Optical image stabilization with a liquid lens

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Abstract: We present an optical image stabilization system (OIS) using a liquid lens component. We give a theoretical estimation of the performances and we describe experimental set-up with a 5Mpix 1/3" sensor camera module.

Keywords: liquid lens, optical image stabilization, OIS, AF, camera module, mobile phone, digital still camera

1. Introduction

The image quality of most of the pictures taken in low light conditions with high resolution miniature camera modules of cellular phones is limited by handshake blur [ref. 1]. In such cameras, the miniaturization has led to degraded light sensitivity, leading to increased exposure time. Electronic and software handshake blur reduction failing to restore good image quality, the implementation of optical image stabilization (OIS) on camera modules is today the main way to improve significantly image quality [ref. 1]. Among the different OIS technologies under development [ref. 2], a liquid lens component based on electro-wetting [ref. 3] can generate an electrically controlled optical tilt in two directions with a tilt range and a response time well adapted to the design of an OIS on a miniature mobile phone camera module . In addition, an OIS liquid lens can also provide focus control [ref. 4] and enable the realization of a miniature OIS auto-focus (AF) camera module without any mobile mechanical parts.

2. OIS liquid lens description and features

We have developed an OIS liquid lens component (Arctic316S) designed to be plugged on a fix focus camera module lens to provide both OIS and AF functions. We give in table 1 the main characteristics of the engineering samples of this component:

Item	Value
Entrance pupil diameter	1.6mm
Optical tilt range	+/-0.6°
Full range tilt response time @90%	30ms
Focus range	0 to 20 diopters
Optical wave front error in AF mode	60nm-rms

Table 1. A316S - OIS liquid lens main features

3. OIS performance simulation

Performance evaluation of an OIS system must be statistical because handshake is highly dependent on users and experimental conditions. We present below a theoretical estimation of the average handshake blur reduction performed by an OIS system which is based on handshake noise spectral density models. Handshake movement can be decomposed into 3 translation components and 3 rotation components. We have experimentally confirmed that image blur contribution induced by translation components of handshake becomes negligible for objects farther than one meter. In the following study, we consider the pitch or yaw rotation components of handshake. For each component, the rms value of the angular handshake tilt generated during a picture integration time T_{pct} is given by:

$$\Theta_{hs\_rms}(T_{pct}) = \sqrt{\frac{1}{T_{pct}} \int_{t=0}^{t=T_{pct}} \left(\Theta(t) - \overline{\Theta}_{T_{pct}}\right)^2 dt} \qquad (1)$$

where $\Theta(t)$ is the instantaneous tilt of the camera. We can estimate the average rms value of the angular handshake tilt generated during picture integration time T_{pct} with the following expression:

$$\Theta^2_{hs\_rms}(T_{pct}) = \int_{\nu=0}^{\nu=\infty} S_{\Theta_{hs}}(\nu) \cdot \left|A_{T_{pct}}(\nu)\right|^2 \cdot d\nu \qquad (2)$$

where the first term $S_{\Theta hs}(\nu)$ is the power spectral density of the handshake tilt and the second term is the amplitude blur generated during T_{pct} by a unitary sine wave component at a frequency ν averaged over a random phase:

$$\left|A_{T_{pct}}(\nu)\right|^2 = 1 - \left(\frac{\sin(\pi \cdot \nu \cdot T_{pct})}{\pi \cdot \nu \cdot T_{pct}}\right)^2 \qquad (3)$$

The principle of an OIS system consists in measuring the instantaneous handshake tilt and generating an opposite tilt with an optical tilt actuator. With picture integration times up to 600ms, we have experimentally observed that a +/-0.5° tilt range is enough to compensate for the handshake tilt. We can simulate the residual handshake blur of an OIS system in a linear model with the following expression:

$$\Theta^2_{residual\_OIS}(T_{pct}) = \int_{\nu=0}^{\nu=\infty} S_{\Theta_{gyro}}(\nu) \cdot \left|A_{LL}(\nu)\right|^2 \cdot \left|A_{T_{pct}}(\nu)\right|^2 \cdot d\nu + \int_{\nu=0}^{\nu=\infty} S_{\Theta_{hs}}(\nu) \cdot \left|1 - F_{gyro}(\nu) \cdot A_{LL}(\nu)\right|^2 \cdot \left|A_{T_{pct}}(\nu)\right|^2 \cdot d\nu \qquad (4)$$

where $A_{LL}(\nu)$ is the frequency response of the optical tilt actuator, $F_{gyro}(\nu)$ and $S_{\Theta gyro}(\nu)$ are respectively the frequency transfer function and the equivalent tilt noise spectral density of the sub-system measuring the handshake tilt of the camera. The first term of expression (4) gives the noise contribution of the tilt measurement sub-system and the second term estimates the intrinsic residual OIS blur according to the type of handshake noise and to the frequency response of the tilt actuator.

