APPLICATION OF AN AUTOMATED LABOUR PERFORMANCE MEASURING SYSTEM AT A CONFECTIONERY COMPANY

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Abstract

This paper focuses on the implementation of a labour performance measuring system at a confectionery company. The computer vision based system is based on the work sampling methodology. It consists of four cameras linked to a central computer via USB extenders. The computer uses a random function in C++ in order to determine when measurements are to be taken. OpenCV is used to track the movement of a target worker's dominant hand at a given work station. Tracking is accomplished through the use of a bandwidth colour filter. The speed of the worker's hand is used to identify whether the worker is busy, idle or out of the frame over the course of the sampling period. Data collected by the system is written into a number of text files. The stored data is then exported to a Microsoft Excel 2007 spread sheet where it is analysed and a report on the labour utilisation is generated.

Keywords: OpenCV, tracking, colour filter, work sampling, labour performance measurement

1. INTRODUCTION

The paper focuses on the implementation of an automated labour performance measuring system at a confectionery company in Cape Town. This is a follow-up paper of a previously published submission to the JNGS journal entitled, "Review and Analysis of Work Sampling Methods: The case of an Automated Labour Performance Measurement System using the Work Sampling Method" (Van Blommenstein et al, 2011). The earlier paper gave details on the development of the system, and the latter paper deals with the application of the system in a 'real world' manufacturing environment.
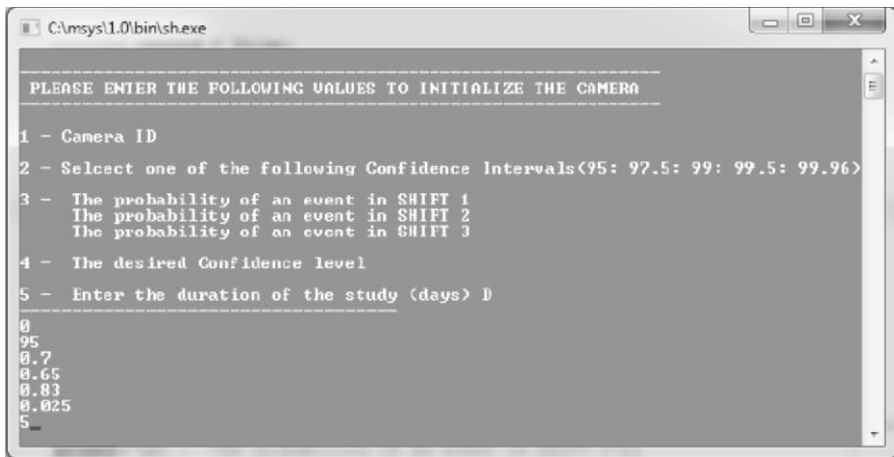
The said confectionery company manufactures a wide variety of speciality, hand-made, baked products. The production process is labour intensive and the performance of the workers is vital in ensuring the success of the company. The company currently employs over 800 employees.

Prior to the implementation of the automated work sampling system the researcher explained the intention of the study to the participants, facilitating free and ready participation. (Freivalds, 2009).

2. BACKGROUND

The system was developed in order to simplify the measurement of labour utilization at certain work stations within a company. This was achieved by automating the work sampling procedure. It was created to reduce the time, costs and complexities associated with the gathering of data, while also increasing the accuracy of the study.

The system consists of a number of webcams linked to a central computer via high speed USB extenders. The central computer runs a 'stand alone' C++ application that automates a basic work sampling procedure. For each camera, the user is required to enter the confidence interval, the probability of time that the worker would be busy, the control limits and the number of days of the study, as shown in Figure 1. These values are used to calculate the number of samples for the study. In this program it is assumed that the only variable is the P value for each of the shifts. It is therefore assumed that the Confidence Interval, Control Limits and the Duration of the Study are the same for each of the shifts, given that more than one shift is likely to be studied per day.


```
C:\msys\1.0\bin\sh.exe

--------------------------------------------------------------
 PLEASE ENTER THE FOLLOWING VALUES TO INITIALIZE THE CAMERA
--------------------------------------------------------------
1 - Camera ID

2 - Selcect one of the following Confidence Intervals(95: 97.5: 99: 99.5: 99.96)

3 -    The probability of an event in SHIFT 1
       The probability of an event in SHIFT 2
       The probability of an event in SHIFT 3

4 -    The desired Confidence level

5 -    Enter the duration of the study (days) D
--------------------------------------------------------------
0
95
0.7
0.65
0.83
0.025
5_
```

