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Friction Measurement System for Hennepin County

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16. Abstract (Limit: 250 words)

A friction measurement system was developed for Hennepin County and installed on a snowplow in their winter road maintenance fleet. The major components of the developed system were a special instrumented wheel, a pneumatic pressure-controlled cylinder, force-measurement load cell and accelerometers, and a data processing micro-processor and LCD display. The project plan initially included interfacing the friction measurement system with an applicator and automatic control of the applicator on detection of a low tire-road friction coefficient on the road. However, due to concerns from Hennepin County about interfacing with the applicator electronics and its potential influence on normal operation of the Force America applicator, the friction coefficient was estimated in real-time and just displayed for the snowplow operator. It was not used for real-time control of the applicator. The stand-alone hardware developed in this project is being used as a platform for development and installation of friction measurement systems on two snowplows in Polk County during the 2012-2013 winter. The Polk County installation is being funded by the Minnesota Local Road Research Board.

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Final Report

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1. Friction Measurement System Hardware

The friction measurement system consists of a 16-inch diameter instrumented tire installed near the front axle of the snowplow. The exact mounting location is determined individually for each snowplow. The instrumented wheel has two modular parts: a lower instrumented wheel and an upper mounting assembly. The lower instrumented wheel consists of a tire, accelerometers and a force measurement load cell. The lower instrumented wheel is common to all vehicle configurations. The upper mounting assembly is tailored to suit the specific vehicle on which the friction measurement system needs to be mounted. The friction measurement system in this project was first developed and verified on a pick-up truck and then installed on the snowplow.

Figures 1 and 2 show photographs of the friction measurement system during fabrication and assembly on the snowplow.

Figure 1: Road friction sensing wheel being installed on a Hennepin Co. snowplow

Figure 2: Road friction sensing wheel being installed on a Hennepin Co. snowplow

The static vertical force on the tire is kept constant using a pneumatic actuator, air supply from the available compressed air cylinder on the truck and a pressure servo loop. The lateral tire force for a given tire typically depends on the vertical tire force F_z, on the slip angle α and on the tire-road friction coefficient μ. If vertical tire force is assumed to be constant and if the slip angle α is assumed to be large enough, then the lateral tire force reaches its maximum value which is given by Equation (1):

$$F_{Lat}(\alpha_0) = \mu \times F \qquad (1)$$

Since the vertical tire force is kept constant in the developed sensor system and the slip angle α is fixed to a value high enough, i.e. $\alpha_0 \cong 6^o$, the lateral tire force F_{Lat} is assumed to be proportional to the tire-road friction coefficient. One can simply determine the tire-road friction coefficient in real time by just measuring the lateral tire force signal and dividing it by the constant vertical tire force. However, if the vertical tire force is assumed to be constant, then the lateral tire force contains all the necessary information for detecting a surface change on the roadway. Hence the friction coefficient can be determined by measuring the lateral tire force and scaling this value appropriately.

It should be noted that the pneumatic servo loop only has a low bandwidth of around 0.1 Hz. Thus it can only maintain a constant "static" vertical tire force. Variations in vertical tire force that happen due to maneuvers such as acceleration and/or cornering and due to vibrations induced by the road cannot be compensated by the pneumatic actuator. It should also be noted that a slip angle of 6^o is high enough to ensure that the lateral force changes with friction coefficient. For very small slip angles of 1^o or 2^o, the lateral force may not change significantly with friction coefficient and may be measured to be about the same value for all friction coefficients.

A pancake type load cell is used to measure the lateral tire force and an inexpensive MEMS accelerometer is employed to detect the vibrations and filter out the noise on the force signal. The signals from the load cell and accelerometer are read by an Atmel 2580 microprocessor and transmitted to the cab over a serial link. In the cab the measurements are processed and the results displayed on a TS-8390 Touch Panel Computer from Technologic Systems. Figure 3 shows components of the friction measurement system during workshop fabrication.

Figure 3: Fabricated road friction sensing system (without wheel and tire) ready for final installation

Figures 4 and 5 show the friction measurement system after assembly and installation on the snowplow.

