# Evaluation of Implement Monitoring Systems

by

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## ABSTRACT

During monitoring of rear-mounted equipment, frequent rearward turning of tractor drivers in awkward postures can cause musculoskeletal disorders related to the back, neck, and shoulders. A camera-based monitoring system, consisting of one or more cameras placed on the implement and a monitor placed inside the tractor cab, has potential ergonomic benefits compared with traditional implement monitoring strategies by reducing the rearward turning and twisting movements of tractor drivers. A camera-based monitoring system was compared with two traditional monitoring strategies (direct looking and using rear-view mirrors) in a lab environment using a Tractor Air-Seeder Driving Simulator. The operator's reaction time and response errors, head/neck movement (acceleration), and neck muscle temperature were compared for the three monitoring strategies. The camera-based monitoring system yielded significantly ($\alpha$=0.05) better outcomes in terms of acceleration and muscle temperature values. No significant difference was observed for response errors.

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# 1. INTRODUCTION

Monitoring of the rear mounted implement is a common practice in most agricultural operations. Rear mounted implement monitoring activity involves awkward postures and uncomfortable turning of the neck, head, shoulders and back. Several types of musculoskeletal disorders have been reported by various researchers in connection with the task of rear monitoring (Torén et al. 2002; Okunribido et al. 2006; Gomez et al. 2003; Bovenzi and Betta 1994). It further adds to the drudgery of agriculture if the operator already suffers from neck or back injuries (or is vulnerable to neck or back injuries). The operator's performance is also affected due to the sharing of his attention between the rear monitoring and driving tasks (Kaminaka et al. 1981).

In order to facilitate tractor driving and rear monitoring of trailing equipment, it is necessary for the operator to have a means by which information from behind the operator's seat can be obtained. Traditional methods include strategies such as direct observation by physically turning to view the trailing machine or by viewing the trailing machine using rear-view mirrors. Some companies are now proposing that camera-based monitoring systems (CBMS) may be used in the field of agriculture for monitoring the operation of rear-mounted equipment. The purpose of this research was to compare use of a camera based monitoring system (CBMS) with two traditional monitoring strategies (i.e., directly looking backward (DL) and using side-mounted mirrors (MI)) in a controlled lab environment using a tractor-air seeder driving simulator

(TAS-DS) system. Evaluation of the three different monitoring scenarios (CBMS, DL and MI) was completed by studying head/neck motion of the operator and by studying muscle temperature of the neck area. Subjective feedback was also collected from the subjects regarding the features, preferences and overall experience while performing monitoring tasks using the three monitoring strategies. Outcomes of this study will quantify the variation of physical workload and performance of the operator during these three monitoring scenarios. These outcomes will contribute to an understanding of the effect of a CBMS system in the reduction of musculoskeletal disorders and in enhancing an operator's performance.

In the following pages all related information regarding this study is divided into different sections. In the literature review section, literature related to the connection of tractor driving and rear monitoring with musculoskeletal disorders or on the performance of the operator is explored. Also literature related to the improvement in the postures of the tractor drivers while driving using various improvement measures has been discussed. The material and methodology section describes the equipment used, the experimental design, and the detailed experimental procedures used for this study. The results and discussion section explains the outcomes and practical implications of the study.

Funding for this study was provided by NSERC under the Engage Grants (EG) program. The industrial partner for this study was Allen Leigh Security & Communications Ltd. of Brandon, MB who donated a CBMS for this study.

# 2. LITERATURE REVIEW

## 2.1. Driving task and musculoskeletal disorders

Tractor driving and simultaneous monitoring of the rear-mounted equipment is associated with frequent backward turning movements of the head/neck, shoulders and back. Due to awkward postures and whole body vibrations, various types of musculoskeletal disorders have been observed in tractor drivers (Boshuizen et al. 1990; Bovenzi and Betta 1994; Gomez et al. 2003). The lack of availability of perfectly ergonomic seats for multitasking requirements during tractor driving further adds to musculoskeletal disorders (Mehta and Tewari 2000). Backward rotation of the neck (30 to 60°) and the trunk (5 to 10°) caused discomfort and higher muscular activity (Electromyography) in both the neck/shoulder and lumbar regions (Wikstrom 1993). “The disorders increased with the twist of the sitting posture and the vibration level” (Wikstrom 1993). A higher level of discomfort was observed in the neck and shoulder area than in the lower back (Wikstrom 1993). Being a tractor operator/owner could increase the risk of neck/shoulder pain about 3.5 times and lower pain about 2.5 times in comparison to other residents because of the effect of whole body vibration and stressed postures (Gomez et al. 2003). Tractor drivers, due to the combined effect of whole body vibration and postural stress (awkward postures), exhibited three times more risk of chronic back pain in comparison to the other unexposed subjects (Bovenzi and Betta 1994). Furthermore, prevalence of various types of musculoskeletal disorders (lower back related pains) increased with the increase in tractor driving duration in the life of the tractor operator (Bovenzi and Beta

1994). Operators of construction machinery like cranes, bulldozers, front end loaders, rollers, backhoes and graders suffered from musculoskeletal disorders mainly due to non-neutral postures (awkward postures) and whole body vibration (Kittusamy and Buchholz 2004). In brief, the combination of driving and awkward postures together with whole body vibration caused several types of musculoskeletal disorders in tractor drivers.

### 2.2. Errors and rear monitoring

Most agricultural operations (like seeding, ploughing and cultivation), particularly when they are not fully autonomous, demand the sharing of the operator’s attention between different tasks. For accurate and safe steering operation, the operator is required to look forward into the field. Simultaneously, the operator needs to look backwards/sideways to monitor the rear-mounted equipment. The duration of looking backwards may affect the steering accuracy and can cause some overlap or skip between two adjacent passes. Similarly, if the operator focuses entirely on steering activity, abnormalities related to the operation of the rear-mounted equipment could be ignored and overall performance of the field operation could be affected. Kaminaka et al. (1981) compared the operator’s performance for the “steering only” task vs. “steering plus rear monitoring”. They observed that the operator’s steering performance was significantly decreased when the operator did steering plus monitoring activity in comparison to the steering activity alone.

### 2.3. Improvement measures

Considerable improvement in the posture is observed by the use of big mirrors on tractors with several machines such as ploughs, harrows, planters, balers, potato diggers and trailers (Sjøflot 1980). A reduction in backward looking time as a percentage of the effective working time in the case of ‘without mirror’ vs. ‘with mirrors’ was observed (39.9% without mirrors and 3.5% with mirrors) (Sjøflot 1980). The number of times the operator looked backward per minute of the effective working time were observed to be 9.2 and 1.2 for “without mirror” vs. “with mirrors” scenario, respectively, for a ploughing operation. Significant reduction in the angle of rotation of the head/neck/shoulder was reported due to the use of mirrors (130-150° vs. 30-40° in total head rotation, 40-50° vs. 3-8° in shoulders rotation and 50-70° vs. 2-5° in neck rotation) for a forage harvesting operation (Sjøflot 1980).

Mirrors would be of little or no help in operating equipment situated very close to the rear of the tractor like mowers, rotators, rotating harrows, some stone picking machines (Sjoflot 1980). Depending on the type of operation (like reaping, harvesting) or functioning area of the equipment (like offset harrow, baler, big ploughs), a combination of mirrors (inside and outside) was recommended (Sjoflot 1980). Use of so many mirrors may cause more distraction and stress to drivers and may not be considered to be a practical option in large and highly advanced machines being used in agriculture.

A swivelling type of seat was also used in tractors to improve the postures of operators particularly during rear monitoring activities. Bottoms and Barber

(1978) used swivelling seats (up to 20° of rotation from normal forward position) and reported significant reduction in the twist angles of three body parts (i.e., hip (11°) and head and shoulders (16°)); decrease in the muscle activity of the shoulder and neck region were observed when measured using EMG.

Rotatable and movable cabins for forestry machines and cranes were evaluated by Eklund et al. (1994) and improvement in postures and viewing angle was observed. They reported 'mean deviation of the head rotation angle' as 7.7° for a rotatable cabin and 22.1° for a conventional cabin in forestry machines. In the case of cranes, 'mean deviation of the head rotation angle' was found to be 14.4° and 33.6° for redesigned cabins (movable and turnable) and conventional types of cranes, respectively (Eklund et al.1994).

### 2.4. Infrared Thermal Imaging

Infrared thermal Imaging is a non-invasive technique used in measuring the temperature of the human body (Ring 1998; Ring 2007; Ring 2010; Ring et al. 2010; Yang et al. 2005). Being homeotherms, the human body can maintain stable temperature which may be different than its environment. In order to preserve a homeostatic state (i.e., stable temperature state) essential for proper body functionality and composition of body fluids and tissues, the human body keeps balance between the heat generation and heat loss activities. Metabolism and flexion of muscles are the main heat producing activities in the body, and heat is released by the body to the surroundings through thermal conduction, forced and natural convection, perspiration and exhalation (Jones 1998). This release of heat occurs through the skin and skin temperature can be measured by infrared thermal imaging (thermograph). Any type of change in the temperature distribution on the human skin can be recognized as an asymmetrical pattern in the thermogram (Jones and Plassmann 2002). When capturing thermal images, standard protocol should be followed (Jones 1998). Ideally, the examining area should have a controlled set of conditions (temperature, humidity and air circulation). Also, the area of interest (body part) of the subject should be made in equilibrium to the surrounding area by exposing it to the surroundings (i.e., clothes around the area of interest should be removed and kept exposed for 10 to 20 min to the environment before capturing any thermal image). Distance of the subject from the thermal camera should also be kept constant during thermography (Jones 1998).

Thermal image analysis has also been used for evaluating different cognitive and physical changes. In a particular study (Pavlidis et al. 2000) related to the anxiety or fear detection, different types of activities were completed by the subject (i.e., relaxation for a few minutes, startle stimulus (subject received a loud noise, 60 dB), gum chewing, leisure walk, treadmill walk). Distinct non-overlapping facial thermal patterns were observed in the thermographs. In another study (Reyes et al. 2009) related to the drivers response to in-vehicle human-machine interface, it was observed that facial temperature (thermograph) reflects drivers' response and interaction with the system. However, one specific area of the face (like nose, eyes) could not alone represent the complete picture of the drivers' response to an in-vehicle human-machine interface system. A composite picture of the facial thermograph provided better explanation to the drivers' state while exhibiting various emotions like frustration, mental effort and accomplishment during the driving period (Reyes et al. 2009). Thermography and electromyography (EMG) were used in a study (Madeleine et al. 1998) related to prolonged manual work performed by standing on two different types of surfaces (hard and soft). Results from thermography data were similar to electromyography data (i.e., increased temperature of legs during standing on a hard surface (aluminum casting) in comparison to a soft surface (mat) and increased EMG activity (right soleus muscle) by standing on a hard surface in comparison to a soft surface).

### 2.5. Accelerometers

Accelerometers are widely used in various clinical and research activities related to the study of physical movements and gait analysis of human beings. Because of technical advancements (both hardware and software), accelerometers are quite efficient, mobile and cost effective for gait and posture analysis studies (Kavanagh and Menz 2008). Most of the accelerometers available in the market can measure up to ± 2 g, ± 5 g or ±10 g of acceleration. Accelerometers used in automotive and industrial applications can have a range up to ± 500 g. However, most of the walking and running activities measured near the foot area are with ±10 g range accelerometers (Lafortune 1991; Kavanagh and Menz 2008).

Orientation of the accelerometer on the subject during the study can impact the data collected during the study. In a static condition, the horizontal axes of the accelerometer coincide to the global horizontal axis and should give the reading of 0 g and the vertical axis should give a reading of ±1 g (-1 g when aligned upright and +1 g when aligned inverted) (Kavanagh and Menz 2008). Errors introduced due to the change in axes alignment from global axes can be considered as 0.4% for every 5 degree alternation of sensing axes from global axes (Kavanagh and Menz 2008). However, for a dynamic tilting accelerometer, it is difficult to determine the errors associated in the data and there were no published studies found to fully determine the errors associated with dynamically changing accelerometer tilt (Kavanagh and Menz 2008).

Accelerometer data consists of both positive and negative values due to the direction of the motion associated with the subject. For data analysis, the arithmetic mean value alone usually does not help in reaching any useful conclusion. During the calculation of the arithmetic mean, negative and positive values of acceleration in the data try to neutralize each other and the final resultant value does not represent the actual acceleration values associated with the experiment. For example, the mean of acceleration values in the horizontal axis generally comes around 0 g and in vertical axis it comes around –1 g or +1 g depending upon the orientation (upright or inverted) of the sensing axes of the accelerometer (Kavanagh and Menz 2008). Measuring dispersion (i.e., standard deviation) of acceleration values gives better understanding of the accelerometer data. Several studies (Bouten et al. 1997; Kavanagh and Menz 2008; Lafortune 1991; Menz et al. 2003; Moe-Nilssen 1998; Schutz et al. 2002) used SD (standard deviation) or acceleration RMS (root mean square) to analyse accelerometer data values.

