Source Localization on Solids Utilizing Logistic Modeling of Energy Transition in Vibration Signal

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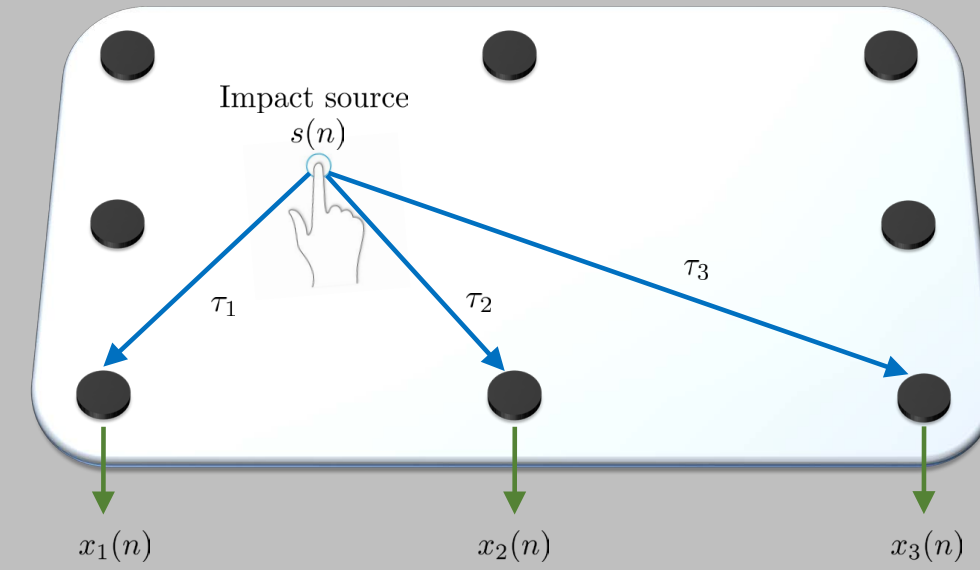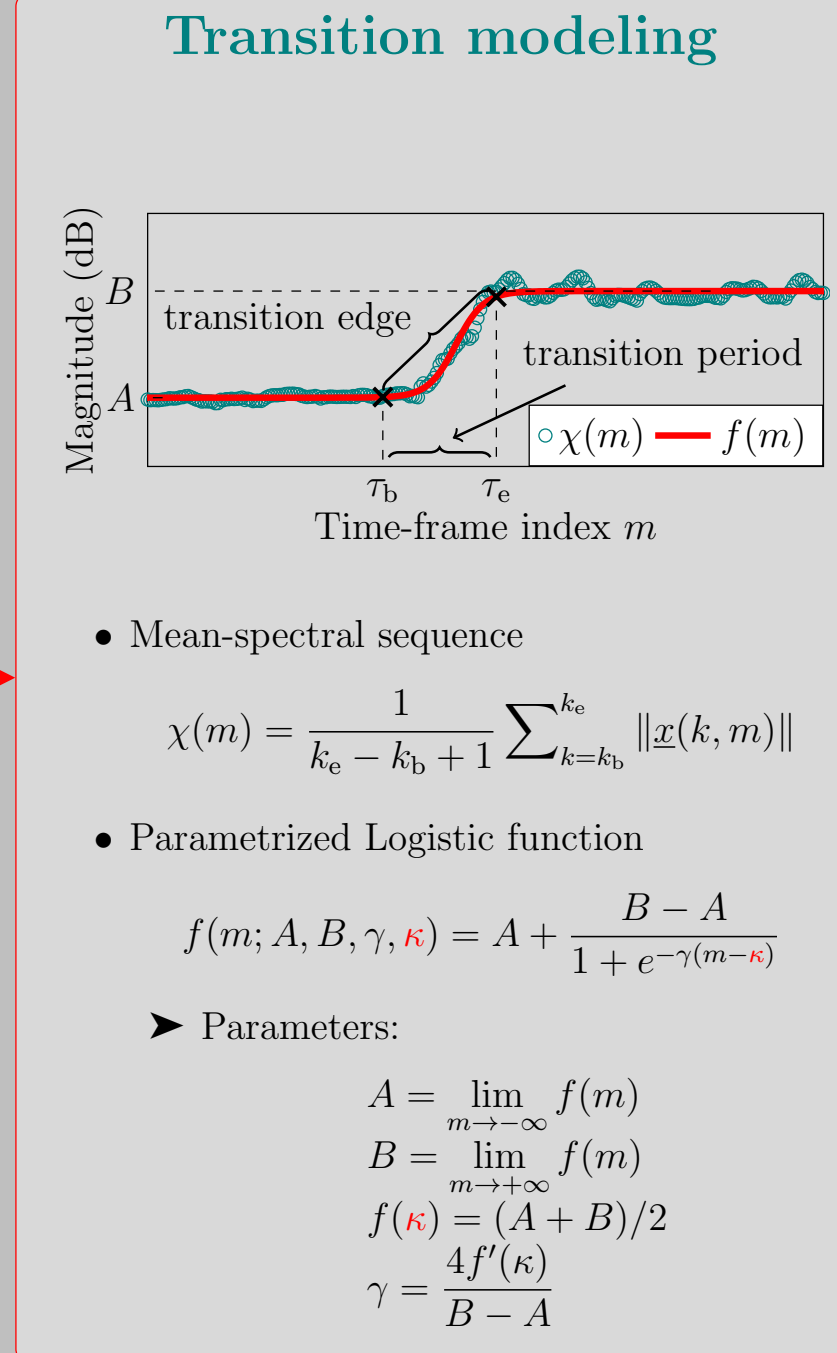