QUASI-STATIC MICROSCANNER WITH LINEARIZED SCANNING FOR AN ADAPTIVE 3D-LASERCAMERA

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ABSTRACT

This paper presents a gimbaled MEMS scanning mirror especially developed for adaptive raster scanning in a novel 3D-ToF laser camera. Substantial quasi-static deflections of ±10° are provided by vertical comb drives in vertical direction in contrast to resonant horizontal scanning of the 2.6x3.6mm elliptical mirror at 1600Hz and 80° FOV. To guarantee the full reception aperture of effective 5mm a synchronized driven array – consisting of five hybrid assembled MEMS devices with integrated position feedback – is used by the 3D camera enabling a distance measuring rate of 1MVoxel/s and an uncertainty of ToF distance measurement of 5mm at 7.5m.

INTRODUCTION

Laser scanners are widely used for time of flight (ToF) 3D-distance measurement due to their advantage of higher measurement accuracy compared to focal plane array ToF cameras. Therefore, a scanning mirror with large aperture is required to collect small amounts of light scattered by the measured target. Traditionally, polygon scanner are used, but for high scanning speeds only heavy (>10kg) and cost intensive scanning units exist. Its replacement by micromechanical scanning mirrors, which have the benefits of high scanning speed, low weight, high mechanical reliability (e.g. no friction), is not straight-forward since the aperture of a single MSM is limited to small values of typically 1…3mm diameter due to the dynamic mirror deformation. To overcome the mentioned problem, Fraunhofer developed the concept for a MEMS-based LIDAR based on an array of identical synchronized driven MEMS elements [1]. A first MEMS prototype were limited to resonant 1D scanning at 250Hz and 60° FOV of a monolithic 2x7 MEMS array with total aperture of 334.2 mm² [2]. Now, we extend the MEMS-based LIDAR to an adaptive 3D-ToF laser camera with foveation properties to allow e.g. future autonomous robots to better interact with their surroundings. The 3D sensor concept of foveation – that is acquiring distance images at video like frame rates with coarse spatial resolution, rapidly detecting regions of interest (ROI), and then concentrating further image acquisition on these ROIs with adaptive scanning – requires a challenging 2D-scanning device with quasi-static actuation, large aperture ≥ 5mm and large FOV > 60°. The best technical compromise of the fast adaptive scanning unit was found in a quasi-static / resonant raster scanning MEMS mirror to (i) meet opposite requirements of fast scanning (> 1000Hz), large FOV combined with large mirror aperture and (ii) to partially enable foveation by adaptive vertical scanning (see Fig. 1).

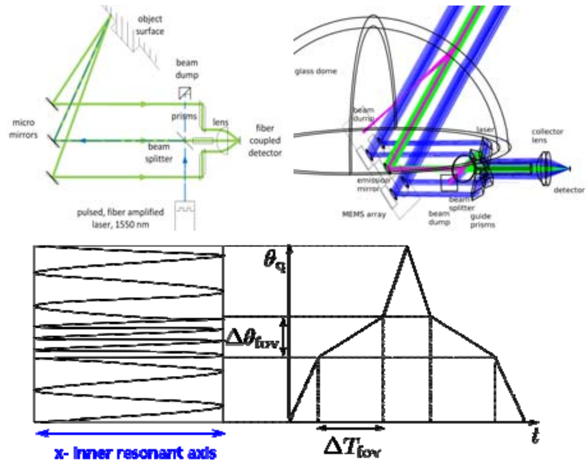

Figure 1. Concept of adaptive MSM based 3D-camera: (above) Optical setup [4] using a 2D-MSM array to provide sufficient aperture; (below) 2D-raster scan with adaptive vertical scanning partially enabling foveation in ROI's $\Delta\theta_{fov}$.

To provide the effective reception aperture of 5mm a MSM array consisting of five hybrid assembled MEMS scanning mirrors are precisely synchronized operated in respect to the sending mirror of the ToF camera enabling an uncertainty of ToF distance measurement of 3…5mm at 7.5m measuring range.

MEMS DEVICE FOR 2D RASTER SCANNING

The 2D-raster scanner (see Fig. 2) consists of a resonant inner mirror gimbal suspended within a quasi-static actuated frame. Whereas the inner mirror is actuated in parametric resonance, 3Dout-of-plane staggered vertical comb drives are used for quasi-static actuation of the outer frame. The SVC comb drives enables a quasi-static deflection of ±10° at 150V DC (see Fig. 3). Resonant horizontal scanning at 1600Hz guarantees a large horizontal

FOV of up to 80° even for the 2.6x3.6mm large mirror with only < 28nm dynamic pp-mirror deformation. To provide the full 5mm effective reception aperture five hybrid assembled MSM must be precisely synchronized. To enable real-time control piezo-resistive position sensors are integrated on chip for both scanning axes.