### 2.6. Camera based implement monitoring systems

A camera based implement monitoring system (CBMS) has the potential to reduce musculoskeletal disorders by reducing awkward postures and minimizing head/neck/shoulder movements and their rotation angles. A CBMS consists of the cameras to be placed at desired locations to capture the activities of the implement and a video display unit placed inside the tractor cab in front of the operator in order to view the rear-mounted implement. Several companies are promoting such systems to ease and improve farming operations. Allen Leigh Security & Communications Ltd. (hereafter referred to as Allen Leigh) has developed an “Implement Quad System” (IQS) which consists of a 1/3” CCD camera of 90° FOV and a 7” LCD monitor capable of using 4 video inputs.

### 2.7. Objectives

The main objectives of the study were (i) to document the perceived ergonomic benefits associated with the use of a camera based implement monitoring system (CBMS) in comparison to conventional monitoring (i.e., directly looking by turning physically (DL) and using rear-view mirrors (MI)), and (ii) to identify design changes necessary to optimize the performance of the CMBS.

The hypothesis of the research was that the CBMS has ergonomic benefits over conventional monitoring strategies. Conventional monitoring can be categorized as direct looking (DL) and using rear-view mirrors (MI). In the DL scenario, the operator looks backward towards rear-mounted equipment by turning physically. In the MI scenario, the operator uses cab-mounted side mirrors to monitor the implement.

In order to quantify the ergonomics benefits, physical workload when using the CBMS was compared with the physical workload when using either DL or MI. Physical workload was analysed by (i) evaluating head/neck motion of the operator using a tri-axial accelerometer and (ii) by evaluating elevated muscle temperature of the neck area using an infrared thermal imaging system. For determining that the usage of CBMS is safe and effective, the operator's performance was evaluated by analysing reaction time and response errors during each type of monitoring scenario. In order to identify any necessary design related changes in the CMBS, subjective feedback about the features, preferences and overall experience during the three types of monitoring scenarios was obtained from each subject after every test session.

# 3. MATERIALS AND METHODS

## 3.1. Material and Setup Overview

### 3.1.1. Tractor-Air Seeder Driving Simulator

This study was completed in the lab environment using a tractor-air seeder driving simulator (TAS-DS). The layout of the setup is shown in the Fig.1.This system consisted of a tractor cabin with side-mounted mirrors. Inside the tractor cab, a monitor was installed in front of the operator.

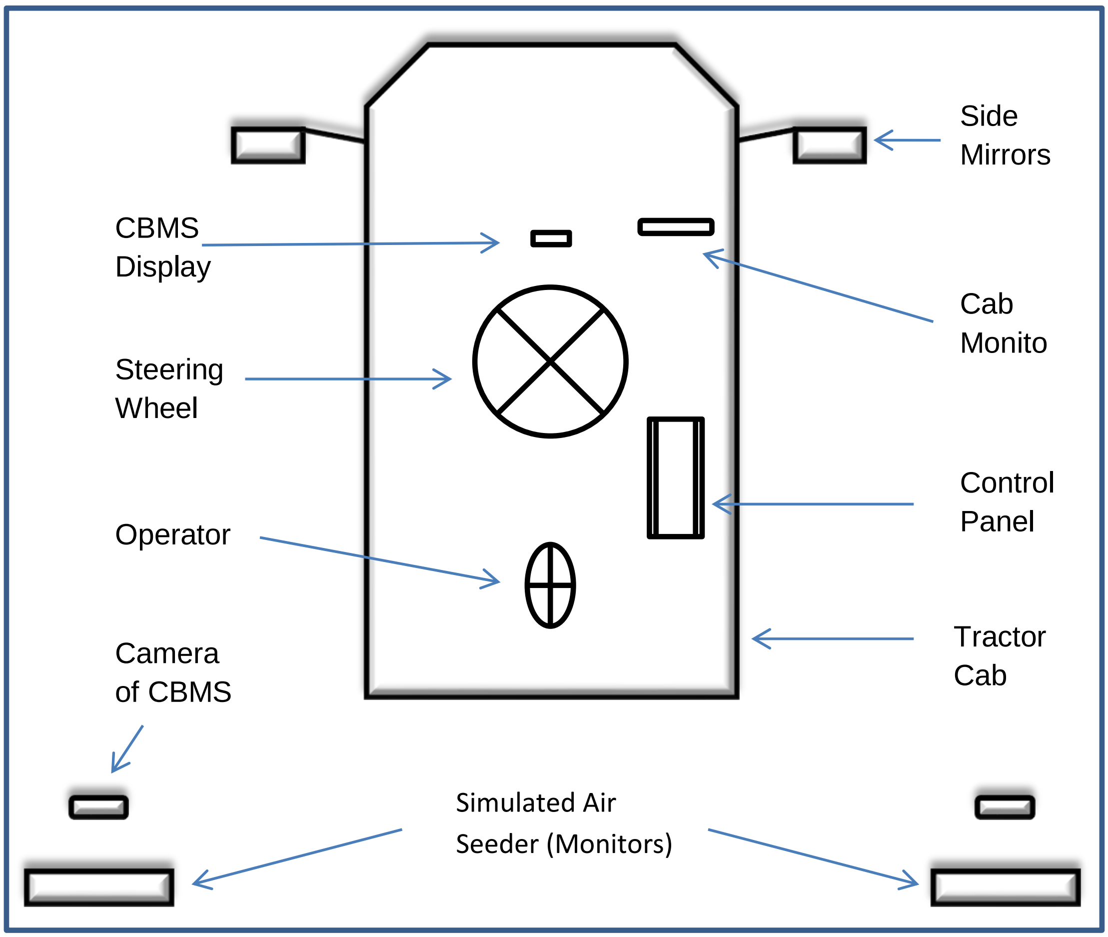


**Fig. 1. Schematic of the experiment setup in the lab environment consisting of Tractor-Air Seeder Driving Simulator (TAS-DS).**

Information like amount of seed or fertilizer in the air seeder tank, seed application rate, fertilizer application rate, tractor forward speed, fan RPM, tool pressure and blocked units during the working of the TAS-DS were displayed (Fig. 2.) on the monitor mounted inside the tractor cab (mentioned as Cab monitor in Fig.1).

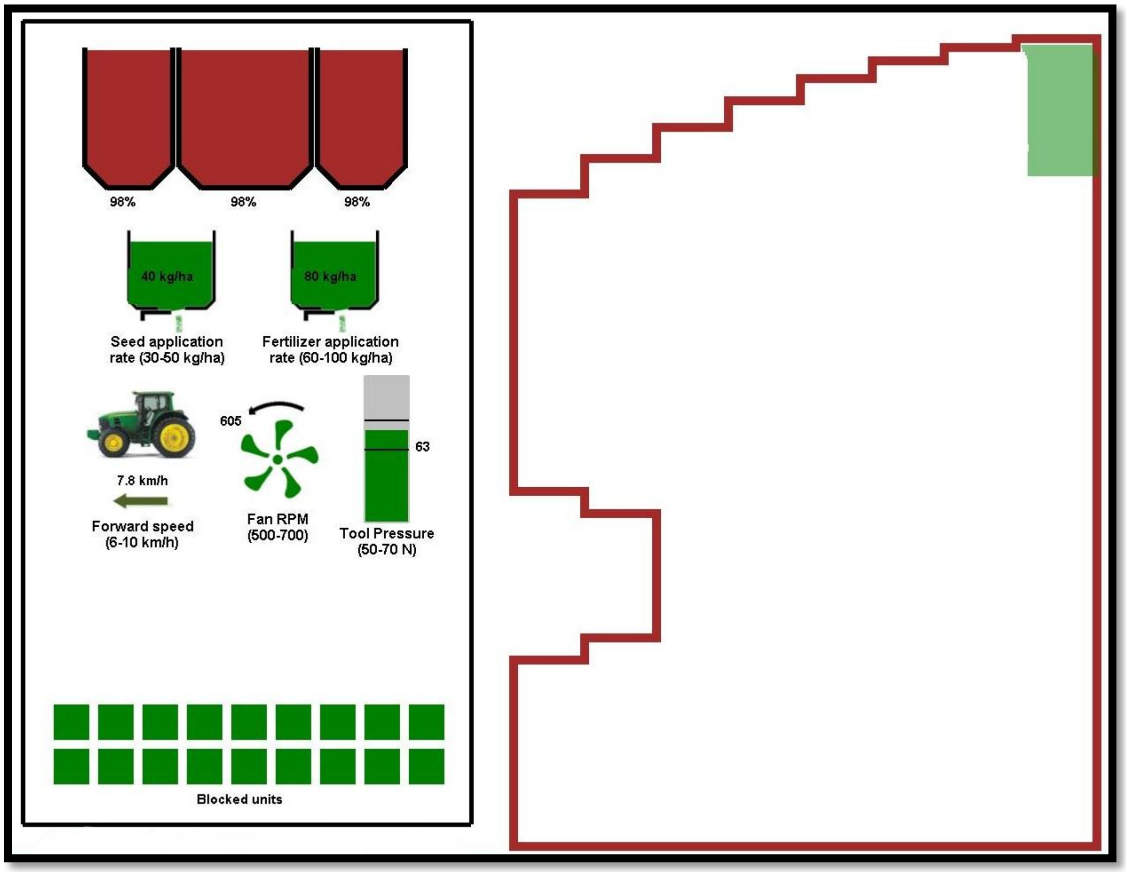


**Fig. 2. Front display showing information regarding Tractor-Air Seeder Driving Simulator (TAS-DS).**

On the right-hand side of the operator, a control panel was installed (Fig.3; also see 'Control Panel' in Fig.1). This panel contained levers to control both indirect information (Fig. 2) like air seeder tank fill, seed application rate, fertilizer application rate, tractor forward speed, fan RPM, tool pressure, blocked units as well as direct information (Fig.4) like depth control, seed spillage and plugging's.


**Fig. 3. Control panel installed inside the tractor cab on right hand side of the operator.**

During the experimental session, under each type of monitoring scenario (DL, MI or CBMS), the operator monitored the TAS-DS by looking at the cab monitor (Fig.1) and also watched the information (Fig.2) displayed on the monitor screen.

Rearwards outside the tractor cab, to the left and right sides of the operator, two monitor screens (size 17”) were placed (Fig.4).

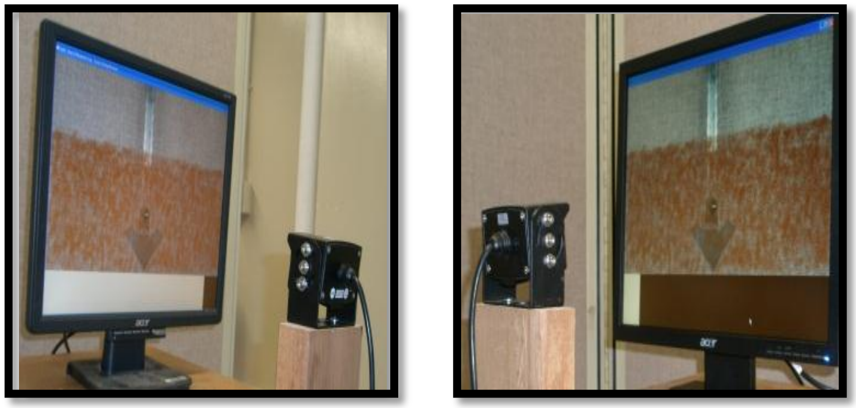

**Fig. 4. Two monitors placed outside the tractor cab showing the images of plugging’s covering the tool.**

With the help of a computer program, simulation of the air seeder was displayed on these two monitors (Karimi 2008). During the experiment, various images (i.e., image of the tool, image of the pluggings, image depicting the depth of tool) were exhibited on the side-mounted monitors. In Fig.4, an image of the tool overlapped by another image is shown; this combination indicates that the seeding tool is plugging with crop residue (referred to as “pluggings” in this thesis). In Fig.5, the left image shows the tool depth of the air seeder and the right image shows seed spillage.