Figure 4: Installed road friction sensing system

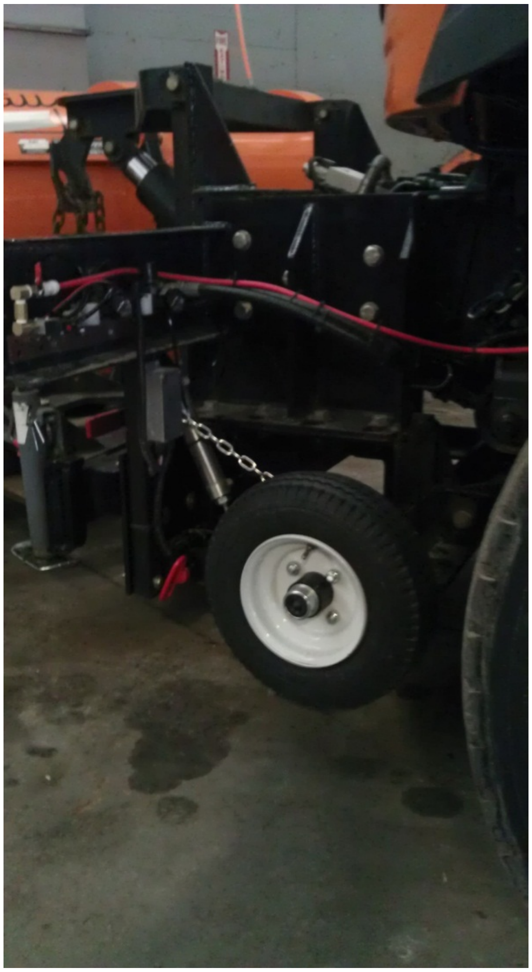

Figure 5: Installed road friction sensing system

2. Sample Experimental Data

The instrumented sensors on the friction measurement system include an Analog Devices ADXL 325 accelerometer and an Omegadyne LC703-500 loadcell. During development and testing of the system, we also utilized a Measurement Specialties Inc. MSP-300-100-P-3-N-1 air pressure sensor, an Automation Direct TRD-S1000BD optical encoder and an Automation Direct SS2-ON-4A photocell.

The photo cell was used in initial testing on a pick-up truck in order to detect the exact locations of the start and end of an artificial slippery patch. Figure 6 shows sample sensor signals and estimates from a test. It can be seen that the load cell signal is noisy due to significant vibrations on the truck. The scaled friction coefficient estimate generated by filtering and using the accelerometer is seen to be significantly less noisy. It can be seen that the drop in friction coefficient estimated by the system coincides with the spikes in the photo cell signals, thus indicating that the slippery patch was correctly detected.

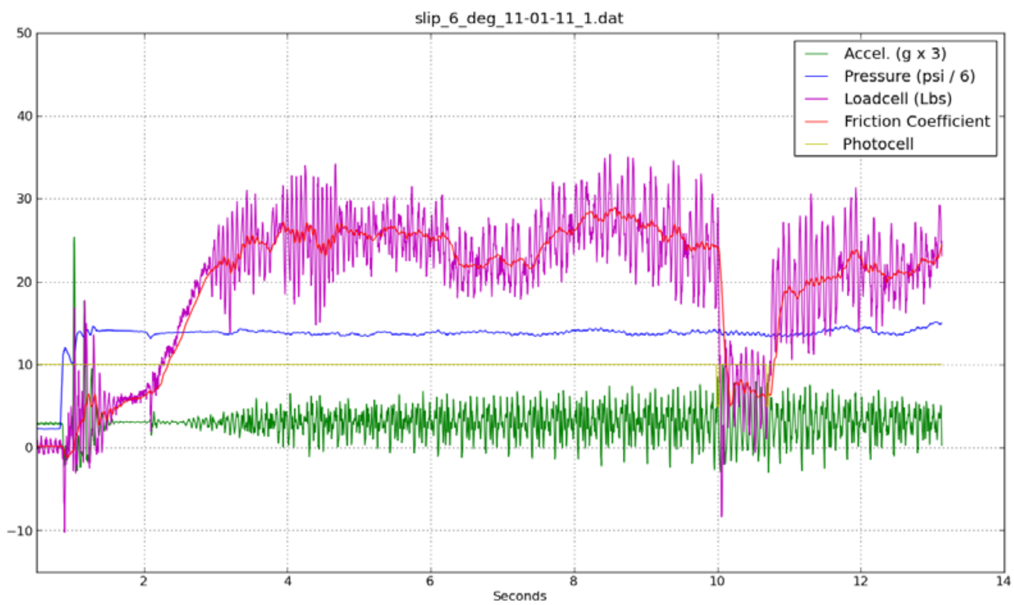

Figure 6: Plot of data from a 10 mph test run

Figures 7 and 8 shows similar data on friction estimation, but at higher vehicle speeds of 20 mph and 25 mph respectively.

