

## INTRODUCTION

The mobile digital imaging market advances in two directions: smaller sensor form factors and increased spatial resolution. These trends lead to a sensitivity decrease [3] and reduced signal-to-noise ratio (SNR) [2].

Offsetting these effects is easily achieved by increasing the exposure time. However, this option inevitably leads to increased motion blur in the image. The increased blur results in lower spatial resolution [1] as well as unacceptable image quality.

We present a study of hand motion, with a focus on implication to mobile imaging. Using these results, we describe the requirements from an IS mechanism aimed at solving the low sensitivity problem. Finally we propose a standard test to assess the quality of different IS mechanisms.

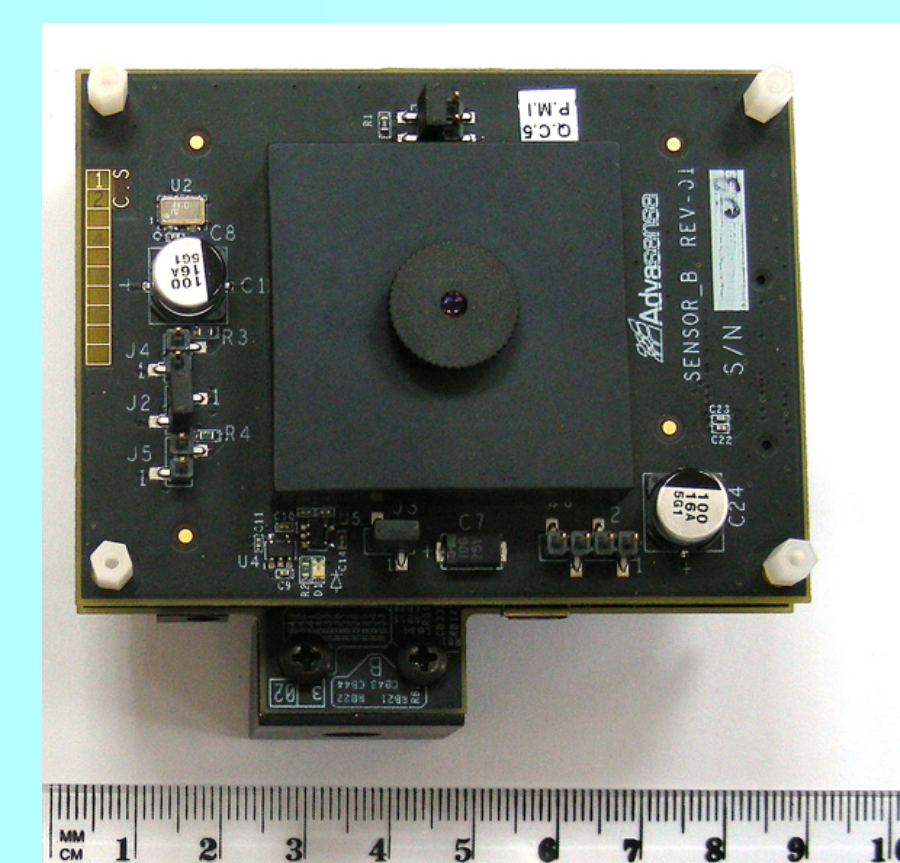
## GOALS

The goals of our research are:

- Measure *relevant* hand-motion for mobile imaging
- Quantify and characterize the motion
- Understand the implication for image stabilization (IS) solutions
- Suggest a benchmark for IS systems

## EXPERIMENTAL DETAILS

We measured hand motion as a function of time, using small board with a CMOS sensor. The board form factor was chosen to resemble that of a camera-phone. It is approximately 5cm by 9cm and can be held like a camera-phone. During each measurement, the sensor recorded VGA video at 96 fps.



The motion was later extracted from the video sequence. The scene emulated a typical indoor scene (300 Lux, target about 2-3 meters away from subject) and the target to be photographed was an ISO-12233 test chart.