Figure 1: Initiation screen

The system calculates the random function to determine observation times and sequences them using a bubble sort function. In order to ensure reliable identification of the worker's state, non-overlapping samples of ten seconds are used (Chandy & Kesselman, 1992). The sampling duration is necessitated by the fact that the time between frames is typically between 100 and 200ms. Although the worker may be productive, the amount of movement during this short period is often minimal. The longer sampling duration provides more information relating to the worker's movements and ultimately results in reliable classification of the worker's state.

The cameras are set up to monitor certain fixed location work stations in a production process. Footage captured by the webcams is converted to a pixel matrix by OpenCV. The matrix is then passed through a bandwidth colour filter in order to enable the unique identification of the gloves worn by workers (Joines & Roberts, 1995: Levin, 2006; Chentao & Feng, 2009; Yu et al, 2004).

The bandwidth filter enables the analyst to set upper and lower limits of the hue, saturation and luminosity values. The variation of these three values covers the full range of colours as represented in Figure 2. This is important as it enables a desired range of possible colours to pass through the filter. Due to the uneven nature of a worker's hand and the variation in illumination, this range setting ability enables the majority of the glove to be passed through the filter, whilst also ensuring that background noise is limited.

	Hue: 122	Red: 71	
	Sat: 160	Green: 210	
Color|Solid	Lum: 136	Blue: 218	
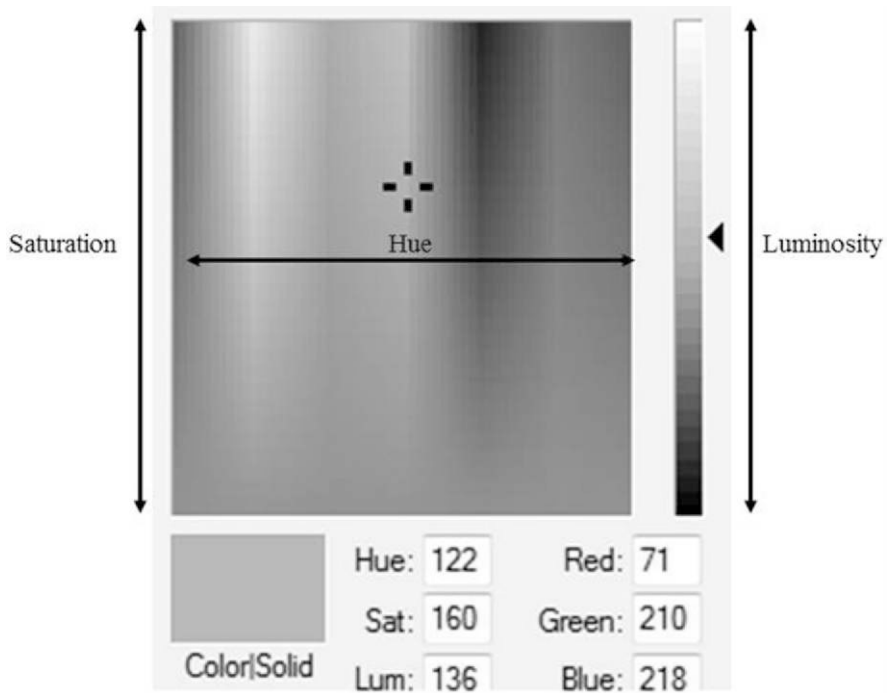
Figure 2: Full range of colours described in terms of hue, saturation and luminosity

The filtered image is analysed and the centre of all pixels, which have passed through the filter, is determined. This centre point is the location used in the analysis. In many instances a small amount of background 'noise' will be present. In order to ensure that the centre point is not tracked for background 'noise', a threshold of 500 pixels is applied. It is important that the centre point is always identified on the worker's glove. It is vital that the glove be distinctly coloured, and that the bandwidth filter is set correctly.

