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VEHICLE TERRAIN PERFORMANCE LABORATORY

Terrain Characterization

Make Everything as Simple as Possible, but not Simpler
or
A Model-Portable, Compact, Physically Meaningful Characterization of Terrain Surfaces

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Compact Terrain Characterization

Background

- Surface Creation - Curved Regular Gridding
- Surface Decompositions
  - Components: Elevation, Banking, Rutting, Crowning…
  - Frequency ranges
- Modeling Surface Components

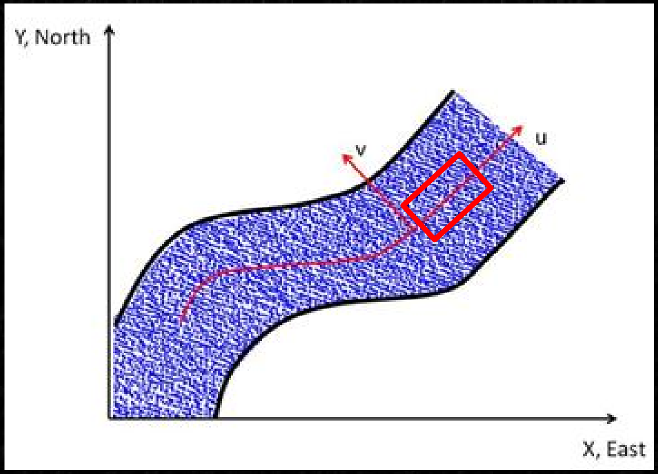
Compact Terrain Characterization

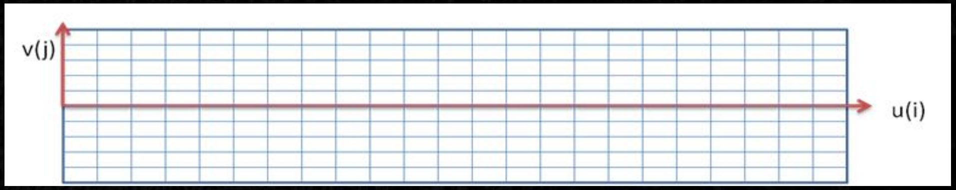
- Defining model parameter vector
- Reducing parameter space
- Proof of Concept

Future Work and Conclusions

Creating Curved Regular Grid (CRG)

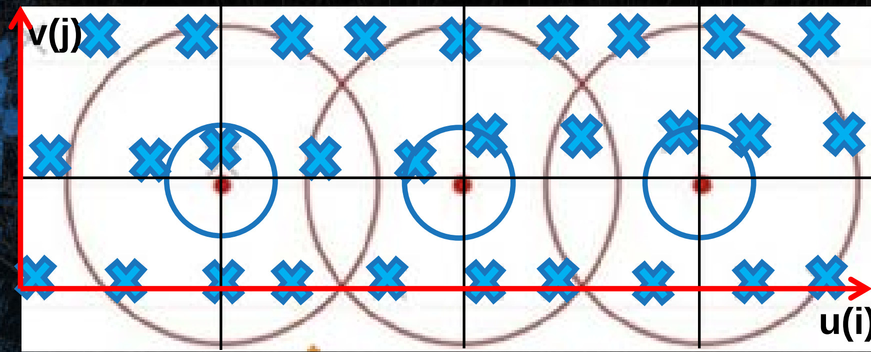
- Measured data is point cloud of irregularly spaced x-y-z data
- Define path coordinate, *u*
- Define perpendicular and coordinate, *v*
- *(u,v)* is then a Regularly Spaced Grid, or “Curved Regular Grid” (CRG) for horizontal plane
- *CloudSurfer* converts point cloud to a CRG automatically

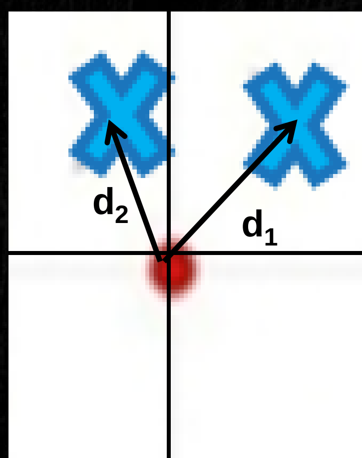




Chemistruck*, H. M., Binns*, R., Ferris, J.B., 2010, “Correcting INS Drift in Terrain Surface Measurements” *Journal of Dynamic Systems Measurement and Control.* Vol. 133, No. 2 (DOI:10.1115/1.4003098).