## EXPERIMENTAL PROTOCOL

The protocol was very straight forward. The subject aims the board to the test chart (using a live view on the PC). The live view is then stopped (as is the case for most mobile handsets).

The subject then holds the board as steady as possible for 2 seconds. The video stream (VGA@90 fps) is recorded. We used 25 subjects, 20 males and 5 females, aged between 25 and 50 years.



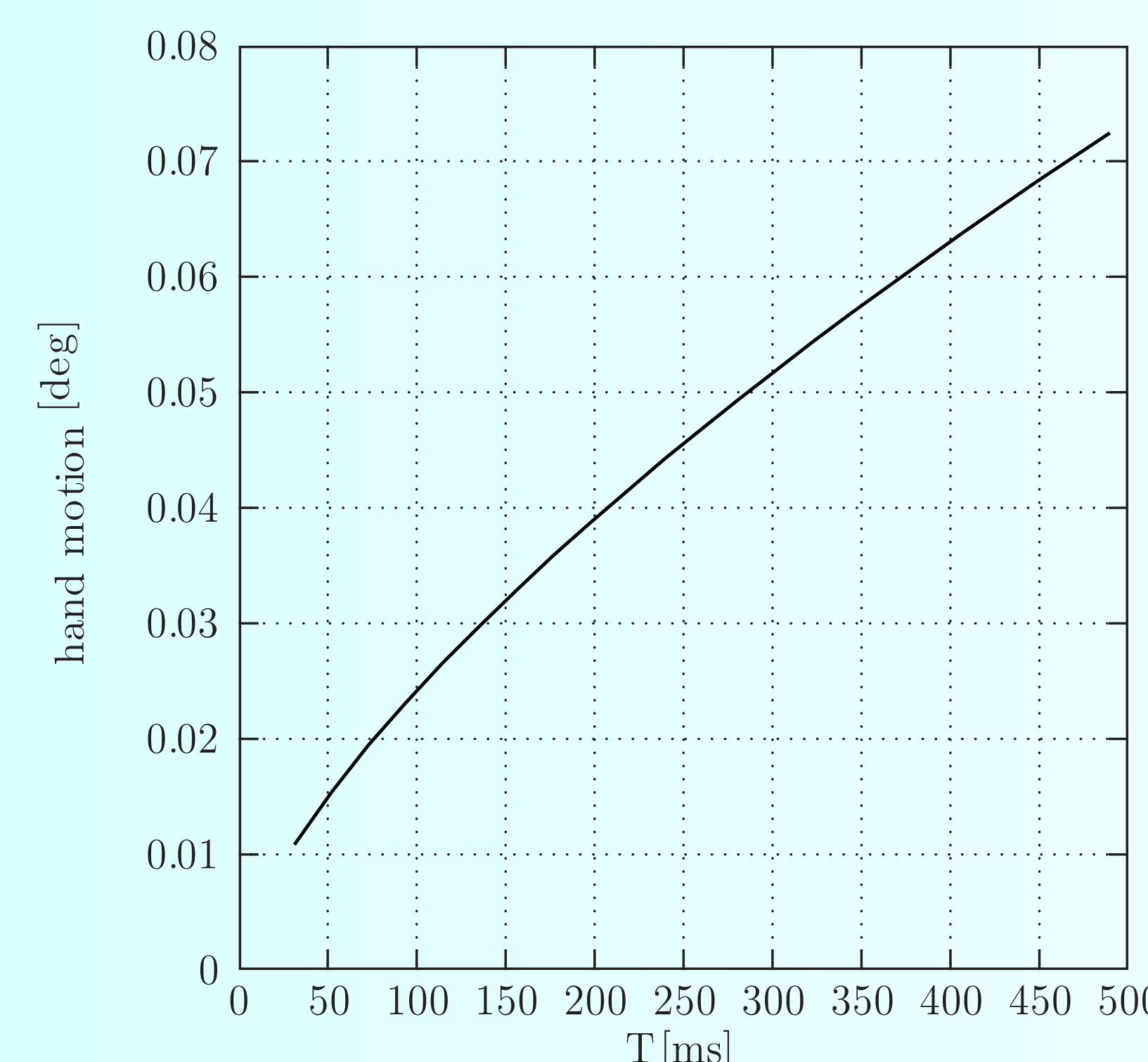
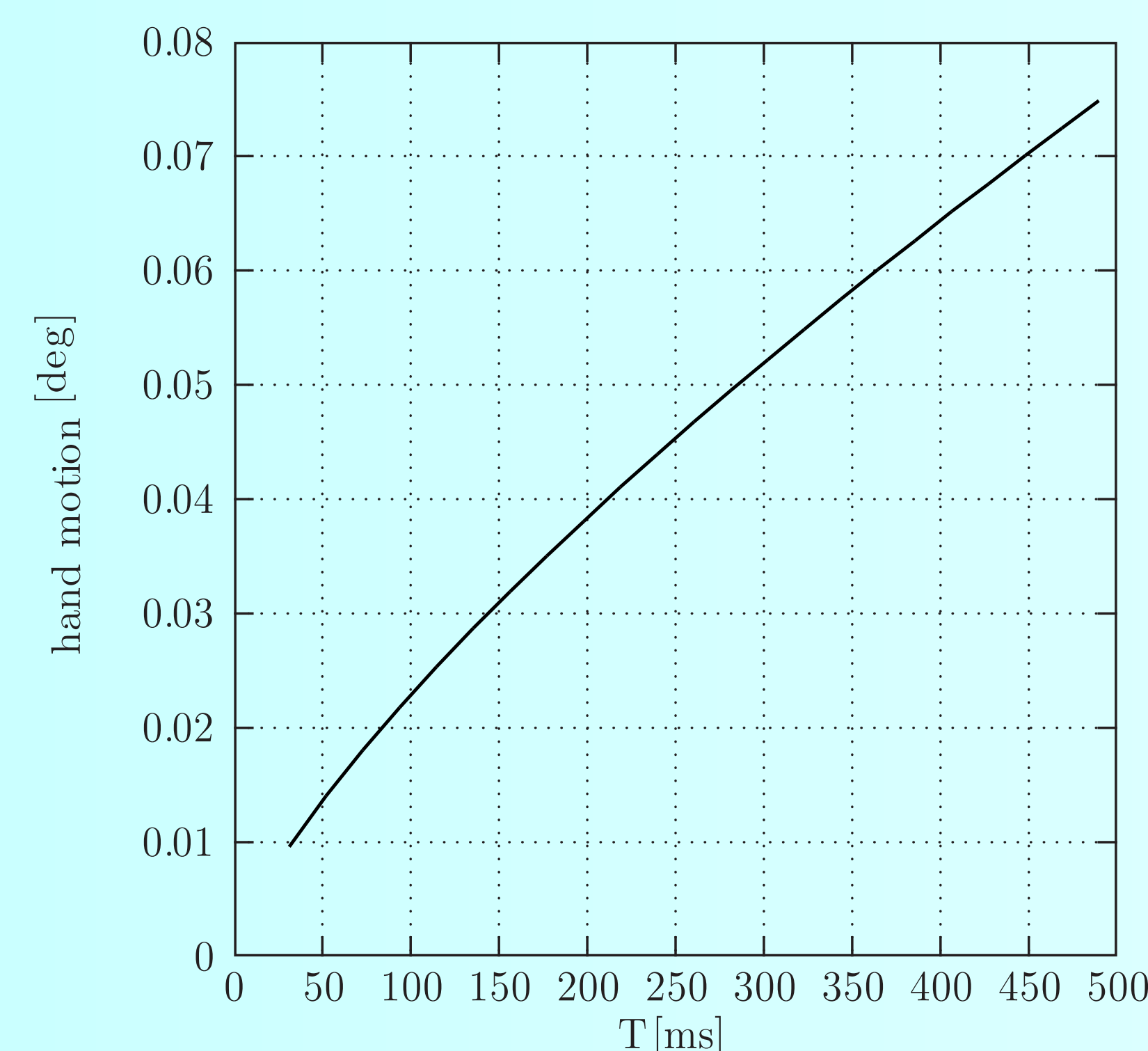
## DATA ANALYSIS