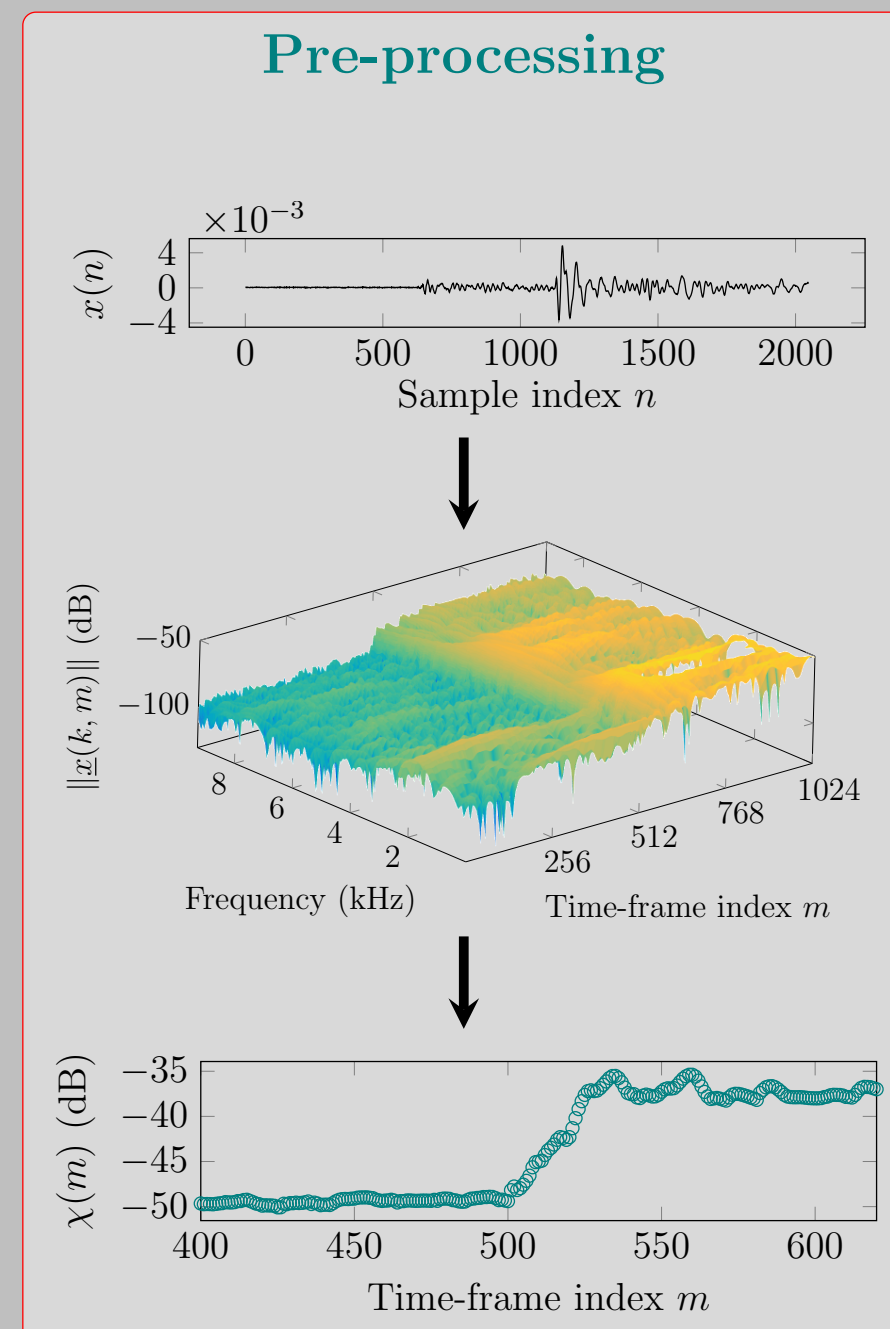
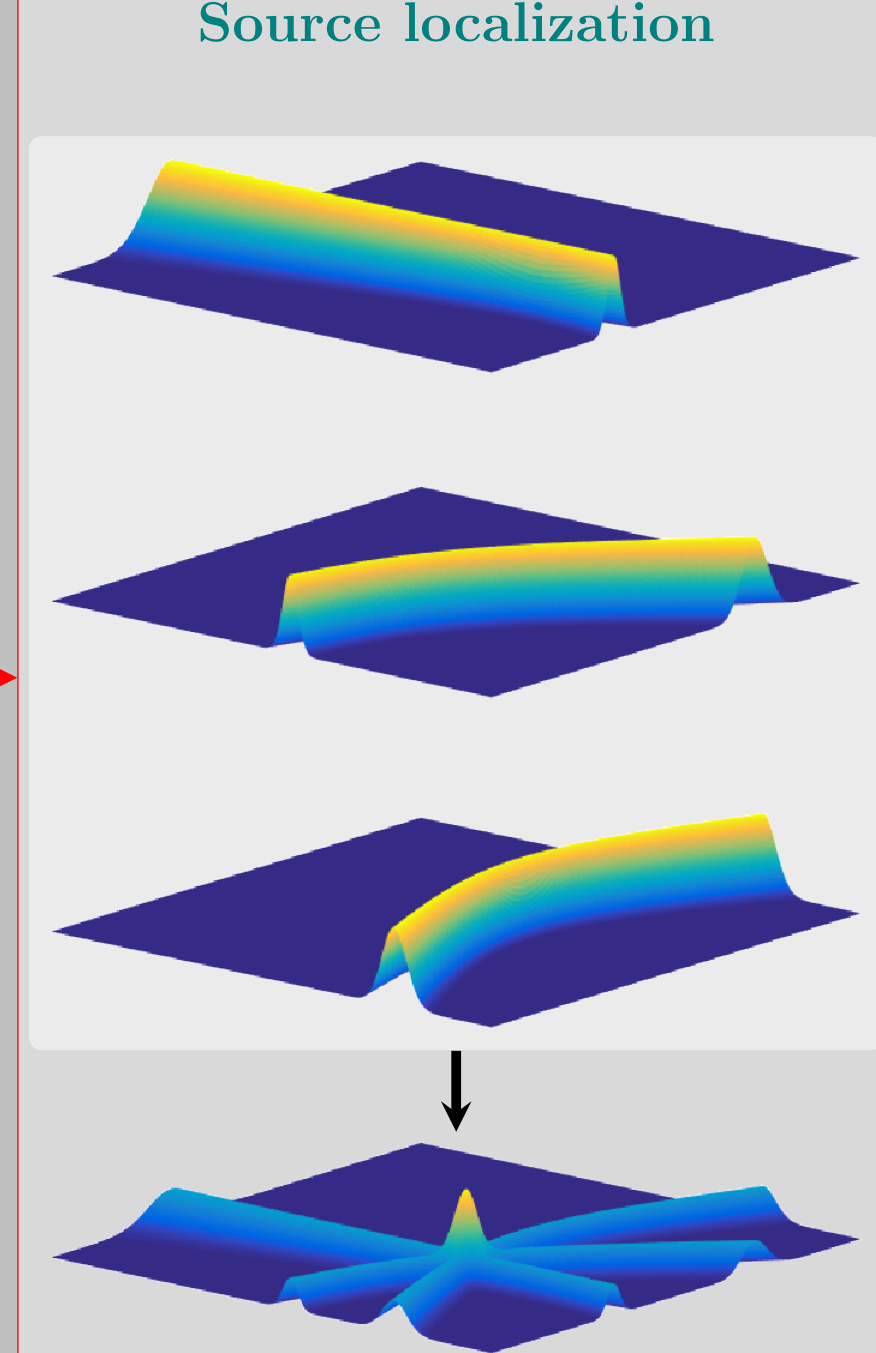NANYANG TECHNOLOGICAL UNIVERSITY