Determining height at each CRG node

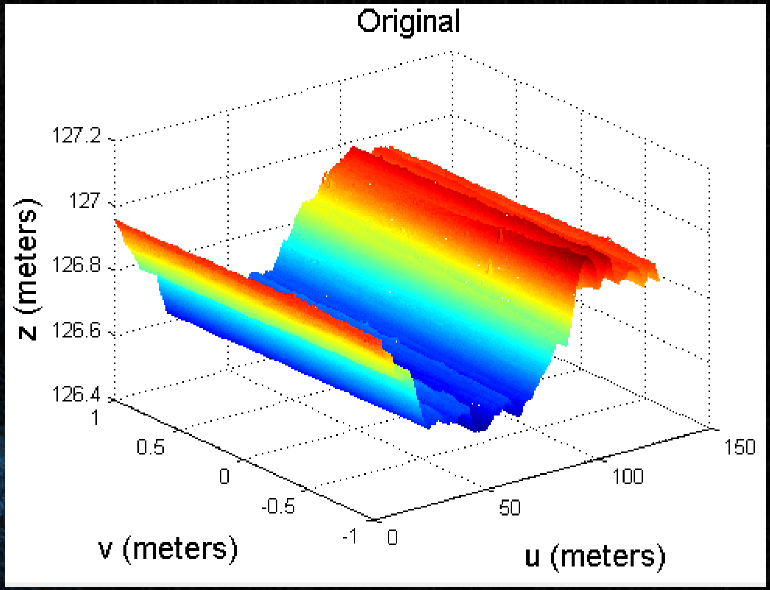




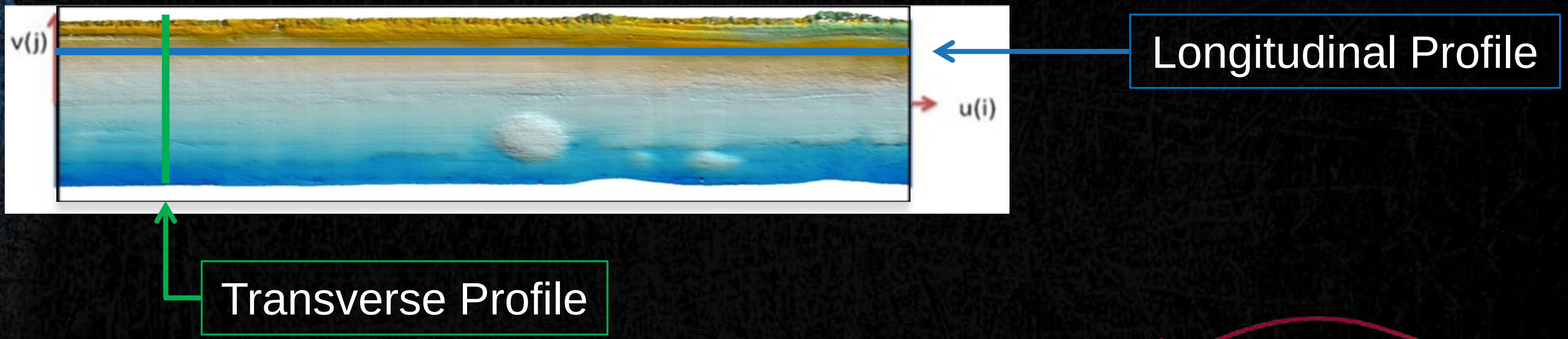
- Consider a CRG node (red dot)
- In estimating the CRG node heights, the measured data points (blue x's) closest to CRG nodes are more influential than those further away
- Influence of node height is based on weighting function that takes into account (d_i) and error in the horizontal measurements (σ)

Ma*, R., Ferris, J.B., 2011, "Terrain Gridding Using a Stochastic Weighting Function," Proceedings of the ASME Dynamic Systems and Control Conference, October 31 – November 2, Arlington, Virginia

Surface Creation



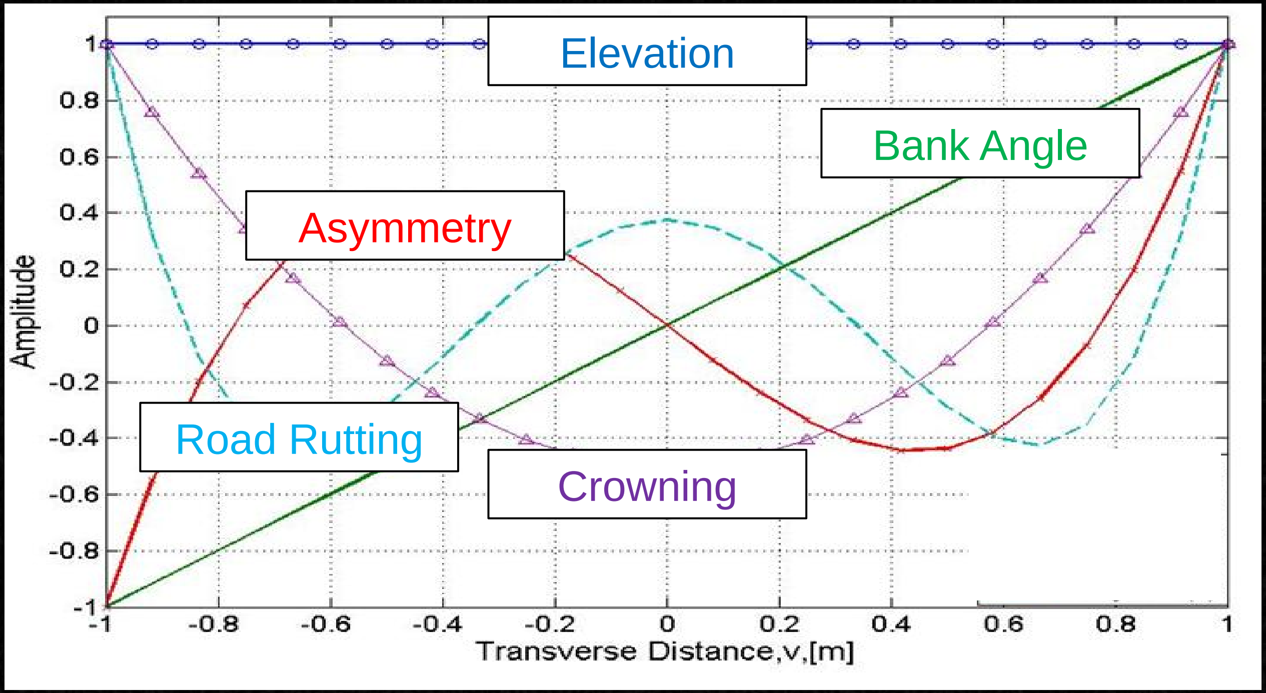
- A probability distribution of the height at each CRG node is created
- Consider the median height values represent surface
- Final surface can be imported into software (e.g. Adams)
  - Ride Simulation
- Surface: collection of…



Surface Decomposition

Transverse profiles decomposed into principal components

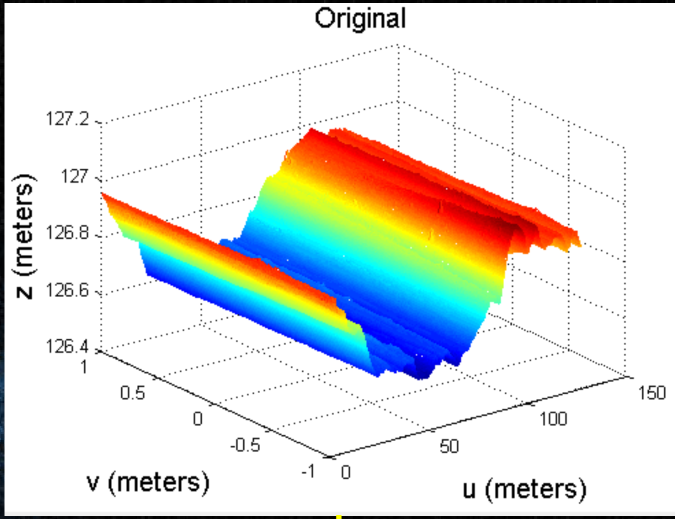
- First 5 Basis Vectors (Legendre Polynomials)