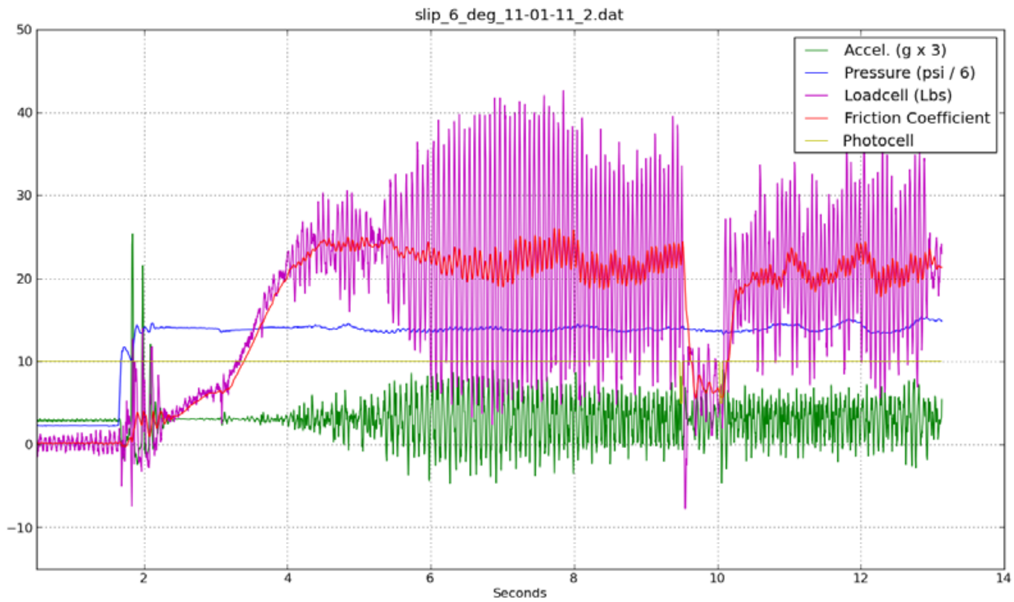

Figure 7: Plot of data from a 20 mph test run

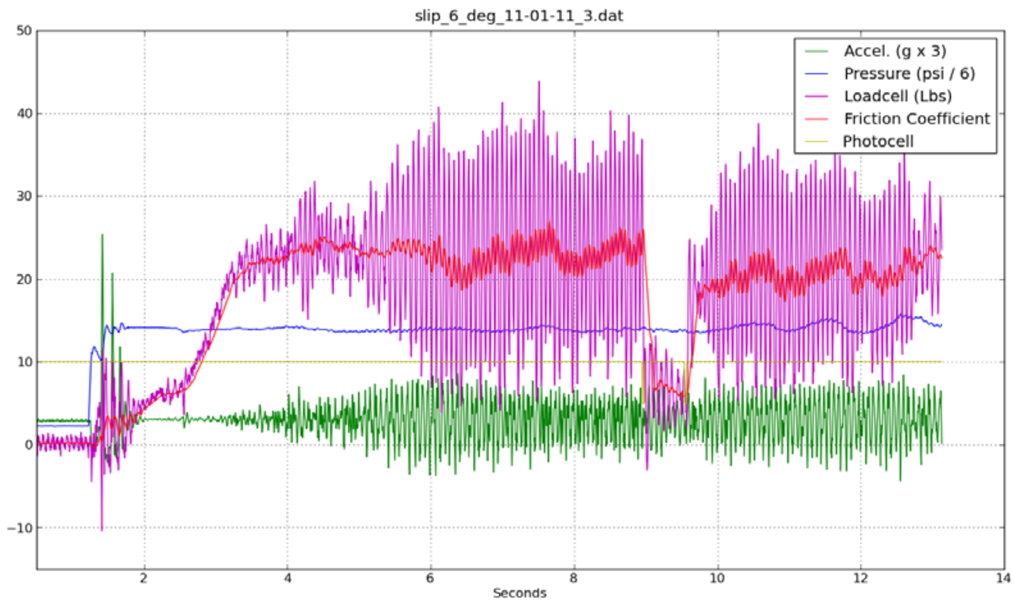

Figure 8: Plot of data from a 25 mph test run

3. Conclusions

A friction measurement system was developed for Hennepin County and installed on a snowplow in their winter road maintenance fleet. The system worked well and was tested on artificial slippery patches created by the research team. Due to lack of snow during the 2011-2012 winter, the system could not be tested in real-world conditions during actual snowplowing operations. There was a change in leadership at Hennepin County due to which the county decided they could no longer provide any matching funds to the research project. Future testing of the friction measurement system will be carried out in Crookston County in a new project funded by the Minnesota Local Road Research Board.