We have estimated the performances of an OIS system with the OIS liquid lens described in §2. The experimental tilt transfer function can be interpolated in a good approximation with the following complex second order filter:

$$A_{LL}(\nu) = \frac{1}{1 + 2jm \cdot \frac{\nu}{\nu_0} - \left(\frac{\nu}{\nu_0}\right)^2} \qquad (5)$$

with m=0.73 and ν_0=14Hz. The handshake power spectral density can be expressed with the model:

$$S_{\Theta_{hs}}(\nu) \approx \frac{2 \cdot a_{hs}}{\nu^b} \qquad (6)$$

The amplitude coefficient a_{hs} has we assumed handshake tilt within the actuator range. Coefficient b is between the extreme values b=2 corresponding to white noise of a random-walk and b=4 for a straight-line-walk pattern. Based on experimental camera shake pattern [ref. 5, ref. 6], we have estimated from equation (2) that b values between 2.25 and 3 are well describing tilt handshake with a DSC or a mobile phone. Assuming $F_{gyro}(\nu)$=1, we have estimated from equations (2) and (4) the performance of a liquid lens in term of rms blur reduction factor (*BRF*) and equivalent number of OIS aperture stop gain as a function of the integration time with b=2.5, see fig. 1. The aperture stop gain corresponds to the increase of exposure time allowed by OIS.

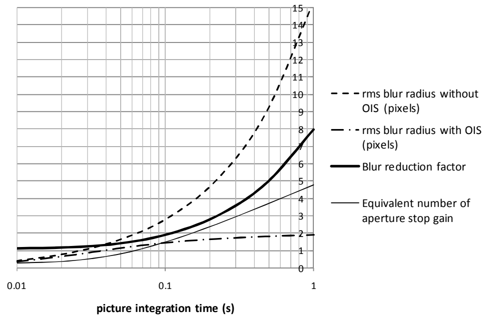

Fig.1. Performance evaluation of OIS system with A316S liquid lens

4. Experimental set-up

We have developed a handheld dual camera in order to make a comparative analysis of images taken with the same camera handshake motion, see figure 2.

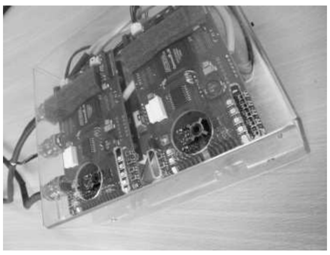

Fig.2. Dual camera set-up

A dual-axis gyroscope measures the tilt acceleration around the 2 axes of the image plane of the camera module. The gyroscope signal is sampled at a 1 kHz frequency and post-processed by a FPGA. Four voltage commands are sent to an OIS lens driver which generates 4 pulse width modulated (PWM) voltages on the electrodes of the AF-OIS liquid lens. The use of a voltage amplitude modulated driver is also possible. The electrical connection of the lens is achieved with a flexible printed circuit board (PCB) glued with conductive glue. The electrical connection of the lens on the PCB can also be obtained with a pressure spring or with an anisotropic conductive film. A connection with wires is also possible. The liquid lens is mechanically plugged onto the fix focus camera lens of a 5Mpix 1/3" camera module (add-on design) to provide both focus and tilt functions. Below on fig. 3 is an example of 2 simultaneous images captured with a 200ms integration time without and with OIS showing blur reduction. We have changed several parameters on this set-up and we have observed a qualitative agreement of image blur reduction with the theoretical estimations presented above.

Fig.3. Images without (left) & with (right) OIS

Several post-processing methods are under evaluation to optimize the OIS performance: synchronization of the gyroscope integration reset with button press, active adaptation of the tilt and focus signals such as under-shoot or over-shoot, according to the gyroscope output signal amplitude, the picture exposure time, the OIS liquid lens temperature and the nature of the handshake.

5. Conclusion

We have estimated that OIS with a liquid lens can perform 3 aperture stops improvement with 300ms integration time corresponding to low light picture conditions and we have experimentally demonstrated the efficiency on a 5Mpix dual camera set-up featuring an OIS liquid lens engineering sample. In bright light conditions, sub-pixel tilts generated by the OIS liquid lens could also bring additional benefits, such as increasing pixel resolution, through the use of so-called super-resolution methods [ref. 7] .

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