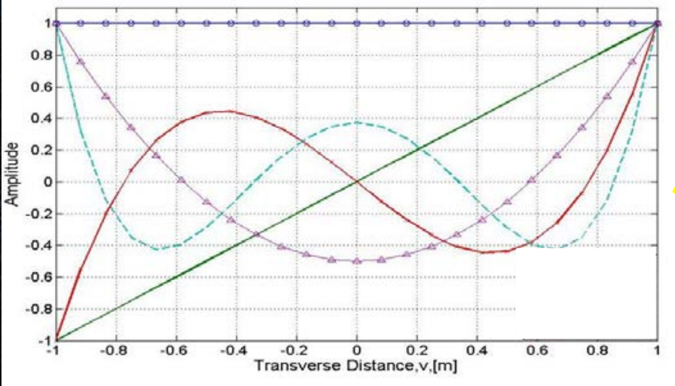


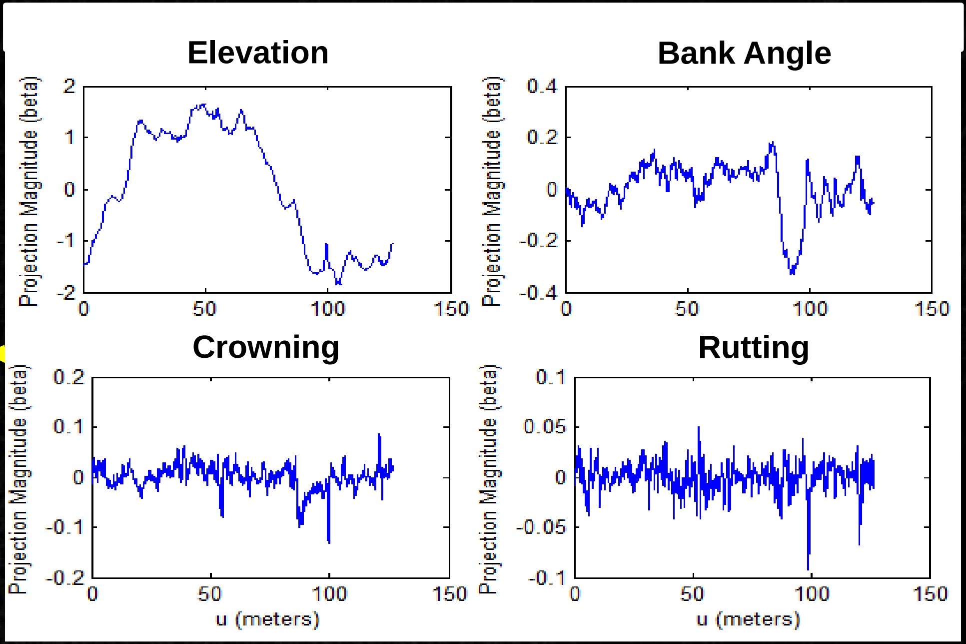
Chemistruck*, H. M., Ferris, J.B., Gorsich, D., 2012. "Using a Galerkin Approach to Define Terrain Surfaces." Journal of Dynamic Systems Measurement and Control, Volume 134, Issue 2, 021017 (12 pages) http://dx.doi.org/10.1115/1.4005271

Surface Decomposition

Transverse Profile projected on **Basis Vectors** yields **Components**







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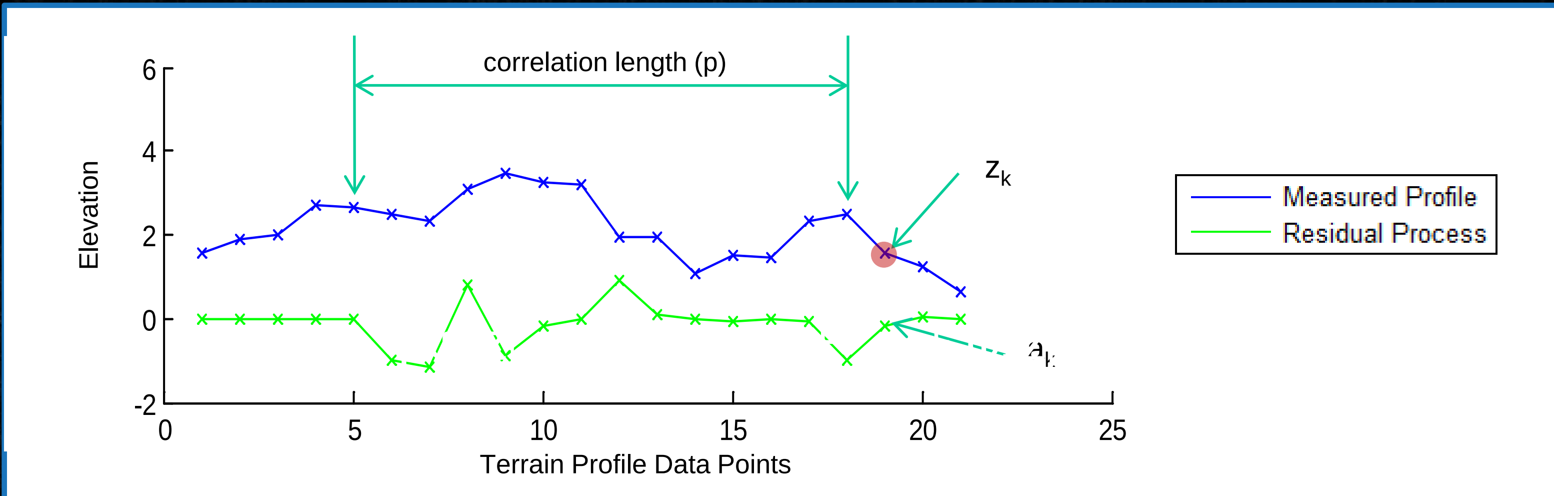
Autoregressive Model

Elevation value at a point = Linear combination of previous values + a residual process (uncertainty)

$$z_k = [\ \phi_1 z_{k-1} + \phi_2 z_{k-2} + \ldots + \phi_p z_{k-p}\ ] + \text{residual}$$



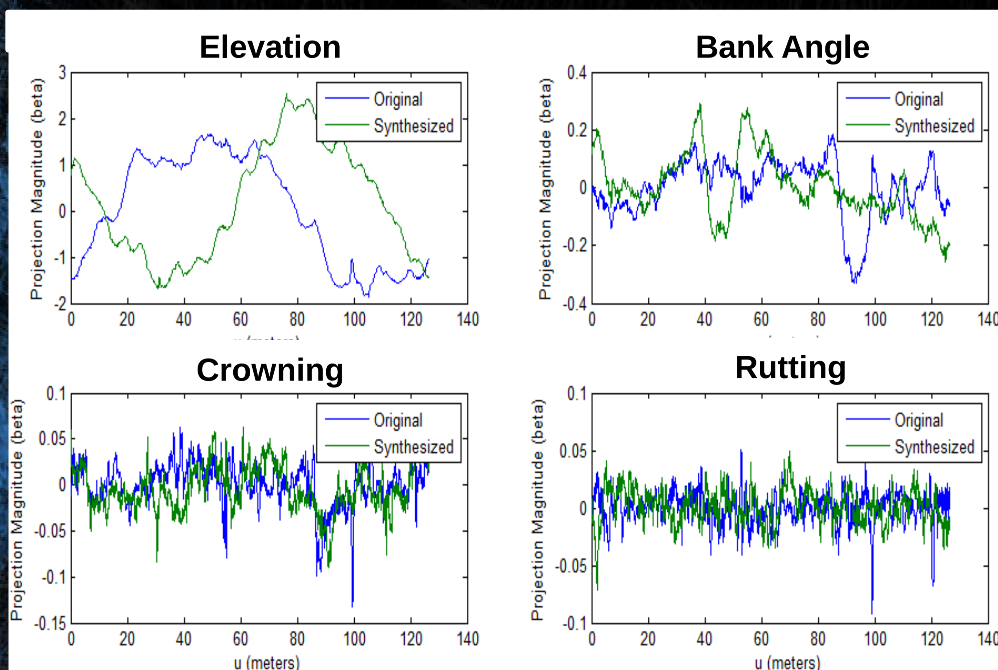
AR models hare parameterized by the ϕ values

