

"MEMSEye" FOR OPTICAL 3D TRACKING AND IMAGING APPLICATIONS

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We demonstrate fast-motion tracking of an object in a 3D volume, while obtaining its precise XYZ coordinates. Any object can be tracked which is marked by a small retro-reflective tape, or a corner-cube retroreflector (CCR.) Two separate MEMS mirror-based optical subsystems which we termed "MEMSEyes" track the position of the object in a 40 kHz loop. A demonstration system capable of full-speed human hand motion provides position information at up to 5m distance with 13-bit precision and repeatability.

Obtaining real-time 3D co-ordinates of a moving object, as depicted in Fig. 1a, has many applications such as gaming [1], robotics and human-computer interaction [2-3], industrial automation, etc. Various technologies have been investigated and used in these applications including sensing via wire-interfaces [2], ultrasound, RFID, and laser interferometry. A simple and low-cost solution that can provide enough precision and flexibility has not been available. Recent proliferation of inertial sensors cannot adequately address this problem. We previously presented [4] results of optically tracking a photodetector in 3D, however this method was not flexible enough for real applications and scanning angle was insufficient. The present solution integrates photodetectors near the MEMS mirrors, allowing any objects with substantial reflection to be tracked. Use of our MEMS mirrors [6] (Fig. 2) with wide-angle lenses enables fast and low-cost tracking in a very large volume.

Each MEMSEye unit (Figs. 3 and 4) has a light source, lenses, a two-axis MEMS mirror, and a quad-cell silicon photodetector. We presently use visible (red) lasers, however future applications may use near-IR. Lenses control beam shapes and increase scanning angle. Typical maximum scanning field of view (FOV) of our devices is 24°, which is increased to 45° with a wide-angle lens. There is a small, low-power high voltage amplifier for each MEMSEye unit to drive the MEMS mirror.

Searching and tracking are the two main modes of operation for each MEMSEye unit. Initially it spiral-searches for a target. When a target returns sufficient light, the unit stops at that location and begins tracking mode to maintain pointing of the laser beam to the center of the target. During tracking the system obtains new azimuth and elevation information about the target at a high rate. A unit can also time-multiplex among multiple targets. Here we demonstrate such a scheme with two targets located on a paddle (Fig. 1c) which allows the system to measure the paddle's orientation vector.

Both mirrors' X and Y axes are driven by separate channels of an FPGA system. When tracking, the FPGA system records the azimuth and elevation angle of pointing of mirror1, θ_{X1} and θ_{Y1}. Second mirror, spaced at a known distance d provides angles θ_{X2} and θ_{Y2} (Fig. 4). Both devices see nearly identical Y readings θ_{Y1} and θ_{Y2}, but due to motion parallax the X readings are different and depend on the distance of the object. We utilize triangulation to obtain distance to the object as:

$$z = \frac{d}{\tan(\theta_{X1}) - \tan(\theta_{X2})}$$

We additionally demonstrate finding orientation angles of a long object (Fig. 1c and Fig. 6b) which can be freely oriented in space. Here we require knowledge of two points marked by two retro-reflectors. The system switches the pointing of both MEMSEyes between those two targets and continually obtains XYZ location for each end of the rod. Therefore a line vector is obtained.

Our MEMS devices provide pointing precision >= the system's electronic 16-bit resolution and successfully track both retro-reflective tape and corner-cube targets (Fig. 5). However due to some noise in the photodiode signals we found that the overall setup was limited to about 13-14 bits of precision, giving ~10000 repeatable positions for each axis (100 "Mpixels",) over the 45° field of view. With improvements in laser stability and photodiode circuitry we expect to exceed 14 bits and reach about 30000 positions for each axis. Examples of measured translation (Fig. 6a) and orientation (Fig. 6b) verify the concept system function.

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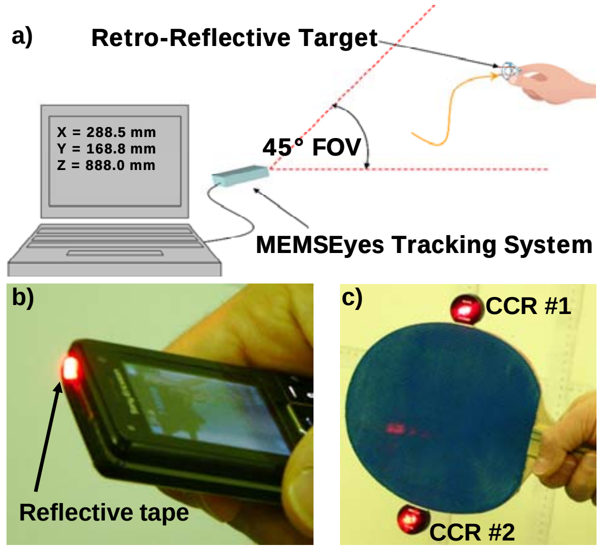

Figure 1a: (a) Schematic diagram of 3D tracking of a hand-held retroreflector in a 45° cone volume. Precise X,Y,Z position is displayed on a PC. (b) Photograph of a cell-phone marked with retroreflective tape (bright area) being tracked with a laser beam, and (c) photograph of a paddle-marked with two CCRs tracked with laser beams, providing orientation and position information.