The tracking provides the location of the worker's hand in terms of pixels. The pixel speed and the weighted average pixel speed of each worker's hand are determined by measuring the distance moved between frames. The time, speed and average speed is written to manageably sized text files, which are exported to a spread sheet application for analysis (Deitel & Deitel, 2007).

The screen shots in Figure 3 show the pixel speeds associated with each of the states. In the top figure the moving average speeds (vAve) as well as the speeds (v) are small. This movement is a result of the inherent noise of the system. Small movements of typically less than 5 pixels per frame indicate the worker's hand is in the screen but stationary. If the worker's hands are stationary it is assumed that the worker is idle.

The screen shot at the bottom of Figure 3 includes measurements used in the classification of the other two states. The first few measurements indicate a speed and moving average speed of 0. This is the result only when the worker's glove is out of the frame of the camera, or when the number of filtered pixels is less than the threshold limit. If the majority of the 10 second sampling duration is 0, the worker will be classified as being out of screen. After the few 0 measurements, the amount of movement increases significantly. The bigger movements correspond to reaching motions and the smaller movements to placing motions. This indicates that the worker's hand is moving and is assumed to be working.
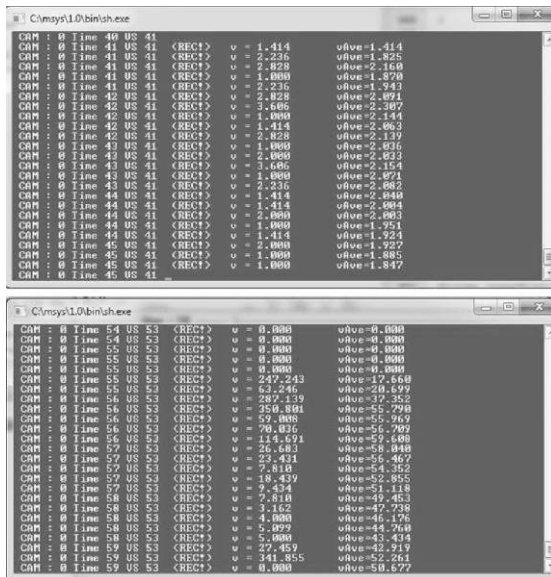

Figure 3: Screen shots of the application indicating the velocities associated with the different classification states; Top: Idle, Bottom: Out of Screen and Busy

After the required number of samples have been collected, they are then exported into a spread sheet application. The spread sheet application generates a report of the labour utilization which is sent to the analyst for review.

The reason why the analysis is completed in the spread sheet application as opposed to the program is due to a number of variables that make standardization of the analysis difficult. These variables are:

- Finer tasks - they require smaller movements and the resultant speed is therefore smaller
- Varying distance between the camera and the worker - as the distance between the camera and the worker increases the observed speed decreases
- Frame size - with higher resolutions, the observed speed increases

Currently the frame size is set at 640 x 480. This value can be adjusted to higher or lower values depending on the performance capabilities of the camera and the computer on which the program is run. Empirical testing has indicated that a 640x480 resolution is adequate and sensitive enough to differentiate between the different possible states, given that the sampling period lasts for 10 seconds.

Strictly controlled tests were conducted which required the worker to occupy a particular state for a set amount of time. These tests were conducted under constant lighting with no similarly coloured items within the capture frame. The largest classification errors, which involved incorrectly classifying the user's state, were less than 6%. The total of the classification errors for the experiment was 2%.

The controlled tests indicated that under ideal conditions, and for tasks requiring frequent and large hand movements; the system was capable of reliably returning positional data and that this information could be used to differentiate between the three states.

