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Method for Determining Measurement Points for Virtual Point Transformation

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In Transfer Path Analysis (TPA) using Virtual Point Transformation (VPT), the primary factors governing accuracy are the physical consistency derived from measurement point placement and the numerical stability of the transformation matrix. This study proposes an algorithm that automatically and objectively selects the optimal configuration to balance these two indicators from a vast number of combinations.

First, to enhance the accuracy of the geometric information—the foundation of the measurement—a digital twin-based approach using 3D scanning was introduced. As shown in Fig. 1, by defining the coordinates and orientation vectors of the virtual point (VP), sensors (u), and impact points (f) on a precise 3D model of the connection point, geometric input errors, which are difficult to avoid with conventional manual measurements, were minimized.

Next, as a guideline for selecting optimal impact point configuration, an integrated score *S* was defined in Eq. (1). This score combines the 5th percentile value of the "specific impact consistency," representing the validity of the physical rigid-body assumption, and the "condition number of the transformation matrix," representing numerical stability.

$$S = \frac{\mathbf{5th\ Percentile(Specific\ impact\ consistency)}}{\log_{10}(\mathbf{cond(R)})} \quad (1)$$

Using the 5th percentile value enables the evaluation of the specific impact consistency across the entire frequency band, thereby ensuring a selection process resilient to localized errors. As shown in the scatter plot in Fig. 2, the combination maximizing the score *S* is located in the ideal region (top-left), achieving both high consistency and a low condition number.

This methodology was applied to TPA measurements of a suspension mounting on an actual vehicle. While it was previously difficult to select the optimal configuration from a vast number of combinations, the proposed integrated score S enables determining it efficiently and objectively. This study demonstrates that the proposed method simultaneously reduces measurement time and improves the accuracy of virtual point data for TPA.

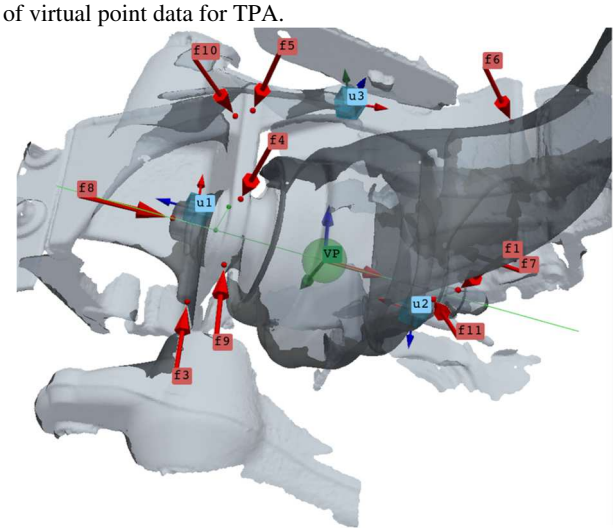

Fig. 1 Digital model for coordinate and orientation extraction.
u: sensors, f: impact points, VP: virtual point

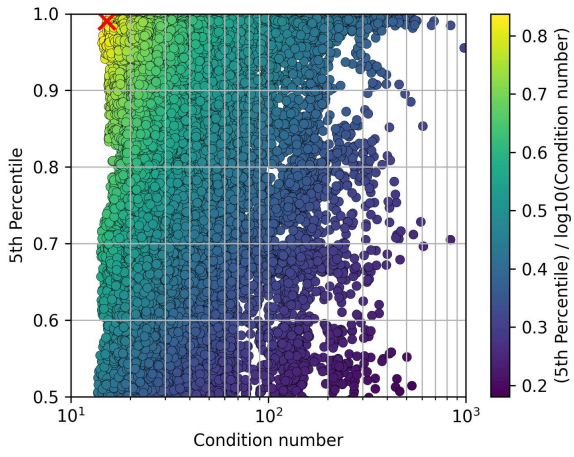

Fig. 2 Relationship between the 5th percentile of consistency and the condition number for all combinations.