Wagner*, S. M. and Ferris, J. B., 2012, "Residual Analysis of Autoregressive Models of Terrain Topology," Journal of Dynamic Systems Measurement and Control, Volume 134, Issue 3, 031003 (6 pages) http://dx.doi.org/10.1115/1.4005502.

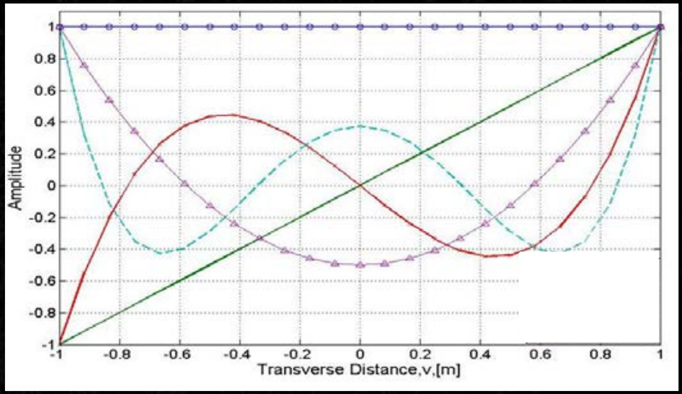
Surface Synthesis

Generating *synthetic terrain*

- Model each component
- Generate *synthetic components* with same essential characteristics of measured

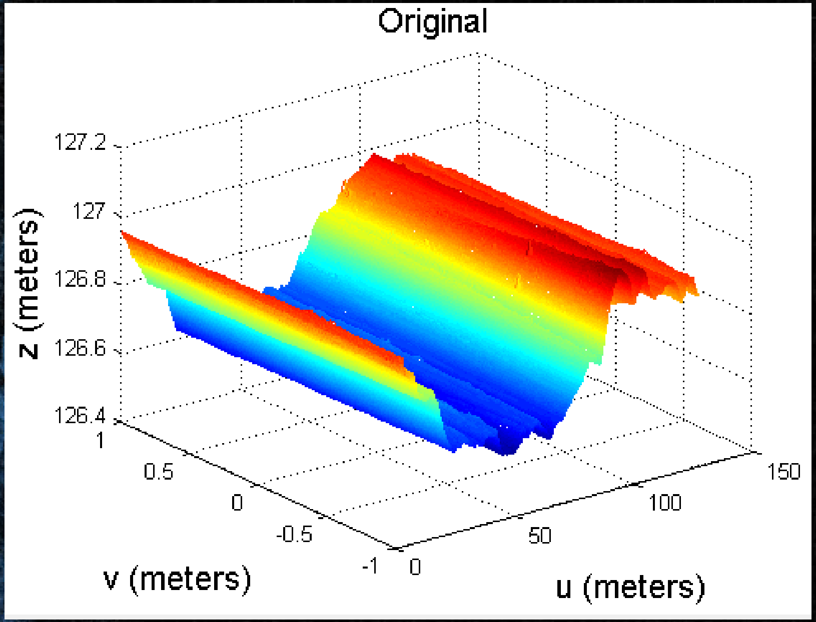


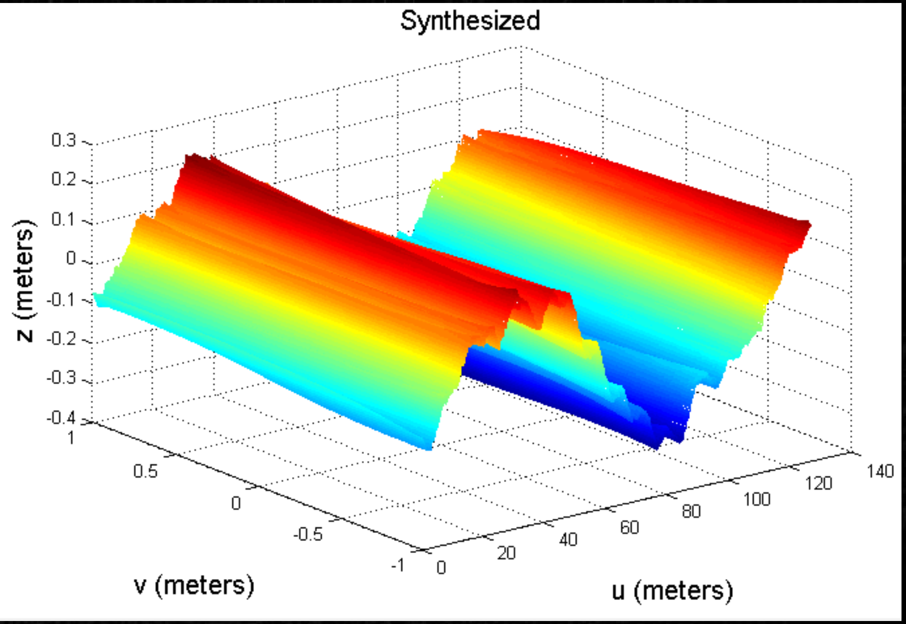
Multiply by basis vectors…



Surface Synthesis

Synthetic components can be synthesized, then combined to form a synthetic surface

