COMPLETE READER FOR MAGNETIC BARCODES

Libor Kadlčík
Master Degree Programme (2), FEEC BUT
E-mail: xkadlc04@stud.feec.vutbr.cz

Supervised by: Jan Mikulka
E-mail: mikulka@feec.vutbr.cz

Abstract: The goal is to develop a complete barcode reader for magnetic barcodes (printed with ink of permeability other than μ_0). Reading is done by coil of an oscillator, producing high-frequency (318 kHz), narrowband FM signal (60 Hz deviation), which is demodulated through complex envelope calculation. Obtained signal is blurry due to convolutional distortion. The blur is removed by variational blind deconvolution. This work proposes methods for barcode detection by failed linear regression, removal of DC drift from the signal, model of convolution kernel uncertainty and its estimation. The reader will emulate USB HID or PS/2 keyboard, transferring alphanumeric string contained in the barcode as a sequence of key presses to PC.

Keywords: barcode detection, blind deconvolution, complex envelope, convolution kernel estimation, deconvolution, drift removal, magnetic barcode, variational methods

1 INTRODUCTION

Barcode stores information as a sequence of bars and gaps of different width, and can be expressed as a bilevel signal with instantaneous values equal to either 0 or 1 (see $\hat{c}[k]$ on fig. 1). Our focus is on magnetic barcodes, permeability of whose bars is different from surroundings. Reading is done by *reading oscillator* whose coil moves over the barcode. The oscillator produces radio-frequency signal containing narrowband FM modulation. FM demodulation results in a low-frequency signal (see $y_{\mathrm{lf}}[k]$ on fig. 1).

The low-frequency signal is strongly blurred by *convolutional distortion* (see $y[k]$ on fig. 1), caused by dispersed sensitivity of the reading oscillator coil. The signal also contains *drift* due to temperature dependence of the reading oscillator (see $y_{\mathrm{lf}}[k]$ on fig. 1). Since maintaining constant movement of the oscillator by hand is difficult, the signal is *compressed unevenly*.

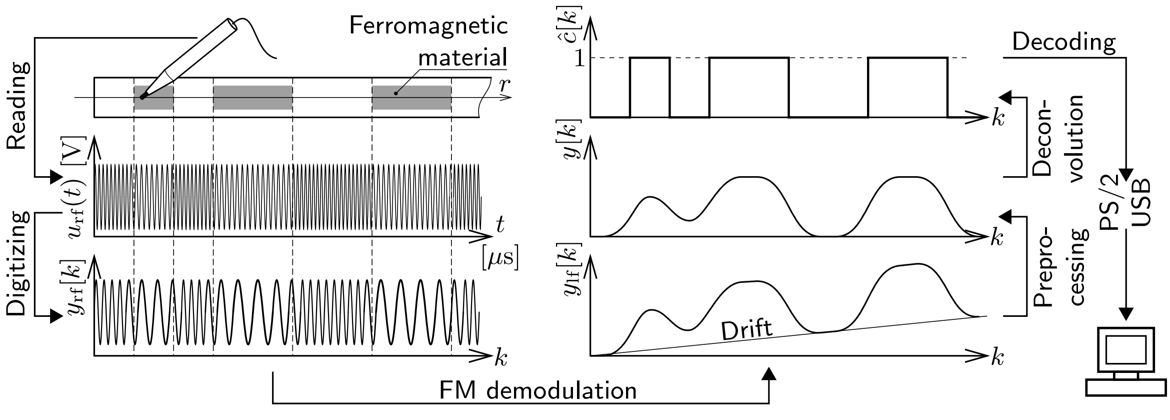

Figure 1: Phases of barcode signal processing

Convolutional distortion is modelled as convolution of undistorted barcode signal $c[k]$ with point spread function (PSF) $h[k]$. The drift is relatively slow, and linear function $ak+b$ approximates it well.

$$y_{\mathrm{lf}}[k] = y[k] + ak + b, \quad y[k] = (c \star h)[k] \tag{1}$$

Reference PSF $h_{\mathrm{ref}}(x)$ can be obtained by calibration procedure. However, the actual PSF $h[k]$ can differ in DC value (K_0) or in width (σ, which depends on velocity of the reading oscillator). This is captured in following proposed model,

$$h[k] = K_0 \cdot \frac{1}{\sigma} h_{\mathrm{ref}}\left(\frac{k}{\sigma}\right), \quad \int_{-\infty}^{\infty} h_{\mathrm{ref}}(x)\,\mathrm{d}x = 1. \tag{2}$$

2 READING OSCILLATOR

The reading oscillator is an LC oscillator with exposed coil (fig. 2). Frequency of the produced signal is approximately 318 kHz. If a bar of magnetic barcode, containing ferromagnetic material, is placed to the coil, the frequency is lowered by about 60 Hz.

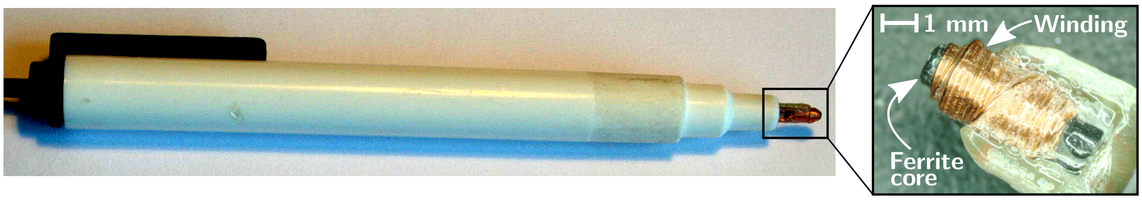

Figure 2: Reading oscillator and its coil

In order to focus sensitivity of the coil (and reduce convolutional distortion), its core should be thin.

