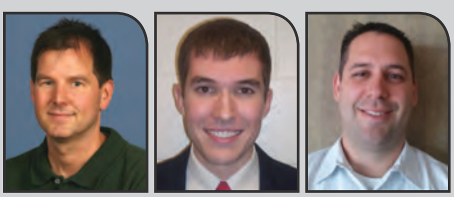
Design of an Active Warning System for Fall Protection

Hazards are ever-present in the steel plant environment, and a heightened awareness and emphasis on safety is a necessary priority for our industry. This monthly column, coordinated by members of the AIST Safety & Health Technology Committee, focuses on procedures and practices to promote a safe working environment for everyone.

Participants



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Comments are welcome. If you have questions about this topic or other safety issues, please contact safetyfirst@aist.org. Please include your full name, company name, mailing address and email in all correspondence.

Don B. Daily Memorial Fund

To Promote Steel Industry Safety and Health

This article is the first in a series of Safety First articles featuring the reports from the recipients of the 2012 Don B. Daily Memorial Fund.

Original Plans and Goals

According to recent U.S. Department of Labor Statistics, falls account for 8% of all traumatic occupational deaths. In general industrial applications, workers are considered at risk any time they are working at an elevation of four feet or greater, or when working above equipment or machinery at any height. Fall protection systems, such as personal fall arrest systems, are required for certain applications, and are useful for preventing injury when a fall occurs.[1]

The goal of this project was the development and construction of an integrated sensing system to warn a ladder user of actions that may result in a fall. The sensing system, coupled with a microcontroller, would be used to detect conditions such as improper setup, overreaching and overloading, and issue a warning signal to the user. This would allow the system to prevent a fall, rather than protect the worker after a fall occurs. The test bed chosen for this system was a stepladder, but the results could be generalized to a variety of ladders, scaffolding and other climbing apparatus used in an industrial environment. The system was designed, prototyped and tested by a mechanical engineering student design team at Milwaukee School of Engineering (MSOE). The deliverables for the project include a working proof-of-concept prototype of an integrated safety system. The steel industry would benefit from the concepts developed in the development of the active fall protection system, both directly in terms of ladder safety management, and indirectly in the potential to adapt the techniques to fixed ladders, scaffolding and other applications of fall protection.

Accomplishments

The project was initiated in September 2012. The initial phase of the project involved extensive background research to determine the likely sources of worker injuries involving ladders. The research indicated that many stepladder accidents in the workplace can be attributed to:[2,3]

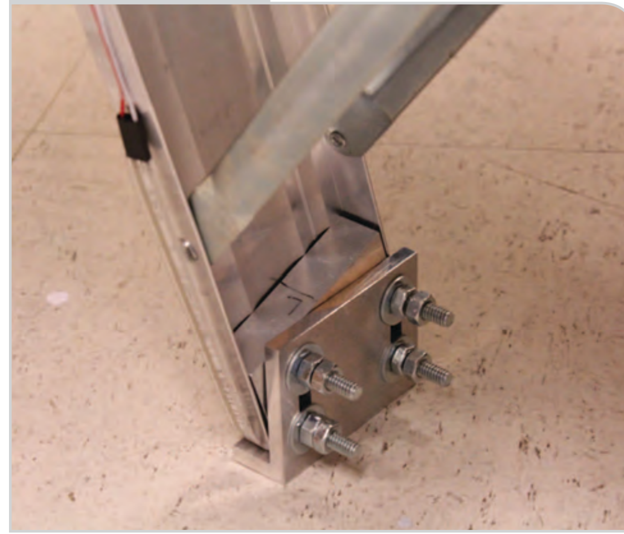
- Improper setup.
- Overreaching while working on the ladder.

Figure 1

Instrumented step ladder.

- Overloading of the ladder with excessive weight.
- Standing on a portion of the ladder not designated for standing (e.g., the top cap).

Figure 2



Instrumented ladder foot detail.

It was decided that these common areas of concern would be addressed in the design of the active warning system as follows:

- Switches would be built into the spreader bars, indicating full engagement during setup.
- Force sensors would be integrated into the feet of the ladder; these sensors would be used to detect proper setup (validating that all feet are touching the floor during setup), overload conditions (detecting the total load seen by the ladder) and overreaching by the user (detecting unusual load shifting in the ladder feet).
- Force sensors would be built into the top cap, detecting a user improperly standing on the top cap.

Figure 3

Instrumented top cap detail.

Figure 4

Instrumented spreader bar detail.