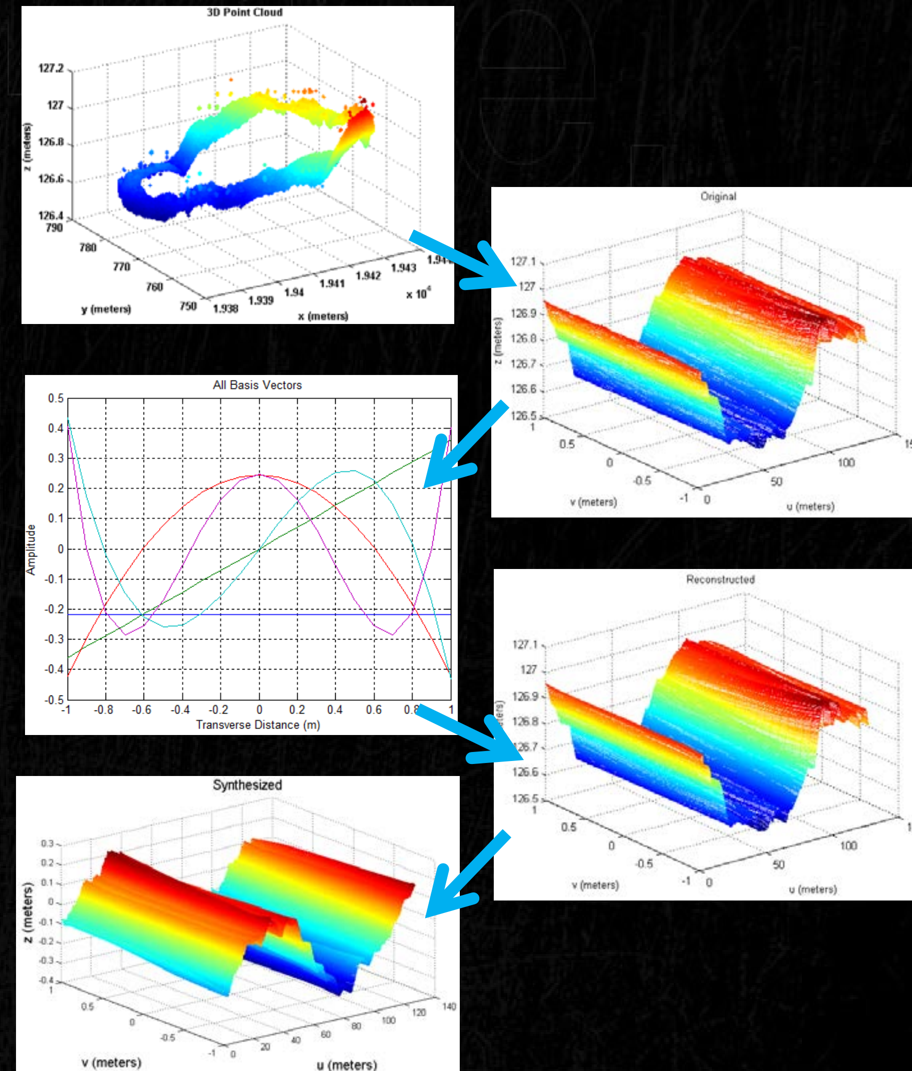




Reconstructed surface is unique but statistically similar to original

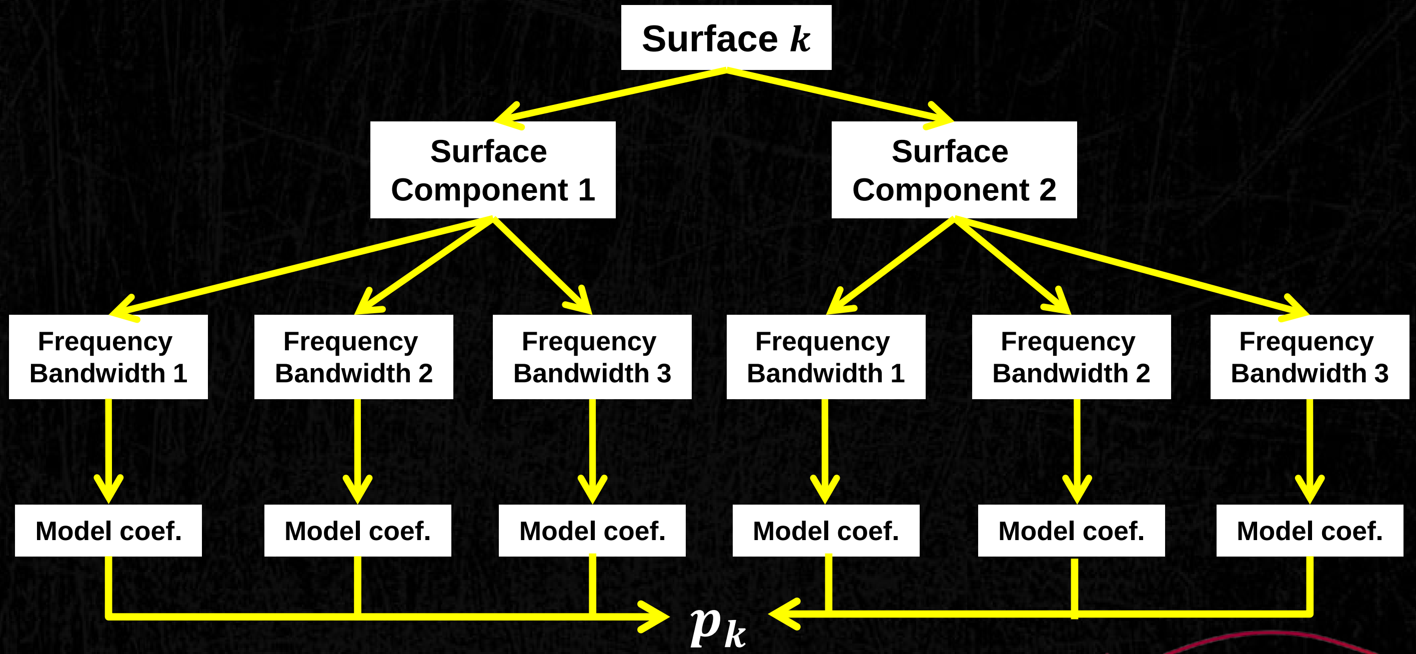
Whew!! Let's recap with an example…

- Typical 100 meter terrain measurement:
  - Original point cloud: ~1.2 billion points
  - 10 mm curved regular grid: ~2 million points
  - 5 principal components: ~50 thousand points
  - 10^{th} order AR model of spectrally decomposed components (3 bandwidths): ~200 coefficients
- Still too large to hold in your hand…
- Can we go a step further?