INTRODUCTION

- □ **Aim**: Accurate TDOA estimation for source localization on solids
- □ **Challenges**: Error-prone TOA/TDOA estimation for gradual noise-to-signal transition
- □ **Existing algorithms**: Assume abrupt transition and estimate TOAs via thresholding
- □ **Proposed approach**: Gradual-transition modeling using parametrized *logistic* function, and TDOA estimated as difference in lateral shift across fitted functions
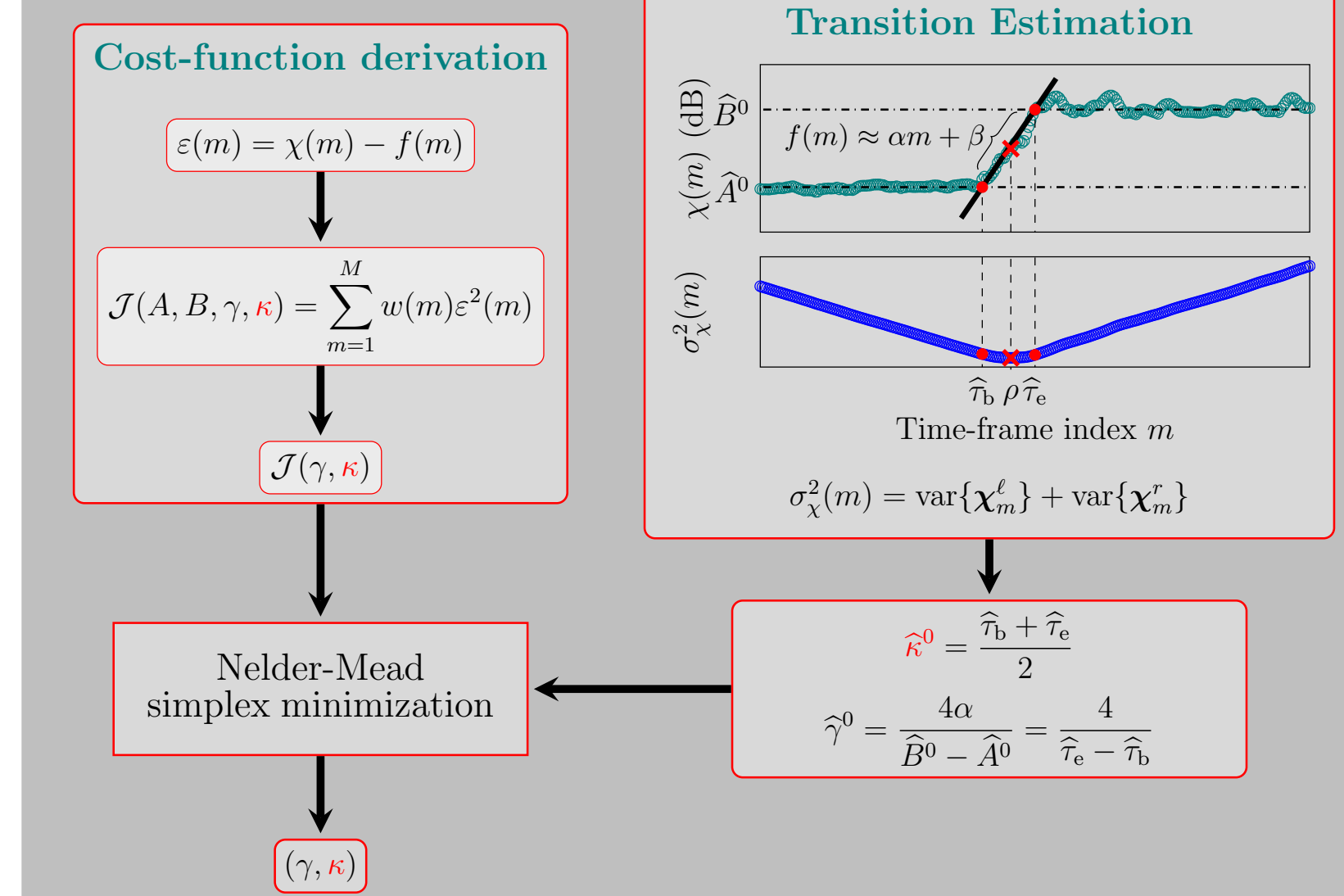

