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ScienceDirect

Procedia CIRP 54 (2016) 152 – 157

www.elsevier.com/locate/procedia

6th CLF - 6th CIRP Conference on Learning Factories

# Using Marker-less Motion Capture Systems for Walk Path Analysis in Paced Assembly Flow Lines

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## Abstract

In recent years, automotive industry is facing a turbulent environment with an increasing demand for mass-customization and shortened product life-cycles. For manual assembly, this trend has led to a rising planning complexity, since growing numbers of product variants are hitting mixed-model assembly lines. In this context, it is crucial for production planning to be aware of the actual state of an assembly line in order to identify inconsistencies between the situation in company-owned learning factories and the shop floor, especially when considering non-value-adding tasks (e.g. walk paths). However, a feedback loop for walk paths linking the assembly line with the planning department is not established in practice. Consequently, discrepancies between planned and real processes remain largely unknown since they only become apparent through production disruptions. In order to provide production planning with an objective tool for walk path assessment, this work proposes a novel tracking approach, being able to reconstruct operators' motion within an assembly line. Based on a distributed depth camera array, a scalable and marker-less tracking system is presented that can be applied in productive environments. An in-depth evaluation underlines the performance of this novel approach and assesses the overall path accuracy. Finally, the proposed system is set up in an automotive final assembly line during operation. The gathered data is investigated regarding planning inconsistencies during operation.

Peer-review under responsibility of the scientific committee of the 6th CIRP Conference on Learning Factories

*Keywords:* Production planning; Monitoring; Motion capture; Automotive assembly

## 1. Introduction

Manual assembly process verification aims to achieve an optimal production process preparation through which efficient, ergonomically viable and robust processes are defined [1]. In practice, these processes are defined during the ramp-up phase in several production preparation workshops. These are typically conducted in company-owned learning factories which provide a "realistic manufacturing environment" through "the adoption of new manufacturing knowledge and technology" – according to the definition of Abele et al. [2].

Rising variant complexity of production sequences coupled with simplifying assumptions of planning models (e.g. abstraction of walk paths ignoring operator drift) lead to a decreasing reflection of reality in process plans. Consequently, real production processes fall short of expectations stemming from the outcome of tests performed in learning factories. Since the real situation at the shop floor is hardly ever compared to the original plans after their deployment, these inconsistencies often remain unidentified. Similarly, not all optimization potentials can be fully grasped in the learning environments. A feedback loop as depicted in Figure 1 – linking the assembly operator with the relevant planning stakeholders – is a valuable tool to help overcome these drawbacks.

Furthermore, by comparing shop floor data and the capabilities of current planning methods and models to depict this data, improvements for future methods and models can be derived. At the same time, the applicability of knowledge gained from learning factories can be reviewed.

This paper presents a novel approach for marker-less walk path recording in order to compare actual walk paths with their corresponding planned ones. The proposed tracking system consists of a distributed depth camera setup and can be used in a manual assembly line during operation.

Peer-review under responsibility of the scientific committee of the 6th CIRP Conference on Learning Factories
doi:10.1016/j.procir.2016.04.125

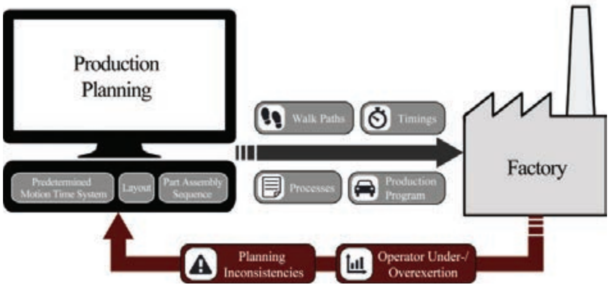

Figure 1: Proposed feedback loop between shop floor operations and planning departments.

The remainder of the paper is structured as follows: First, an overview of current methods for planning walk paths is given. Second, the state of the art of motion capture techniques is reviewed and requirements for such systems on the specific use case “walk path assessments” are derived. On this basis, a marker-less tracking system is proposed, being tailored to the identified needs. Finally, the overall technical performance and applicability of the novel approach is evaluated both in laboratory conditions and in operating final assembly line work places. The paper concludes with a holistic assessment and outlook on further optimizations.

