2006-2429: DEVELOPMENT OF A DATA ACQUISITION SYSTEM FOR THE MEASUREMENT OF RESIDUE TRANSFER COEFFICIENT

Wayne Johnson, Armstrong Atlantic State University

Wayne Johnson is currently an Assistant Professor in Engineering Studies at Armstrong Atlantic State University in Savannah, GA. He recently received his Ph.D. in mechanical engineering from Georgia Tech. His current research interests include mechatronics, functionally graded materials, and engineering education.

Alesia Ferguson, University of Arkansas for Medical Sciences

Alesia Ferguson is currently an Assistant Professor in the Department of Environmental and Occupational Health at the College of Public Health at the University of Arkansas for Medical Sciences. She has collaborated with a series of University, Government and Corporate bodies interested in quantifying activity patterns relevant to understanding human exposure and dose and her current research work focuses on exposure assessment in various residential and occupational settings.

Patrick Hager, Armstrong Atlantic State University

Patrick Hager is a sophomore civil engineering student at Armstrong Atlantic State University in Savannah, GA. He plans to complete his Bachelor of Science degree at Georgia Tech.

Aristide Sanou, Armstrong Atlantic State University

Aristide Sanou is a sophomore mechanical engineering student at Armstrong Atlantic State University in Savannah, GA. He plans to complete his Bachelor of Science degree at Georgia Tech.

Daniel Shenoda, Armstrong Atlantic State University

Daniel Shenoda is a sophomore mechanical engineering student at Armstrong Atlantic State University in Savannah, GA. He plans to complete his Bachelor of Science degree at Georgia Tech.

Development of a Data Acquisition System for the Measurement of Residue Transfer Coefficient

Abstract

Surface residue transfer coefficients (SRTC's) are used in the quantification of dermal exposure to chemicals (e.g., pesticides). A SRTC is the percentage of the chemical residue that transfers from a surface to the human skin during contact. This paper describes the design and construction of a data acquisition and control system used to measure these SRTC's in a controlled apparatus. The system utilizes the PC-based LabVIEW software program to calibrate, monitor, and control contact time and pressure between a skin sample and a pesticide-laced surface via a pneumatic system. The data acquisition system records all sensor information over the user-specified contact time and pressure.

Introduction

In this paper, we present the progress of the design and construction of a data acquisition and control system used in an apparatus to measure surface residue transfer coefficients (SRTC's). The apparatus is part of a larger research effort by the second author to understand and quantify young children's dermal exposure to pesticides in and around home. STRC's when combined with residue concentrations and contact date (i.e., frequency and duration of contact) will provide estimates of the mass loading of a chemical on the human skin over time. In general, the study of STRC's provide a basis for better understanding of the dynamics of chemical transfer. Additionally, the apparatus and its associated data acquisition and control system can be used in the study of other chemicals (e.g., metals) and other exposure scenarios (e.g., contact with cleaning agents).

Previous attempts have been made to determine STRC's of pesticides and other chemicals from various surfaces to the human skin by developing and employing techniques to perform the contact. Some of the techniques used in previous studies include PUF (polyurethane foam) and CDFA (California Department of Food and Agriculture) rollers [1, 2], the Drag Sled [3], wipe sampling [4, 5] and the foliar wash technique [6]. Other residue transfer experiments have used adult human subjects to perform the dermal contact with surfaces. For example, human subjects wear cotton dosimeter clothing and act out scripted activities (Jazzercise) contacting treated carpets and floors [2, 7]. Other times human hand presses, with the skin or with cotton gloves have been used to measure chemical transfer [8, 9].

These studies have produced residue transfer coefficients that range from 0.1% to 35%. The variation in residue transfer coefficients between studies is not surprising. In general, the surface residue transfer measurement techniques used lack reproducibility, consistency, and accuracy for a number of reasons. There is variation in the sampling devices (e.g., rollers, hand presses) and sampling media (e.g., polyurethane, cotton gloves) used. The sampling devices may produce varied contact pressures on the sampling surfaces and the sampling media may exhibit different absorption/adhesion characteristics. Previous studies also use varying contact times and lack detail in other experimental factors (e.g., environmental conditions and interactions between surfaces, chemicals and sampling media).

In light of these issues, we have designed and constructed an apparatus to effectively facilitate the contact between cadaver skin, and common residential surfaces to measure the residue transfer coefficients for two target pesticides as a function of contact pressure, contact time, co-present solvents, temperature and humidity. Once the skin has been exposed to the pesticide-laden surface within the apparatus, it will be removed, isolated, and chemically treated to extract the pesticide absorbed by the skin. Finally, the mass of the pesticide that transferred to the skin under the varying environmental and pressure conditions will be determined using Reverse-Phase High Performance Liquid Chromatography.