Impact source $s(n)$

τ_1 τ_2 τ_3

$x_1(n)$ $x_2(n)$ $x_3(n)$

PROPOSED STFT-LOGISTIC ALGORITHM

Pre-processing

$x(n)$ $\times 10^{-3}$

Sample index n

$\|\underline{x}(k,m)\|$ (dB)

Frequency (kHz)   Time-frame index m

$\chi(m)$ (dB)

Time-frame index m

$\chi(m)$ →

Transition modeling

Magnitude (dB)

transition edge   transition period

$\circ \chi(m)$ — $f(m)$

$\tau_{\rm b}$ $\tau_{\rm e}$

Time-frame index m

- Mean-spectral sequence

$$\chi(m) = \frac{1}{k_{\rm e} - k_{\rm b} + 1} \sum_{k=k_{\rm b}}^{k_{\rm e}} \|\underline{x}(k,m)\|$$

- Parametrized Logistic function

$$f(m; A, B, \gamma, \kappa) = A + \frac{B - A}{1 + e^{-\gamma(m-\kappa)}}$$

➤ Parameters:

$$A = \lim_{m\to-\infty} f(m)$$
$$B = \lim_{m\to+\infty} f(m)$$
$$f(\kappa) = (A+B)/2$$
$$\gamma = \frac{4f'(\kappa)}{B - A}$$

$\widehat{\tau}_{ij} = \dfrac{\widehat{\kappa}_i - \widehat{\kappa}_j}{f_{\rm s}}$ →

Source localization

MODEL FITTING

Cost-function derivation

$\varepsilon(m) = \chi(m) - f(m)$

↓

$\mathcal{J}(A, B, \gamma, \kappa) = \sum_{m=1}^{M} w(m)\varepsilon^2(m)$

↓

$\mathcal{J}(\gamma, \kappa)$

Transition Estimation

$\chi(m)$ (dB) $\widehat{B}^0$ $\widehat{A}^0$

$f(m) \approx \alpha m + \beta$

$\sigma_\chi^2(m)$

$\widehat{\tau}_{\rm b}$ ρ $\widehat{\tau}_{\rm e}$

Time-frame index m

$\sigma_\chi^2(m) = \mathrm{var}\{\boldsymbol{\chi}_m^\ell\} + \mathrm{var}\{\boldsymbol{\chi}_m^r\}$

$\widehat{\kappa}^0 = \dfrac{\widehat{\tau}_{\rm b} + \widehat{\tau}_{\rm e}}{2}$

$\widehat{\gamma}^0 = \dfrac{4\alpha}{\widehat{B}^0 - \widehat{A}^0} = \dfrac{4}{\widehat{\tau}_{\rm e} - \widehat{\tau}_{\rm b}}$

Nelder-Mead simplex minimization

↓

(γ, κ)

EXPERIMENT RESULTS

RMSE (m)

STFT-Logistic   TiF-HA [16]

Metal stylus/ Small plate   Finger/ Small plate   Metal stylus/ Large plate   Finger/ Large plate

STDE (m)

STFT-Logistic   TiF-HA [16]

Metal stylus/ Small plate   Finger/ Small plate   Metal stylus/ Large plate   Finger/ Large plate

Width $L_{\rm y}$ (m)

Length $L_{\rm x}$ (m)