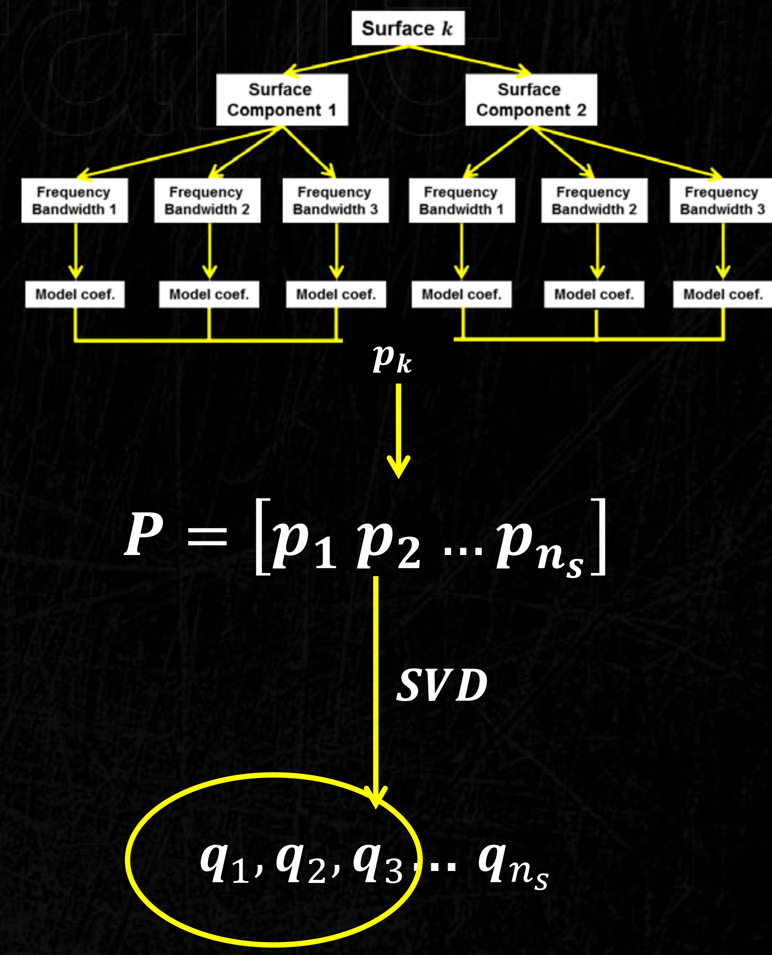
Defining Model Parameter Vector

- Consider a collection of different surfaces, each being indexed by *k*
- Each surface is decomposed into components: elevation, banking,…
- Each component is further decomposed into different frequencies (wavelengths)
- A unique model is used for each "profile": AR models are parameterized by ϕ
- Entire set of parameters for k^{th} surface can be held in vector: $\boldsymbol{p}_k$
- Is there a pattern across different surfaces?



Reducing Parameter Space

- Obtain diverse and extensive surfaces (*k* = 1, 2, 3,… n_s)
- Decompose and model each surface and obtain a model parameter vector, $\boldsymbol{p}_k$, for each surface
- Combine all parameter vectors into a single matrix, ***P***
- Find principal patterns in the parameter vectors using Singular Value Decomposition (SVD)
- Keep the 3 “most important” basis vectors: $\boldsymbol{q}_1$, $\boldsymbol{q}_2$, $\boldsymbol{q}_3$



Approach: Project on Basis Vectors

- Consider surface modeled with 72 parameters
- Estimate parameters using basis vectors

$$\boldsymbol{p} = \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ \vdots \\ p_{72} \end{bmatrix}$$

$$\boldsymbol{p} \approx a_1\boldsymbol{q}_1 + a_2\boldsymbol{q}_2 + a_3\boldsymbol{q}_3$$

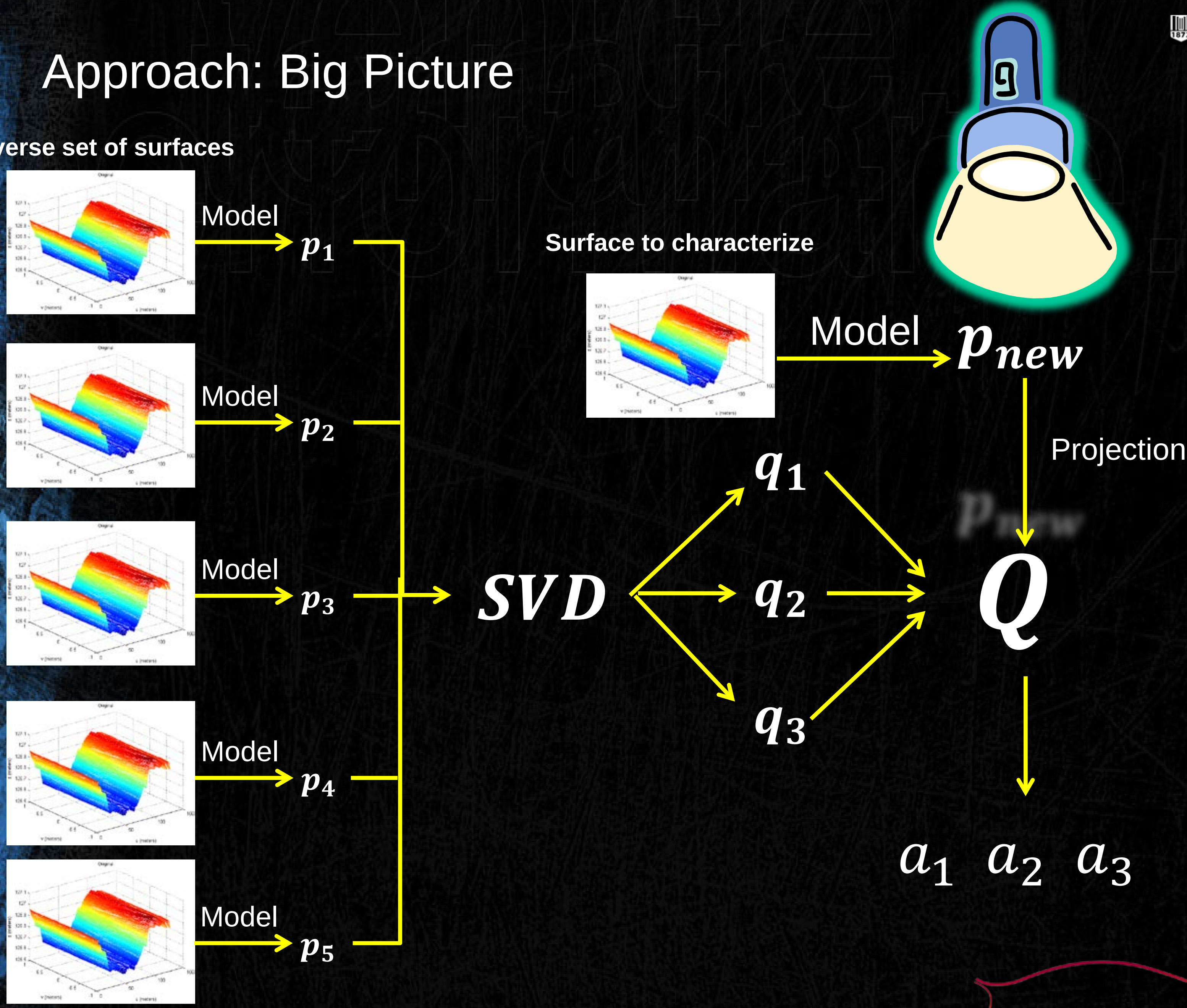
$$\boldsymbol{p} \approx [\boldsymbol{q}_1\ \boldsymbol{q}_2\ \boldsymbol{q}_3] \begin{Bmatrix} \boldsymbol{a}_1 \\ \boldsymbol{a}_2 \\ \boldsymbol{a}_3 \end{Bmatrix}$$