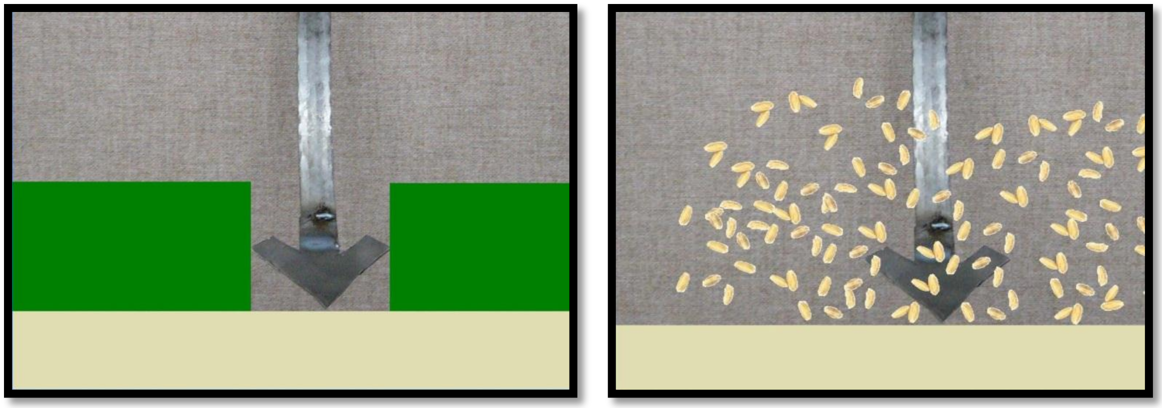

**Fig. 5. Images displayed on the two rear mounted monitors placed outside the tractor cab showing tool depth (left) and spillage seeds (right).**

During the experimental session, the operator was required to respond to two types of information (indirect and direct) by using various controls on the control panel (Fig. 3). Indirect information was monitored by watching the cab monitor (see Fig. 1 and Fig. 2) and direct information was monitored by watching rear-mounted monitors (see Fig. 4 and Fig. 5). For example, if the operator identified (Fig. 2) that fan RPM was not within the recommended limit (i.e., either less than 500 RPM or greater than 700 RPM) then he/she needed to respond to the situation by using the appropriate control on the control panel (see Fig. 3, knob labeled as ‘Fan Speed’). How quickly and accurately the operator responded to a situation was automatically recorded by the computer program and was used later to compare the three monitoring scenarios.

### 3.1.2. Implement Quad System

For comparing conventional monitoring tasks (when operator used cab-mounted side mirrors and directly looking rearwards for monitoring rear mounted equipment) with a camera based monitoring system (CBMS), the Implement Quad System (IQS) from Allen Leigh (Brandon, MB) was used. This system consists of two 1/3” CCD (Sony of Canada Ltd., 115 Gordon Baker Road, Toronto, ON) cameras with a field of view up to 92°.

**Fig. 6. Displaying two images simultaneously on a 7" LCD screen captured from two rear-mounted monitors with the help of two CCD cameras.**

A 7” color LCD monitor was part of the IQS to view the video input from these cameras. Input could be displayed as a single image on the whole screen or as two images shown simultaneously side-by-side on the screen. This LCD monitor was capable in displaying four images simultaneously side-by-side on the screen, however, in the current study, input from only two cameras was used. The input was displayed as two simultaneous images side-by-side on the 7” LCD screen (Fig. 6).

### 3.1.3. Thermal Camera

In order to quantify the elevated muscle temperature of the neck region due to the physical movement of the operator during three monitoring scenarios, thermal images of the neck area were captured using an FLIR SC 500 thermal camera (FLIR Systems Ltd.). This camera works in the long wavelength infrared region (7.5 to 13 µm), in a temperature range from -40 to +2000°C. This camera had a thermal sensitivity of 0.07°C @ 30°C.

**Fig. 7. Infrared thermal camera FLIR SC500 used for capturing thermal images of the subjects.**

Thermal images of the specific region of the neck were captured before and after each test session. Each test session consisted of three monitoring scenarios (DL, MI and CBMS); for every subject, six thermal images were captured. The thermal image captured before the test session served as a baseline image to identify any temperature related changes due to the monitoring sessions.

### 3.1.4. Accelerometer

For analysis of the motion of head/neck of the operator during the three monitoring scenarios (i.e., DL, MI and CBMS), a wireless triaxial accelerometer (‘G-link’ of Microstrain Inc., Williston, VT) was used. This accelerometer was

**Fig. 8. Wireless triaxial accelerometer fitted on a helmet used by the operator during experiment sessions.**

installed on a helmet used by the operator during the experimental sessions (Fig. 8). Live streaming data from the accelerometer were collected wirelessly using a propriety software (Node Commander) and by attaching a USB base station with the computer. The USB base station employs a 2.4 GHz transceiver for wireless communication. The number of active channels during the streaming mode of the accelerometer were three (for x, y and z axis) and the data sample rate was 617 samples per second.

### 3.2. Methodology Overview

This study received human ethics approval by the Education/Nursing Research Ethics Board (ENREB), University of Manitoba.

Thirty university students were recruited in the study (24 male, 6 female). Subjects volunteered to participate and provided informed written consent. In this study, three types of monitoring systems were evaluated: (1) conventional monitoring system where the operator was to physically turn rearward or sideways to view the rear-mounted implement (DL), (2) monitoring with the use of rear-view mirrors when the operator used only cab-mounted side mirrors for viewing the rear-mounted implement (MI), and (3) monitoring with the use of a camera-based system where the operator was viewing the implement using an implement-mounted camera and a dash-mounted display (CBMS).

Randomized complete block (RCB) design was used in the experiment. The sequence of each test scenario (DL, MI, and CBMS) followed during the experiments for all 30 subjects is shown in Table 1.

**Table 1. Random sequence of test scenarios followed during the experiment sessions.**

| ***Subject*** | ***First Session*** | ***Second Session*** | ***Third Session*** |
|---|---|---|---|
| Sub01 | DL | CBMS | MI |
| Sub02 | CBMS | MI | DL |
| Sub03 | MI | CBMS | DL |
| Sub04 | CBMS | DL | MI |
| Sub05 | MI | CBMS | DL |
| Sub06 | MI | DL | CBMS |
| Sub07 | CBMS | MI | DL |
| Sub08 | MI | CBMS | DL |
| Sub09 | DL | MI | CBMS |
| Sub10 | CBMS | MI | DL |
| Sub11 | MI | CBMS | DL |
| Sub12 | DL | MI | CBMS |
| Sub13 | CBMS | MI | DL |
| Sub14 | DL | MI | CBMS |
| Sub15 | MI | DL | CBMS |
| Sub16 | MI | CBMS | DL |
| Sub17 | MI | CBMS | DL |
| Sub18 | CBMS | DL | MI |
| Sub19 | CBMS | MI | DL |
| Sub20 | MI | CBMS | DL |
| Sub21 | DL | MI | CBMS |
| Sub22 | CBMS | DL | MI |
| Sub23 | MI | DL | CBMS |
| Sub24 | CBMS | DL | MI |
| Sub25 | DL | CBMS | MI |
| Sub26 | DL | MI | CBMS |
| Sub27 | MI | CBMS | DL |
| Sub28 | DL | MI | CBMS |
| Sub29 | MI | DL | CBMS |
| Sub30 | DL | MI | CBMS |

A driving scenario was created using a tractor-air seeder driving simulator (TAS-DS) (Fig. 9). The subject needed to drive the “tractor” and simultaneously monitor the “air seeder.” This TAS-DS system included displays that provided indirect (Fig. 2) and direct (Fig.4) information. Indirect information was observed by monitoring a front-mounted display placed inside the tractor cab. Direct information was monitored by watching two rear-mounted displays placed outside the tractor cab. During the monitoring session, these rear-mounted displays were either monitored as looking directly by turning rearwards (in DL scenario) or by viewing them through cab mounted side mirrors (in MI scenario) or monitored through an LCD screen (in CBMS scenario). This LCD monitor (as part of the CBMS) was placed in front of the operator and was displaying two images simultaneously (Fig.6) which were captured by two CCD cameras mounted in front of the two monitors placed outside the cab (Fig. 4).

**Fig. 9. A subject operating the tractor air seeder driving simulator during one of the experiment sessions.**

The operator was required to monitor all information from different displays. On the basis of this information, the operator needed to control all parameters (i.e., tractor speed, fan rpm, tool depth) by using the control panel located on a console to the right of the operator's seat (Fig. 3). A wireless accelerometer was mounted on the helmet used by the operator during the experimental session (Fig. 10).

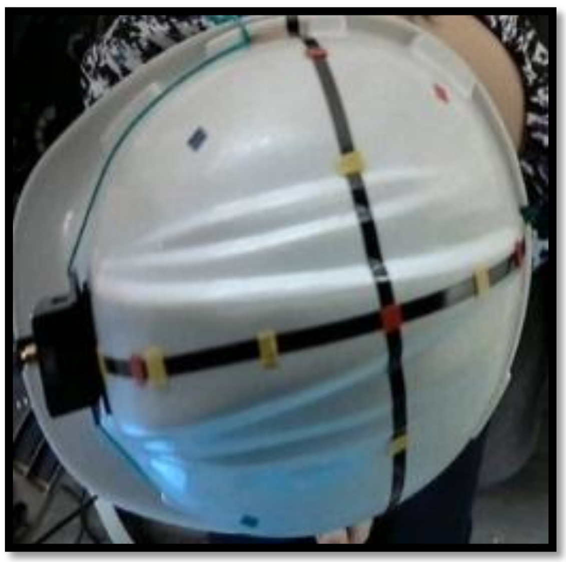

**Fig. 10. Operator wearing helmet installed on an accelerometer.**

As the head/neck of the operator moved during the trial, the acceleration trend associated with the head/neck movements of the operator was captured with the help of a USB base station (Fig. 11) connected to a computer.


**Fig. 11. A USB base station to attach with a computer for receiving data input from wireless accelerometer.**

Plot/variation of the acceleration as displayed on the computer screen during the monitoring activities is shown in Fig. 12.

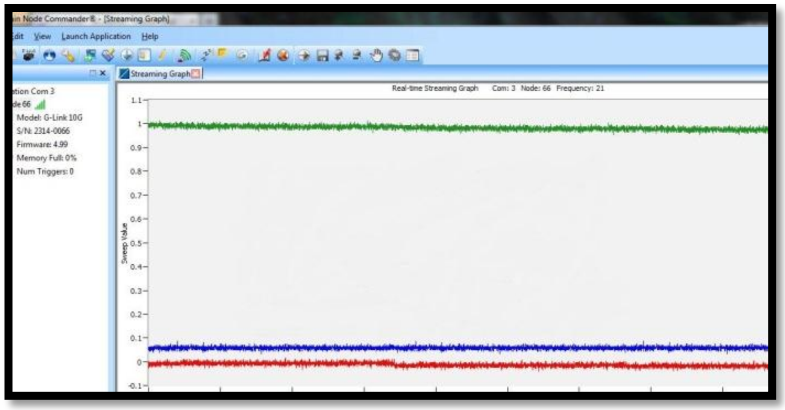


**Fig. 12. Live data streaming from accelerometer node to base station as displayed on the computer screen.**

Reaction time and response errors of the operator (while monitoring activity during three types of monitoring scenarios) were automatically tracked by a computer program built as part of the TAS-DS system. Subjective feedback about the various features liked and disliked by the operators in all three types of monitoring systems was also collected after each trial in the form of a questionnaire (Appendix A). Thermal images of the subjects were captured before and after each session (i.e., total of six times in each trial) using the infrared camera. Figs. 13, 14 and 15 show sample thermal images from one subject captured after DL, MI and CBMS scenarios. In the rectangular section (Figs. 13, 14 and 15), the yellowish color zone indicates higher temperature in comparison to the brownish area in all three images.

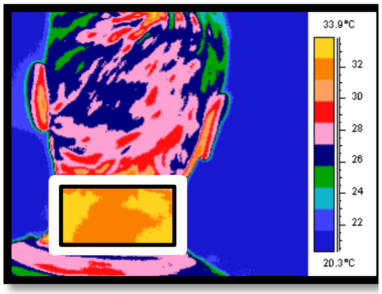


**Fig. 13. Thermal image after direct looking scenario.**

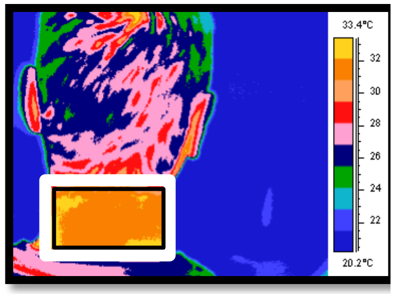


**Fig. 14. Thermal image after mirrors scenario.**

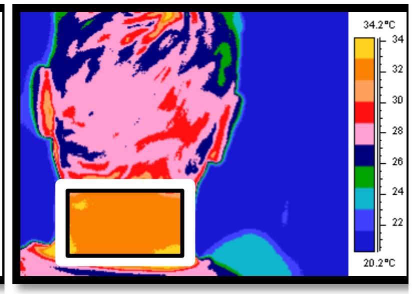


**Fig. 15. Thermal image after camera based monitoring scenario.**

### 3.3. Test Protocol

The detailed procedure used in the experiment session is as follows:

i. Subject had to relax about 10 min with the neck and upper shoulder muscles exposed. The purpose of this relaxation activity was to minimize the effects of muscle fatigue due to routine daytime activity by the subject as well as to create a baseline for thermal imaging analysis (Pavlidis et al. 2000).

ii. Immediately after this relaxation period, a thermal image of the defined area of the neck was captured.

iii. The subject operated the TAS-DS system using one of the three implement monitoring strategies for 10 min.

iv. Immediately after completion of the trial, a thermal image of the subject was captured again.

