Summary of REG(KIT) work

Future production processes will focus on shorter production times as well as on more reliable processes. This means that Large Volume Metrology (LVM) has to deliver reliable results, even for kinematic applications, so that e.g. the alignment process of large modules could be quicker than it is currently possible. Cooperative and self-guided robots will replace conventional production methods and demanding in-process proof of quality for spatiotemporal information. This requires the real-time determination of reliable spatiotemporal uncertainties of the arbitrarily moving objects, namely position and orientation, both with respect to time.

Recent research shows, that straight-forward calculations of spatiotemporal uncertainties for LVM using current standards specifications is currently not acceptable, as on the one hand, the behaviour of the measuring instrument observing moving objects is not satisfactorily known, and on the other, analysis methods based on Bayesian theory deliver more precise results as they use additional process information.

In order to achieve a spatiotemporal uncertainty calculation in real time a Bayes filtering technique is applied. The performance and the reliability mainly depend on the description of the kinematic process within the system model and the stochastic model as well as the description of the measurement process. A measurement model for the two types of laser trackers was considered this is the beam steering mirror model and the gimbal mounted beam source model. The required information about the system model can be either estimated via a hybrid system filter approach, or the robot control system can be integrated into the analysis method. The integrated method uses the information from the robot control system directly, without any additional noise leading to a more reliable state and uncertainty estimate.

The kinematic uncertainty of a laser tracker measurement is also dependent on the meteorology within the measurement volume and the reflector used. During kinematic experiments with a glass reflector like a cat's-eye reflector the centre beam of a laser is not always perpendicular to the outer surface of the reflector. This results in an increased divergence angle leading to an additional deviation of the centroid of the back reflected beam. A crucial part of a meteorology model within a laser tracker analysis method is the refractive index. Unfortunately the common meteorology models only deal with the distance measurements of a laser tracker, the angle measurements are not considered. However, the behaviour of the fluctuating part of the refractive index field is described by the turbulence theory and so a more realistic variance for the angle and distance measurement can be deduced.

To verify the analysis method for kinematic laser tracker measurements a multilateration system consisting of four laser tracers was used to generate a ground truth. Throughout these experiments an industrial robot carried a reflector along certain trajectories at different velocities, while a laser tracker and the multilateration system were measuring it simultaneously. The results of these experiments reveal that the proposed analysis method can be used in real time for process monitoring like assessing robot path deviations. Furthermore, with real time uncertainty information about the trajectory, now external observations like kinematic laser tracker measurements can be suitable used for online corrections of an industrial robot while the actual process keeps running.

List of publications

T Ulrich, Uncertainty modelling of real-time observation of a moving object: photogrammetric measurements, *Metrologia* **52** (2) 201-213 (2015), DOI: 10.1088/0026-1394/52/2/201

T Ulrich and S Irgenfried, Kinematic Uncertainty Estimation of Laser Tracker Measurements Using Control Information of an Industrial Robot, Indoor Positioning & Indoor Navigation, Rep. Korea October 2014, http://www.ipin2014.org/wp/SessionView.asp?code=1C&idx=1569939479

T Ulrich, Kinematic Uncertainty Estimation of Laser Tracker Measurements Using Control Information of an Industrial Robot, LVMC, Manchester UK November 2014, http://www.lvmc.eu/posters/Thomas-Ulrich.pdf