The Influence of Machine Speed on Human Performance for Simple and Highly Repetitive Work Processes: A pilot study

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ABSTRACT

Partially automated processing of horticultural products often contains simple and highly repetitive manual work processes. The handling of susceptible products, especially the feeding of conveying units, is difficult to mechanise. The machine capacities continuously increase and in consequence a higher material input is necessary. This is commonly realised by boosting the speed of material transport, but in practice a full capacity is rarely achieved. The manual material input is a shortcoming that needs to be optimised, taking into account that there are motivating aspects for the worker like a belt speed increase, but also risk factors resulting from the work task itself. Highly repetitive work can cause work related disorders. Job satisfaction is generally low in this work environment, offering no substantial task variation, with stress commonly present due to high production speeds. There should be a balance between task demands and worker's motivation and abilities. The purpose of this pilot study is to introduce a motion-based approach for assessing the effects of machine speed on worker's performance in a simple repetitive task.

A conveyor belt and wooden sticks are used to simulate a simple and highly repetitive process of placing products on a moving belt. The influences of increasing machine speeds on the human performance and motion are investigated in this study.

A 3-D-motion analysis system collects objective data (Jakob, 2005). Active infrared light emissive diodes are attached to the upper extremities of the subjects to record the motions.

Three different machine capacities are run from 7300 pieces up to 10300 pieces per hour. The speed of the moving belt respectively rises from 0.19 m/s to 0.3 m/s. To decide on the optimal speed, knowledge about the product and the complexity of product placement is also essential. Within the experiments it was possible to determine major influence factors on the human performance, which is again influenced by many internal factors like abilities, health status or motivation and external factors like work technique and process organisation. Two different work techniques were identified. A synchronous work style proved to be more efficient, but at the same time caused more body movement as an asynchronous work style.

Although the experimental work task was very simple, large variations in the human capacities were noticed. The operation breakdown limits the maximum human capacity and needs to be optimised first. The synchronous work style showed a greater potential for a performance increase induced by the machine speed but also by large variations in the individual performance-rate. To explain these variations the precise analysis of the motion tracks revealed more differences in the efficiency of individual job performance.

Keywords: human performance, motion analysis, manual work

1. INTRODUCTION

The processing of horticultural products often contains simple and highly repetitive manual work processes. Solutions found for mechanisation of post harvest production are site-specific and often incomplete. One of the technological gaps is the mechanisation of processes, demanding human judgement and dexterity. This is most challenging especially regarding the characteristics of fresh market perishable fruit and vegetables.

The feeding of conveying units, that are transporting the goods from one step of processing to the other, is a practical example of a technological gap (Figure 1) still requiring manual work. Large and constantly growing machine capacities meet a varying human performance. This became obvious in the investigations of various horticultural enterprises (Jakob & Geyer, 2004), established in the production of white asparagus. Unsatisfactory machine utilisation for the automatic processing and sorting units was found in nearly all cases. This was, among other reasons, caused by strong interpersonal performance variations. On the one hand too little attention was paid on selecting, training and controlling the workers at the key positions of the processing line, the product supply. On the other hand part of the work force was wasted due to emerging waiting times. This reveals the basic phenomenon that work design in the manufacturing environment is traditionally technology-driven, focussing on machine capacities but neglecting the role of people in production processes (Paquet & Lin, 2003).

Figure 1. Manual supply of white asparagus for automatic washing and sorting

The capacities of automated processing units continuously increase and in consequence a higher material input is necessary. This is commonly realised by boosting the speed of material transport and at the same time increasing the number of workers for material supply to meet the increased demands. In practice it was found (Jakob & Geyer, 2004) that full load of the conveying units was rarely achieved. Therefore in most cases the manual material input is a constructive shortcoming that needs to be optimised.

If the belt moves faster the speed is motivating the workers to increase the work speed, but it is also a risk factor, that can cause stress or increase the error ratio. Under the given circumstances the job satisfaction is low, offering no variation in the actions over the whole day. Highly repetitive work is not recommendable regarding the physiological motivation and connected with causing work related disorders (Calisto, 1999). In order to achieve system reliability, the expected task demands has to be balanced with the worker's abilities and motivation. The knowledge of process time and other influencing work factors are essential to calculate the system's potential. Process time is usually determined by REFA time studies or predetermined motion times like MTM-charts are applied (REFA, 1984), but the duration of a process does not explain the observed output variations. For the explanation of interpersonal performance variations an alternative method is needed.

Digital motion analysis was successfully used for the investigation of human performance by various scientists in the area of sports and medicine (Stallkamp, 1998; Reinisch, 1993 or Datta et al, 2001). The application of a comparable system in work science is described by Jakob (2005). Various indicators are gained from the spatial coordinates describing the human motion. These are used to compare different workers and experimental settings. The purpose of this pilot study is to explore the use of a motion-based approach to evaluate the effects of machine speed on worker's performance.