**v.** The previous four steps were repeated for the remaining two monitoring scenarios.

# 4. RESULTS AND DISCUSSION

Three types of data were collected and analysed to compare the CBMS with conventional monitoring systems: (i) Automatic data generated by a computer program regarding reaction time and response errors performed by an operator during three monitoring scenarios, (ii) Live streaming data from the accelerometer node regarding the head/neck motion of the operator, and (iii) Data generated from the thermal images captured before and after each monitoring scenario to estimate any change in temperature in the neck region due to the head/neck movement of the operator. All data were analysed using mathematical and statistical procedures to determine any significant differences ($\alpha$=0.05) among the three monitoring scenarios.

## 4.1. Performance Errors

During the 10 min trials of each scenario (i.e., DL, MI and CBMS), performance of the operator was compared by analyzing errors made by the operator in the eleven types of performance parameters. These parameters were seed application rate, fertilizer application rate, air seeder tank status (Bin1, Bin2, Bin3), fan RPM, tractor speed, blockage, tool pressure, left depth, right depth, seed spillage, and pluggings. Out of these eleven parameters, seven (i.e., seed application rate, fertilizer application rate, air seeder tank status (Bin1, Bin2, Bin3), fan RPM, tractor speed, blockage, and tool pressure) were classified as indirect tasks which were monitored by watching the display installed on the front of the operator. The other four tasks (i.e., left depth, right depth, seed spillage, and pluggings) were categorized as direct tasks which were monitored by watching backward/sideways placed monitors.

There was no significant difference (α=0.05) observed in the errors for DL, MI and CBMS. Detailed ANOVA tables for each task can be found in Appendix B. In each table (Appendix B1 to Appendix B9), error values for individual parameter (e.g. errors in seed application rate in DL vs. MI vs. CBMS scenario ) were compared for all three monitoring scenarios to determine if there was any significant difference. A summary of all ANOVA tables is shown below (Table 2).

**Table 2. Summary of the statistical analysis (ANOVA, α=0.05, n=30) of the observed errors among three types of monitoring scenarios (DL, MI and CBMS).**

| ***Task*** | ***Task Type*** | $F_{value}$ | $F_{critical}$ | ***Remarks*** |
|---|---|---|---|---|
| Seed Application Rate | Indirect | 0.8555 | 3.1013 | Not significantly different |
| Fertilizer Application Rate | Indirect | N/A (no errors observed) | 3.1013 | Not significantly different |
| Air Seeder Tank Level (Bin1) | Indirect | N/A (no errors observed) | 3.1013 | Not significantly different |
| Air Seeder Tank Level (Bin2) | Indirect | N/A (no errors observed) | 3.1013 | Not significantly different |
| Air Seeder Tank Level (Bin3) | Indirect | N/A (no errors observed) | 3.1013 | Not significantly different |
| Blockage Flag | Indirect | 0.4988 | 3.1013 | Not significantly different |
| Tool Pressure | Indirect | 0.7327 | 3.1013 | Not significantly different |
| Tractor Speed | Indirect | 0.9795 | 3.1013 | Not significantly different |
| Fan RPM | Indirect | 1.1128 | 3.1013 | Not significantly different |
| Left Depth | Direct | 0.7991 | 3.1013 | Not significantly different |
| Right Depth | Direct | 0.0298 | 3.1013 | Not significantly different |

| | | | | |
|---|---|---|---|---|
| Spillage Flag | Direct | 0.2593 | 3.1013 | Not significantly different |
| Plugging Flag | Direct | 1.0547 | 3.1013 | Not significantly different |

The three monitoring scenarios were also compared in the indirect task and direct task categories. To compare the indirect task category, arithmetic means (averages) of all indirect tasks were determined. Then this average value was compared for DL, MI and CBMS as shown in Table 3. From ANOVA section (Table 3), the F value is less than the F critical value (0.0657<3.1013) indicating that there was no significant difference (α=0.05) in error values among DL, MI and CBMS scenarios.

**Table 3. ANOVA table (α=0.05, n=30) comparing average of errors for indirect tasks among DL, MI and CBMS scenarios.**

**SUMMARY**

| ***Groups*** | ***Count*** | ***Sum*** | ***Average*** | ***Variance*** |
|---|---|---|---|---|
| DL-average errors indirect task | 30 | 23.922 | 0.797 | 0.354 |
| MI-average errors indirect task | 30 | 27.151 | 0.905 | 0.746 |
| CBMS-average errors indirect task | 30 | 25.384 | 0.846 | 2.881 |

**ANOVA**

| ***Source of Variation*** | ***SS*** | ***df*** | ***MS*** | ***F*** | ***P-value*** | ***F crit*** |
|---|---|---|---|---|---|---|
| Between Groups | 0.174 | 2 | 0.0871 | 0.0657 | 0.9365 | 3.101 |
| Within Groups | 115.448 | 87 | 1.3270 | | | |
| Total | 115.622 | 89 | | | | |

Similarly, for comparing error values in the direct task category, an arithmetic mean (average) of error values of all tasks belonging to the direct task category was determined. Then this average value was compared for DL, MI and CBMS scenarios. There was no significant difference (α=0.05) observed when averages of errors for direct tasks among three monitoring scenarios (DL, MI and CBMS) were compared (Table 4).

**Table 4. ANOVA table (α=0.05, n=30) comparing average of errors for direct tasks among DL, MI, CBMS scenarios.**

**SUMMARY**

| ***Groups*** | ***Count*** | ***Sum*** | ***Average*** | ***Variance*** |
|---|---|---|---|---|
| DL-average of errors direct task | 30 | 335.164 | 11.172 | 240.581 |
| MI-average of errors direct task | 30 | 267.045 | 8.902 | 196.861 |
| CBMS-average of errors direct task | 30 | 297.522 | 9.917 | 324.193 |

**ANOVA**

| ***Source of Variation*** | ***SS*** | ***df*** | ***MS*** | ***F*** | ***P-value*** | ***F crit*** |
|---|---|---|---|---|---|---|
| Between Groups | 77.6224 | 2 | 38.811 | 0.1529 | 0.8585 | 3.101 |
| Within Groups | 22087.43 | 87 | 253.879 | | | |
| | | | | | | |
| Total | 22165.05 | 89 | | | | |

Arithmetic mean of the error values of all tasks (both indirect and direct) was compared among DL, MI and CBMS scenarios (Table 5). There was no significant difference (α=0.05) observed.

**Table 5. ANOVA table (α=0.05, n=30) comparing average of errors for all type of tasks (indirect and direct) among DL, MI, CBMS scenarios.**

**SUMMARY**

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| DL-average of all errors | 30 | 119.689 | 3.990 | 25.360 |
| MI-average of all errors | 30 | 100.964 | 3.366 | 21.869 |
| CBMS-average of all errors | 30 | 109.118 | 3.637 | 39.494 |

**ANOVA**

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 5.876 | 2 | 2.938 | 0.1016 | 0.9035 | 3.101 |
| Within Groups | 2514.984 | 87 | 28.908 | | | |
| | | | | | | |
| Total | 2520.859 | 89 | | | | |

From the statistical analysis of the errors, it is evident that monitoring strategy (i.e., DL, MI or CBMS) does not exhibit any significant effect on the performance (errors) of the operator. In other words, we cannot say that any particular equipment monitoring strategy improves or degrades the performance of the operator.

## 4.2. Head motion analysis using accelerometer

For evaluating physical workload (work) associated with each type of monitoring scenario, a tri-axial accelerometer was used. Mechanical work is directly proportional to the force (work=force x distance), and force is directly proportional to the acceleration (force=mass x acceleration), so from the analysis of acceleration involved in the three monitoring scenarios (i.e., DL, MI and CBMS), the workload involved in three monitoring scenarios can be compared.

From the accelerometer data, information about acceleration (in units of g) in all three axes (x, y and z-axis) can be found. Depending on the orientation of the accelerometer, in static conditions, one sensing axis of the accelerometer when placed in global vertical direction indicates -1 g acceleration and indicates +1 g acceleration if placed inverted (Kavanagh and Menz 2008). Similarly, in static conditions, the sensing axis placed in the horizontal axis will correspond to 0 g acceleration (Kavanagh and Menz 2008).

During the experimental session, for every scenario of 10 min duration, data were collected wirelessly in a PC with the help of a USB base station for wireless communication with accelerometer node. A data file (.csv) for each 10 min session duration contains approximately 370200 rows of data. One complete experiment had three 10 min test scenarios which made it approximately 30 min of data for one subject. Data for 30 subjects was quite large for later analysis. This data was analysed using Microsoft Excel.

Acceleration values among three monitoring scenarios were summarized and compared by analysing the standard deviation (SD) values which is the measure of dispersion of acceleration values relative to the mean. The SD values represent the dispersion of the acceleration values in either direction (positive or negative) from the mean value. As a sample, a plot of the acceleration values for one of the subjects is shown in Fig. 16.

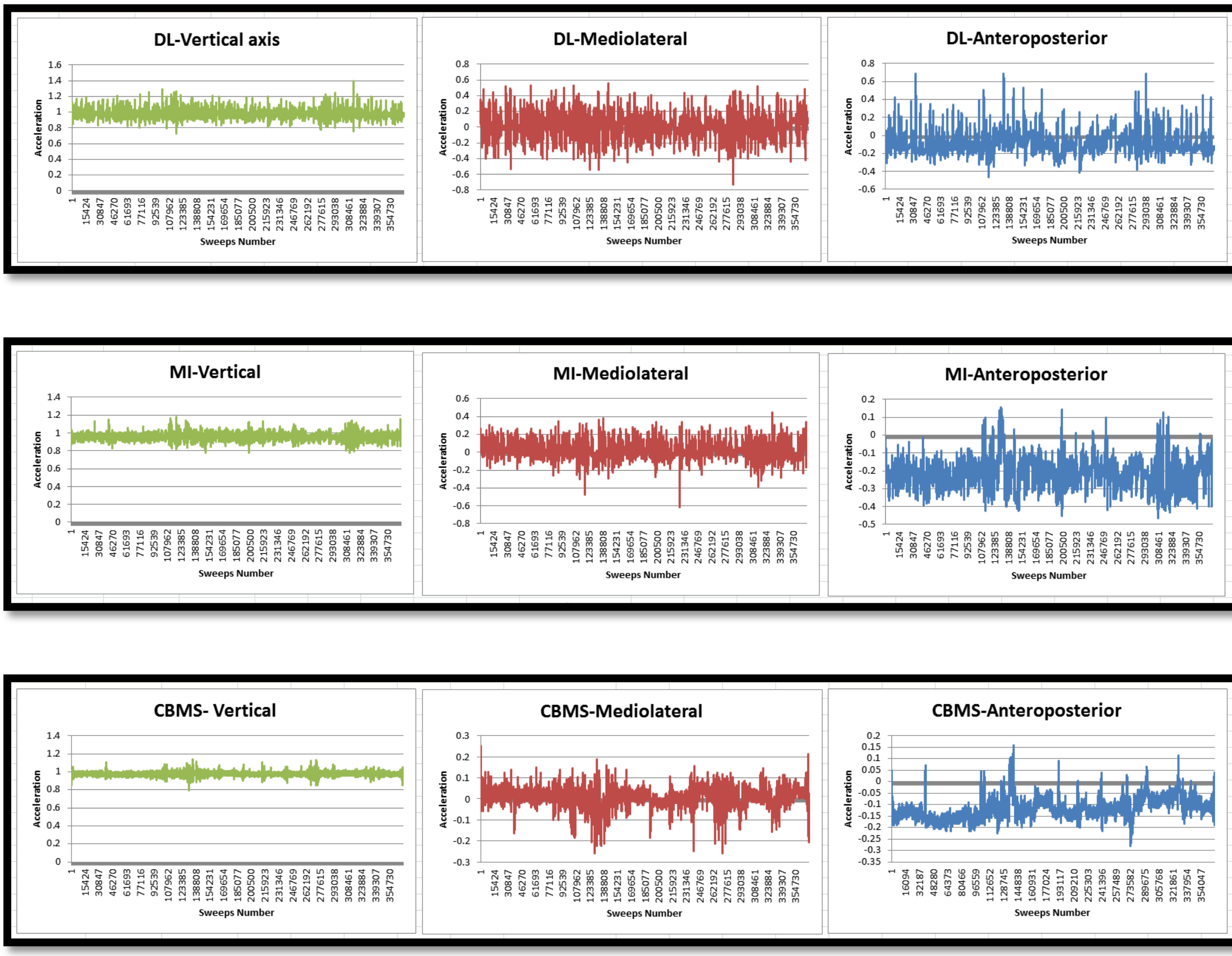


**Fig. 16. Plot of the acceleration values for Direct Looking (DL), Mirrors (MI) and Camera Based Monitoring Scenario (CBMS) in vertical, mediolateral and anteroposterior axis for one of the subjects.**

Overall, results of the acceleration variation for all 30 subjects among three axes of motion (vertical, mediolateral and antroposterior) were summarized by analysing the SD values among the three monitoring scenarios (DL, MI and CBMS). Statistical ANOVA (single factor) test was performed to identify any significant difference (α=0.05) between the three monitoring scenarios. From Table 6, SD values for the vertical axis are significantly different (α=0.05) among DL, MI and CBMS monitoring scenarios (F value is greater than $F_{critical}$ (i.e., 12.51 > 3.10).

