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1 Improving the Kinematic Calibration of a Coordinate 2 Measuring Arm using Configuration Analysis

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6 **Abstract**

7 Portable coordinate measuring arms (CMA) represent a special class of co-
8 ordinate measuring machines providing high accuracy combined with high
9 flexibility. To obtain high accurate and reliable 3D coordinates, the kine-
10 matic model has to represent precisely the mechanical construction of the
11 CMA. Thus, a reliable and accurate calibration is essential to preserve the
12 CMA's accuracy. However, due to its redundant characteristics, estimating
13 the kinematic parameters has to deal with linear dependencies and, there-
14 fore, with rank deficiencies. A profound statistical analysis of the existing
15 calibration approaches has not yet been performed. For this reason, this
16 paper introduces an innovative and replicable least-squares calibration ap-
17 proach based on the general case of adjustment (Gauß-Helmert model). This
18 rigorous optimization procedure integrates the original observations and en-
19 ables a statistical evaluation of the estimated parameters as well as of each
20 observation, based on the configuration analysis. The applicability of the
21 approach is proofed using simulated and real measuring data. Thanks to the
22 configuration analysis and supported by experimental results, it is shown that
23 an accurate solution of the calibration can be obtained using measurements
24 only located in a small part of the workspace.

25 *Keywords:* coordinate measuring arm, Denavit-Hartenberg transformation,
26 kinematic parameter identification, Gauß-Helmert model, partial
27 redundancy, configuration analysis

28 **1. Introduction**

29 Measuring 3D coordinates with high accuracy and reliability is an impor-
30 tant task in manufacturing industry. Different types of coordinate measuring

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