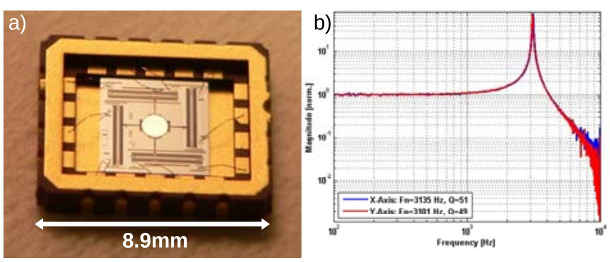

Figure 2. Gimbal-less dual-axis device used in this work: (a) device in an LCC package which reaches mechanical tilt from -6° to +6° on both axes. Mirror diameter is 1mm. (b) Frequency response of the device used in current MEMSEye prototype. First resonance is above 3kHz, giving a wide bandwidth of operation for agile target tracking.

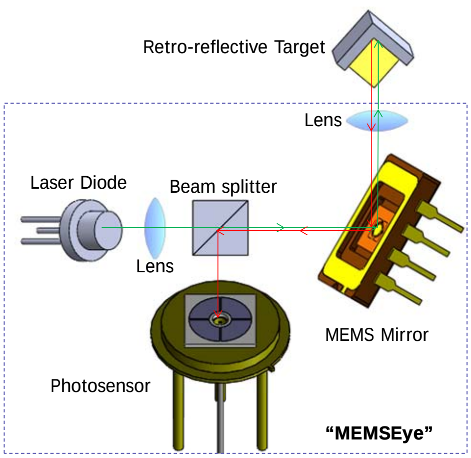

Figure 3. MEMSEye for optical 3D tracking: schematic of a single sub-system and its components.

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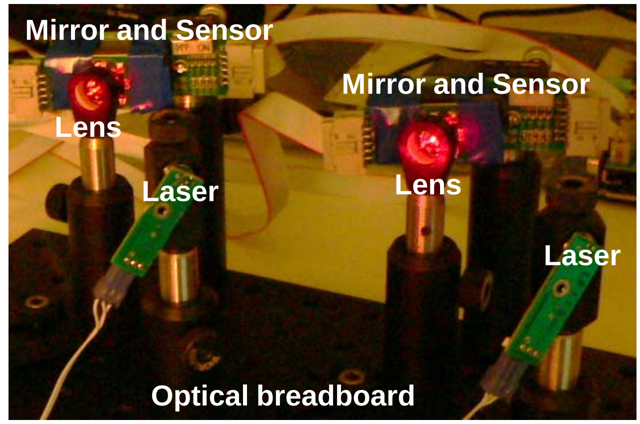

Figure 4. MEMSEyes for optical 3D tracking: photograph of the present demonstrator with two MEMSEyes at 127mm distance actively tracking a retro-reflector.

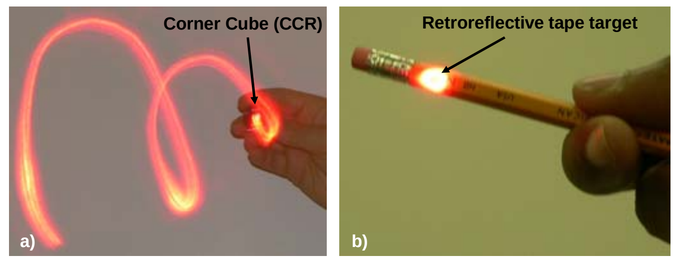

Figure 5. Examples of objects being tracked (targets are bright because the tracking system is actively pointing the laser beam onto them: (a) moving corner-cube retro-reflector and (b) a pencil with a retroreflective tape target.

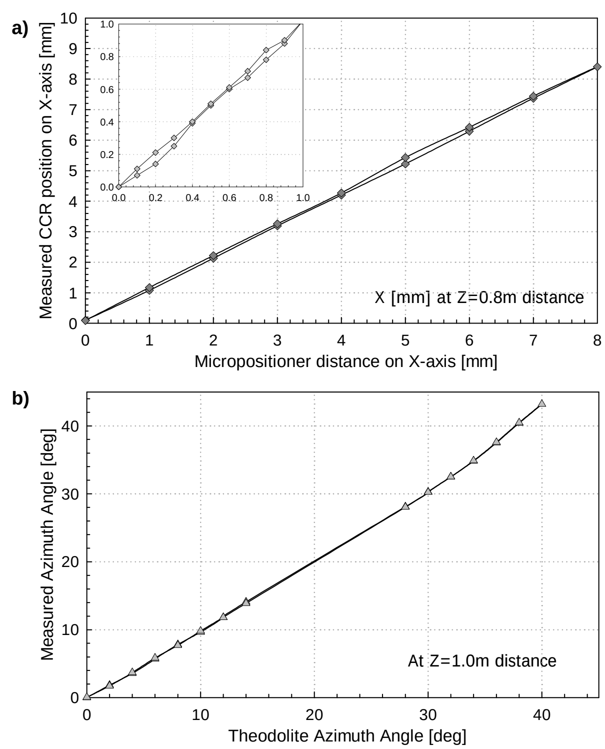

Figure 6. Example characterizations of (a) position measurement and (b) azimuth orientation measurement.