**Table 6. ANOVA table (α=0.05, n=30) comparing acceleration values (SD) among direct looking, mirrors and camera based monitoring scenario along vertical axis.**

**SUMMARY**

| ***Groups*** | ***Count*** | ***Sum*** | ***Average*** | ***Variance*** |
|---|---|---|---|---|
| DL | 30 | 1.160488 | 0.038683 | 0.000183 |
| MI | 30 | 0.986331 | 0.032878 | 0.000148 |
| CBMS | 30 | 0.696539 | 0.023218 | 0.000108 |

**ANOVA**

| ***Source of Variation*** | ***SS*** | ***df*** | ***MS*** | ***F*** | ***P-value*** | ***F crit*** |
|---|---|---|---|---|---|---|
| Between Groups | 0.003662 | 2 | 0.001831 | 12.5147 | 1.67E-05 | 3.101296 |
| Within Groups | 0.012728 | 87 | 0.000146 | | | |
| | | | | | | |
| Total | 0.01639 | 89 | | | | |

Higher values of acceleration (SD) are observed in DL scenario followed by the MI and CBMS scenarios (Table 6, ‘Average’ column). As SD values represented the dispersion of acceleration values, it is evident that higher values of acceleration (considering magnitude only) were involved in the DL scenario compared with the MI and CBMS scenarios. For the purpose of comparison and illustration average values of SD in DL, MI and CBMS were plotted (Fig. 17). The average values of SD may not be equivalent to the statistical SD of the group but is a means of comparison of the dispersion of acceleration values among three types of monitoring scenarios. If the accelerations (SD) are compared (i.e., 0.038683, 0.032878, 0.023218 (Table 6)), SD values in the DL scenario are 66.61% higher than the CBMS scenario and in the MI scenario are 41.61% higher than the CBMS scenario.

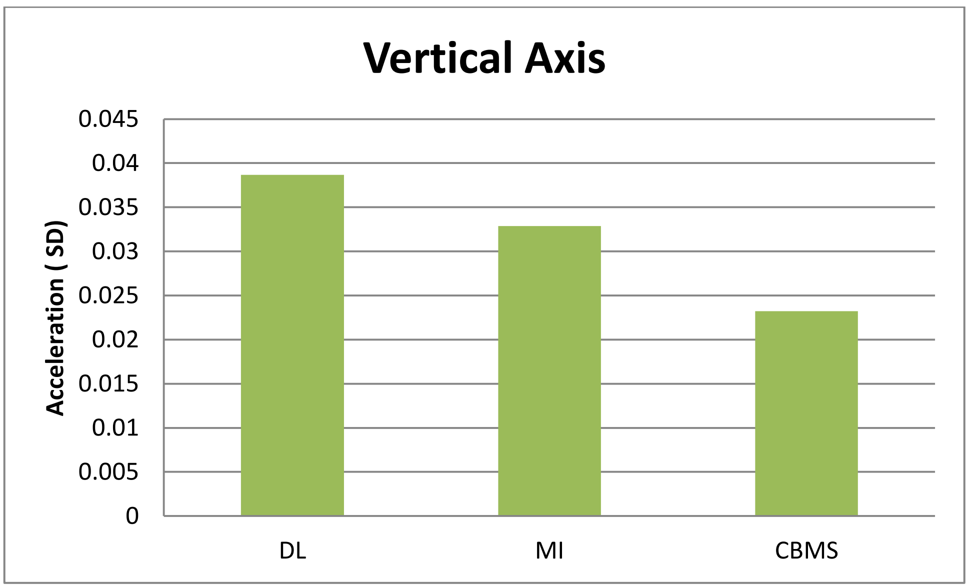


**Fig. 17. Acceleration values (SD) for direct looking, mirrors and camera based monitoring scenarios along vertical axis.**

For the mediolateral axis, acceleration values were also found to be significantly different (α=0.05) for DL, MI and CBMS (F value is greater than $F_{critical}$ ; 55.02 > 3.10) as shown in Table 7.

**Table 7. ANOVA table (α=0.05, n=30) comparing acceleration values (SD) among direct looking, mirrors and camera based monitoring scenario along mediolateral axis.**

**SUMMARY**

| ***Groups*** | ***Count*** | ***Sum*** | ***Average*** | ***Variance*** |
|---|---|---|---|---|
| DL | 30 | 3.4937 | 0.1164 | 0.0017 |
| MI | 30 | 1.8267 | 0.0609 | 0.0002 |
| CBMS | 30 | 1.4180 | 0.0473 | 0.0003 |

**ANOVA**

| ***Source of Variation*** | ***SS*** | ***Df*** | ***MS*** | ***F*** | ***P-value*** | ***F crit*** |
|---|---|---|---|---|---|---|
| Between Groups | 0.080603 | 2 | 0.0403 | 55.0157 | 3.6E-16 | 3.101296 |
| Within Groups | 0.063731 | 87 | 0.0007 | | | |
| Total | 0.144334 | 89 | | | | |

In the mediolateral axis (Fig. 18), the SD of acceleration values in the DL scenario was higher followed by MI and CBMS. Referring to the average values in Table 7 (0.116457, 0.060889 and 0.047270), acceleration values (SD) in DL scenario are 146.37% higher than the CBMS and in MI scenario are 28.81% higher than the CBMS scenario.

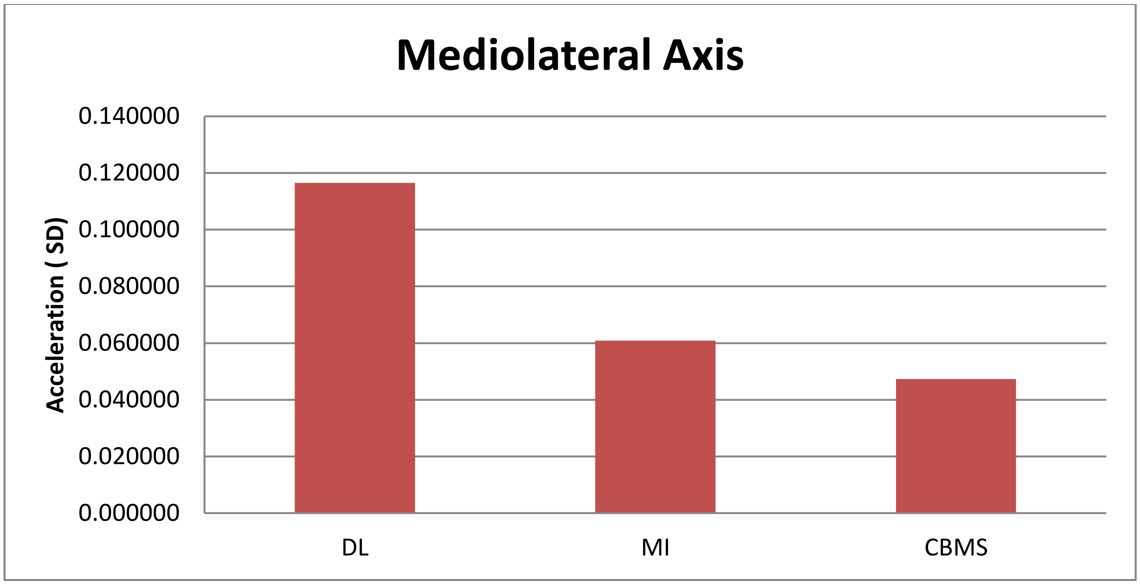


**Fig. 18. Acceleration values (SD) for direct looking, mirrors and camera based monitoring scenarios along mediolateral axis.**

Similarly, for the anteroposterior axis, SD of acceleration values among the three monitoring scenarios were significantly different (F value found greater than $F_{Critical}$ ; 43.99 > 3.10 for α=0.05) (Table 8).

**Table 8. ANOVA table (α=0.05, n=30) comparing acceleration values (SD) among direct looking, mirrors and camera based monitoring scenario along anteroposterior axis.**

**SUMMARY**

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| DL | 30 | 4.09301 | 0.136434 | 0.001412 |
| MI | 30 | 2.743557 | 0.091452 | 0.000835 |
| CBMS | 30 | 1.948365 | 0.064946 | 0.000425 |

**ANOVA**

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 0.078365 | 2 | 0.039183 | 43.99237 | 6.29E-14 | 3.101296 |
| Within Groups | 0.077488 | 87 | 0.000891 | | | |
| Total | 0.155853 | 89 | | | | |

For the anteroposterior axis, referring to the average acceleration values (SD) in Fig. 19 and Table 8 (0.136434, 0.091452, 0.064946), acceleration values in the DL scenario were 110.07% higher than the CBMS and in the MI scenario were 40.84% higher than the CBMS scenario.

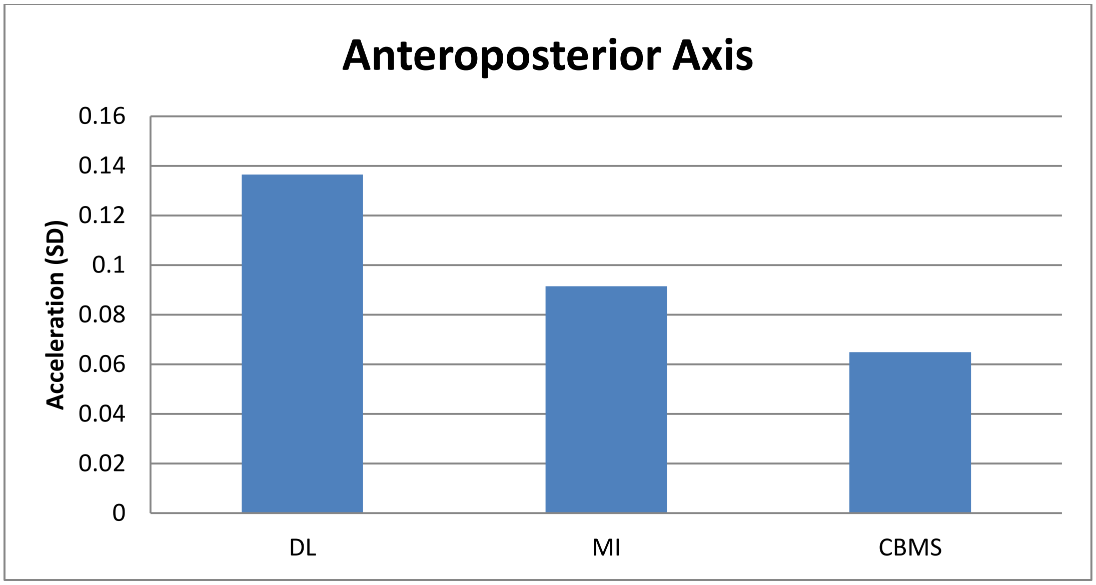


**Fig. 19. Acceleration values (SD) for direct looking, mirrors and camera based monitoring scenarios along anteroposterior axis.**

Overall acceleration (SD) values were determined by calculating the vector sum of the individual components of acceleration in vertical, mediolateral, and anteroposterior directions. Overall acceleration values were found to be significantly different (α=0.05) among the three monitoring scenarios (Table 9).

**Table 9. ANOVA table (α=0.05, n=30) comparing resultant acceleration values (SD) among direct looking, mirrors and camera based monitoring scenario along.**

**SUMMARY**

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| DL | 30 | 5.5563 | 0.1852 | 0.0027 |
| MI | 30 | 3.4737 | 0.1158 | 0.0009 |
| CBMS | 30 | 2.5340 | 0.0845 | 0.0007 |

**ANOVA**

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 0.1595 | 2 | 0.0797 | 56.3596 | 1.9991E-16 | 3.1013 |
| Within Groups | 0.1231 | 87 | 0.0014 | | | |
| | | | | | | |
| Total | 0.2826 | 89 | | | | |

Comparing acceleration values (SD) (Table 9, ‘Average’ column), in the DL scenario 119% higher values were observed in comparison to the CBMS, and in MI scenario 37% higher values were observed in comparison to the CBMS (Fig. 20).