Appropriate sensors were identified and appropriate microcontroller for system integration was selected. Mechanical design for integrating the hardware into a commercially available four-foot stepladder was undertaken. A preliminary design concept was presented at Charter Steel in December 2012.

Fabrication, system integration and sensor calibration were completed in March 2013. The instrumented ladder is shown in Figures 1–4.

In order to validate the sensing system design, the force sensors in the ladder feet were used to collect data under typical climbing and use conditions. Figure 5 shows sensor data from the foot force sensors collected during a slow-speed climb.

Figure 6 shows similar data for the same climber making a high-speed climb.

Figure 7 shows data for the same climber standing and working on the ladder, simulating a light bulb change.

Initial testing validated system performance and allowed for force sensor calibration.

With the system integrated and calibrated, the safety monitoring system was developed. The system performs the following operations:

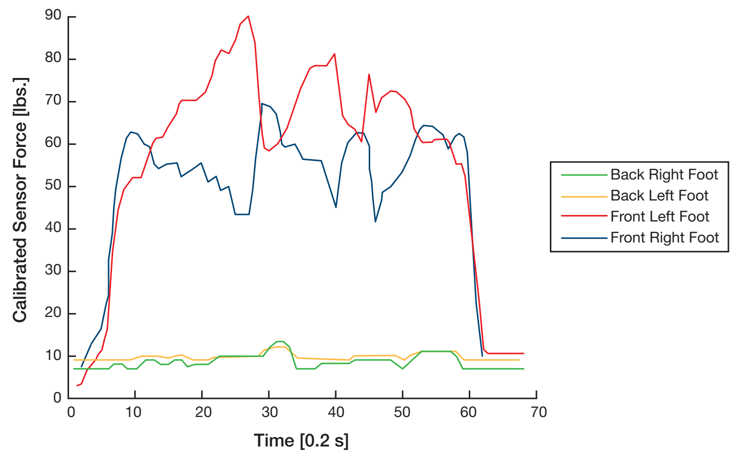
- Monitors spreader bar position and foot force at setup, in order to verify that the ladder is properly erected and level.
- Monitors foot distribution during use, to detect the sudden changes and/or unequal distributions in foot load that signal overreaching and impending tipover.
- Monitors load on the top cap, signifying improper use of the top cap as a standing platform.

The system responds to potentially unsafe setup and/or usage with an audible alarm. A flowchart for the safety system software is shown in Figure 8.

Results

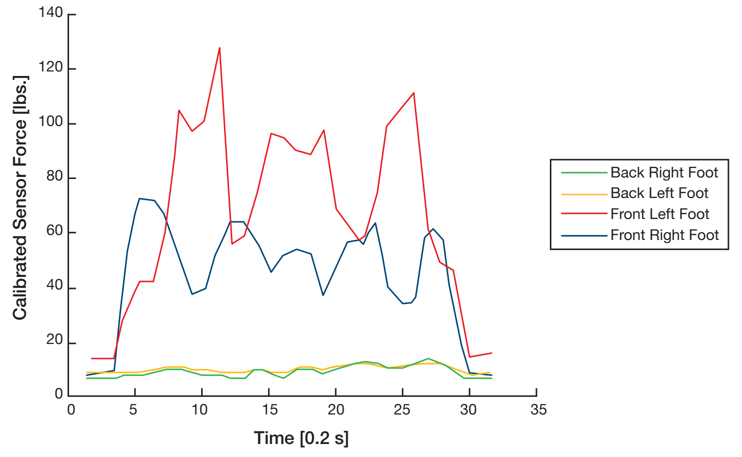
The safety monitoring system is currently undergoing extensive testing. Preliminary testing involves the simulation of various

Figure 5



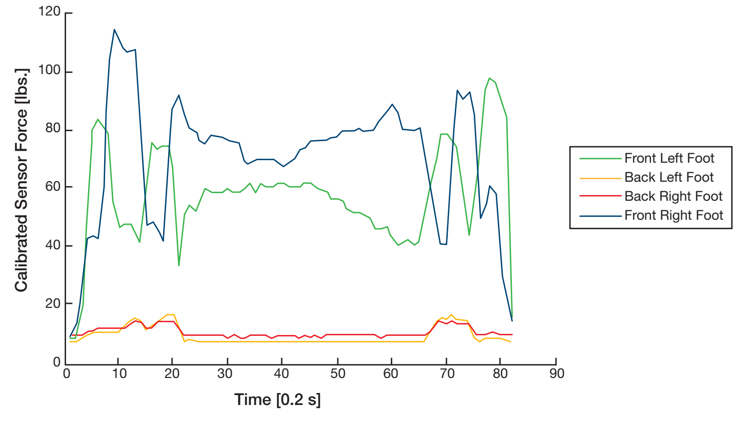
Forces in ladder feet during a slow-speed climb.

