Automatic Transcription of the Basic MTM-2 Motions in Virtual Reality

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Abstract. This paper presents our approach for the automatic transcription of the MTM-2 basic motions in VR. We give an overview of what Methods-Time Measurement (MTM) is and how it is used for the improvement of manual workplace layouts. We describe the conventional approach used to deliver MTM codes by the MTM experts and explain the benefits of using automatic transcription in comparison to the conventional approach. We discuss the reasonability of using our approach and potential use cases for it, followed by presenting the hard- and software used for our implementation. Further, we explain the user study procedure that was used to receive data for the assessment of the proposed automatic transcription. Lastly, we present the metrics we used to evaluate our algorithm and deliver measurable results based on those metrics. In conclusion, we summarize our work and present ideas for future work on this topic.

Keywords: Methods-Time Measurement, Virtual reality, Action Detection, Workplace Optimization.

1 1 Introduction

Despite the increase of process automization, manual operations still play an important role in production. To assess and improve the ergonomics of the manual workplace, different techniques are used. One of them is called Methods-Time Measurement (MTM) and was proposed by Maynard et. al. [3] in 1948. MTM is a predetermined motion time system, meaning that for each basic motion determined in this system there is a predefined time value. Currently, various MTM systems are used for different production types, such as MTM-1, MTM-2, MTM-UAS, and MTM-MEK. Each of those systems differs in terms of the granularity of the transcribed MTM basic motions.

For the assessment of the existing workplaces using the conventional MTM, a standard procedure is followed. Firstly, the working process is recorded using video capturing. Secondly, this video is getting manually analyzed and divided into the sequence of the basic motions by multiple MTM experts to avoid human errors. Thirdly, based on the obtained transcription, improvements in the ergonomics of the workplace are suggested.

To assess the workplaces that are not exiting yet, two approaches are used. One is to use a less detailed system, such as, MTM-UAS. This system doesn't consider human behavior, thus the assessment can be obtained based on the plan of the workplace. This system uses geometric distances between objects, if a detailed plan of the planned workplace is available, it allows to assess the ergonomics of the workplace based on the plan. Another option is to use a cardboard mock-up of the workplace. To reduce the costs and receive a sufficient representation of the workplace, cardboard engineering is used.

However, none of those methods allows a realistic representation of the planned workplace, although workplaces are already created using 3D CAD [1]. These models could then be imported in a Virtual Environment (VE) for the visualization and assessment purposes. Virtual Reality (VR) allows precise tracking of virtual objects as well as human positions. This data can be used to enable an automatic transcription of the basic motions, reducing the efforts required from the MTM expert for the manual transcription.

Gorobets et al. [2] investigated the possibility of using VR for assessment purposes using MTM-2 system. Their study shows that time values manually obtained from the MTM-2 analysis conducted in VR correspond to the MTM-2 values obtained from an identical layout and task performed in reality. This study proves the reasonability to perform an MTM-2 analysis within VE.

Our paper presents an approach to automatically detect and transcribe MTM-2 basic motions performed in VR. This will reduce the efforts for manual transcription and allow visualization of the planned workplace using VR technology.

2 2 Methodology

For our approach, we used an existing VR system HTC Vive Pro, which consists of the head-mounted display (HMD), two controllers, and three trackers. Controllers allow interactions with the virtual objects inside the VE. Trackers are placed on the feet and hip and are used to receive tracking data from the corresponding parts of the body. To compile the VE and enable interactions in VR, Unity software is used. Additionally, we included a human avatar to improve the sense of embodiment in the VE.

To automatically transcribe MTM-2 basic motions, we developed a decision-tree approach which is based on the positions of the virtual objects and avatar, and time, distance, and speed thresholds. This approach doesn't require preliminary training of the algorithm and aligns well with the MTM-2 approach. Currently, our algorithm is designed to automatically transcribe the following basic MTM-2 motions: Get, Put, Put Correction, Sequence Get-Put, Regrasp, Apply Pressure, Foot Motion, Step, and Bend & Arise.

We conducted a user study with 30 participants to test our algorithm. In addition, we capture video footage of an avatar performing a task in VR from a third-person perspective, which is intended for subsequent manual analysis by an MTM expert.

3 3 Findings

To assess our transcription algorithm, we were comparing the results we obtained from the automatic transcription provided by our algorithm with the manual transcription done by the MTM expert based on the video footage of the avatar performing a task in the VE. For assessment purposes we used the following metrics: True Positives (TP) – correct recognition of the performed action, False Positives (FP) – false transcription of the action that was not performed by the user, False Negatives (FN) – no detection of the performed action. Based on that terminology we introduced the following statistical metrics: Precision (Pr) and Recall (Rc).

$$Precision = \frac{\sum TP}{\sum(TP+FP)};\ Recall = \frac{\sum TP}{\sum(TP+FN)} \tag{1}$$

Table 1: TPs, FPs, TNs, Precision, and Recall for the automatically transcribed MTM motions.