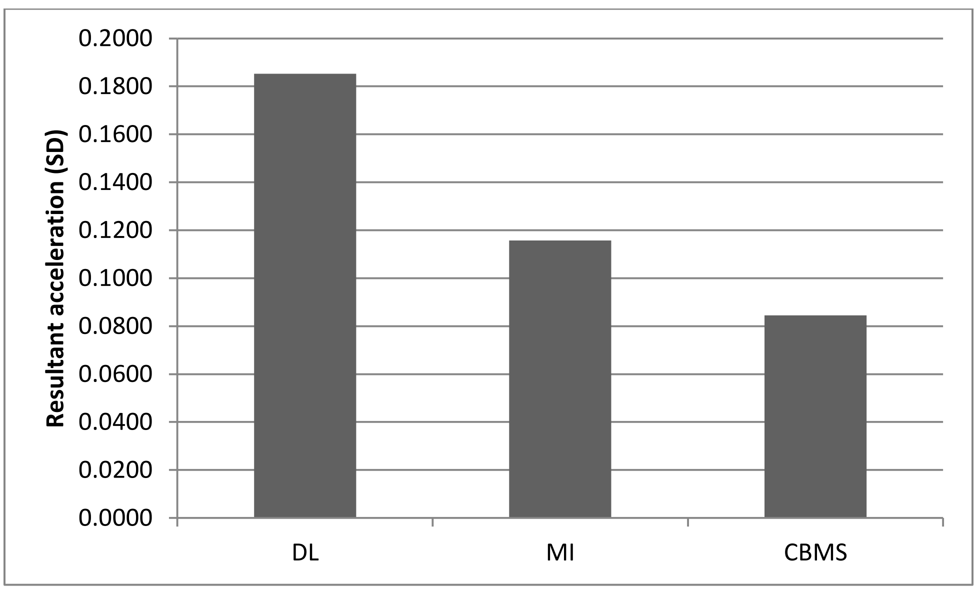


**Fig. 20. Resultant acceleration (SD) for direct looking, mirrors and camera based monitoring scenarios.**

In summary, for all three axes individually as well for the resultant of three axes, dispersion (SD) of the acceleration among all three monitoring scenarios is significantly different. Higher values of acceleration (SD) were observed for the

DL monitoring scenario in comparison to the MI and the CBMS among all three axes indicating that higher workload was involved in the DL scenario. The CBMS scenario had the least acceleration (SD) values indicating that the least workload was involved when using the CBMS strategy for monitoring rear-mounted equipment.

### 4.3. Thermal Imaging

For evaluating elevated muscle temperature due to the rotation of head/neck during three monitoring scenarios, thermal images of the neck area were analysed. Semispinalis Capitis and Splenius Capitis are the muscles mainly responsible for extension and rotation movement of the neck (Sommerich et al. 2000). However area of the neck captured by the thermal camera may include other muscles than Semispinalis or Splenius Capitis muscles. With the help of proprietary software available with the FLIR camera, average temperature of the exposed area of neck was determined. Elevated muscle temperature was determined by calculating the difference between the baseline and post-monitoring activity temperature for all three monitoring scenarios. Elevated muscle temperatures among the three monitoring scenarios were compared using statistical ANOVA test (single factor). Significant differences ($\alpha$=0.05) were observed among the three monitoring scenarios (Table 10).

**Table 10. ANOVA table (α=0.05, n=30) comparing the changed muscle temperature due to the head/neck movement of the operator among direct looking, mirrors and camera based monitoring scenario.**

**SUMMARY**

| ***Groups*** | ***Count*** | ***Sum*** | ***Average*** | ***Variance*** |
|---|---|---|---|---|
| DL | 30 | 25.6 | 0.853333 | 0.134299 |
| MI | 30 | 15.1 | 0.503333 | 0.101023 |
| CBMS | 30 | 6.7 | 0.223333 | 0.052885 |

**ANOVA**

| ***Source of Variation*** | ***SS*** | ***df*** | ***MS*** | ***F*** | ***P-value*** | ***F crit*** |
|---|---|---|---|---|---|---|
| Between Groups | 5.978 | 2 | 2.989 | 31.11307 | 6.41E-11 | 3.101296 |
| Within Groups | 8.358 | 87 | 0.096069 | | | |
| | | | | | | |
| Total | 14.336 | 89 | | | | |

Higher temperature of the neck area was observed in the DL scenario followed by the MI and CBMS scenarios (Fig. 21). Referring to the average values of elevated temperature in Table 10, the average temperature increase

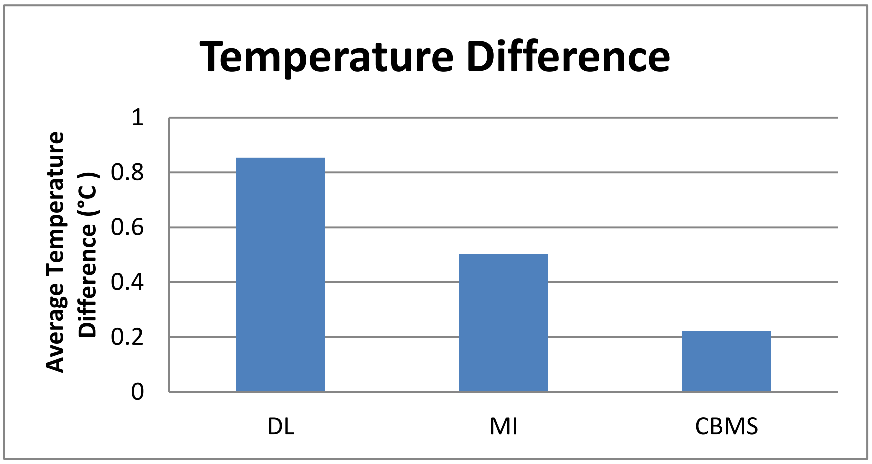


**Fig. 21. Average changed temperature for direct looking (DL), mirrors (MI) and camera based monitoring scenario (CBMS).**

was 0.85°C in the DL scenario, 0.50°C in the MI scenario, and 0.22°C in the CBMS scenario.

During working - even if it is lighter work - muscle temperature rises (Buchthal et al. 1944). Higher elevated muscle temperature in the DL scenario in comparison to the MI and CBMS scenarios indicates that higher work was involved in the DL scenario in comparison to the MI and CBMS scenarios.

### 4.4. Subjective feedback

After the completion of every experimental session, a questionnaire was provided to each subject to obtain subjective feedback about all monitoring scenarios. Subject's likings/dislikings, preferences and overall experience among the three monitoring scenarios were collected and summarized (Table 11).

**Table 11. Summary of the subjective feedback obtained from operators after performing three types of monitoring strategies (DL, MI and CBMS) during the experimental session.**

| Subject | Image Size | Number of Images | Screen Brightness | Image Quality | Ease In Usage | Information Conveying | Mental Workload | Fatigue | Overall Preference |
|---|---|---|---|---|---|---|---|---|---|
| **1** | Ok | Two | Ok | Blurred | CBMS | DL | MI | CBMS | CBMS |
| **2** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **3** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **4** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **5** | Ok | Two | Ok | Ok | CBMS | CBMS | MI | CBMS | CBMS |
| **6** | Ok | More than two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **7** | Ok | Two | Ok | Ok | CBMS | DL | DL | CBMS | CBMS |
| **8** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | MI | CBMS |
| **9** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **10** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **11** | Ok | Two | Ok | Ok | MI | MI | MI | MI | MI |
| **12** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **13** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **14** | Ok | Two | Ok | Blurred | CBMS | DL | DL | CBMS | MI |
| **15** | Ok | Two | Ok | Blurred | CBMS | CBMS | CBMS | CBMS | CBMS |
| **16** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **17** | Ok | Two | Not enough | Ok | CBMS | MI | MI | CBMS | CBMS |
| **18** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **19** | Ok | Two | Ok | Ok | CBMS | CBMS | MI | CBMS | CBMS |
| **20** | Ok | More than two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **21** | Ok | More than two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **22** | Ok | Two | Ok | Blurred | CBMS | DL | CBMS | CBMS | DL |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **23** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **24** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **25** | Ok | More than two | Ok | Ok | CBMS | DL | DL | CBMS | CBMS |
| **26** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **27** | Ok | Two | Not enough | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **28** | Ok | Two | Ok | Ok | CBMS | MI | CBMS | CBMS | CBMS |
| **29** | Ok | Two | Ok | Ok | CBMS | CBMS | CBMS | CBMS | CBMS |
| **30** | Ok | Two | Ok | Blurred | CBMS | CBMS | CBMS | CBMS | CBMS |

Size of the images displayed on the monitoring screen was found to be appropriate by all subjects. However, a few subjects (approximately 13%) suggested that more than two images could be displayed on the monitor screen. About 87% of subjects agreed that displaying two images on the screen was good. No participant supported the idea of displaying one image on the monitor screen and manually switching between the cameras. Regarding the brightness of the display, 93% of the subjects found the brightness level comfortable. About 7% of subjects wished for a brighter screen. About 17% of the subjects indicated that the images on the screen were blurred; however, 83% of the subjects indicated acceptable quality of the images. About 97% of the subjects ranked the CBMS on top based on physical comfort. Only 3% of the subjects ranked the MI scenario above the other two scenarios. For ease in communication of the information, the CBMS was ranked best by 73% of the subjects followed by the DL scenario (17% of subjects) and the MI scenario (10% of subjects). From the mental workload point of view, the CBMS was ranked on top by 73% of the subjects; 17% of the subjects preferred the MI scenario whereas only 10% of the subjects liked the DL strategy of monitoring rear-mounted equipment. Considering fatigue, the CBMS was ranked best by 93% of the subjects whereas only 7% of the subjects liked the MI scenario. No subject liked the DL scenario. In one of the questions regarding overall preferred monitoring strategy, 90% of the subjects indicated CBMS, followed by MI (7 %) and DL (3%).

Overall preferred method of monitoring based on the response of subjects for (i) “Comfort during usage” (ii) “Ease in information communication” (iii) mental workload and (iv) fatigue, was determined by taking the average. The CBMS was rated as best by approximately 84% of the subjects followed by MI (approximately 9% of subjects) and last DI (about 7% of subjects).

### 4.5. Design changes in Implement Quad System (IQS)

The CMBS used in the study was provided by Allen Leigh. This system is called the “Implement Quad System” (IQS). It consisted of a 1/3” CCD camera of 90° FOV and a 7” LCD monitor capable of using 4 video inputs. Allen Leigh wished to evaluate the performance of the IQS system compared with traditional implement monitoring systems so that further innovations can be implemented.

Based on the subjective feedback obtained (total of 30 subjects) at the end of every complete experiment session (which included three monitoring scenarios in random order of sequence), some suggestions were made. A few subjects (17%) indicated that the image quality was blurred. Out of these 17% subjects, one subject detailed that it was hard to distinguish between different types of errors among the two images displayed simultaneously on the monitor screen due to blurred images. Similarly, one other subject reported that the difference in the color between images from the two cameras which were displayed simultaneously on the screen and the image quality was blurred. No other quality or design issue was reported regarding the IQS.

From this feedback it is evident that there is scope for improving the picture quality of the display. It is recommended to use higher resolution for the display to enhance picture quality.

# 5. CONCLUSIONS

In this study, a camera based monitoring system (CBMS) was evaluated and compared with conventional monitoring systems (i.e., when operator looked directly (DL) toward rear mounted implement by turning physically backwards and/or using side mounted mirrors (MI) to monitor rear mounted implement). The operator’s performance (i.e., reaction time and response errors) and physical workload involved in the three monitoring strategies were evaluated using a TAS-DS, tri-axial accelerometer, and thermal imaging system.

There was no significant difference (α=0.05) observed regarding response errors and reaction time of the operator during three monitoring scenarios (i.e., DL, MI and CBMS). This signifies that, as far as operator’s performance and efficiency is concerned, the type of monitoring strategy (DL, MI or CBMS) did not make any difference in current lab setting environment.

Analysis of the motion of the head/neck during three monitoring scenarios (DL, MI and CBMS) indicated significant difference (α=0.05) in acceleration. In order to compare acceleration values along three axes of motion (i.e., mediolateral, anteroposterior and vertical axis), acceleration (SD) values were compared for the DL, MI and CBMS scenarios. Overall for all three axes, the DL scenario displayed the highest values of acceleration (SD) followed by the MI scenario and the CBMS scenario.

For the vertical axis, acceleration (SD) values in the DL scenario were 66.61% higher than the CBMS scenario and in the MI scenario they were 41.61%

higher than the CBMS scenario. For mediolateral axis SD of acceleration values in the DL scenario were 146.37% higher than the CBMS and in the MI scenario 128.81% higher than the CBMS scenario. Similarly for anteroposteriors axis acceleration values (SD) in the DL scenario were 110.07% higher than the CBMS and in the MI scenario they were 40.84% higher than the CBMS scenario. Resultant acceleration (SD) values (vector sum of three axes) also showed displayed highest values for DL scenario (119% higher than CBMS) followed by MI scenario (37% higher than CBMS).