The motion data was extracted from the video sequences using the Lucas-Kanade ([4]) algorithm for *rigid motion* (i.e. only rotation and translation). The paths were then translated from image plane motions (in pixels) to *angular camera motion* (in degrees). It can be shown that the camera translational motion is negligible ([5]).

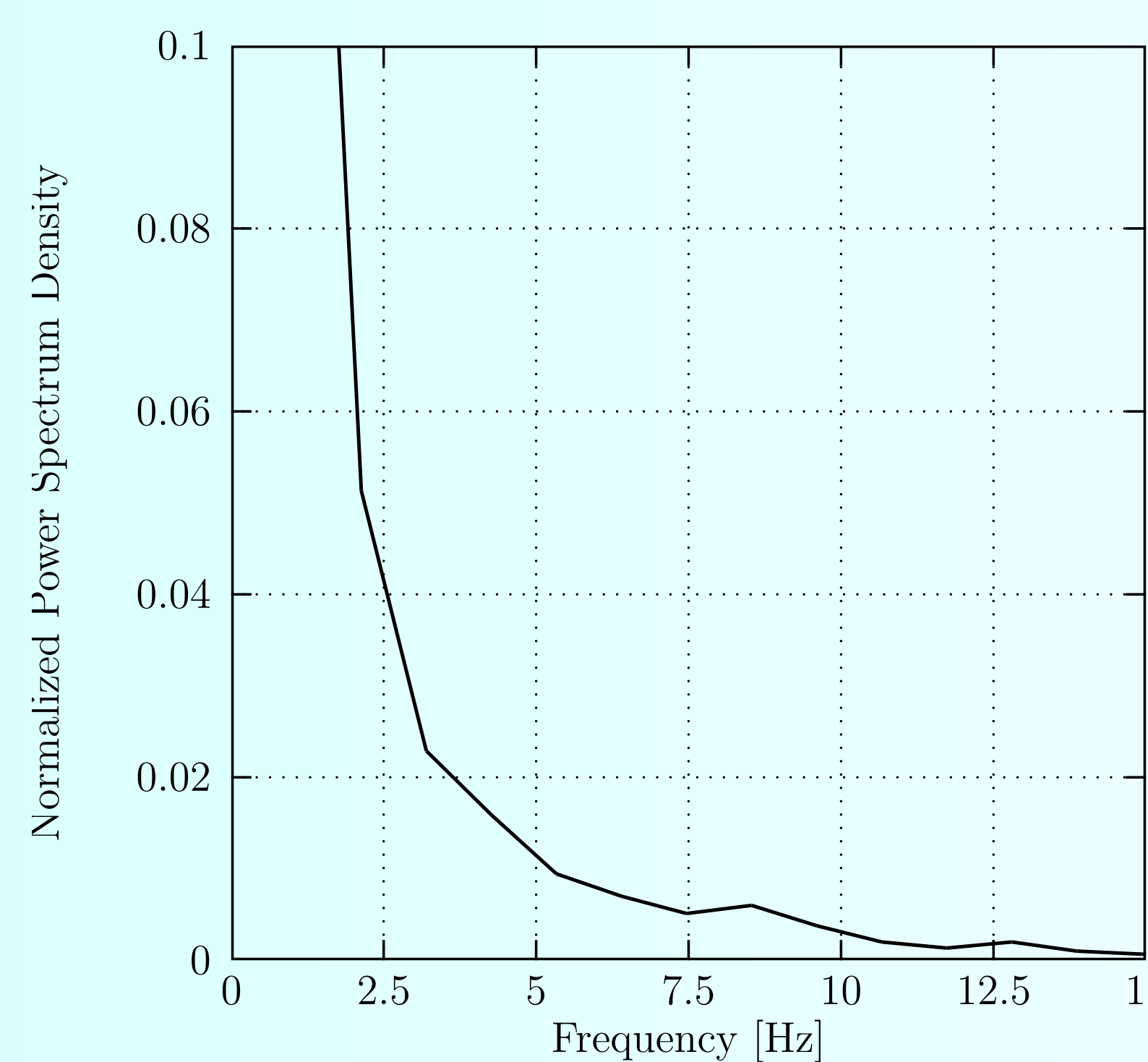
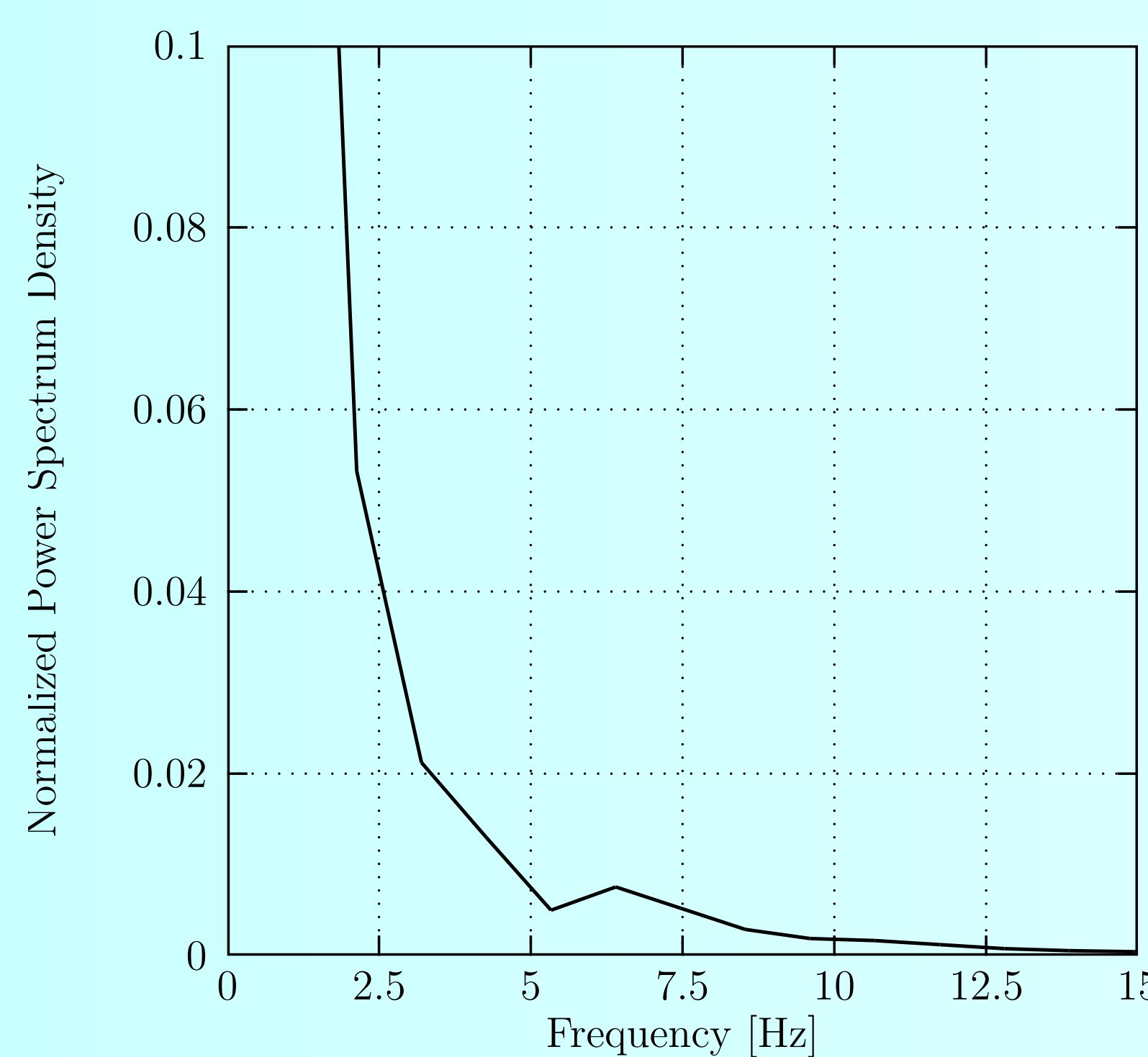
The results were validated by comparing the registration results with measurements taken from a 3-axis gyroscope (carefully mounted in parallel to the sensor board). The angular motions recorded by the gyroscope were small, thus justifying the rigid motion assumption.

