# Application of High-Speed Line Scan Camera for String Vibration Measurements

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- Accurate high-quality measurements of the string vibration
- Experimental apparatus that is easy to use and to set up
- Test the accuracy of the mathematical and physical models
- Better understanding of the mechanical properties of stringed musical instruments



# Line scan camera (LSC)



- Relatively inexpensive and easy to use
- Works with standard hardware: regular PC; frame-grabber circuit board connects to PCIe slot
- Several LSCs may be used simultaneously



# LSC sensor geometry and recording principle



- Single array of light sensitive pixels (CCD or CMOS)
- Global shutter technology i.e. all pixels collect light simultaneously
- High frame rate values are available (up to  $10^6$  fps)



# LSC video footage



Photo-finish camera (low spec LSC) footage. The individual recorded frames form a 2D image.



# String vibration measurement

Two LSC measurement set-up



Two LSCs placed perpendicularly to each other's optical axes.



# String vibration measurement

#### Single LSC and a mirror measurement set-up



Mirror is placed under 45° with respect to the camera's optical axis. This set-up is capable of recording string's vibration in vertical and horizontal vibration planes simultaneously.



# Obtained image

#### Monochrome image as recorded by the LSC



Vibration of a nylon string in a monochord. Triangularly shaped initial condition. Recorded by using the single LSC and a mirror set-up.



### Vibration data extract methods

### Frame correlation/convolution method



where p represents the pixel depth values of the selected frame and the function k is an appropriately selected kernel (or vice versa).



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The second method of vibration data extraction is based on the well developed edge detection techniques (e.g. Canny edge detection).

# Example: Finger plucked guitar string





## Example: Plectrum plucked guitar string





# Example: Bowed string, Helmholtz motion

### Bowed violin string



String vibration was measured by Montserrat Pàmies-Vilà and Ibrahim Atakan Kubilay from Aalto University.

- The novel contactless optical method for measuring the vibration of strings was presented and explained
- Working principle of the LSC was explained
- Two vibration data extraction methods based on digital image analysis were proposed:
  - Frame correlation/convolution with suitable kernel
  - Edge detection method
- String vibration measurement examples were presented

