Variability Study Paper - Statistical Methodology

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Resulting Outline

Plan for level/focus:

Focus on adaptations to the model for *spatially dependent* data and *paired similarity score* data.

Introduce two-dimensional signature data and forensic pairwise framework but only for the purpose of alternative response data structures that are of interest.

Focus on a single barrel type to avoid over-complicating forensic perspective and study design?

Introduction/Background

Gauge R&R study framework is used to evaluate a measurement system or measurement process. The goal is to quantify the variability in resulting measurement data when measurements are taken under identical environmental conditions and when environmental conditions are varied.

Uses traditional mixed-effects models. Quantifying magnitude of random effect variance components is the goal.

Innovations in microscopy have increased use of 3D microscopy to capture surface topographies of physical objects. R&R framework is defined for singular measurement values.

Quantifying repeatability and reproducibility of more complex topographical structures captured in 3D microscopy is of interest.

We propose an extended R&R framework for modeling that maintains the same modeling assumptions and resulting model structure, but accounts for more complex data structures.

This paragraph will talk about forensic firearms analysis and that automated methods have two data structures not typical for R&R studies. Talk about the pairwise nature of comparison.

Here I will describe that two-dimensional signature data is captured through a microscopic measurement system. Operators and microscopes are varying parts of measurement process. Processing steps are present to get 2D sig., but are held constant in this case.

Define bullets as parts we are going to measure. (We will focus on individual lands rather than a pooled model for this case.)

Pairwise similarity structure results in data on $[0, 1]$. Measuring reproducibility of similarity scores across bullets, operators and machines using pre-defined algorithm applied to pairs of extracted signature data.

Methodology

Traditional three-factor Gauge R&R Model:

- Parts
- Operators
- Devices

Some fixed, unknown process mean μ, and random effects for each study factor. Also state assumptions (independence, variance components).

Summary values obtained from random effects modeling results: $\sigma_{repeatability}, \sigma_{reproducibility}$.

Model adaptation, dependent data

Describe dependent data structure of signatures, $(\mathbf{X}, \mathbf{Z})$.

Here discuss lack of independence assumption and autocorrelation structure of signatures due to striations.

Here lay out the subsampling approach.

Next lay out including location interaction with study factors.

Model adaptation, pairwise data

Describe pairwise data structure of similarity scores.

Here discuss relationship of paired study factors.

Here discuss structure of same-source scores as opposed to different-source scores.

Reframing of study factors as paired levels within paired data context

Data Collected

Repeated data collected for operators and machines, with 5 repetition rounds.

Signatures extracted using identical processing steps. Pairwise scores calculated for each pair within the set.

Results

Signature Results

Pairwise Results

Conclusion

We have developed an extension of the traditional Gauge R&R framework that maintains the traditional mixed-effects modeling assumptions and results structure - still working on a better way to say this - for spatially dependent measurement data as well as pairwise similarity metric measurement data.

Working Backwards

Conclusion

We have developed an extension of the traditional Gauge R&R framework that maintains the traditional mixed-effects modeling assumptions and results structure - still working on a better way to say this - for spatially dependent measurement data as well as pairwise similarity metric measurement data.

New methodology that gets us to that conclusion

- Subsampling spatially dependent data to account for dependence and allow for assumption of independence when modeling
- Accounting for differences across spatial locations by including location interaction with study factors
- Reframing of study factors as paired levels within paired data context

Underlying methodology to get us to our adaptations

Traditional three-factor Gauge R&R Model:

- Parts
- Operators
- Devices

Some fixed, unknown process mean μ, and random effects for each study factor. Also state assumptions (independence, variance components).

Summary values obtained from random effects modeling results: $\sigma_{repeatability}, \sigma_{reproducibility}$.

Background about our data types needed

Forensic firearms analysis poses the "pairwise" question: did a pair of objects originate from the same source or a different source?

Data used to complete that comparison: two-dimensional signature data, represents striation patterns engraved by gun barrel.

Two-dimensional signature data is captured through a microscopic measurement system. Operators and microscopes are varying parts of measurement process.

There are data processing steps which extract a two-dimensional signature from a three-dimensional data object. Processing steps held constant throughout study.

How pattern is engraved on each bullet also introduces variability; bullet of origin represents "parts".

Pairwise similarity structure results in data on $[0, 1]$. Measuring reproducibility of similarity scores across bullets, operators and machines using pre-defined algorithm applied to pairs of extracted signature data.

Background about Gauge R&R

Gauge R&R framework is typically used to evaluate a measurement system, often used in engineering.

Uses traditional mixed-effects models. Quantifying the magnitude of random effect variance components is of interest.

Innovations in microscopy have increased the use of 3D microscopy to capture surface topographies of physical objects.

Traditional microscopy R&R uses single measured response value, directly applying traditional R&R framework.

Repeatability and reproducibility of the captured *objects* is often more relevant than microscope measurement repeatability of a singular response value. Why? Operator staging differences and their interaction with individual microscopes.