The remainder of this article details the implementation and evaluation of the system in a confectionery factory. The purpose was to assess if the system could be implemented in real world situations.
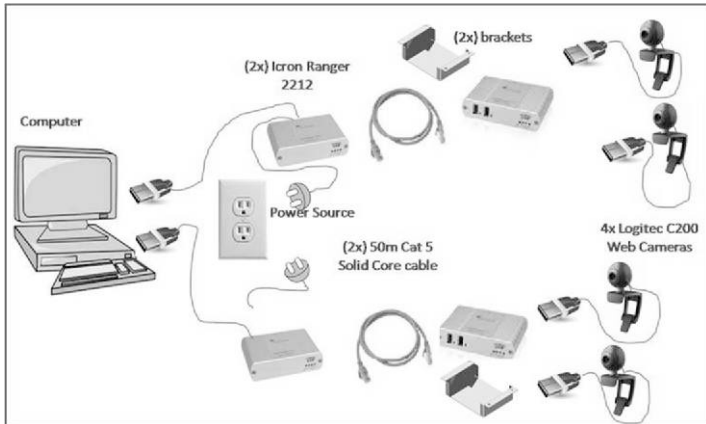
3. SET-UP OF THE LABOUR PERFORMANCE MEASURING EQUIPMENT

The components used at the confectionery factory in the installation of the labour performance measuring system were:

- Central computer
- Two (2) sets of Icron Ranger 2212 USB extenders

- Two (2) x 50m CAT5 solid core cables (wired straight)
- Four (4) x Logitech C200 web cameras
- Blue nitrile gloves

The installation process took approximately two and a half hours to plan and complete. A schematic layout of the system is included in Figure 4.

Figure 4: Labour performance measuring equipment.

The equipment was set up in the Processing and Packaging Departments as shown in Figures 5 and 6. A number of production lines run in parallel to one another in these departments. An Icron Ranger 2212 USB extender was mounted above one of these parallel lines in the Processing Department and another in the Packaging Department (http://www.usbextensionCable.com). These were linked to a central computer via the 50m extension cables. In Figure 6 the USB extender is circled with a blue ring. Two web cameras were connected to each USB extender and mounted above the stations which were to be measured. The cameras are circled by green rings in Figures 5 and 6. The cameras were mounted in such a way that both cameras observed stations on the same production line. The 1.8m USB cabling ensured that each camera was located far enough apart so that the frames did not overlap. The cameras were mounted in such a way that they had a small degree of flexibility to rotate. The workers that were studied were located at a specific station for the duration of the study. A blue nitrile glove was worn on the right hand by the individual being studied.

Figure 5: Image of the cameras set above a line in the processing department

Figure 6: Image of the cameras and USB extender set above a line in the packaging department

The confectionery company operates three eight hour shifts per day from Monday to Friday. The workers are given production breaks as listed in Table 1.

Table 1: Disruptions in production

Activity	Day	Start Time	End Time
Processing Break Shift 1	All	11:30	12:00
Processing Break Shift 1	All	11:00	11:30
Processing Break Shift 2	All	19:30	20:00
Processing Break Shift 2	All	19:00	19:30
Processing Break Shift 3	All	03:30	04:00
Processing Break Shift 3	All	03:00	03:30

## 4.	INITIATION

The program was set up to run for four days as a pilot study. The purpose of this pilot study was to determine the initial probability P of the occurrence of an event in each shift. This was done because there was no historical data available. An application was opened for each of the four cameras and all four applications were initialized with the following values:

- Confidence interval - 95%
- Probability of an event in shift 1 - 70%
- Probability of an event in shift 2 - 70%
- Probability of an event in shift 3 - 70%
- Control limits - 2.5%
- Number of days - 4

These initial values resulted in the program taking an average of 322 observations per shift. This is close to the program limit of 325 observations per shift, as indicated by Van Blommenstein et al (2011). This was done in order to test the capabilities of the program used for the data analysis. The pilot test proved that the probability of an event occurring in any shift was approximately 70%, as previously assumed for a confidence interval of 95%.

