Development of Video Motion Magnification techniques for biomedical applications

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The Video Motion Magnification techniques have been used, until recently, in a qualitative way to reveal minute motions on the videos by amplifying subtle changes in luminance or local phase. This doctoral thesis focuses on using VMM techniques in a quantitative way in order to provide a non-contact, long-range, and relatively low-cost modality for measuring small motions in biomedicine, such as the corneal pulse or body sway. Thus, the first purpose of this work was to ascertain whether a method of VMM can be used for measuring single-frequency microdisplacements. For this, standard video devices (a digital single-lens reflex camera and a webcam) were used to record subtle movements of an object, and the results of the VMM technique were contrasted with an air-coupled ultrasonic sensing method that could achieve sub-micron accuracy. The results of the VMM technique highly correlated with those achieved using the ultrasonic sensor, showing that the former can accurately measure displacements in the range from about 5 μm to about 40 μm from a distance of about one meter. The single-frequency temporal characteristics of the moving object were well-preserved. In the next step, current VMM techniques were shown to have incorrect frequency responses when handling dynamic measurements consisting of multiple frequencies. To resolve this problem in this doctoral work a new phase-based VMM method utilizing radial fractional steerable 2D Hilbert transform is developed and contrasted, in terms of the frequency response, with two other established VMM methods. The typical VMM workflow is analyzed and described. It includes amplifying phase changes between subsequent video frames on many spatial frequencies separately using image pyramids, which are then collapsed forming new, motion magnified video. In this work, Hilbert transform is used to extract local phase changes. The modified Kullback-Leibler divergence was calculated between the spectral estimates of the time series of vibrating plate measured using a high-speed video camera and a reference time series synchronously acquired with high-precision air-coupled ultrasonic transducer. Time series consisted of micrometer range multi-component vibrations (one, two and three sine frequencies) recorded with different motion magnification factors. The results show that in the majority of cases, the developed method, out of three considered, resulted in the most uniform frequency response and generated the lowest amount of unwanted frequencies. Finally, the new method is used as an example in biomedical measurement of corneal pulse. The results were again contrasted with the ultrasonic technique showing high correspondence of signals in both time and frequency domains. Concluding, the VMM is shown to be suitable for microdisplacements measurements but being prone to generating spurious frequencies, then a novel approach to VMM is proposed, which substantially improves frequency response and makes this technique more suitable for the measurements of phenomena consisting of multiple frequencies, which is shown on an example of measuring the corneal pulse.