A schematic of the apparatus is shown in Figure 1. The design consists of an inner and outer housing to maintain the temperature and relative humidity conditions; pneumatic cylinders to apply the contact pressures; and various instruments and a data acquisition system to calibrate and record system conditions. The undergraduate authors were heavily involved in the design and documentation (orthographic projection and 3-D CAD drawings) of the housing; sensor selection; and data collection for the calibration of the pneumatic system. In what follows we will further describe the instrumentation and data acquisition system, and the initial calibration results for the pneumatic system.

.

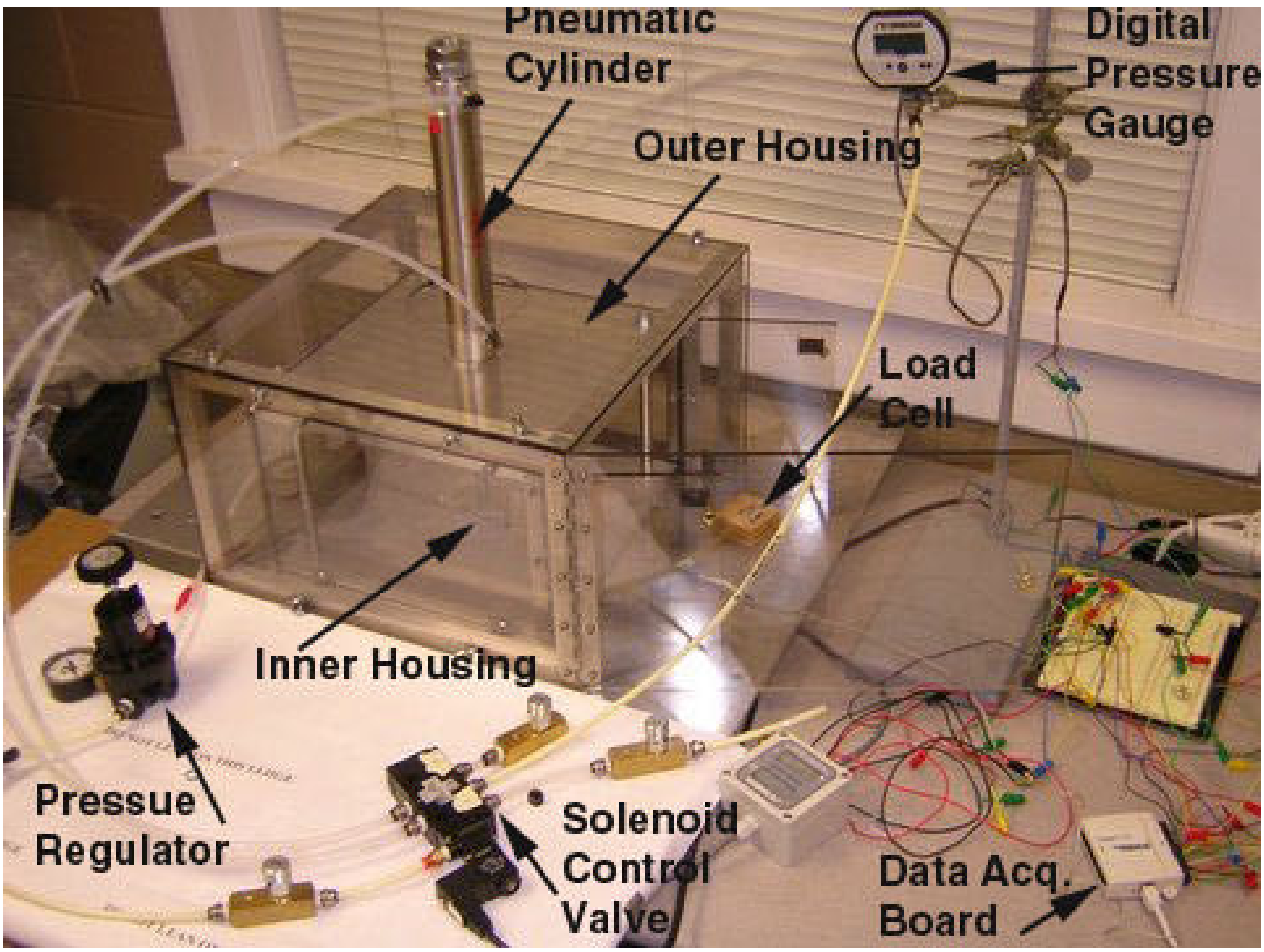

Figure 1. Schematic for apparatus for the measurement of reside transfer coefficient