2. EXPERIMENTAL SETTING

A conveyor belt for transporting the material and wooden sticks are used to simulate an easy and highly repetitive work process. The work task is simply described by grabbing a bundle of wooden sticks stored in a box on the left hand side of the belt and placing the material one by one on the moving belt. The distance between the box and the belt is kept as short as possible. The conveying unit is divided into sections for single product placement. The box contains 91 wooden sticks. Three different machine capacities are run in the experiment, ranging from 7300 pieces up to 10300 pieces per hour. The speed of the moving belt respectively rises from 0,19 m/s to 0,3 m/s over ground.

A 3-D-motion analysis system (Wente/Thiedig, Braunschweig, Germany) collects objective motion data (Jakob, Geyer & Ivanov, 2004; Jakob, 2005). Active infrared light emissive diodes are attached to the upper extremities of the subjects to record the motions of hands, elbows and shoulders. The frequency of images per second is 8 for the application of six markers. The distance travelled between two images was below 4 cm for approximately 75 % of the data concerning the hands. The position of each marker is described by its spatial coordinates throughout the process of recording. A custom made software transforms the raw data into indicators to describe and evaluate the human motions.

Three workers, two male and one female, were observed. The two male workers were aged between 40 and 50 years, employed at the research institute as blue-collar workers. The female subject was a student worker aged 25 years with a body height and elbow height above the 50th percentile. The elbow heights of the subjects were 116 cm for A, 113 cm for B and 104 for C, all wearing shoes. The subjects practised the work process before the measurements took place.

The number of repetitions for each machine capacity and subject was ten, one set of data contained the handling of 91 pieces.

Figure 2. Experimental setting with arrows pointing at marker positions

3. RESULTS

Although the experimental work task was very simple, large interpersonal variations in the human performance were noticed (Figure 2).

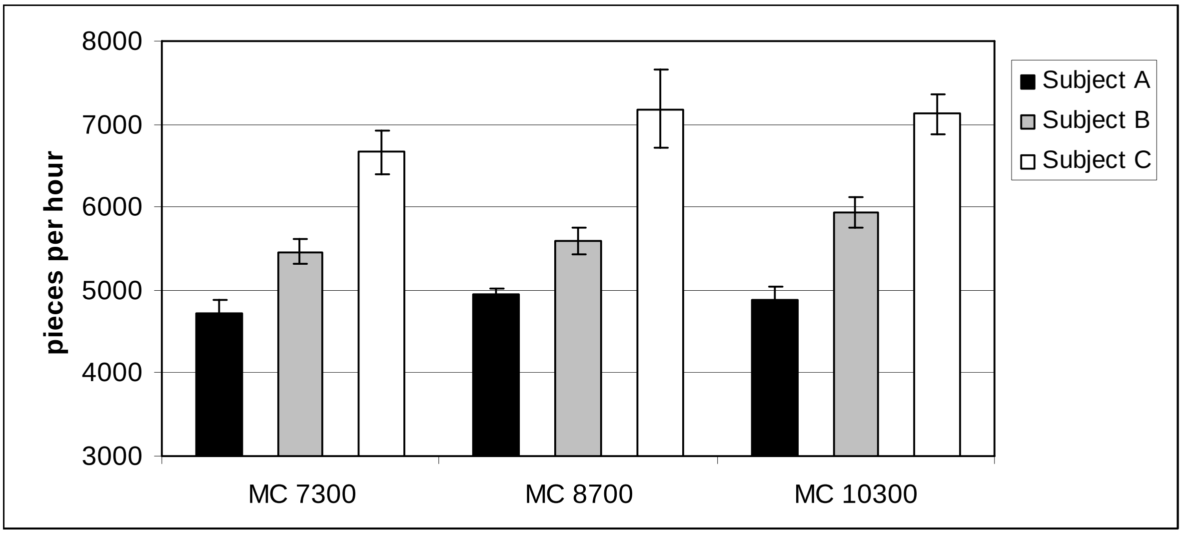

Figure 3. Human performance of three subjects at different maximum machine capacities (MC) in pieces per hour

Subject A showed a difference in the operation breakdown resulting in apparently lower work performance for all machine speeds (see figure 3). Subject A used one hand for grabbing and the other hand for placing the wooden sticks on the belt. In contrast to that subject B and C showed a synchronous work style, using both hands within the whole process, resulting in a greater potential for a performance increase induced by the machine speed but also large variations in the individual performance-rate (see standard deviation fig. 3). To explain the inter- and intra-personal variations of subject B and C the precise analysis of the motion tracks follows. Subject A is neglected for further analysis, because the shown performance is unsatisfactory.

