**]: Input devices and strategies, Vision I/O, Interaction styles

**Additional Keywords and Phrases:** orientation-aware systems, mobile devices, pen-based computing, tablet interaction

## MOTIVATION
Tablet PCs were originally developed to allow interaction inspired by paper and pencil. Today's devices are handwriting-enabled and they include a few desktop GUI widgets that are modified to control the on-screen cursor with a stylus rather than a mouse. These devices typically support the simple notion of absolute orientation in 90° increments (landscape vs. portrait modes). However, people often interact with conventional media in much less restrictive ways than landscape or portrait orientation implies.

Fitzmaurice and colleagues [4] studied how artists take advantage of reorienting their work surface during sketching and writing. They introduced and explored many issues relating to what they called Rotating User Interfaces (RUIs): applications and toolkits for pen-based computing systems that take into account *workplane orientation*—the angle of rotation, relative to the user, around the axis perpendicular to the user's work surface. To provide Tablet PCs with such capabilities, a method to sense workplane orientation is required.

A number of researchers [7, 5, 8] have used absolute-orientation sensing to enter data and manipulate the way content is displayed. In contrast, we are interested in making possible systems in which the content creation and manipulation environment and the GUI components dynamically react to changes in workplane orientation. Also, we wanted to create a mobile sensing system that could be easily added to current Tablet PC computers; therefore, we ruled out non-portable or tethered sensors, as well as sensors that require the installation of infrastructure external to the Tablet PC (e.g., the electromagnetic tracker used in Fitzmaurice's Chameleon [3]).


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Figure 1: Face tracking used to determine workplane orientation. Orientation-aware note-taking application. (Inset face is shown from camera's point-of-view.)

We have developed two independent and complementary techniques for automatically measuring workplane orientation in mobile systems at granularity smaller than 90°. One uses computer vision for face tracking and requires that a small camera be mounted near the display. This method computes workplane orientation relative to the user's face. The other method is based on stylus-pose tracking, a hardware technology that is widely available on some higher-end electromagnetic digitizer tablets that have not yet been integrated into Tablet PCs. In contrast to the first method, this approach computes workplane orientation relative to the user's hand.

## WORKPLANE ORIENTATION FROM FACE TRACKING
We observed that users tend to change their head pitch and yaw angles relative to the Tablet PC when using it, but they do not change their head roll angle significantly. Therefore, we attempted to determine if changes in head roll angle—as seen from a tablet-mounted camera aimed at the user—are a useful indicator of workplane orientation relative to the user's face.

We mounted a Logitech Notebook Pro camera (640×480 pixels) on the edge of an HP TC1100 Tablet PC, oriented to continuously capture video of the user looking at the screen. We use a Haar-feature–based face detector [6] to first find the user's face. Once found, the position and size of the bounding box enclosing the face, and color information extracted from the bounding box, are used to initialize the search window of a face-tracking system. We use the Continuously Adaptive Mean Shift (CAMShift) tracking algorithm [1] for face tracking. Using the color information provided by the face detector, CAMShift represents the face as a 2D probability distribution of hue values. It derives four degrees of freedom from the image as it continuously tracks the face in real-time. We use the head roll angle to infer workplane orientation.

We have found that this vision-based recognition method works well in informal experiments. It tracks head tilt in increments consistent with Bradski [1], who determined that CAMShift's standard deviation of tracking differences was 2.4° for roll angle (when compared with a Polhemus tracker that obtained 2.5° accuracy in his lab) giving us quite small workplane-orientation granularity. However, to avoid visual jitter, we quantize the output, updating the display only when the inferred workplane orientation has changed more than a preset value from the last update (15° in the case of the video).

## WORKPLANE ORIENTATION FROM STYLUS POSE

While watching users write or sketch, we noted that pen angle relative to the writing surface—*stylus pose*—remains fairly constant over time for each writer. Using this stylus-pose information alone, we tried to determine workplane orientation relative to the user's hand.

To explore how well stylus-pose can be used to determine workplane orientation, we asked eight subjects to each write the same sentence repeatedly, and we affixed paper templates to the tablet to guide their writing at measured angles (with the orientation of the tablet itself freely controlled by the user and not measured in this study). We collected stylus writing samples written at 15° inclinations from 0° to 90°, and we annotated this data according to its writing angle. The Wacom Intuos2 digitizer tablet we use indicates stylus-pose values by reporting stylus *tilt* and *azimuth* in addition to the typical $x$ and $y$ tip coordinates and stylus pressure. Since each subject's stylus position varies due to individual writing style, a naïve tilt/azimuth-to-workplane orientation-mapping solution is not adequate. Therefore, we trained a simple machine-learning classifier ($k$-nearest neighbor [2]) with the stylus-pose data from these individual user writing samples.

Using cross validation, we found $k$=5 provided the best accuracy scores during testing without over generalizing. We also tested the same stylus-pose data—originally in tilt/azimuth coordinate space—projected to Cartesian space (assuming a stylus of unit length) and realized greater accuracy. We used this technique to predict workplane orientation for our subjects with a mean accuracy of 94% (and a range from 88.6% to 99.6%) at 15° granularity.

## CONCLUSIONS

We have shown that efficient means exist for sensing workplane orientation. By applying existing computer vision and machine learning techniques, we are able to reliably determine workplane orientation with a granularity of 15° or better, without the use of sensors that require external infrastructure that could not be incorporated in a Tablet PC. We believe that we have not reached the lower bound on the granularity achievable with our modeling techniques, and we are working to improve upon our current results.

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