Instrumentation

In order to achieve the desired contact pressures with the various contact areas, four separate pneumatic cylinders are required. The selected cylinder bores are 0.794 cm, 2.7 cm, 4.45 cm, and 6.35 cm. The apparatus housing and pneumatic instrumentation were selected and designed to accommodate all of these cylinders. The pneumatic instrumentation consists of a pressure regulator, solenoid control valve, digital pressure gauge, load cells, and a photoelectric sensor. Each instrument will now be discussed in detail.

The pressure regulator (Parker Hannifin Corporation R230-02C) is used in the apparatus to vary the cylinder pressure and thus, the contact pressure. It has a maximum operating (inlet) pressure of 250 psi and a regulated pressure output of 0-60 psi. It is capable of flow rates of up to 80 SCFM (Standard Cubic Feet per Minute) and can also relieve downstream pressure starting at 0.1 psi above the set pressure. This is vital in order to maintain the desired contact pressure once the pressure plate contacts the bottom plate of the inner housing. This model has a repeatability of +/- 0.01 psi, which is also very important in achieving the same contact pressure regardless of the pressure plate and cylinder used in the apparatus.

The actuation of the pneumatic cylinder is accomplished using a solenoid control valve. This valve uses a solenoid to control the air flow to the piston/rod extension and retraction ports on the pneumatic cylinder. The selected solenoid control valve is a four way, two-position valve for service with double acting cylinders. It is pilot operated such that input and output pressures in the valve can be as low as necessary. The valve is model number B5E1KDB45C with a female electrical connector (model number PS2430J79P), both manufactured by Parker Hannifin Corporation. The solenoid operates at 12 Vdc. The valve has 0.25 inch ports and is configured so that it will push or extend the cylinder rod and pressure plate against the lower plate of the inner housing when energized. When the solenoid is not energized, the cylinder will be in the retracted position.

A digital pressure gauge, model number DPG1000L-30G from Omega Engineering Corporation is used to display the regulated pressure from the pressure regulator (R230-02C). The pressure gauge has a range of 0-30 psi with a digital and analog current output (4-20mA). The accuracy of the device is +/- 0.25 % Full Scale. With a maximum pressure reading of 30 psi, this results in a pressure measurement error of +/- 0.075 psi. The pressure gauge requires 8-32 Vdc to operate and produces an output current proportional to the measured pressure. This current output is converted to a voltage by placing a 470 Ohm resistor in series with the gauge, and measuring the voltage across the resistor.

The pressure applied to the sample will be verified and correlated to the regulator (set) pressure via a load cell activated by the cylinder rod, before and after skin tests are performed. The load measured in the load cell is the force in the rod, and as stated previously, the plate or contact pressure can then be determined by dividing the rod force by the plate area.

Due to the significant variation in the rod force and the accuracy of the load cells as a percentage of full-scale output, two load cells are used. The Omega Engineering LCKD-10 is used for loads up to 10lbf and operates on 5-7 Vdc, while the Omega Engineering LC305-100 is used for loads up to 100 lbf and operates on 10-15 Vdc. The load cell signals are amplified using the Omega Engineering DMD-465 AC powered conditioner. The gain is adjusted to provide a load cell output voltage ranging from 0 to 2 V. In addition to signal amplification, the DMD-465 serves as a regulated, low noise, adjustable output bridge excitation source for the load cells.

The contact between the pressure plate and sample is determined via an AC powered photoelectric transmitter and receiver (Banner SMU31E and 31 R) with a built-in electromechanical relay. The transmitter uses an 880 nm wavelength infrared beam and is placed opposing the receiver at a height where the beam is blocked whenever the pressure plate is in contact with the lower plate of the inner housing. The relay will be wired with the data acquisition system to signal when the pressure plate has made contact.

Data Acquisition

The National Instruments USB 6009 data acquisition board (DAQ) and Virtual Instruments (VI's) are used to interface all instruments in the apparatus with a PC. The DAQ has two analog output channels, four differential analog input channels, and 12 digital input/output channels, 14-bit resolution and uses the USB 2.0 interface [10]. A schematic of the DAQ board connected to the various instruments in shown in Figure 2. The load cells use the fourth differential input (AI3) only during system calibration. This calibration will be discussed in more detail in the following section.