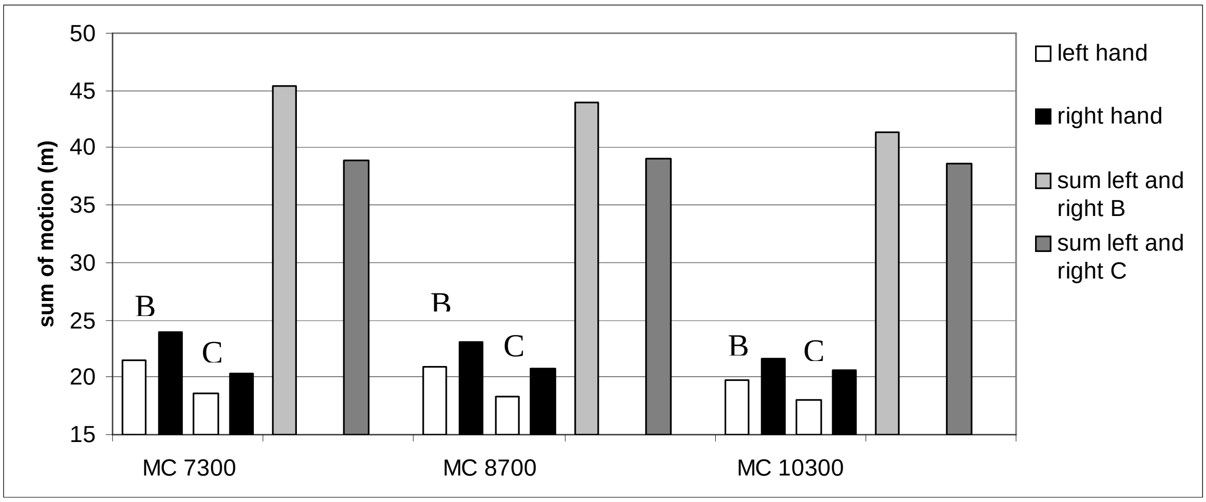

Figure 4. Sum of motion for the left and right hand of subject B and C for different MC in pieces per hour

Looking at the sum of motion, defined as the total path length between all recorded spatial coordinates, there is an apparent difference between the left and right hands for both subjects. Subject B shows significantly higher values at all machine capacities than subject C. This means that subject B had to execute more motion to do the same job.

If a person has to fulfil the task of bringing material from one point to the other the motion track commonly describes a curve, which means that the travelled distance always exceeds the direct distance measured between the origin and destination. The progression of the motion curve is subject to many different influences. One characteristic for the curve progression is the saddle point, describing the maximum distance from the work surface for bringing the material to the conveyor belt. The saddle points for selected bringing and reaching actions are shown in figure 5. All in all, subject B showed higher saddle points for all machine capacities.

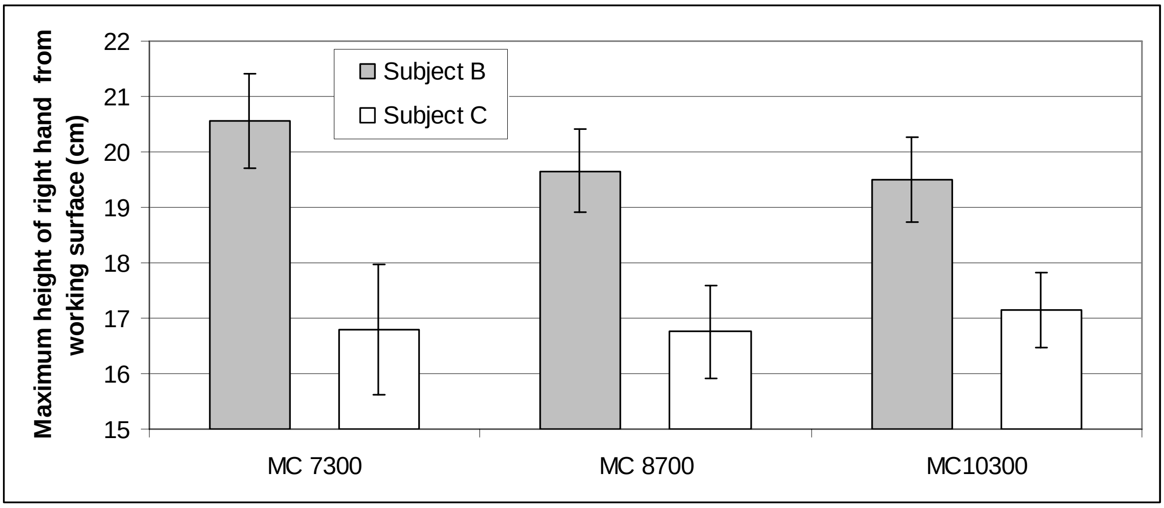

Figure 5. Maximum height of the right hand from the working surface for subject B and C at three machine capacities (MC) in pieces per hour

In contrast to the results displayed in figure 4 the average distance for bringing and reaching was 50 cm for subject B and 62 cm for subject C at the highest machine speed. Therefore B showed a smaller area of activity than C, but a larger extension upwards. B also moved slower than C. This is one explanation for the lower performance rate.