	TP	FP	TN	Pr	Rc
Bend & Arise	176	29	2	0,859	0,989
Step	3060	59	26	0,981	0,992
Foot Motion	1184	51	23	0,959	0,981
Get	536	21	4	0,962	0,993
Regrasp	106	24	3	0,815	0,972
Put	643	39	9	0,943	0,986
Put Correction	61	58	1	0,513	0,984
Sequence Get-Put	69	13	2	0,841	0,972
Apply Pressure	63	0	0	1	1
Pedal Press	33	12	1	0,733	0,971
Overall	5931	306	71	0,951	0,988

As seen in Table 1, the overall precision and recall of our algorithm exceed 95%, meaning that it can be used as a reliable tool to detect most of the basic MTM-2 motions. Many of the FPs for the Put Correction and Pedal Press stem from the current implementation. These can be reduced by improving the script.

4 4 Conclusion, Limitations, and Future research

In this paper, we presented a novel approach to transcribe the MTM-2 motions performed in VR. For our algorithm, we neglected eye and crank actions. Additionally, further testing in an industrial environment should be conducted. Future work will concentrate on the automatic transcription of the MTM-1 basic motions, as well as automatic suggestions for manual workplace ergonomics improvement based on the obtained MTM values.

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1. Introduction and literature review

Introduction

There are different existing approaches to analyze and optimize the ergonomics of a manual workplace. One of the popular approaches is to use so-called *predetermined motion time systems* (PMTS). These systems analyze the basic human motions required to complete a given manual task. The time corresponding to each basic human motion is retrieved from a database unique to each particular PMTS system. Therefore, these systems do not provide the task completion time measured by direct observation. Instead, they provide a sum of all predefined times from the database that correspond to every basic human motion performed by the manual worker.

One of the most popular PMTS is Methods-Time Measurement (MTM). It was first introduced in 1948 by Maynard, Stegemerten, and Schwab. It has different variations (MTM-1, MTM-2, MTM-UAS, etc.) that mainly differ by their granularity and, therefore, time and effort to perform MTM analysis.

As nowadays more and more workplaces are designed using computer-aided design (CAD), 3D models of the workplaces are usually available during the planning stage, before the real workplace is built. Virtual Reality (VR) technology allows us to visualize and assess the model of the workplace before it is built in real life. If the workplace's ergonomics should be improved, it is easier to make changes in the model rather than in an existing workplace.

Research question

Can we create an algorithm that transcribes MTM-2 basic motions in VR?

Literature review

Previous research has demonstrated the feasibility of using MTM-2 assessment in VR. Gorobets et al. investigated the efficiency of assessing manual workplaces using both MTM-2 analysis and the time obtained by direct observation. Findings revealed that the time obtained by direct observation in VR is, on average, higher for the same task in VR than in reality. MTM-2 analysis, however, showed similar assessments for the same scenarios in VR and reality.

2. Methodology

User study setup

For this study, we used an HTC Vive Pro headset, consisting of one head-mounted display (1), two controllers (2, 3), and three trackers attached to the lower back (4) and feet (5, 6). We created a Virtual Environment (VE) in which participants were asked to perform a task, following the oral instructions of the experimenter.

We developed a decision-based tree approach to derive the corresponding MTM-2 basic motion codes from the executed sequence of motions. Additionally, our algorithm provides the Time Measurement Units (TMUs) for each transcribed basic motion, as well as the total TMUs for the entire task.

To enhance the user experience, we incorporated a male avatar, which was calibrated individually for each user.

Virtual environment design. Red cross identifies the starting position of the user.

3. Results and discussion

Statistics

To assess our algorithm, after it delivered MTM codes, we manually transcribed the user motions and compared the results obtained manually and automatically. We used the following metrics:

True Positive (TP) – a motion was performed by the user and was detected by the algorithm;

False Negative (FN) – a motion was performed by the user but was <u>not</u> detected by the algorithm;

False Positive (FP) – a motion was detected by the algorithm but was <u>not</u> performed by the user.

Additionally, we introduced two following metrics based on TPs, FNs, FPs:

$$Precision(Pr) = \frac{\sum TP}{\sum(TP+FP)};\ Recall(Rc) = \frac{\sum TP}{\sum(TP+FN)}$$

	TP	FP	TN	Pr	Rc
Bend & Arise	176	29	2	0,859	0,989
Step	3060	59	26	0,981	0,992
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Overall	5931	306	71	0,951	0,988

Table: Summary of Results for TPs, FPs, FNs, Precision, and Recall for Each Basic Motion.

4. Conclusions and recommendations

Conclusions

Technology can greatly facilitate the MTM-2 approach by minimizing the time and effort required to conduct manual MTM-2 analysis. Additionally, it allows us to assess non-existent in reality workplaces by means of the MTM-2 system.

We presented our approach that allows us to visualize and assess planned workplaces using VR. We developed a decision-tree approach that automatically delivers MTM-2 codes and their TMU values by dividing the working process into corresponding sequences of basic motions. We assessed our implementation by comparing the manually performed and automatically delivered MTM-2 analysis for 30 participants in the user study.

Recommendations

Firstly, it is suggested to verify the algorithm using an industrial setting.
Secondly, the possibility of implementing more detailed systems (e.g., MTM-1) in VR should be investigated.
Thirdly, the possibility of extending the implementation of automatic transcription to reality should be researched.
Additionally, some minor improvements in the code can be made.

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