The analog output (A0.0) is used to power the relay for control of the solenoid (B5E1KDB45C). The onboard +5V power supply on the DAQ board is wired to the relay on the photoelectric sensor. This

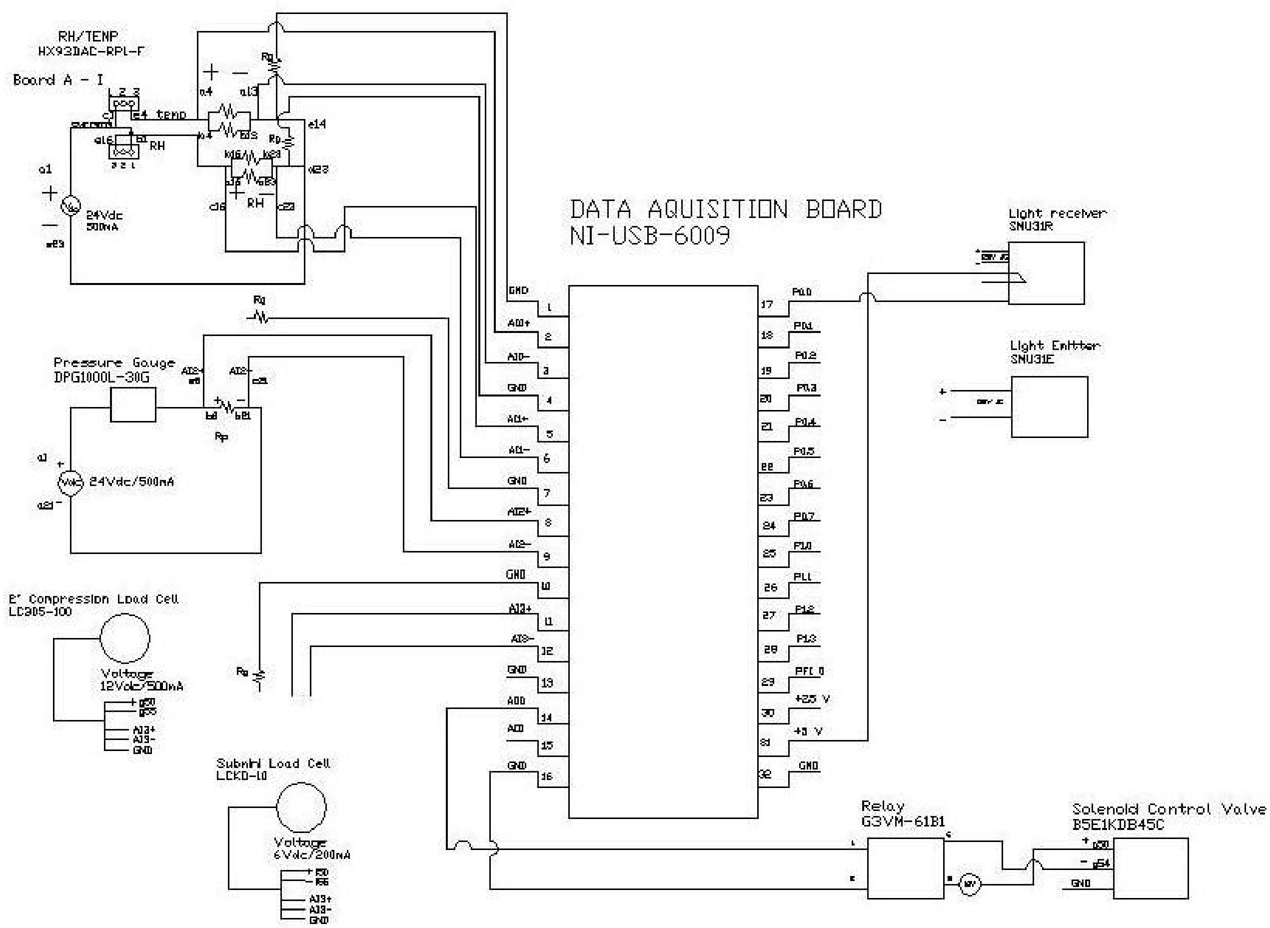

Figure 2. Schematic of data acquisition board with instruments

+5V is sent into the digital input on the DAQ board to indicate when the pressure plate makes contact. Several LabVIEW VI's have been written to provide a user interface to the instruments via the USB 6009. An example of one such VI is shown in Figure 3.

