Data Synchronization for Cognitive Load Estimation in Driving Simulator-based Experiments

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ABSTRACT

Analyzing the effects of driver distraction and inattention on cognitive load has become a very important issue given the substantial increase in the number of electronic devices which are finding their way into vehicles. Typically separate equipment is used for collecting different variables sensitive to cognitive load changes. In order to be able to draw reliable conclusions it is important to possess dependable ways of synchronizing data collections between different equipment. This paper offers one low-cost solution which enables synchronizing three types of devices often used in driving research: driving simulator, eye-tracker and physiological monitor.

Categories and Subject Descriptors

H.5.m [Information Interfaces and Presentation]: Miscellaneous

General Terms

Measurement, Experimentation.

Keywords

Data synchronization, cognitive load, eye tracking, driving simulator, physiological measurements.

1. INTRODUCTION

In recent years we have seen a major increase in research concerned with driver distraction and the influence of various in-vehicle devices on driving performance and cognitive load. This development is not surprising for two reasons. First, the amount of time people spend in their vehicles has been steadily increasing, with 86.1% of American citizens commuting in a car, truck or van in 2009 and spending on average 25.1 minutes driving to work (one way) daily [1]. And second, with the proliferation of computers and the expansion of communication networks, new types of electronic devices are becoming available and being introduced in vehicles at a rate never seen before. Those new devices typically make the driving experience more interesting and enjoyable. However, this comes at a price of an increased number of accidents caused by driver distraction and inattention [2]. Therefore it is necessary to have reliable tools which can detect the potential for distraction that an in-vehicle device has before it is introduced in vehicles.

There are many measures that can be sensitive to changes in cognitive load and they can be divided into three general groups: driving performance (such as steering wheel angle and lane position), physiological (such as skin conductance and visual attention) and subjective measures (such as NASA-TLX). However, many studies have shown that none of these measures is a panacea, thus requiring researchers to often collect more than one measure using different equipment. The fact that different equipment has to be used leads directly to the main problem addressed in this paper: a reliable solution for data synchronization between different data collections is necessary.

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2. BACKGROUND

Given the variety of equipment used in driving research it is practically impossible to devise a universal data synchronization solution. Some solutions in that direction do exist, however, at least in the case of equipment which is based on personal computers (PCs).

One example application is called NTP FastTrack [3]. The purpose of this application is to synchronize computer clocks over a data network. It is based on the Network Time Protocol (NTP) [4], where one computer acts as the reference (server) with which other computers (clients) on the network should synchronize. The synchronization is performed by applying small changes to the local clocks of the client computers in order to reduce the difference with respect to the reference clock. The accuracy of this procedure depends on the propagation delay (i.e. load) on the network and can range from 100 microseconds up to several tens of milliseconds. Even though the accuracy is typically high, our experience indicates two problems with this approach. First, it can take a significant amount of time for the synchronization to stabilize (on the order of minutes to hours), which can be impractical if any of the computers need to be restarted or turned off during an experimental session. And second, the equipment which cannot be networked, such as some physiological monitors in our lab, cannot use this protocol.

Recently some commercial solutions for data synchronization have been introduced as well, such as the Tobii StimTracker [5]. The purpose of this device is to enable synchronizing eye-tracking data coming from a Tobii TX300 eye-tracker with several commercially available physiological monitors. It also allows interfacing with a parallel port, thus enabling synchronization with other PC-based equipment. However, this solution has somewhat limited usability, because it was developed for one particular device. Nevertheless, this indicates that the original equipment manufacturers are starting to acknowledge the importance of data synchronization between different equipment.

3. PROPOSED SOLUTION

The main idea behind our solution is in sending the synchronization messages to all the equipment which is used in an experimental trial. Our driving research studies typically involve the following equipment: driving simulator (by DriveSafety), eye-tracker (by SeeingMachines) and physiological monitor (by

Thought Technology). Even though our solution was devised for the equipment made by the above manufacturers, many elements of the proposed approach can be generalized to other equipment as will be indicated in the following sections.

3.1 Hardware Side

Figure 1 shows the block diagram which outlines all the equipment as well as the communication paths.

The first element in the system is the synchronization source PC. It represents the origin of all synchronization messages which are simultaneously sent to other equipment in the system when initiated by an experimenter. In our case this computer runs under Microsoft Windows XP, however, other operating systems that support TCP/IP and serial (RS-232) communication can be used as well.

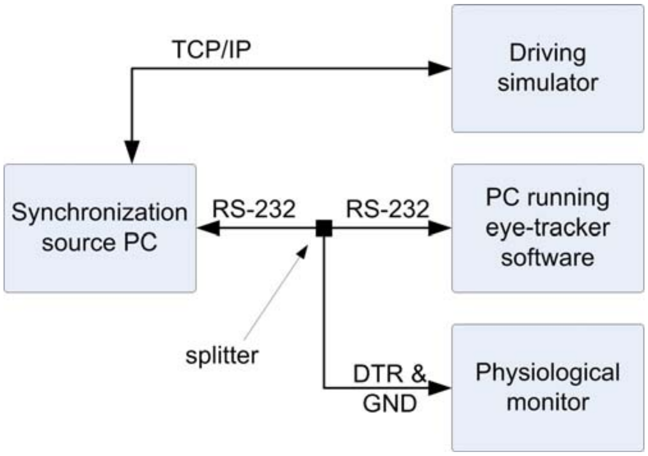

Figure 1. Block diagram of the system.

