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# Volumetric Error Compensation for the MScMS-II

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**Abstract**

Large scale measuring systems, i.e. measuring systems characterized by a measurement volume from some meters up to some hundreds of meters, are gaining importance in industry to check large parts or track the position of automated vehicles. In contrast with classical monolithic measuring systems, modern large scale measuring systems are constituted by constellations of sensors able to track the position of objects by triangulation or trilateration. This new design allows a greater system flexibility, scalability, and portability, together with a general reduction of costs. The MScMS-II is a large scale measuring system based on infrared triangulation. It has been designed to guarantee the maximum flexibility and reconfigurability, so every set-up procedure has been reduced as much as possible, so that its deployment and calibration requires a short time. However, its accuracy could benefit of a more complete volumetric calibration through the definition of a model of the volumetric error to be compensated. In this paper a self-calibration procedure based on a simple one-dimensional uncalibrated artifact is proposed to define a volumetric error model of the MScMS-II. Self-calibration can be performed in short time and can improve system performance by reducing systematic errors. Experimental results complete the work.


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## 1. Introduction

Large Scale Dimensional Metrology [1, 2] deals with all those 3D measurement tasks which involve a large measurement volume (from some meters up to some hundreds of meters). Application of these systems are more and more often found in industry, e.g. for the geometric control of large products (aerospace industry, large machine tool manufacturing), and to locate and track the position of robots or automated vehicles within large environments.

Traditional Large Scale Measuring Systems are simply larger version of classical coordinate measuring systems, e.g. large Coordinate Measuring Machines. However, the improvements in optics and laser systems have given rise to a new generation of Large Scale Measuring Systems, which instead of being monolithic measuring machines are constituted by smaller devices, able to locate the objects within the measurement volume usually by means of triangulation or trilateration. Several instruments of this kind are already available (laser trackers, laser radars, digital photogrammetry systems, indoor GPS). These instruments are usually cheaper than traditional measuring systems of comparable size, and often more portable, flexible and scalable.

The Mobile Spatial coordinate Measuring Machine System – II (MScMS-II) [3] is a large scale measuring system based on (at present six) infrared cameras which take images of one or more infrared targets. The position of the target(s) within the measurement volume can then be identified by means of triangulation. A mobile measuring probe has been developed which can measure points on the surface of any object by contact. Compared to other large scale measuring systems, the MScMS-II shows advantages in portability, flexibility, handiness,

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scalability, and cost. The MScMS-II has in fact been developed to guarantee a system which can be easily relocated and set-up with a simple and lean procedure.

MScMS-II main drawback is its accuracy, which can be evaluated in the order of 1 mm in a measurement volume equal to 2 X 2 X 2 m [3]. This performance is influenced by both random errors, which cannot be corrected, and systematic errors, which are due to an imperfect determination of the system calibration parameters and to other not corrected aberrations, like camera lens distortion, and can be compensated if known. Therefore, the knowledge of a model of the systematic (volumetric) error can lead to an improvement of the system performance.

The definition of the volumetric error of a machine is a well-known problem, both for measuring machines and machine tools [4, 5]. The evaluation is usually based on the measurement of calibrated artifacts, or the adoption of an high accuracy auxiliary measuring system, like a laser interferometer or, in recent years, a laser tracker. However, classical volumetric error models are designed for measuring systems structured like Cartesian or anthropomorphic robots. Large scale measuring systems are completely different, so the model needs to be redesigned. Moreover, managing a calibrated artifact system can be difficult for a measuring system which can be frequently reconfigured and is not usually located in a metrology laboratory, but instead at shop-floor level. Therefore, self-calibration methodologies should be considered instead.

Classical self-calibration methodologies [4, 6] involve artifacts constituted by grids of *n* subartifacts (e.g. ballplates), measured in *v* locations (views) of the measuring volume. The assumption on which these methodologies are based is that the geometry of the artifact is perfectly stiff. Raugh [7] basing on this has studied which constraints must be satisfied in the artifact placements in order to allow a complete evaluation of the volumetric error and has proposed a methodology that, given a generic form for a model of the volumetric error, is able to evaluate the parameters of the model itself. Moreover, perfect stiffness involves that the distance between couples of subartifacts is constant. Kruth et al. [8] considered this property to develop a similar methodology. These methodologies consider the problem of evaluating the volumetric error as the generation of an analytic function which can forecast the volumetric error at each location of the machine working volume, that is, a global model for the volumetric error. Other authors concentrated on the evaluation of a local model for the volumetric error by means of reversal techniques, that is, the evaluation of the volumetric error at discrete locations, possibly minimizing the number of required views (i.e. the measurement effort). Ye et al. [9] have then proposed a methodology which allows the evaluation of the 2D volumetric error on a grid of points with only three views of the uncalibrated artifact. A similar methodology has been proposed by Zhang and Fu [10], but this methodology requires a partially calibrated artifact. Finally, basing on Ye et al. work Dang et al. [11] proposed a full 3D self-calibration methodology.

Regardless of the chosen methodology, a limitation of self-calibration methodologies is that they define the volumetric error up to a scale factor. The scale factor can usually be evaluated by means of the measurement of some (simple, like a gauge block) calibrated artifact.

Anyway, the need for a complex artifact like a grid of subartifacts still contrasts with the ease of use needed by a system like the MScMS-II. A differing kind of artifact has to be considered.

In this work a methodology for simultaneously refining the calibration parameters and defining a model of the volumetric error of the MScMS-II is proposed. The methodology will be a "self-calibration" one, as it will be based on the adoption of an uncalibrated but rigid artifact. The chosen artifact is a simple bar with two targets located at its edges which will be moved and measured with continuity in the measurement volume, so data collection will require short time, in accordance with the MScMS-II philosophy. Based on measurement results and the rigid body assumption cameras calibration parameters will be optimized and the volumetric error model will be assessed. As initial result, experimental comparison of the system performance with or without systematic error compensation will be proposed on a reduced measurement volume.

## 2. The MScMS-II

MScMS-II is an indoor coordinate measuring system designed for large-scale dimensional metrology [12]. The system, in its prototype version, is made of three basic units (Fig. 1):

- a network of wireless devices, suitably distributed within the measurement volume in order to guarantee the best compromise between coverage and accuracy;
- a data processing unit connected via Bluetooth to each network device;
- a portable wireless and armless probe to "touch" the measurement points.

The distributed network consists of a number of wireless optical devices, each one able to establish a visual link with the optical markers that are visible in its "field-of-view" (FOV). In detail, each network device is an electronic device provided with a low-cost IR camera, characterized by an interpolated resolution of 1024×768 pixels (native resolution is 128×96 pixels), a maximum sample rate of 100 Hz, and an angular FOV of approximately 45°×30°. In addition, each camera is