This VI is used to calibrate the set pressure with the actual contact pressure using the load cells. The user selects the desired contact pressure in the VI and then by manually adjusting the regulated (set) pressure, achieves the actual contact pressure when the pressure plate makes contact with the load cell. The VI adjusts the calculations depending on the pressure plate being used to convert the rod force into the appropriate contact pressure. The data from the load cell, digital pressure gauge, and other calculated quantities (actual contact pressure) can be recorded to a text file if the user opts.

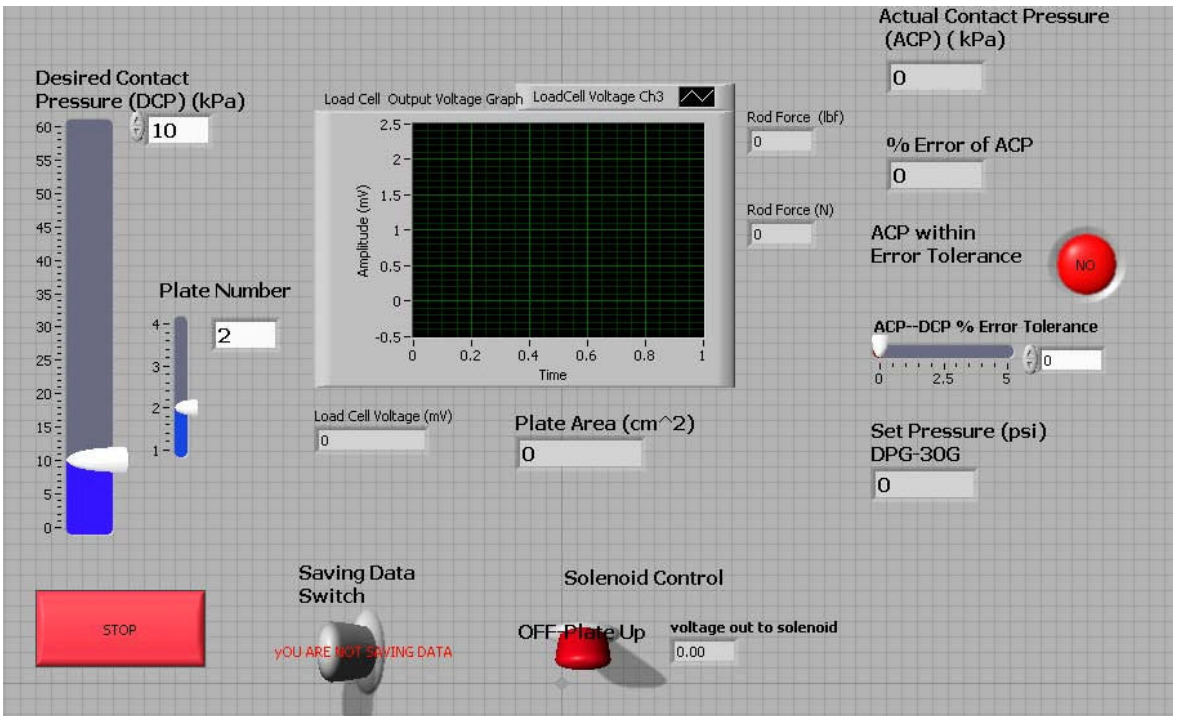

Figure 3. Set and contact pressure calibration virtual instrument.

Pneumatic System Calibration Procedure

The purpose of the pneumatic system calibration is two-fold. First, an estimate of the smallest contact time required for the actual plate or contact pressure to equal the desired contact pressure needs to be determined. Second, a relationship between the set pressure and actual contact pressure is required so that the user can know what set pressure to use to get a specific contact pressure when running experiments.

The apparatus was configured with the 9 cm^2 pressure plate and a 10 lbf load cell was used to measure the force in the rod for a given pressure (set pressure) with the pressure regulator. The actual contact pressure can then be calculated based on the force from the load cell divided by the pressure plate area. The VI discussed in the previous section records the corresponding set pressure from the digital pressure gauge. Once the plate made contact with the load cell, set pressure and load cell data was collected for

60 seconds. Three trails were performed for desired contact pressures from 10 to 45 kPa in increments of 5 kPa. Unfortunately, 1 and 5 kPa contact pressures were not possible since the required set pressure was insufficient to extend or retract the pressure plate. Thus, for this set-up, the lowest contact pressure that can be achieved is 10 kPa.