## RESULTS — TIME EVOLUTION AND POWER SPECTRA

- *The camera Roll is negligible* ( $< 1^\circ/\text{sec}$ ). Most of the motion lies in the Pitch and Yaw.
- *The motion is mostly random* The two plots below show the standard deviation of the angular motion as a function of the exposure time. Notice that both plots follow a “random walk” pattern —  $\sigma \sim t^\alpha$ .



- *Most of the energy is in low frequencies* (99% below 10Hz) The power spectrum for the average Yaw and Pitch are presented below.



## IMPLICATIONS FOR IMAGE STABILIZATION SYSTEMS (IS)

- Only rigid motion needs to be corrected on image plane. This simplifies the detection and correction considerably.
- Low frequencies ( $< 5\text{Hz}$ ) are important. This implies that one cannot count only on a Gyroscope for an image stabilization solution. Gyroscopes have problems with low frequencies.
- Medium frequencies (5 – 10Hz) also play a part.

## 1/f MYTH — IS IT STILL RELEVANT?

A well-known rule-of-thumb among photographers states that the exposure should not exceed  $1/f$  (where  $f$  is the focal length given in millimeters for a 35mm camera). It has been shown that motion blur is affected (among other factors) by camera mass ([1]), and so the situation in camera-phones and other hand-held devices might be different.

Using our results, we find that the exposure time corresponding to  $1/f$  for our system would lead to a standard deviation of approximately  $0.009^\circ$  per axis. For a typical consumer digital camera (5 mega-pixels camera with  $2592 \times 1944$  resolution) this translates into a total standard deviation of 0.7 pixels.

*For a hand-held digital camera —  $1/f$  is too severe!*

## IS BENCHMARKING

IS system are typically evaluated by performing two manual shots of the same scene — with IS enabled and with IS disabled. This method has *limited reproducibility and meaningfulness*. In order to address these issues we propose a *standard, meaningful and reproducible* benchmark for IS systems.

The benchmark system consists of:

- Motion reproduction system (“Mechanical Hand”), capable of reconstructing a motion with band-limited frequencies of up to 10Hz.
- Standard scene to be photographed : test chart (ISO-12233).
- A standard corpus of motions with average spectrum similar to the measured one. The variations between the motions should also be representative of the expected variations in the population (i.e. similar to those in the figure).

The benchmark itself is performed as follows:

- For each motion, capture images at increasing exposure times. If the IS is sensitive to the illumination conditions, repeat this at appropriate conditions.
- For each image, measure the modulation transfer function (MTF) using horizontal edges and vertical edges.
- For each MTF, compute the MTF width  $(k_0, \text{s.t. } MTF(k_0, t_{\text{exp}}) = MTF(0, t_{\text{exp}})/e^{1/2})$ .
- Average the MTF widths over all motions. This number represents an *average motion blur* at a given exposure time.

The resulting function,  $\sigma_{\text{benchmark}}(t)$  represents the average motion blur as a function of time. This can be used to determine the maximal exposure time as a function of the maximal allowable motion blur. A replacement for the  $1/f$  rule.

## REFERENCES

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