- Knowing the basis vectors, written compactly as $\boldsymbol{Q} = [\boldsymbol{q}_1\ \boldsymbol{q}_2\ \boldsymbol{q}_3]$ only the 3 "a" coefficients are needed to characterize the surface

$$\boldsymbol{p} \xrightarrow{\ projected\ } \boldsymbol{Q} \rightarrow a_1\ a_2\ a_3$$

Characterization Coefficients

Approach: Big Picture



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Proof of Concept: Model Choice

- Several surfaces are modeled using settings below

Model Type	AR
Residual Distribution	Logistic
Model Order	10
Cutoff Frequencies	0.25 [1/m], 0.025 [1/m]
Principal Components	Elevation, Banking
Number of Basis Vectors, n_b	3

- Profiles from each surface are plotted and compared to the synthetic profiles using the characteristic coefficients

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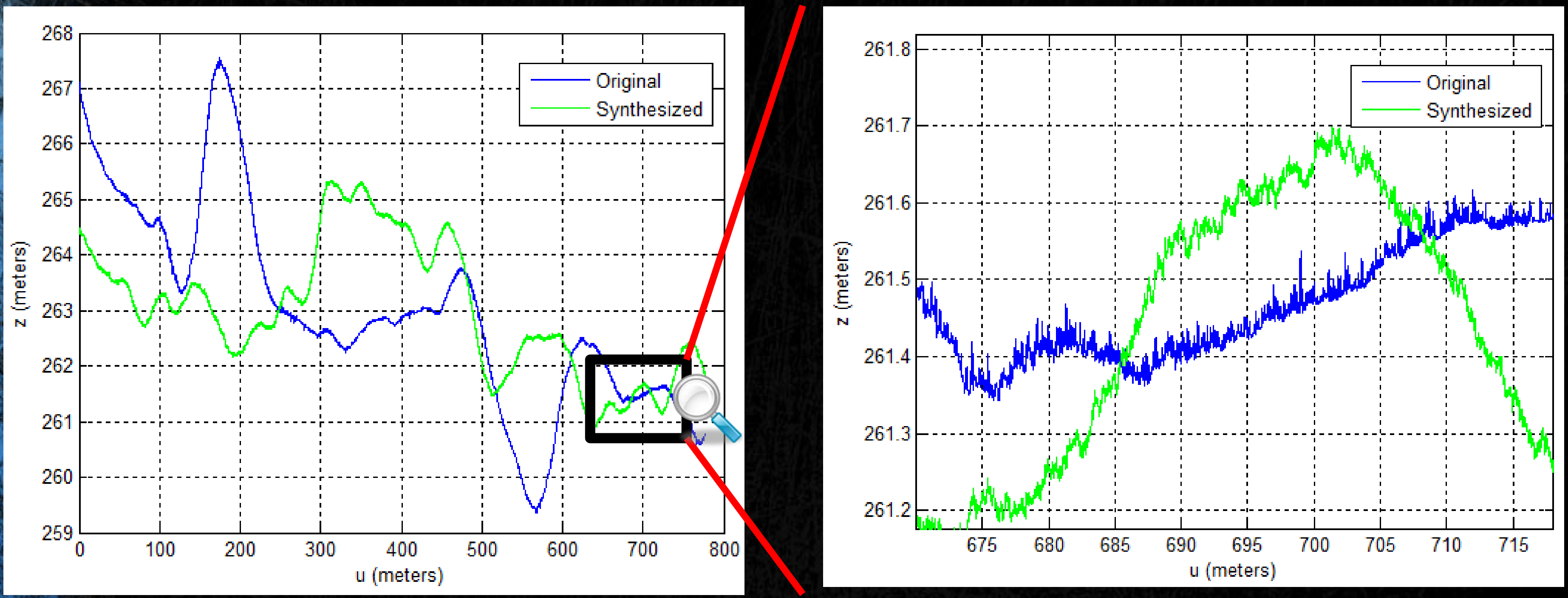
Proof of Concept: Results

Profile 1

$$a_1 = -3.016$$
$$a_2 = 1.009$$
$$a_3 = -1.546$$



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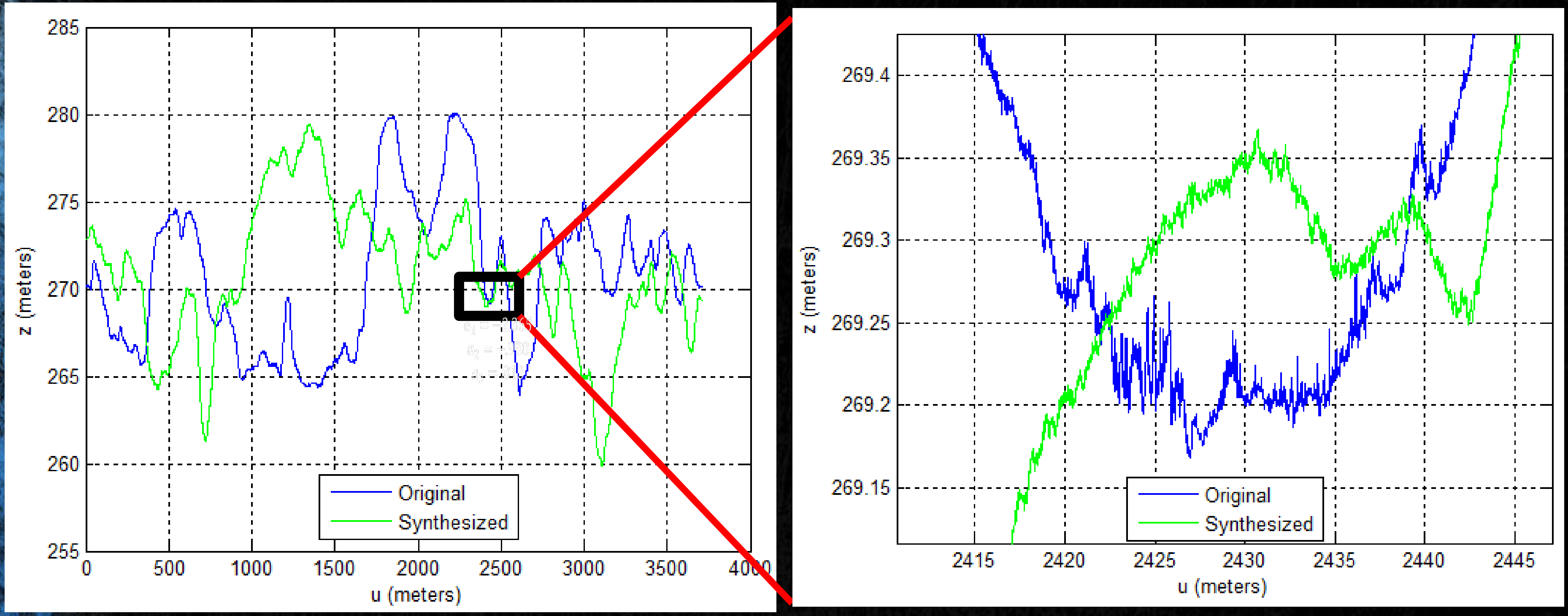
Proof of Concept: Results