Pneumatic System Calibration Results and Analysis

The data was collected and further analyzed using three MATLAB scripts. These tools were developed to plot the actual contact pressure as a function of time for multiple trials. They also plotted the percent error of the actual contact pressure with respect to the desired contact pressure, and performed a least squares fit between the set pressure and maximum actual contact pressure using data from all trials. The resulting plots were then used to assess the minimum contact time for each desired contact pressure (DCP). The percent error—that is, how well the actual contact pressure (ACP) matched the DCP was also plotted allowing a correlation between the actual contact pressure and the set pressure to be developed. Two representative plots for the ACP as a function of time and percent error for a DCP= 10 kPa are shown in Figure 4 and Figure 5.

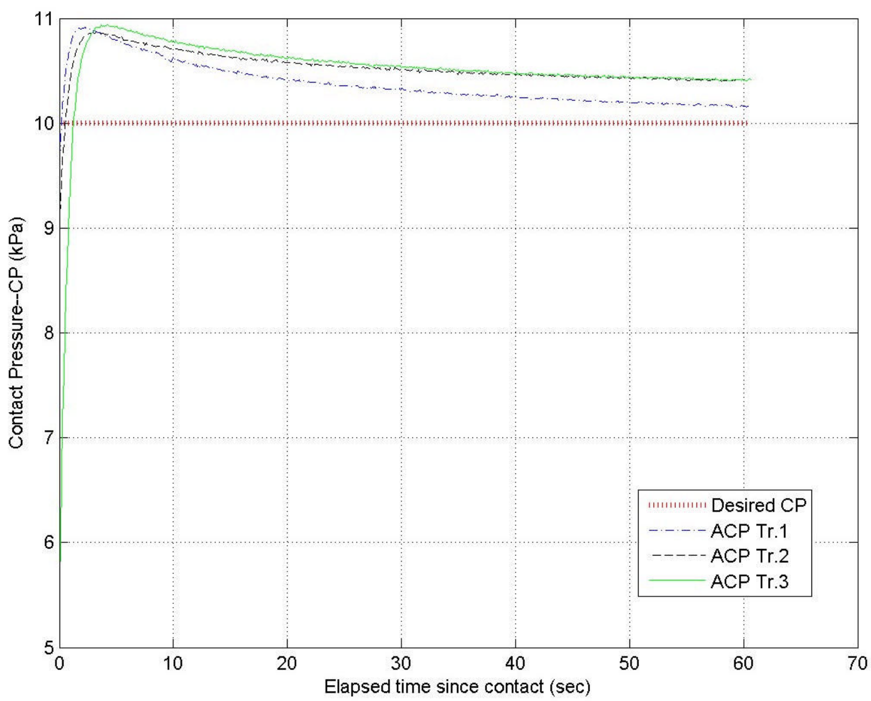

Figure 4. ACP and DCD as a function of elapsed contact time for 9 sq. cm pressure plate.