The following communication paths were established between the synchronization source PC and different equipment:

1. TCP/IP communication with our driving simulator, which is only supported by its scenario scripting system. The local network used for communication supports speeds of up to 100Mb/s. Note that this approach can be extended to PC-based driving simulators as well, which are also commonly used among researchers. Depending on their capabilities either TCP/IP or serial communication could be used.

2. Serial communication with the PC that is running the eye-tracker software. We initialized the following characteristics of the serial communication: 8 data bits, no parity, 1 stop bit, 9600 baud and software flow control set to on.

3. Modified serial communication with the physiological monitor. Our physiological monitor is a standalone A/D converter which can sample multiple physiological signals simultaneously. In that respect it is not able to communicate with other equipment used in experiments. However, it can sample raw electrical signals supplied to any of its inputs. Therefore, we created a splitter (the black square in Figure 1) which isolates two signals from the RS-232 port: Data Transmit Ready (DTR) and ground (GND). These signals are then connected to the physiological monitor through an opto-insulator, that is an electrically insulated switch, and a custom adapter. Whenever the DTR signal is changed to a high voltage level, the switch closes, which then results in a voltage change at the physiological monitor's input. Finally, this voltage change is sampled by the A/D converter. The custom adapter was designed in order to be able to connect the switch to our physiological monitor. In general, this adapter would have to be adjusted based on the particular brand of the monitor. However, the same general approach can be applied.

3.2 Software Side

As we saw in the previous section all three pieces of equipment use different communication alternatives. Therefore, different synchronization messages have to be sent by the synchronization source PC. Although the messages can be sent at any point during the experiment, we propose sending them at the beginning of the experiment. This way the instants in time when the individual synchronization messages are received by each device can be treated as the origins (zero points) on each device's time scale. We designed a custom application (implemented in C++) running on the synchronization source PC, which is capable of sending the following messages:

1. The word "*SYNC*" to the driving simulator over a specified TCP/IP port. The simulator's scripting system periodically polls the selected port at the frequency of 60 Hz. If the word "*SYNC*" is detected, the receipt of the synchronization signal is acknowledged in the driving simulator's database.

2. The symbol "*s*" to the eye-tracker's PC over the RS-232 port. Our eye-tracker's software is unable to check the contents of the serial port. It is for this reason that we created a custom application (again in C++) whose main purpose is to keep checking the contents of the serial port. In order to ensure that the received synchronization signal will be detected in the shortest possible period of time, we ensured that the checking of the serial port is performed in a separate thread by a blocking read call. This means that the application essentially switches to a "listening" state until "*s*" is received. Once this happens, the application immediately reads the local time on the computer and writes it to a log file. This information can then be used to indicate the location of the origin in the eye-tracker's data collection, which is updated at up to 60 Hz and each entry is assigned a local time stamp.

3. The DTR line on the source PC's serial port is toggled from low to high voltage level for a period of 0.5 seconds. During that time the electrically insulated switch is closed, which results in a voltage change on the physiological monitor's input. After 0.5 seconds elapses, the DTR line is toggled back to a low voltage level, which opens the switch. Our physiological monitor samples the changes in voltage levels at the frequency of 256 Hz.

3.3 Testing the Proposed Solution

The precision of the whole system is determined by its slowest component. In our case the slowest components are the driving simulator and the eye-tracker which provide data at the frequency of 60 Hz. Therefore, the synchronization messages should arrive at their destinations within the data sampling period of 1/60 = 16.67 msec.

Let us assume that we want our final data collection to contain observations sampled from all equipment N times per second (this can be accomplished either by setting the sampling rate on each device to be equal to N, or by down-sampling from a higher sampling rate). In this case the maximum transportation delay for our synchronization signal should not exceed $1/N$ seconds. This can be tested by measuring the round-trip delay which takes the synchronization signal to travel from the source PC to the desired destination and back. Based on this information we can then obtain a one-way transportation delay by dividing the round-trip delay by 2.

We performed the above test by periodically (approximately every 2 seconds) sending each of the three synchronization messages 2000 times. The following results have been obtained for the one-way delay:

1. Towards the driving simulator: maximum delay 7.5 msec, minimum delay 0 msec, average delay 6.33 msec, standard deviation 2.73 msec.
2. Towards the eye-tracker's PC: maximum delay 8 msec, minimum delay 0 msec, average delay 7.98 msec, standard deviation 0.198 msec.