A blue nitrile glove was worn on the right hand by the target worker to identify the worker's hand from the surroundings. The colour filters were set up and arranged to track the glove. Figure 7 is a "print screen" of the computer screen as seen in the factory. In the image the application window and filter/capture frame for camera 1 are presented against the desktop background. The application window in the image is red, indicating that an observation was being recorded. The light green tracking dot can clearly be seen on the worker's glove, it is however off-centre. This is a result of a small amount of noise resulting from the other similar coloured items in the capture frame, such as the worker's collar and hair cap.
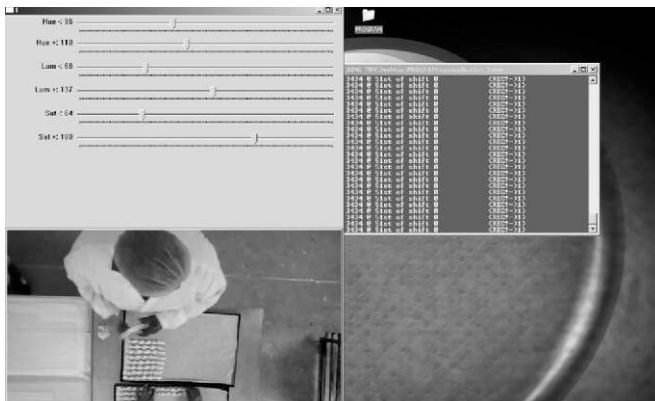

Figure 7: Print screen of the computer screen at the factory

5. DATA ANALYSIS

After the initial test, data was collected for one day to demonstrate the real-world applicability of the system. The data was then exported from the text files into the analysis sheet in Microsoft Excel 2007. A screen shot of the analysis sheet is represented in Appendix 1. Graphs of the speed and moving average speed were plotted on the spread sheet. The graph for the second processing shift is represented in Figure 8.
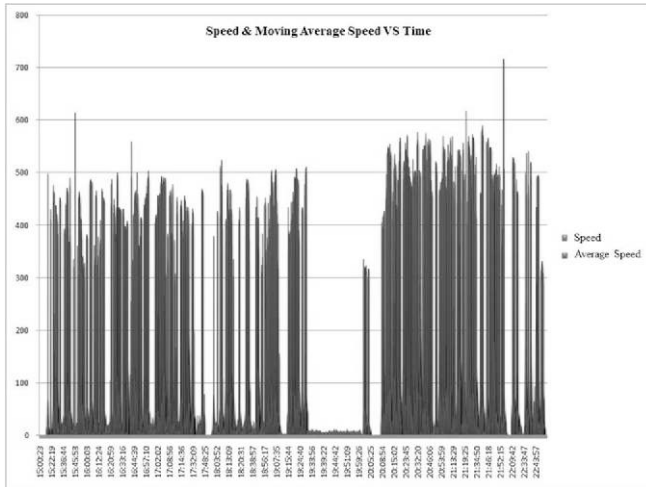
Figure 8: Speed & Moving Average Speed vs. Time for the 2nd shift on the processing line.

Figure 8 offers the analyst a broad overview of the occurrences within the processing shift 2. It can be seen that movement was recorded for most of the period. Furthermore, the 19:30 – 20:00 production break period is clearly visible (which includes the 19:33:56 – 19:59:26 time interval, with low peaks). During this period the workers cover the work in process with blue plastic sheets. These sheets are passed through the filter and result in the small amount of movement being recorded, also termed "noise". Fortunately, humans are rarely as motionless as inanimate objects and a distinction can be made. In the final analysis of the data, this "noise" is excluded from the calculations by increasing the upper limit of the out of screen classification from 0 to 4 pixels per frame. The presence of the blue food covers does however increase the number of incorrect classifications. This issue could be simply remedied by wearing different coloured gloves. These would need to be ordered specifically as they are not widely available.

The periods, during which the worker was "idle" or "out of screen", are clearly indicated as troughs in the graph. As an example, it can be seen in Figure 8 that at 16:20:59, the moving average speed of the worker was relatively small.

This indicates that the worker was "idle" and therefore not working. At 19:15:44 the speed was zero and the user was therefore "out of screen". If the "idle" time or the "out of screen" time is excessive, the causes for these occurrences should be investigated by the production manager.

Table 2 includes the data that complements information represented in the graph showing working speed in Figure 8. These values represent the exact numbers relating to the performance of the workers during this period.

The percentage utilisation, U, is given by Equation 1 (Allan et al, 1999)

$$U = \frac{n_{busy}}{n_{Total}} \dots (1)$$

Where n_{Total} is the number of samples excluding the "noise" and nbusy is the number of captured samples during which the worker is actively working.