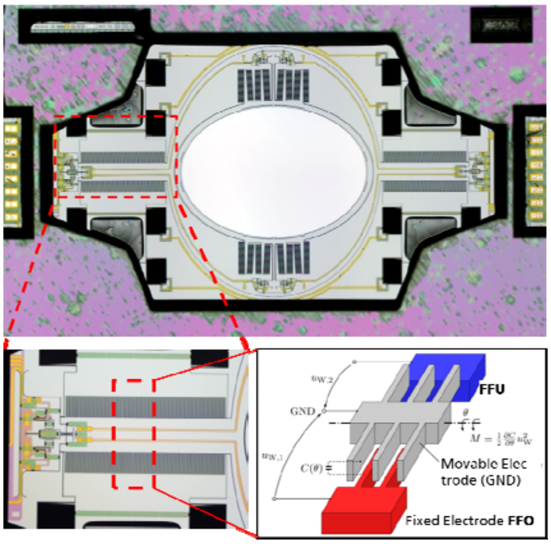

Figure 2. Photograph of quasi-static / resonant 2D-MSM raster scanning mirror; (below) details of quasi-static staggered vertical comb (SVC) drive.

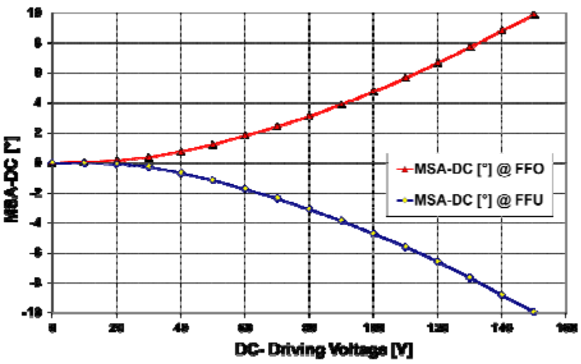

Figure 3. Static deflection characteristic of the quasi-static frame, mechanical tilt angle vs. DC driving voltage of positive and negative scan direction.

Driving control of quasi-static axis is a challenge due to poor Eigen dynamics of the MSM because it still represents a high Q spring mass system only very lowly damped by the surrounding viscous gas. Typically (i) symmetric triangular scanning patterns at 10Hz or (ii) symmetric linear scan patterns with reduced scanning velocity are required for higher resolved ROI`s. In addition, the maximum deviation of temporal angular scan position is limited to only 0.05° for all five MSM over the entire scan range due to the small FOV of the fiber coupled detector to guarantee the full effective reception aperture of the 3D-camera. Several methods for open loop MEMS driving control were tested. The best results were achieved by using a flat based OL control [5], some experimental scan trajectories are shown in Fig. 4 for different scan patterns successfully verifying and demonstrating the potential of adaptive scanning.

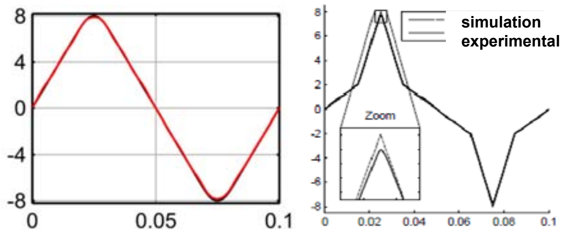

Figure 4. flat based OL driving control of quasi-static axis with linearized triangular (left) and foveated (right) scan trajectories at 10Hz.

CONCLUSION

A gimbal-suspended quasi-static / resonant 2D-raster scanning MEMS mirror was presented enabling a static tilt angle of MSA = ±10° and variable scan frequencies from DC…125Hz not possible with a common resonant MSM. Resonant horizontal scanning at 1600 Hz guarantees a large optical scan range of up to 80° even for the 2.6x3.6mm single mirror. To provide the full 5mm effective reception aperture – required by the ToF camera – five frequencies selected 2D-MEMS raster scanning mirrors were hybrid assembled and driven in synchronized 2D operation with respect to the sending mirror enabling the best technical compromise of opposite requirements: partial foveation, fast scanning speed, large scan range, sufficient effective aperture, high yield and low cost. The adaptive 3D-ToF camera provides a distance measuring rate of 1MVoxel/s and an uncertainty of ToF distance measurement of 3…5mm at 7.5m measuring range enabling e.g. 3D-images with 1Mpixel per second or 10 frames of 100kpixel per second, respectively, over a 40°x60° (potentially 60°x80°) large FOV. The presented work was supported by the EC within the FP7 project TACO. The authors acknowledge for the public founding.

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