Figure 6



Forces in ladder feet during a high-speed climb.

Figure 7



Forces on ladder feet during a working task.

unsafe setup and use conditions. In the test shown in Figure 9, a test load was fixed to the ladder and a strap was used to tilt the ladder, simulating an impending tipover. The corresponding force data at the feet is shown in Figure 10.

The results of this and other testing indicate that the use of an automated monitoring system for fall protection is feasible. Additional testing is under way; remaining technical challenges include:

- More properly characterizing the foot force signatures corresponding to potentially unsafe user actions.
- Maintaining proper calibration of the force sensors, both during and between ladder uses.
- Transitioning the mechanical design of the modifications to a more robust and market-ready product design.

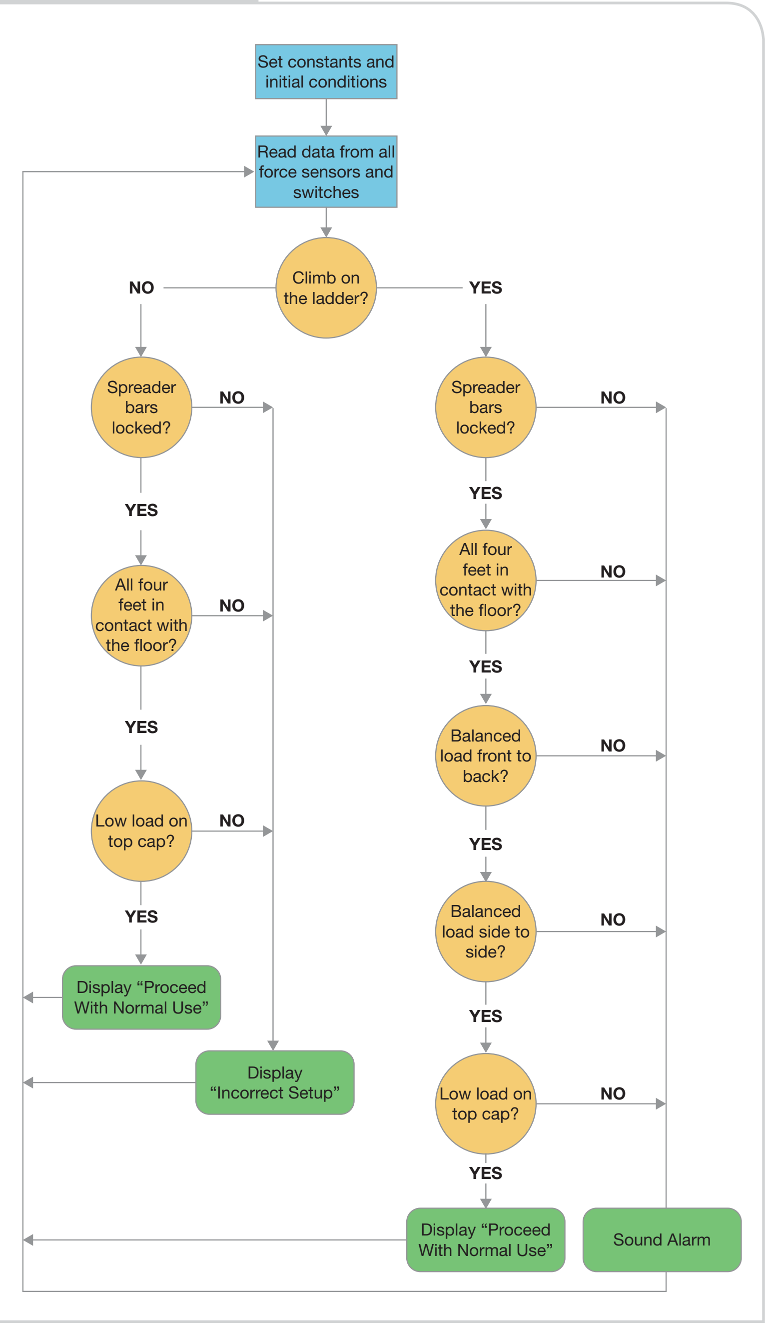
Full resolution of these technical issues may go beyond the one-academic-year scope of this effort.

