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Presenting a Novel Motion Capture-based Approach for Walk Path Segmentation and Drift Analysis in Manual Assembly

Philipp Agethen[a,*], Michael Otto[a], Felix Gaisbauer[a], Enrico Rukzio[b]

[a]Daimler AG, Wilhelm-Runge-Str. 11, 89081 Ulm, Germany
[b]Ulm University, James-Franck-Ring, 89081 Ulm, Germany

* Corresponding author. Tel.: +49-731-5052426; fax: +49-711-3052156294. E-mail address: philipp.agethen@daimler.com

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Abstract

Automotive industry is currently facing the challenge to cope with the market demand for mass-customization whilst remaining competitive. In production planning, this trend towards product-diversification leads to a rising complexity, since growing numbers of variants are hitting mixed-model assembly lines. Due to these changing preconditions, traditional planning models and respective simulations tend to decreasingly reflect reality. Actual manual assembly processes can deviate significantly from their corresponding plans due to simplified assumptions of simulation models, methods and tools. In order to contribute to a better prediction quality of planning models, this paper investigates walk paths in real assembly situations with regard to their deviation from corresponding plans. A novel algorithm set for walk path reconstruction and neural network based classification of work tasks is introduced. Therewith, data gathered by a mobile tracking setup can be automatically segmented and subsequently assigned to the process plans. This novel approach enables an assessment of predetermined assembly times by comparing reference to real walk paths. The method's technical performance is verified in laboratory evaluation scenarios and its applicability is proven in a productive automotive final assembly line during operation.

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Keywords: Time determination; monitoring; motion capture; automotive assembly; neuronal networks; walk path; segmentation; operator drift

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1. Introduction

In the automotive industry, manual assembly planning is becoming increasingly complex since the demand for product variants with shorter life-cycles is growing continually. As a consequence of this development, traditional planning methods tend to decreasingly reflect reality since simplifying assumptions are leading to higher uncertainties within these models. For instance, previous work indicates that walk paths (see [1]) and process times (i.e. [2,3]) of real assembly operators can deviate significantly from their corresponding process plans. In this context, it is crucial to review planning models with regard to their applicability in order to unveil inconsistencies between planned and real processes, especially when considering walk paths in mixed-model assembly flow lines. Therefore, an efficient method for investigating actual task execution times of manual assembly processes is a valuable tool towards a better planning performance.

This paper presents a novel approach to analyze the disparity between planned and actual assembly times of manual processes based on the operator's walk paths.

Therefore, an optical tracking system is utilized to unobtrusively record the routes of each assembly operator within a particular work place. These trajectories are subsequently processed and segmented via a neural network approach. These resulting subtrajectories are being matched and assigned to the process plan afterwards. Therewith, the actual assembly times can be compared with predetermined process plans for each cycle.

The remainder of the paper is structured as follows: First, the state of art in the context of assembly time determination is reviewed. Second, a non-intrusive approach is presented being able to compare predetermined and actual assembly times for each product using multiple distributed depth cameras. Subsequently, the applicability and technical performance of the proposed method is verified within two holistic evaluations,

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the former verifying the neuronal network algorithm classification performance and the latter assessing the overall applicability of this novel spatial disparity (drift) calculation approach. The paper concludes with an outlook on further optimization potentials and the resulting impact on future planning paradigms.

2. Assembly time in mixed-model assembly flow lines

Time determination systems are commonly used in industrial production systems for organization, planning and efficiency appraisals [4]. The resulting data sets are utilized among others for development, calculation, incentive systems, production program planning, production sequence and manufacturing planning. Within manual assembly planning they are commonly used to assign times to assembly processes, which are previously defined in workflow descriptions. The latter enables planners to optimize geometric and time-based interplay of the operator, workpieces, resources, material, energy and information within a working system [5].

Time management systems have brought up multiple methods for work time determination, which can be clustered in target time determination and actual time determination:

2.1. Determination of reference assembly times and predetermined motion time systems

Target times are defined as times, which have been derived from previously captured actual times [6]. This includes the category of “predetermined motion time systems” (PMTS), which are based on large studies with determined and fixed influence factors. They cluster basic work tasks in a tabular form [7] and are used to assign reference assembly times or so-called target times to workflow descriptions. Multiple standards exist to plan assembly times:

In Europe [8] commonly used PMT-systems are “methods-time measurement” (MTM) [9], MTM-UAS or various company proprietary systems such as “C-values”. In NAFTA region, MODAPTS [10] technique is wide-spread in automotive industry as well. Depending on the manufacturing type, repetitiveness, cycle time and type of workplace, the used planning method abstraction level highly differs. For example, highly repetitive, monotonous mass-production with short cycle times can be planned via MTM-1 on a low abstraction level, whereas for custom-made products higher-aggregated and therefore simplified planning methods, such as MTM-UAS or MEK are applied.

Limitations: Whilst target time and predetermined motion time systems inherit advantages in terms of simplicity, feasibility, planning speed and harmonization, they also have some drawbacks in contrast to actual time determination methods.

Analyzing human work is especially difficult since it is highly flexible, statistically distributed and varies to a large-scale [2,3]. Modeling statistic variances can help enhancing model and simulation quality, dealing with variance and optimizing the overall planning quality. Using reference assembly times, this variance is neglected. This could lead to unexpected errors during operation in production as well as to an overexertion of assembly operators. Therefore, reference assembly times have to be compared to actual shop-floor data in order to verify their validity.

2.2. Determination of actual assembly times

In contrast to PMTS and target time determination, actual times are defined to be real times which humans or resources need to execute certain process steps [6]. Various research has already been carried out in the field of determination of real assembly times (see [4,7,8]), ranging from methods of self-documentation over direct to indirect measuring principles. According to Deuse and Busch [7], direct measuring approaches, in which a third person or sensor is gathering temporal data from the shop-floor, are usually applied when analyzing manual assembly lines. In most cases, the execution time is determined using stopwatches [8], whereas recent approaches (see [11]) utilize sensors like inertial measurement units or RFID-Tags (i.e. [12,13]) being attached to parts or the human body.

Limitations: Even though these methods are frequently used in practice, they neglect important influence factors. Generally, the manual documentation of process times using stopwatches lacks of objectivity since the unambiguous determination of particular actions (i.e. screwing) in human motion is error-prone and depends on the respective person (see 4.1). Additionally, commonly used RFID approaches enable binary process monitoring on abstract level only. These approaches only monitor binary process acknowledgements during production.

In contrast to the state of the art, in the following chapter a method will be introduced which produces highly detailed information on spatiotemporal relations within a production environment to gain deeper insights on the processes itself and to overcome drawbacks of the previously mentioned systems.

3. Markerless Motion Capture for assembly time analysis

This paper presents a non-intrusive approach to automatically determine the disparity between planned and actual assembly times of manual processes based on the operator’s walk paths. In order to implement such a system, a common definition of trajectories is given in the following.

3.1. Concept

Following Buchin et al. (see [14]) a discrete trajectory τ is defined as “a mapping from a series of time stamps $t_0, t_1, \dots, t_n$ to the plane (or a higher-dimensional space).” For any timestamp t_i, the location in the plane at time t_i is denoted by $\tau(t_i)$. For any two times $t_i, t_j \in \{t_0, \dots, t_n\}$ with $t_i \leq t_j$, the subtrajectory of τ from time t_i to time t_j is defined as $\tau\,[t_i, t_j]$ [14].

Based on this definition, Figure 1 depicts the concept of analyzing the spatial distance between the reference and real walk path in order to deduce the underlying time gap in the course of time. Assuming that the operator drift x_{Diff} represents the vector between a corresponding point pair being

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