As acceleration is directly proportional to the workload involved (force=mass x acceleration and work=force x distance), from the mentioned results, it is evident that the DL monitoring scenario is associated with the highest workload and the CBMS scenario involved the least workload.

In order to understand workload associated with the head/neck movement from another paradigm, an infrared thermal imaging technique was used. Elevated muscle temperature of the neck region was determined by measuring pre- and post-activity temperature for each monitoring scenario (DL, MI and CBMS). Significant differences ($\alpha$=0.05) in the rise in temperature among three monitoring scenarios were observed. For the DL scenario, 0.85°C average rise in temperature with respect to the baseline temperature was observed whereas for the MI and CBMS scenarios temperature increases of 0.50°C and 0.22°C, respectively, were observed. More rise in temperature in the DL scenario indicated that more physical activity was involved in the DL scenario, followed by the MI scenario and the CBMS scenario.

Based on the subjective feedback from the subjects regarding the Implement Quad System (IQS) which was used as the CBMS in this study, one design/quality related change is recommended. A few subjects (17%) indicated that the image quality was blurred. It is recommended to use a display with higher resolution in the Implement Quad System to enhance picture quality.

## 6. RECOMMENDATIONS FOR FUTURE STUDY

In this study elevated temperature of the neck area were compared using thermal images of the neck area. Exact location of two main muscles (Semispinalis Capitis and Splenius Capitis) which are chiefly responsible for the rotation and extension movement of the neck may not be easily traceable in the thermographs. Due to the challenge in identifying the exact location of these muscles in thermal images, the area captured in thermographs included some portion of the neck belonged to some other muscles. Although this unwanted neck surface area was quite common during comparison for baseline and post-activity temperature, this factor may still have some erroneous effect in determining overall elevated muscle temperature.

For future studies it is recommended that before capturing the thermal image of the subjects, the region of interest should be marked with some material visible in the thermograph. Then while capturing the next thermal image for comparing it with its baseline image it would be quite helpful in accurately determining the change in temperature of the region of interest only.

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## 8. APPENDIX A: QUESTIONNAIRE FOR SUBJECTIVE FEEDBACK

**Subject Sr. No.________** **Date:____________(dd/mm/yy)**

1. Please rate the size of the images on the monitor.

   a. Too small

   b. Ok

   c. Too large

2. The system was set to display images from two cameras simultaneously. Given that the purpose of the system is to assist with the task of monitoring the equipment, please indicate your preference.

   a. Display only one image at a time (and manually switch between cameras)

   b. Displaying two images simultaneously was fine

   c. More than two images could be displayed simultaneously

3. Please rate the brightness of the display screen.

   a. The images were not bright enough

   b. The brightness of the images was ok

c. The images were too bright

4. Please rate the quality of the images.

a. The images were ok

b. The images were blurred

5. Do you have any suggestions regarding placement of the monitor? Select all that apply.

a. Monitor placement was ok

b. Monitor should be placed closer to the operator

c. Monitor should be placed to the right of the steering wheel

d. Monitor should be placed to the left of the steering wheel

6. Rank the three monitoring strategies based on level of physical comfort experienced. (1 = most comfortable; 3 = least comfortable)

____ Physical turning

____ Using rear-view mirrors

____ Using camera monitoring system

7. Rank the three monitoring strategies based on the ease of communicating monitoring information. ( 1 = easiest to understand; 3 = most difficult to understand)

____ Physical turning

____ Using rear-view mirrors

____ Using camera monitoring system

8. Rank the three monitoring strategies based on the level of mental workload required. (1 = least mental effort; 3 = most mental effort)

____ Physical turning

____ Using rear-view mirrors

____ Using camera monitoring system

9. Rank the three monitoring strategies based on contribution to fatigue. (1 = caused least fatigue; 3 = caused most fatigue)

____ Physical turning

____ Using rear-view mirrors

____ Using camera monitoring system

10. Rank the three monitoring strategies based on your overall preference.

    (1 = highest preference; 3 = lowest preference)

____ Physical turning

____ Using rear-view mirrors

____ Using camera monitoring system

11. Please provide any comments about the “physical turning” strategy.

12. Please provide any comments about the “use of rear-view mirrors” strategy.

13. Please provide any comments about the “use of camera monitoring system” strategy.

# 9. APPENDIX B: ANALYSIS OF VARIANCE (ANOVA) TABLES COMPARING ERRORS BETWEEN THREE MONITORING SCENARIOS (DL, MI AND CBMS) FOR VARIOUS TASKS.

**Appendix B 1. ANOVA table (α=0.05, n=30) comparing errors for monitoring seed rate task during DL, MI and CBMS scenario.**

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| SeedRate-DL | 30 | 0.4442 | 0.0148 | 0.0033 |
| SeedRate-MI | 30 | 12.9718 | 0.4324 | 5.2295 |
| SeedRate-CBMS | 30 | 2.1932 | 0.0731 | 0.1476 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 3.068667645 | 2 | 1.5343 | 0.8555 | 0.4286 | 3.1013 |
| Within Groups | 156.031565 | 87 | 1.7935 | | | |
| Total | 159.1002326 | 89 | | | | |

**Appendix B 2. ANOVA table comparing errors for monitoring fan RPM task during DL, MI and CBMS scenario.**

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Fan-DL | 30 | 62.7011 | 2.0900 | 4.2555 |
| Fan-MI | 30 | 76.7439 | 2.5581 | 14.6750 |

| | | | | |
|---|---|---|---|---|
| Fan-CBMS | 30 | 45.3314 | 1.5110 | 3.3211 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 16.50723723 | 2 | 8.2536 | 1.1128 | 0.3333 | 3.1013 |
| Within Groups | 645.2978037 | 87 | 7.4172 | | | |
| | | | | | | |
| Total | 661.8050409 | 89 | | | | |

**Appendix B 3. ANOVA table (α=0.05, n=30) comparing errors for monitoring left side tool depth during DL, MI and CBMS scenario.**

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Ldepth-DL | 30 | 499.8345 | 16.6612 | 494.4425 |
| Ldepth-MI | 30 | 311.0727 | 10.3691 | 323.4104 |
| Ldepth-CBMS | 30 | 344.5914 | 11.4864 | 451.3205 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 676.1665 | 2 | 338.0832 | 0.7991 | 0.4530 | 3.1013 |
| Within Groups | 36806.03 | 87 | 423.0578 | | | |
| | | | | | | |
| Total | 37482.2 | 89 | | | | |

**Appendix B 4. ANOVA table (α=0.05, n=30) comparing errors for monitoring right side tool depth during DL, MI and CBMS scenario.**

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Rdepth-DL | 30 | 307.0923 | 10.2364 | 316.0529 |
| Rdepth-MI | 30 | 308.8524 | 10.2951 | 314.1733 |
| Rdepth-CBMS | 30 | 278.3020 | 9.2767 | 355.6311 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 19.61442 | 2 | 9.8072 | 0.0298 | 0.9706 | 3.1013 |
| Within Groups | 28589.86 | 87 | 328.6191 | | | |
| Total | 28609.48 | 89 | | | | |

**Appendix B 5. ANOVA table (α=0.05, n=30) comparing errors for monitoring blockage task during DL, MI and CBMS scenario.**

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| BlockageFlag-DL | 30 | 86.3616 | 2.8787 | 7.0167 |
| BlockageFlag-MI | 30 | 83.8775 | 2.7959 | 4.3776 |
| BlockageFlag-CBMS | 30 | 137.7584 | 4.5919 | 174.0669 |

ANOVA

| Source of Variation | SS | Df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| Between Groups | 61.677273 | 2 | 30.8386 | 0.4988 | 0.6090 | 3.1013 |
| Within Groups | 5378.37235 | 87 | 61.8204 | | | |
| Total | 5440.04963 | 89 | | | | |

**Appendix B 6. ANOVA table (α=0.05, n=30) comparing errors for monitoring tool pressure task during DL, MI and CBMS scenario.**

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Tpressure-DL | 30 | 63.2467 | 2.1082 | 11.4884 |
| Tpressure-MI | 30 | 70.5855 | 2.3528 | 14.5752 |
| Tpressure-CBMS | 30 | 42.8201 | 1.4273 | 2.1887 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 13.8002 | 2 | 6.9001 | 0.7327 | 0.4836 | 3.1013 |
| Within Groups | 819.3167 | 87 | 9.4174 | | | |
| Total | 833.1169 | 89 | | | | |

**Appendix B 7. ANOVA table (α=0.05, n=30) comparing errors for monitoring tractor speed task during DL, MI and CBMS scenario.**

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| Speed-DL | 30 | 2.5416 | 0.0847 | 0.1730 |

| | | | | |
|---|---|---|---|---|
| Speed-MI | 30 | 0.1754 | 0.0058 | 0.0005 |
| Speed-CBMS | 30 | 0.3497 | 0.0117 | 0.0041 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 0.1159 | 2 | 0.0580 | 0.9795 | 0.3796 | 3.1013 |
| Within Groups | 5.1482 | 87 | 0.0592 | | | |
| Total | 5.2641 | 89 | | | | |

**Appendix B 8. ANOVA table (α=0.05, n=30) comparing errors for monitoring seed spillage task during DL, MI and CBMS scenario.**

Anova: Single Factor

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| SpillageFlag-DL | 30 | 215.0122 | 7.1671 | 236.7141 |
| SpillageFlag-MI | 30 | 310.6612 | 10.3554 | 370.6530 |
| SpillageFlag-CBMS | 30 | 292.4004 | 9.7467 | 386.9436 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 171.9014 | 2 | 85.9507 | 0.2593 | 0.7722 | 3.1013 |
| Within Groups | 28835.0113 | 87 | 331.4369 | | | |

| | | |
|---|---|---|
| Total | 29006.9127 | 89 |

**Appendix B 9. ANOVA table (α=0.05, n=30) comparing errors for monitoring plugging's task during DL, MI and CBMS scenario.**

Anova: Single Factor

SUMMARY

| Groups | Count | Sum | Average | Variance |
|---|---|---|---|---|
| PluggingFlag-DL | 30 | 318.7167 | 10.6239 | 406.8260 |
| PluggingFlag-MI | 30 | 137.5924 | 4.5864 | 68.5735 |
| PluggingFlag-CBMS | 30 | 274.7922 | 9.1597 | 370.9515 |

ANOVA

| Source of Variation | SS | df | MS | F | P-value | F crit |
|---|---|---|---|---|---|---|
| Between Groups | 595.1015 | 2 | 297.5507 | 1.0547 | 0.3527 | 3.1013 |
| Within Groups | 24544.1802 | 87 | 282.1170 | | | |
| | | | | | | |
| Total | 25139.2817 | 89 | | | | |

# 10. APPENDIX C: AMBIENT TEMPERATURE INSIDE THE ROOM AND INSIDE THE TRACTOR CAB RECORDED DURING THE EXPERIMENTS

| Subjects | Date | Session | Temp A | Temp B | Difference (Temp A-Temp B) |
|---|---|---|---|---|---|
| Subject 1 | 6-Oct-11 | Session one | 21.5 | 21.1 | 0.4 |
| | | Session Two | 21.5 | 21 | 0.5 |
| | | Session Three | 21.5 | 21.1 | 0.4 |
| Subject 2 | 12-Oct-11 | Session one | 22.3 | 21 | 1.3 |
| | | Session Two | 22.6 | 21.6 | 1 |
| | | Session Three | 22.9 | 22 | 0.9 |
| Subject 3 | 12-Oct-11 | Session one | 22.4 | 21.5 | 0.9 |
| | | Session Two | 22.4 | 21.7 | 0.7 |
| | | Session Three | 22.5 | 21.9 | 0.6 |
| Subject 4 | 25-Oct-11 | Session one | 23.3 | 21.8 | 1.5 |
| | | Session Two | 23.4 | 22.5 | 0.9 |
| | | Session Three | 23.3 | 22.2 | 1.1 |
| Subject 5 | 26-Oct-11 | Session one | 23.7 | 21.8 | 1.9 |
| | | Session Two | 24.1 | 22.4 | 1.7 |
| | | Session Three | 24.1 | 22.3 | 1.8 |
| Subject 6 | 27-Oct-11 | Session one | 22.9 | 22.2 | 0.7 |
| | | Session Two | 22.5 | 22.3 | 0.2 |
| | | Session Three | 22.4 | 22.3 | 0.1 |
| Subject 7 | 28-Oct-11 | Session one | 22.3 | 22.2 | 0.1 |
| | | Session Two | 22.4 | 22.5 | -0.1 |