Implications for Safety and Health Awareness for the Steel Manufacturing Industry

The project has been successful in raising the awareness of safety in the following ways:

- The students involved in the project had no previous exposure to industrial safety in general and ladder safety in particular. After touring Charter Steel, interacting with industry professionals and doing significant background research on U.S. Occupational Safety and Health Administration (OSHA) requirements and the latest literature, the students involved in the project developed significant expertise in this area.
- The student team has developed a presentation of their work on ladder safety. It will be delivered at the 27th National Conference on Undergraduate Research (NCUR) in La Crosse, Wis., in April 2014.

Figure 8



Safety system software flowchart.

Applicability and Evaluation

The results of this project have both short-term and long-term applicability for the steel industry. In the short term, the instrumented ladder shows promise as a safety training tool. The system makes the user aware of typical setup errors and misuse conditions. When used under controlled conditions, the system could be used to give immediate feedback to users during ladder safety training.

Longer term, the system has shown that an integrated monitoring system can be built into a ladder. While significant engineering effort would be needed to develop the prototype system into a robust and cost-effective ladder product, such a system could become a practical safety aid for ladders used in safety-critical applications. Further development, where the ladder monitoring system could be integrated with wireless communication networks, could not only provide users with feedback on unsafe usage, but could also provide corporate safety personnel with data on unsafe ladder usage throughout the operation. This data could be used to guide targeted retraining.

While the prototype system used a portable step ladder as the test bed, the methods developed in this project can be broadly applied to other portable ladders. The student team has conceptualized a direct extension of the safety system to monitor setup angle in a straight ladder. The concept uses commercially available sensors and a low-cost microprocessor, and could be developed as an add-on accessory for straight and extension ladders. Since improper setup angle is a major contributor to accidents involving straight and extension ladders, this shows promise for implementation in an industrial environment. Future work for the team will focus on the development of this low-cost accessory for sensing proper setup angle in a straight ladder.

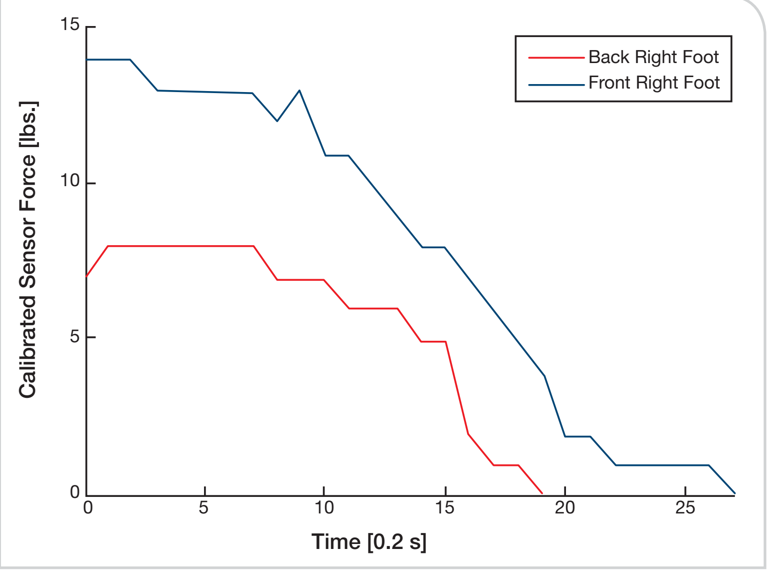
Summary

The student/faculty team at Milwaukee School of Engineering is grateful to the support of the Don B. Daily Memorial Fund and Charter Steel for support of this effort. All funds went directly to support the student effort, including prototyping costs and project dissemination. Awareness of safety engineering was raised among the design team by exposure to concepts in ladder

Figure 9

Impending tipover test.

Figure 10



Forces at the feet during impending tipover.

safety and fall protection, and their work brought that experience to a number of other students through the materials and testing they developed. The prototype developed during this effort has potential for use as a safety training tool, and additional development could result in safety products. The project was a technical success, and the students were rewarded with a high-quality engineering experience that would not have been possible without the support of this grant.

References

1. U.S. Department of Labor, www.osha.gov/SLTC/fallprotection/index.html.
2. Knox, E.H.; Van Bree, M.P.; Kenner, M.T.; and Wilkinson, J.A., "Structural Stepladder Failure: Analysis of Root Cause," *Proceedings of the ASME 2009 International Mechanical Engineering Congress & Exposition,* 2009, pp. 433–441.
3. DiComenico, A.T.; Lesch, M.F.; Blair, M.F.; and Hu, Y.H., "Reaching on Ladders: Do Motivation and Acclimation Affect Risk Taking?" *Professional Safety,* February 2013, pp. 50–53.

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