Since the physiological monitor is not capable of sending the synchronization signals, we were unable to directly measure the one-way delay. However, we have three reasons to believe that the delay is shorter than the ones observed towards the driving simulator and the eye-tracker's PC. First, by logging the local time we found that the three synchronization messages were always sent at the same instant. This means that no delays (at least on the order of milliseconds) have been introduced between sending different messages. Second, the message towards the physiological monitor is not a data packet, but rather a simple voltage change on the DTR line. Since we selected a baud rate of 9600, the maximum time for this voltage change to occur should be about 1/9600 = 0.104 msec. And third, the physiological monitor's sampling rate is 256 Hz, which means that it can detect a voltage change as fast as 1/256 = 3.9 msec. Therefore, we can assert that the synchronization with the physiological monitor is faster than with the driving simulator and eye-tracker.

4. CONCLUSIONS

Based on these results we can conclude that our proposed low-cost data synchronization solution provides very good performance. For all three types of equipment that we used in our experiments the transport delay of the synchronization signals is much shorter than the data sampling periods of the individual equipment. Specifically, in case of the driving simulator a 7.5 msec delay would allow data sampling rates of up to 133 Hz. For driving performance measures data sampling rates observed in the literature range from 5 to 50 Hz, with 10 Hz being very common [6-8]. In case of the eye-tracker, a delay of 8 msec would allow up to 125 Hz data sampling rates. The rates observed in the literature for eye-tracking data range from 30 to 60 Hz, with 60 Hz being very common [6;7;9;10]. Finally, in case of the physiological monitor, 0.104 msec change in voltage level on the DTR line would allow a maximum data sampling rate of 9.6 kHz (typical data sampling rates in the literature range from 20 to 250 Hz [11-13]).

In the previous section we noted that our driving simulator and eye-tracker provide sampling rates of up to 60 Hz, which results in a 16.67 msec sampling period. Therefore, the overall sampling accuracy of the whole system is determined by these two components. As we had a chance to see, our synchronization procedure provides a maximum delay of 8 msec which is 52% faster than the slowest sampling rate of 16.67 msec.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] B. McKenzie and M. Rapino, Commuting in the United States: 2009, U.S. Census Bureau, Washington, DC,American Community Survey Reports, ACS-15, Nov.2011.

[2] NHTSA, Distracted Driving 2009, NHTSA's National Center for Statistics and Analysis, Washington, DC,DOT HS 811 379, Sept.2010.

[3] Seeing Machines, Guide to using NTP FastTrack, Nov.2005.

[4] D. L. Mills, *Computer Network Time Synchronization: the Network Time Protocol on Earth and in Space*, Second Edition ed CRC Press, 2011.

[5] Tobii. StimTracker for Tobii TX300 Eye Tracker. www.tobii.com. Date accessed 8/28/2012.

[6] Y. Wang, B. Mehler, B. Reimer, V. Lammers, L. A. D'Ambrosio, and J. F. Coughlin, The Validity of Driving Simulation for Assessing Differences Between In-Vehicle Informational Interfaces: A Comparison with Field Testing, *Ergonomics*, 53, 3 (2010), 404-420.

[7] B. Reimer, B. Mehler, V. Lammers, Y. Wang, and J. F. Coughlin. A Comparison of Three Manual Destination Entry Methods on Their Impact on Visual Attention and Driving Performance: An On-Road Evaluation. In *Proc. Proceedings of the Human Factors and Ergonomics Society 53rd annual meeting* (2009), 1757-1761.

[8] J. R. Sayer, J. M. Devonshire, and C. A. Flannagan, The Effects of Secondary Tasks on Naturalistic Driving Performance, UMTRI-2005-29, 2005.

[9] S. L. Chisholm, J. K. Caird, J. Lockhart, L. Fern, and E. Teteris. Driving Performance While Engaged In MP-3 Player Interaction: Effects of Practice and Task Difficulty On PRT and Eye Movements. In *Proc. Driving Assessment 2007* (2007)

[10] L. M. Nunes and M. A. Recarte, Cognitive demands of hands-free-phone conversation while driving, *Transportation. Research. Part F.: Traffic. Psychology. and Behaviour*, 5, 2 (2002), 133-144.

[11] B. Mehler, B. Reimer, J. F. Coughlin, and J. A. Dusek. The Impact of Incremental Increases in Cognitive Workload on Physiological Arousal and Performance in Young Adult Drivers. In *Proc. Transportation Research Board 88th Annual Meeting* (2009)

[12] B. Mehler, B. Reimer, and J. F. Coughlin. Physiological Reactivity to Graded Levels of Cognitive Workload across Three Age Groups: An On-Road Evaluation. In *Proc. Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting* (2010), 2062-2066.

[13] R. W. Picard, E. Vyzas, and J. Healey, Toward Machine Emotional Intelligence: Analysis of Affective Physiological State, *IEEE Transactions on Pattern Analysis and Machine Intelligence 2001*, 23, 10 (2001), 1175-1191.