The most important influence on the personal performance was found, when the number of travels between box and conveyor were counted. Whereas subject B grabbed 12.8 times into the box to empty it, subject C only needed 10.1 times at the highest machine speed. The speed of the conveyor belt did not influence the number of times grabbed into the box.

The increase of machine capacity had a positive influence on the personal performance, which is displayed in figure 2. The sum of motion (figure 4) was not influenced for subject C, subject B showed a slight decrease. The machine speed does not show an apparent influence on the distance from the working surface (figure 5).

4. DISCUSSION

In order to decide on the optimal speed of a conveyor belt, knowledge about the product and the complexity of product placement is essential. The case study comprised a product handling ranging from 1.3 to 2 pieces per second. No manual method seems suitable to measure the duration of the motion elements for this process. Therefore a manual measurement for more complex motions or an automatic time recording would have to be carried out to receive valid information about the expected process time. The applied motion analysis system automatically recorded the process time. This was used to calculate the performance rates.

It was also possible to determine major influencing factors on the human performance, which is again influenced by many internal factors like abilities, health status or motivation and external factors like work technique and process organisation. Two different work techniques were identified. The synchronous work style proved to be more efficient by the means of the performance rate, but at the same time caused more body movement as the asynchronous work style (no figure). The asynchronous work style, which was adopted by subject A, was neglected for further evaluation, because no significant increase in the performance was noticed.

Although subject B and C showed a similar work style, the difference in the individual performance was apparent. For Subject C a smaller amount of hand movement was measured (figure 4) for all machine capacities. A precise comparison of the selected motion elements bringing and reaching indicated in contrast to a lower sum of motion in total (figure 4) larger values for C. This resulted in a larger area of activity. The curve progression of bringing and reaching recorded for subject C again was characterised by a lower inclination. The inclination was described by the maximum distance from the surface of the moving belt (figure 5). Subject B showed a high inclination with a larger distance from the working surface and at the same time shorter motions for bringing and reaching. In consequence the target precision of B can be described as less distinctive.

The negative aspect of subject C's larger area of activity was compensated by an excellent ability of grabbing large bundles of material as well as the fast work speed. The grabbing capacity and the work speed showed the largest influence on the overall performance.

The observed variability of the individual performance rates pointed out the difficulty of predicting system capacities and the importance of controlling the human work force. The difference between the highest and the lowest performance measured was 33 % for all subjects and speeds.

Finally this pilot study does not allow to generally transfer the results, because the number of subjects is not representative. Nevertheless a trend of possible performance increase, if line speed is faster, became obvious, as well as the necessity of training no matter how simple a process is. The regarded work situation was simplified to demonstrate the ability of the motion-based approach to capture changes in worker performance. In reality, the processing machines demand more than one worker feeding the conveyor. The efficiency of each additional worker in the row is expected to decrease, because some of the belt is already filled with material and gaps need to be looked or waited for.

5. CONCLUSIONS

The applied motion analysis system has provided suitable and meaningful indicators to objectively compare different workers under the influence of gradually increased machine speeds. Traditionally applied time studies (REFA, 1984) are based on the determination of the duration of motion elements, which are in this case too short to be recorded manually. Furthermore the simple comparison of process times is not sufficient to identify the reasons for variation or derive measures for improvement.

In accordance with the observed unsatisfactory machine utilisation in horticultural enterprises (Jakob & Geyer, 2004) the experimental performance rate was variable, which limits a reliable prediction of the expected system performance. Although the work process is very simple, the role of the human seems to be very influential.

The evaluation of the motion tracks allows to individually train the subject to improve their individual performance. Subject B needs to work faster and grab more pieces at once. Subject C has probably reached the maximum performance, but part of its motion is misguided. C could diminish the distance for bringing the material to the conveyor, increasing its area of activity.

This approach can be used to determine worker's optimal performance in highly repetitive tasks such as the processing of horticultural products. Any negative influences on the worker's health due to the work task itself cannot be proven, but selected indicators, like body postures or the speed of movement could allow some conclusions.

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