3 DIGITIZING AND FM DEMODULATION

As the radio-frequency signal from the reading oscillator is digitized, bandpass sampling uses aliasing to transpose (without corruption) the spectrum of the signal to lower frequencies (in order to avoid another, unwanted aliasing during following processing).

FM demodulation is the next step. Simple counting of signal periods cannot be used, because resolution of this method would be insufficient. Complex envelope of the signal is computed instead, derivative of argument of the envelope then reveals the frequency.

4 PREPROCESSING

Following methods have been developed for preprocessing: barcode detection, drift removal, and estimation of the PSF.

First, the demodulated signal is split into segments, each subjected to linear regression. Unlike drift, barcode signal is curved (see $y_{\mathrm{lf}}[k]$ on fig. 1), therefore large residual of the regression indicates its presence.

Then line is constructed between two points of the signal: before and after the barcode (see $y_{\mathrm{lf}}[k]$ on fig. 1). The line is nearly identical to the actual drift, and is subtracted from the signal.

The PSF is estimated using model (2) (n is length of the signal),

$$K_0 \approx 2 \cdot \frac{1}{n} \sum_{k=0}^{n-1} y[k], \quad \sigma \approx \frac{\max\{y_{\mathrm{smooth}}[k]\} \cdot \max\{h_{\mathrm{ref}}(x)\}}{\max\{|(\Delta y_{\mathrm{smooth}})[k]|\}}. \tag{3}$$

Finding K_0 is possible due to mean value of $c[k]$ being $^1/_2$ (because amount of bars and gaps in barcode is usually the same). Calculation of σ is based on the fact that increase in width of the PSF results in reduction of slope of edges in the distorted signal $y[k]$ (the calculation should be preceded by minor smoothing in order to increase noise immunity).

5 DECONVOLUTION

Original signal $c[k]$ is obtained from $y[k]$ in (1) by finding signal that minimizes following functional (Δ is the first difference operator, n is length of the signals),

$$E(\hat{c}) = \sum_{k=0}^{n-1} \left\{ (y - \hat{c} \star \hat{h})^2[k] + \lambda_{\text{dif}} (\Delta \hat{c})^2[k] + \lambda_W W(\hat{c}[k]) \right\}, \quad W(x) = x^2(1-x)^2. \tag{4}$$

There are three addends affecting result of minimization. The first leads to deconvolution, the second prevents excessive amplification of noise, the third shapes the result into being bilevel. The second and third are regularizations; their impact is controlled by coefficients λ_{dif} and λ_W. [1, eq. 41]

However, the PSF $\hat{h}[k]$ is not precisely known at this point. An empirical solution has been developed: if deconvolution is performed with the correct kernel, following functional attains its minimum,

$$E_{ch}(\hat{c}, \hat{h}) = \sum_{k=0}^{n-1} (y - \hat{b} \star \hat{h})^2[k], \quad \hat{b}[k] = \text{thresholding}(\hat{c}[k]). \tag{5}$$

6 CONCLUSION

All mentioned signal processing methods are being implemented into the PIC32MX250F128D microcontroller, which is suitable for this task (having 32 KiB of RAM, 1 Msps A/D converter and support for multiply-and-accumulate operation). The microcontroller will emulate USB HID or PS/2 keyboard – information obtained from barcode will be sent as a sequence of key presses to PC.

To test the methods, magnetic barcode (fig. 3) was read by the reading oscillator. The microcontroller performed demodulation. Preprocessing and deconvolution was provisionally done in MATLAB.

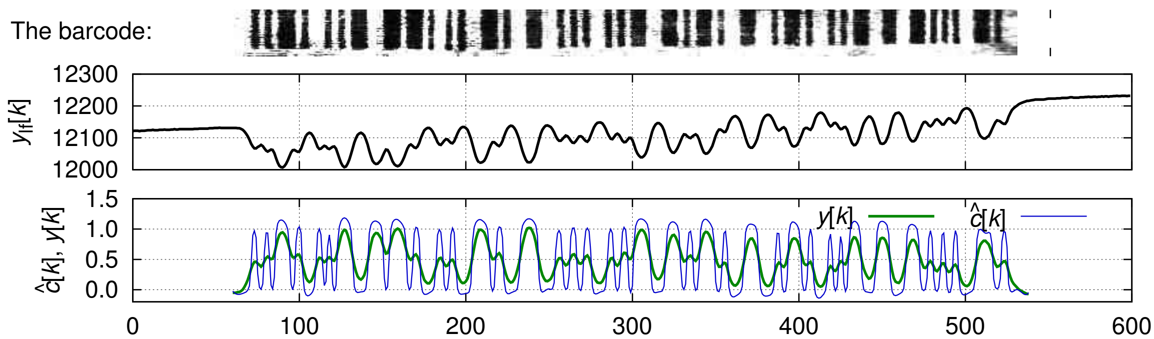

Figure 3: Magnetic barcode, demodulated ($y_{\text{lf}}[k]$), preprocessed ($y[k]$) and deconvolved signal ($\hat{c}[k]$)

Barcode was detected and drift removed. After deconvolution, bars and gaps are distinguishable.

REFERENCES

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URL: <*ftp://ftp.math.ucla.edu/pub/camreport/cam03-70.pdf*>