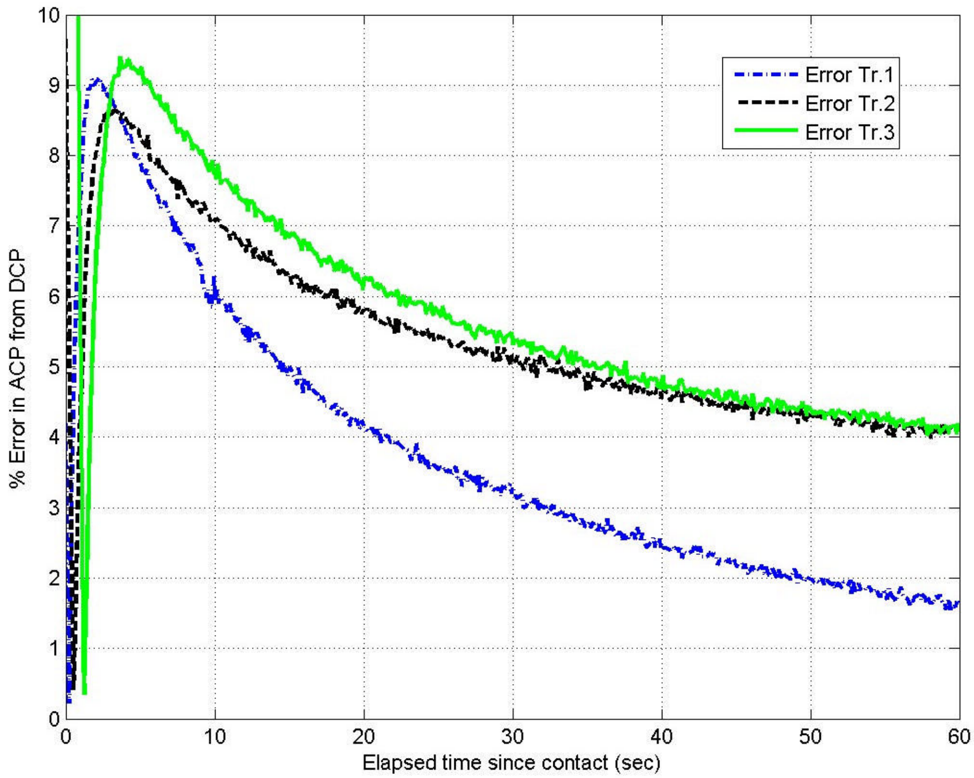

Figure 5. Percent error of ACP with respect to DCP for 9 sq. cm pressure plate.

Analysis of the plots for all DCP's show that the ACP is at the most, approximately 1 kPa over the DCP (percent error less than or equal to 10%). The value of the ACP then slowly drops to a value slightly greater than the DCP for an elapsed contact time of 60 secconds (percent error less than or equal to 5%). Thus, it is possible by repeating these trails with a slightly lower set pressure, to achieve a percent error range from +5% to –5%. For example, if the DCP=10 kPa (Figure 1) is rerun at a slightly lower set pressure, it may be possible to get a maximum ACP of approximately 10.5 kPa, and a final ACP (elapse time at 60 seconds) of 9.5 kPa. The overshoot occurs in all trials due to the system transitioning from a dynamic to a static response. The slower the pressure plate travels, the less of an overshoot in the ACP; however, the reduced pressure plate velocity results in the plate getting stuck as it travels due to stick/slip friction effects.

Figure 4 and Figure 5 can also be used to estimate the minimum contact time. As illustrated in the figures, the ACP starts off at zero, for contact time equal to zero. The contact pressure then increases up to and beyond the DCP. Depending on the DCP, the ACP takes a finite amount of time to reach the DCP. This time is the minimum contact time for a given DCP. Examination of all the plots shows that the ACP takes approximately 4 to 10 seconds (depending on the DCP) to reach the maximum value. Although the smallest contact times are greater than those specified in the design criteria: 1) the ACP is known for all contact time; 2) in modeling, as with the actual phenomenon of skin contacting a surface, the contact pressure will rise from zero to some final value; thus, there will always be a minimum contact time. The difference between the model based on the apparatus and the actual phenomenon is the amount of time necessary for the contact pressure to reach the final value. It is possible to study this further by recording the force over time from touching a load cell with a finger with varying force/pressure.

A vital part of this calibration effort was to develop a correlation between the set pressure and the ACP. This will allow the user to know what pressure to set the regulator in order to get the desired contact pressure. Figure 6 shows the relationship between the set (regulated) pressure and the actual contact pressure. Data from all three trails was used to generate this plot. There is good correlation between the quantities for the 9 cm^2 pressure plate as indicated by an R^2 of 0.9999.