| | | | | | |
|---|---|---|---|---|---|
| | | Session Three | 22.2 | 22.4 | -0.2 |
| Subject 8 | 31-Oct-11 | Session one | 22.1 | 22 | 0.1 |
| | | Session Two | 22 | 22 | 0 |
| | | Session Three | 22.4 | 22.1 | 0.3 |
| Subject 9 | 31-Oct-11 | Session one | 22.1 | 22.1 | 0 |
| | | Session Two | 22 | 22 | 0 |
| | | Session Three | 22.4 | 22 | 0.4 |
| Subject 10 | 1-Nov-11 | Session one | 21.7 | 21.7 | 0 |
| | | Session Two | 21.8 | 21.7 | 0.1 |
| | | Session Three | 21.9 | 21.8 | 0.1 |
| Subject 11 | 2-Nov-11 | Session one | 22.3 | 21.8 | 0.5 |
| | | Session Two | 22.1 | 21.8 | 0.3 |
| | | Session Three | 22.1 | 22 | 0.1 |
| Subject 12 | 2-Nov-11 | Session one | 22 | 22 | 0 |
| | | Session Two | 22.3 | 22.4 | -0.1 |
| | | Session Three | 22.2 | 22.8 | -0.6 |
| Subject 13 | 3-Nov-11 | Session one | 22.2 | 22.2 | 0 |
| | | Session Two | 22.3 | 22.4 | -0.1 |
| | | Session Three | 22.3 | 22.3 | 0 |
| Subject 14 | 3-Nov-11 | Session one | 22.3 | 22.2 | 0.1 |
| | | Session Two | 22.1 | 22.2 | -0.1 |
| | | Session Three | 22.4 | 22.3 | 0.1 |
| Subject 15 | 4-Nov-11 | Session one | 21.6 | 21.4 | 0.2 |
| | | Session Two | 21.7 | 21.6 | 0.1 |
| | | Session Three | 22.1 | 22.4 | -0.3 |

| | | | | | |
|---|---|---|---|---|---|
| Subject 16 | 7-Nov-11 | Session one | 22.3 | 22.6 | -0.3 |
| | | Session Two | 22.6 | 22.2 | 0.4 |
| | | Session Three | 23.2 | 22.3 | 0.9 |
| Subject 17 | 7-Nov-11 | Session one | 22.7 | 22.2 | 0.5 |
| | | Session Two | 22.6 | 22.4 | 0.2 |
| | | Session Three | 22.5 | 22.5 | 0 |
| Subject 18 | 8-Nov-11 | Session one | 22.4 | 21.6 | 0.8 |
| | | Session Two | 23 | 22.1 | 0.9 |
| | | Session Three | 22.5 | 22.1 | 0.4 |
| Subject 19 | 8-Nov-11 | Session one | 22.2 | 21.9 | 0.3 |
| | | Session Two | 22.8 | 22.4 | 0.4 |
| | | Session Three | 22.4 | 22.5 | -0.1 |
| Subject 20 | 9-Nov-11 | Session one | 22.5 | 22.3 | 0.2 |
| | | Session Two | 22.1 | 22.1 | 0 |
| | | Session Three | 22 | 22.4 | -0.4 |
| Subject 21 | 10-Nov-11 | Session one | 22.1 | 21.9 | 0.2 |
| | | Session Two | 22.6 | 22.4 | 0.2 |
| | | Session Three | 22.7 | 22.6 | 0.1 |
| Subject 22 | 10-Nov-11 | Session one | 22.4 | 21.9 | 0.5 |
| | | Session Two | 22.6 | 22.4 | 0.2 |
| | | Session Three | 22.7 | 22.6 | 0.1 |
| Subject 23 | 14-Nov-11 | Session one | 23.4 | 22.2 | 1.2 |
| | | Session Two | 23.5 | 22.4 | 1.1 |
| | | Session Three | 23.3 | 22.3 | 1 |
| Subject 24 | 15-Nov-11 | Session one | 23.2 | 22 | 1.2 |

| | | | | | |
|---|---|---|---|---|---|
| | | Session Two | 23.4 | 22.3 | 1.1 |
| | | Session Three | 23.2 | 22.3 | 0.9 |
| Subject 25 | 15-Nov-11 | Session one | 22.9 | 22.3 | 0.6 |
| | | Session Two | 22.7 | 22.7 | 0 |
| | | Session Three | 22.8 | 22.7 | 0.1 |
| Subject 26 | 16-Nov-11 | Session one | 23.2 | 22.2 | 1 |
| | | Session Two | 23.3 | 22.4 | 0.9 |
| | | Session Three | 23.4 | 22.5 | 0.9 |
| Subject 27 | 17-Nov-11 | Session one | 23 | 22.2 | 0.8 |
| | | Session Two | 22.2 | 22.3 | -0.1 |
| | | Session Three | 23.4 | 22.3 | 1.1 |
| Subject 28 | 18-Nov-11 | Session one | 23.1 | 22.2 | 0.9 |
| | | Session Two | 23.2 | 22.1 | 1.1 |
| | | Session Three | 23.5 | 22.4 | 1.1 |
| Subject 29 | 21-Nov-11 | Session one | 22.6 | 21.7 | 0.9 |
| | | Session Two | 22.7 | 21.8 | 0.9 |
| | | Session Three | 22.6 | 22.3 | 0.3 |
| Subject 30 | 25-Nov-11 | Session one | 22.7 | 22 | 0.7 |
| | | Session Two | 22.7 | 21.8 | 0.9 |
| | | Session Three | 23.3 | 22.1 | 1.2 |

Temp A: Ambient temperature inside the room (°C)

Temp B: Ambient temperature inside the TAS-DS cab (°C)

# 11. APPENDIX D: CONSENT FORM FOR FARMERS

## D1. Research Objective

A challenge associated with farming is the task of monitoring the operation of a machine trailing behind the tractor while simultaneously looking ahead of the tractor to guide it safely and accurately across the field. The rear-monitoring task becomes even more difficult for anyone who has experienced an injury to the back and/or neck (or even those susceptible to back and/or neck pain). A number of different companies are now promoting video surveillance systems at relatively low cost. Such systems consist of cameras that can be mounted on an implement wherever desired and a monitor that mounts in the cab of the tractor. The idea is that the tractor operator can have a close-up view of the rear-hitched machine without having to physically turn to the rear.

Agricultural safety and health is an on-going concern. Video surveillance systems have the potential to alleviate pain and hardship for farmers with back and/or neck injuries, however, it is important to also demonstrate that use of such video monitoring systems is safe (i.e., that the number of monitoring errors is no more than the number of monitoring errors committed by operators using the usual technique for rear-monitoring).

The objective of the project is to generate new research information about implement monitoring systems. Specifically, the proposed research will endeavor to quantify monitoring performance achieved during use of a driving simulator equipped with a camera and dash-mounted display. Use of a driving simulator is proposed to ensure that uncontrollable factors associated with field research can be avoided.

**D2.Research Procedure**

The Principal Investigator will conduct a series of simulator experiments to compare the tractor driver's task in three scenarios: 1) in a conventional setting (i.e., driver required to physically turn to monitor the trailing equipment), 2) with the use of cab-mounted rear-view mirrors, and 3) with the use of a video surveillance system. A driving scenario will be created that requires subjects to "steer" the simulator and to both monitor and control a simulated air seeder located behind the simulator's seat. Three categories of monitoring tasks will be included in the research: 1) monitoring to obtain guidance information, 2) monitoring of routine operation of a machine, and 3) monitoring for detection of abnormalities. A minimum of 10 subjects will be recruited to participate in this research project. Allen Leigh Security & Communications Ltd. markets a system known as the "Implement Quad System" which consists of a 7" monitor that can simultaneously display the input from four CCD cameras. The cameras are capable of night vision. The Implement Quad System is the implement monitoring system that will be used in this research.

Monitoring performance will be assessed by observing reaction time and response errors. The simulator code has been programmed to automatically track both reaction time and response errors. Subjective feedback will be obtained from the research subjects regarding features that are liked/disliked with each of the monitoring systems. The Department of Biosystems Engineering also has an infrared camera that is capable of detecting elevated muscle temperature associated with muscle fatigue. The IR thermal imaging system will be used to obtain a physical measure of the impact of the monitoring systems on the operator.

**D3.Risk**

All experimental procedures will be conducted using a stationary tractor-driving simulator located in the Agricultural Ergonomics Laboratory. Therefore, you will be subject to no risk as a result of this study.

**D4.Instruments**

Monitoring performance (i.e., reaction time, errors) will be automatically recorded by the simulator's control system while the experiment is in session.

**D5.Assurance of Confidentiality**

Your name will never be used with reference to this research. Only the principal investigator, Aadesh Rakhra, and his advisor, Dr. Danny Mann, will have access to the information collected. The data will be stored in the research lab of Dr.

Danny Mann until it has been entered into the computer. Once entered into the computer, it will be coded (i.e., subjects will not be identified by name). The names and coded numbers will be stored separately. The original data will be kept until December 31, 2012. The data will be saved on PC hard drives for analysis; the PC is password protected and can be accessed only by the main investigator. At least one backup copy of the data will be saved on CDs to ensure safety. The collected data may be used in manuscripts written for presentation in conferences and/or publication in scientific journals. Finally, after December 31, 2012, the data will be removed from the hard drives and the backup copies will be destroyed.

**D6.Availability of Research Results**

Results of this experiment will be available in the form of a summary sheet six months after the date of experiment.

☐ Check the box to the left if you would like to receive a summary of the research. Please provide your e-mail or postal address so that I can contact you when it is ready.

____________________________________________________________

**D7.Remuneration**

You will receive an honorarium of $ 20 for participating in the experiments.

## D8.Assurance of Voluntary Participation

Your participation in this research is voluntary. If at any time you wish to withdraw from the project, you may do so without consequence. If you decide to do so any time during the experiment, you should notify the experimenter. If you make such a request, the experiment will be stopped and the any data collected will be deleted immediately.

## D9.Human Subject Research Ethics Approval

This research has received approval by the Education/Nursing Research Ethics Board (ENREB). Any complaint regarding a procedure may be reported to either the Human Ethics Secretariat (474-7122) or the Head of Biosystems Engineering (474-9819).

If you have any questions or concerns, please contact the primary investigator, Aadesh Rakhra, or his advisor, Dr. Danny Mann:


| | |
|---|---|
| Aadesh Rakhra | Dr. Danny Mann, P.Eng. |
| Department of Biosystems Engineering | Department of Biosystems Engineering |
| University of Manitoba | University of Manitoba |
| Winnipeg, MB R3T 5V6 | Winnipeg, MB R3T 5V6 |
| Phone: (204) 474-7966 | Phone: (204) 474-7149 |
| E-mail: umrakhr2@cc.umanitoba.ca | E-mail: Danny_Mann@umanitoba.ca |

My signature indicates that I have read and understand the above conditions. I hereby give my consent for, and agree to participate in, this research project.

Name:___________________________ Date:______________________________

_ _

Witnessed by:____________________ Date:______________________________

# 12. APPENDIX E: ETHICS APPROVAL CERTIFICATE

UNIVERSITY OF MANITOBA | Ethics
Office of the Vice-President (Research)

CTC Building
208 - 194 Dafoe Road
Winnipeg, MB R3T 2N2
Fax (204) 269-7173
www.umanitoba.ca/research

**APPROVAL CERTIFICATE**

April 19, 2011

NSERC ENGAGE

TO: **Aadesh Rakhra**
Principal Investigator

**FROM:** **Stan Straw, Chair**
Education/Nursing Research Ethics Board (ENREB)

**Re:** **Protocol #E2011:028**
**"Evaluation of Implement Monitoring Systems"**

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Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement. This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

**Please note:**

- **If you have funds pending human ethics approval, the auditor requires that you submit a copy of this Approval Certificate to the Office of Research Services, fax 261-0325 - please include the name of the funding agency and your UM Project number. This must be faxed before your account can be accessed.**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

**The Research Ethics Board requests a final report for your study (**available at: http://umanitoba.ca/research/ors/ethics/ors_ethics_human_REB_forms_guidelines.html**) in order to be in compliance with Tri-Council Guidelines.**

*Bringing Research to Life*

# 13. APPENDIX F:DATA CD

This thesis is accompanying a CD. All the data used in this thesis is recorded on this CD. Data files are in Microsoft Excel format (.xls).There are total nine .xls files in the CD.

**Accelerometer data analysis summary file** This file contains statistical summary (min, max, median, mean, stdev, skewness, and kurtosis) of all thirty subjects' accelerometer data.

**Accelerometer data files** These are six files in total. Each file contains data for five subjects. All thirty subject's accelerometer data is covered in these six files.

**TAS-DS systems data file** This file contains data generated from TAS-DS systems which is related to the reaction time and response time of the operator during monitoring scenarios.

**Thermal Imaging data file** This file contains the data related to the infrared thermal imaging for all thirty subjects.