The avoidable delay allowance is determined by the following Equation 2 (Allan et al, 1999).

$$D_{avoidable} = A \left(\frac{n_{stationary}}{n_{Total}} \right) \dots (2)$$

Where $n_{stationary}$ is the number of samples captured when the worker was idle.

Table 2: Analysis results of processing shift 2 - an extract of Appendix 1

Number of Samples	334
Noise	62
Number of Samples for Analysis (without noise) = 334 - 62	272
Idle	47
Busy	191
Out of Frame	34
Percentage Utilization = 191/272	**70.22%**
Percentage Avoidable Delays = 47/272	**17.28%**
Percentage Out of Frame Ratio = 34/272	**12.5%**

The values indicate that the worker was located at the specific measurement station for a large portion of the shift, as indicated by the 87.5% value [(47+191)/272]. This enables an effective analysis of the shift. From the analysis, it can be seen that for 17.5 % of the shift time, the worker was idle, for 12.5% of the time he was out of the work station, and for 70.22% of the time he was doing productive work.

However, there are also a number of disadvantages of this automated system and these are represented in Table 3.

Table 3: Disadvantages of the automated approach

Disadvantages	Reasons
Setting up the camera filter presents difficulties	Time consuming; Determining acceptable noise is difficult
Glove may influence the performance of the operator	Cause discomfort; Difficulties with performing fine tasks
Less detail available than in manual work sampling	More states identified in manual studies

Despite the highlighted disadvantages, there are several advantages of incorporating an automated work sampling method in the labour performance measuring system and these are highlighted in Table 4 (Fitzgerald, 2009; Freivalds, 2009; Sitting, 2000).

Table 4: Advantages of the automated approach

Advantage	Elaborations
Time saving	Observer not required; Data entry not required
Fewer resource requirements	No observers
Higher accuracy	More samples per day possible; Multiple stations analysed in parallel
More accurate representation of the work environment	Hawthorne effect minimal; More data available
Lower cost	Observers expensive
Can become a permanent installation	No time frame at which it must leave the organization
Data on the activity speed is available	Speed of the worker recorded
Flexible	Determines machine utilization; Any number of cameras may be used

6.   CONCLUSIONS

In conclusion by making use of 'off-the-shelf' components, a system has been created to automate a simple work sampling implementation. The system has been proven to work in a confectionery industry since it adequately classifies an operator according to the three possible states: "idle", "busy" or "out of screen". The classification was done by assessing the speed and moving-average speed of the worker's dominant hand. The created text files provided a sound data repository for analysis in a spread sheet application. The Microsoft Excel 2007 spread sheet application handled the quantity of data efficiently.

The implementation of the system yielded valuable data on the utilization of the workforce, returning a reasonable value of 70.22%. If the system is implemented on a long term basis, the results of an extensive study could be used to identify variations in worker patterns and could be useful in identifying possible areas of concern, highlighting any variations from the normal values. The usefulness of the study is dependent on a number of factors, the most important being Management's commitment to the study.

- Managers are required to ensure that workers always wear gloves and work within the demarcated area.
- The colour of the gloves needs to be unique and the presence of similarly coloured items within the capture frame needs to be restricted. Gloves always need to be available to workers, particularly after returning from breaks.
- Power must remain uninterrupted for the duration of the study.

The following guidelines will eliminate most of the problems encountered in the case study.

- A laptop computer should be used in the system. The battery power will ensure that the program runs uninterrupted through brief power failures.
- The commitment of the management team should be realised before the installation of the system.
- Distinctly different coloured gloves should be sourced although they may be at an elevated cost. The cost of the gloves will still be significantly less expensive than using an analyst to perform the study.

The elimination of data gathering and data entry into a program reduces the time and costs required for the analysis. The automated approach also ensures that more observations can be made each day, thereby increasing the accuracy of the results. Although the system has disadvantages these are out-weighed by the advantages.

The successful implementation of this system in the confectionery factory warrants further investigation of the extent to which computer vision-based approaches can be used to assess labour performance.

7.   REFERENCES

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Appendix 1