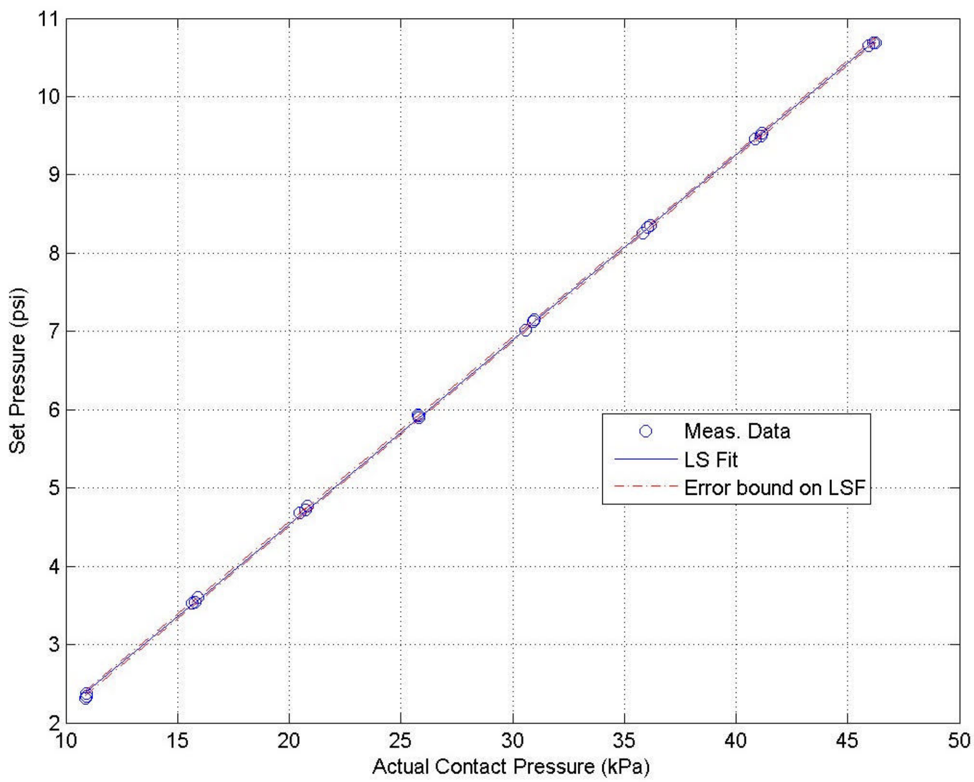

Figure 6. Regression model for set and actual contact pressure data for 9 sq. cm pressure plate.

Conclusion

We have presented the details of the data acquisition system used in an apparatus for the measurement of surface residue transfer coefficient. The system uses a USB data acquisition board for the control and monitoring of various apparatus parameters including pneumatic cylinder actuation, contact pressure, contact time. Details of the calibration of the pneumatic system were also presented for the 9 cm^2 pressure plate. The actual contact pressures varied by no more than 1 kPa from the desired contact pressures. The smallest contact times ranged from 4-10 seconds depending on the DCP. These are larger times than the desired values, but more assessments are needed to determine if smaller times can be achieved with the current system or with modifications to the system. In further work, the system will be expanded to monitor temperature and relative humidity.

Bibliography

1. Camann, D.E., Harding, H. J., Geno, P. W., and Lewis, R. G. *Relationship Among Drag Sled, PUF Roller and Hand Press Transfer of Pesticide Residues From Floors*. in *Proceedings of the US EPA and ADWMA International Conference*. 1994. Durham, N C.
2. Ross, J., Fong, H. R., Thongsinthusak, T., Margetich, S., and Krieger, R., *Measuring Potential Dermal transfer of Surface Pesticides Residue Generated from Indoor Fogger Using the CDFA Roller Method.* Chemosphere, 1991. **22**(9-10): p. 975-984.
3. Vaccaro, J.R., and Nolan, R. J. *Evaluation of Dislodgeable Residues and Absorbed Doses of Chlorpyrifos following Indoor Broadcast Applications of Chlorpyrifos Based Emulsifiable Concentrate (EC)*. in *11th Annual SETAC Meeting*. 1990. Arlington, VA.
4. Fenske, R.A., Black, K. G., Elkner, K. P., Lee, C., Methner, M. M., and Soto, R., *Potential Exposure and Health Risks Following Indoor Residential Pesticide Applications.* American Journal of Public Health, 1990. **80**: p. 689-693.
5. Fenske, R.A., Curry, P. B., Wandelmaier, F., and Ritter, L., *Development of Dermal and Respiratory Sampling procedures for Human Exposure to Pesticides in Indoor Environments.* Journal of Exposure Analysis and Environmental Epidemiology, 1991. **1**(1): p. 11-30.
6. Black, K.G.a.F., R. A., *Dislodgeability of Chlorpyrifos and Fluorescent Tracer Residues on Turf: Comparison of Wipe and Foliar Wash Sampling Techniques.* Archives of Environmental Contamination Toxicology, 1996. **31**: p. 563-570.
7. Krieger, R., I., Dinoff, T. M., and Peterson, J., *Human Disodium Octoborate Tetrahydrate Exposure Following Carpet Flea Treatment is not Associated with Significant Dermal Absorption.* Journal of Exposure Analysis and Environmental Epidemiology, 1996. **6**(3): p. 279-288.
8. Yang, Y.a.Y., S., *Frictional Transition of Pesticides From Protective Clothing.* Archives of Environmental Contamination and Toxicology, 1993. **25**(2): p. 279-284.
9. Roberts, J.W., and Camann, D. E., *Pilot Study of a Cotton Glove Press Test for Assessing Exposure to Pesticides in House Dust.* Bull. Environ. Contam. Toxicol., 1989. **43**: p. 717-724.
10. *USB 6008/6009 User Guide*. 2005, National Instruments.