## 2. Walk paths in paced mixed-model assembly flow lines

Automotive assembly is typically carried out on a series of connected assembly lines, consisting of continuous conveyor belts that carry cars through assembly stations at a constant speed. The system is therefore continuously and strictly paced. In this case, unless the conveyor stops due to a disruption in the assembly process, the time that a car spends inside a station is fixed and defined as cycle time [3]–[5]. This represents the available mean time for an assembly operator to work on a car, assuming that operators are assigned to stations and do not move along with the cars. On the other hand, the assembly operations to be carried out on a certain car at a certain station can vary with each customer order, especially when considering mixed-model assembly lines. An actual sequence of cars (“production program”) may have a mean total assembly time per car that fits into the accumulated cycle time of all available stations. However, inside that sequence there might be subsequences of cars that exceed the available cycle time at a station, whilst others have an assembly time below the mean [5], [6]. Therefore, when planning an assembly line, it is crucial to not only look at the production program average, but also at the momentary peaks.

In reality, the point in time at which an assembly operator starts to work on the next car is not exactly synchronous with the pace of the flow line, but “floats”. For example, on one occasion the operator might start working on the next car only ten seconds after the car has entered his station because he was held up with the previous car, on another occasion he might be able to start ten seconds before, when the car has not yet entered his station. The term drift is used to describe this effect [6]. The drift at a certain cycle results from a variety of variables, a major one being the accumulated task times of the preceding cars up to that moment. Accounting for drift in assembly planning is especially difficult, because the amount of drift at a station depends on the sequence of the production program, which is typically not known in advance.

When assessing the efficiency of a planned assembly line, in the spirit of lean production, often the ratio of value-adding and non-value-adding task times is regarded. The non-value-adding portion is usually comprised to a large extent by walking. Thus, when optimizing an assembly line, minimizing walking distances is important. In practice, walk paths are often planned with pen-and-paper methods, such as spaghetti charts. The time needed for walking activities is usually determined using predetermined motion time systems (PMTS) and mainly depends on the traveled distance [3].

For the sake of feasible modelling and planning effort, walk paths in process plans are usually static and do not reflect any drift situation. The typical planned situation is that the car is in the middle of the station. It is apparent that the more drift occurs at an assembly station, the more plans will deviate from reality. This can lead to overexertion of assembly operators as well as plans overestimating assembly line capacity. With the current trend of increasing product variance hitting mixed-model assembly lines, practitioners are starting to pay more and more attention to the impact of drift on assembly line performance and line balancing.

One possibility to account for drift-related walk paths is to perform simulations of assembly plans and production programs using station layout-based digital planning tools such as IPO.Log (see *www.ipoplan.de*). However, actions of real assembly operators can deviate significantly from the simulation, as is depicted in section 5. Frequent reasons are plan inconsistencies and the operator optimizing his work methods on his own.

## 3. State of the art techniques for walk path assessments

In order to improve the reliability of learning environments and to benefit from self-optimization processes, it is crucial to compare the predetermined plans with the real situation at the shop floor. Since the domain of manual assembly focusses on human work, the main subject of such an evaluation is operators’ motion, which needs to be captured precisely.

Tracking systems are the enabling technology for reconstructing human movements. This includes Motion Capture (MoCap) techniques using various physical effects ranging from spatial scan procedures like e.g. time of flight and phase-difference sensing over inertial sensing to mechanical linkages [7], [8].

Currently, in the automotive industry MoCap technology is frequently used for virtual assembly scenarios such as virtual training, maintenance and virtual process verification tasks. In practice, typical assessment scopes are production-oriented product optimizations, ergonomics, time planning or process verification [9]–[11].

### *3.1. Marker-based Motion Capture systems*

Optical marker-based tracking systems consist of multiple fixed infrared cameras, being positioned on the edges of the