Profile 2

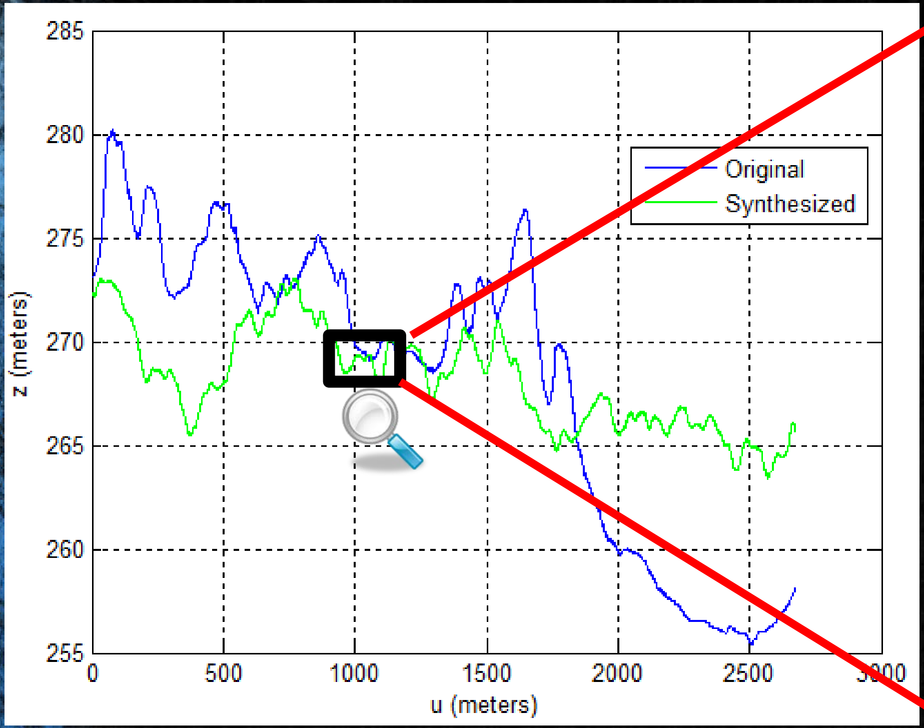
$$a_1 = -2.365$$
$$a_2 = -.938$$
$$a_3 = .813$$

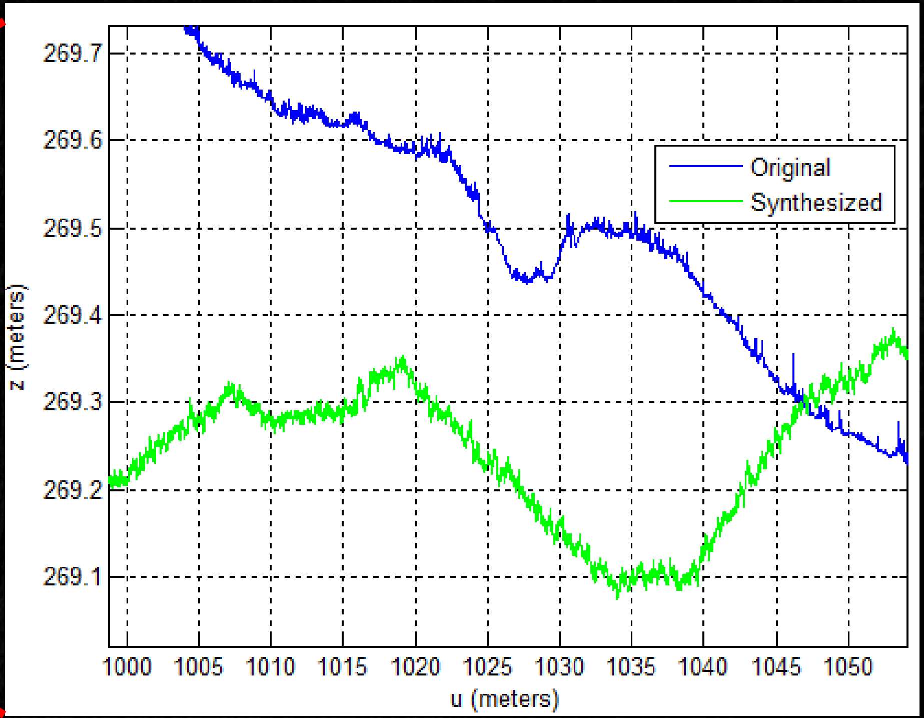


Proof of Concept: Results

Profile 3

$$a_1 = -2.682$$
$$a_2 = .985$$
$$a_3 = -.548$$





Future Work

- Concept must be applied to roads outside the set used for SVD
- A more complete and diverse road set is needed to finalize SVD
- Separate models must be investigated
    - Model type: AR, CMC, Hybrid, etc.
    - Frequency bandwidths
    - Surface principal components
    - Model order
    - Characteristic distribution for residuals (Logistic, Normal, Cauchy, etc.)
- Portability between models
  (same characteristic coefficients for multiple models)
- Physical interpretation of coefficients
- Techniques to avoid model instability

Conclusions

- Preliminary results are very encouraging
- Characterization must be applied to new courses outside SVD set
- Numerous modeling choices to be researched
- Thanks!