Optimal Design of Excavator Buckets for Post Building Collapse Rescue Operations

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Introduction

Building collapses often bury people beneath debris, necessitating search and rescue operations following such incidents. This was made from events like the surfside condominium collapse in Miami, which led to the deaths of 98 individuals. While significant attention has been given to the search for trapped individuals in previous literature, the rescue process itself has not received adequate scholarly focus. This highlights the need for more in-depth investigations into rescue operations to improve its efficiency.

Rescue efforts heavily rely on the use of heavy machinery to remove debris and reach trapped individuals. Among these, the excavator bucket plays a critical role as a primary tool on disaster sites. This study aims to enhance the efficiency of rescue operations by optimizing the design of the excavator bucket. The proposed improvements focus on minimizing pressure exerted on trapped individuals during operation and completing tasks in the shortest possible time.

Methodology

This study employed a quantitative research approach and was split into two parts:

Pilot Experiment:
A preliminary four-month pilot experiment was conducted to familiarize the team with excavator operation. Once operation of bucket was deemed suitable for each colleague, five trials for each bucket were performed without standardized training to understand the baseline performance. The team then collaborated to develop a uniform operation technique, followed by five additional trails using the standardized method.

Experimental Procedure:
1. Each trial involved a 200 g pile of debris randomly placed on a sensor-equipped plate.
2. Sensors were calibrated before each trial.
3. Each team member individually conducted trial using the standardized technique to ensure consistency in debris handling.
4. A collective trial was performed to verify adherence to the developed methodology and minimize variability.

Arduino Software and the Data Streamer Excel add-on were used to collect real time data on pile pressure and time for all trails before and after training. Trials were recorded to validate adherence to the standardized technique.

Main Experiment
The main experimental procedure repeats the pilot studies', now incorporating a 3D-printed human figure placed beneath debris piles. We specifically tested "void zones"–spaces created when two debris slabs fall in a way that forms a protective pocket for the human, acting as a survival mechanism. Using various bucket designs, we extracted debris while observing how each bucket impacted the void zone. Thin-film pressure sensors on the three sensitive areas of the body collected pressure data. This data will train a machine learning model to predict the force on trapped individuals and estimate debris removal times for different bucket designs, paving the way for data-driven improvements in rescue equipment.

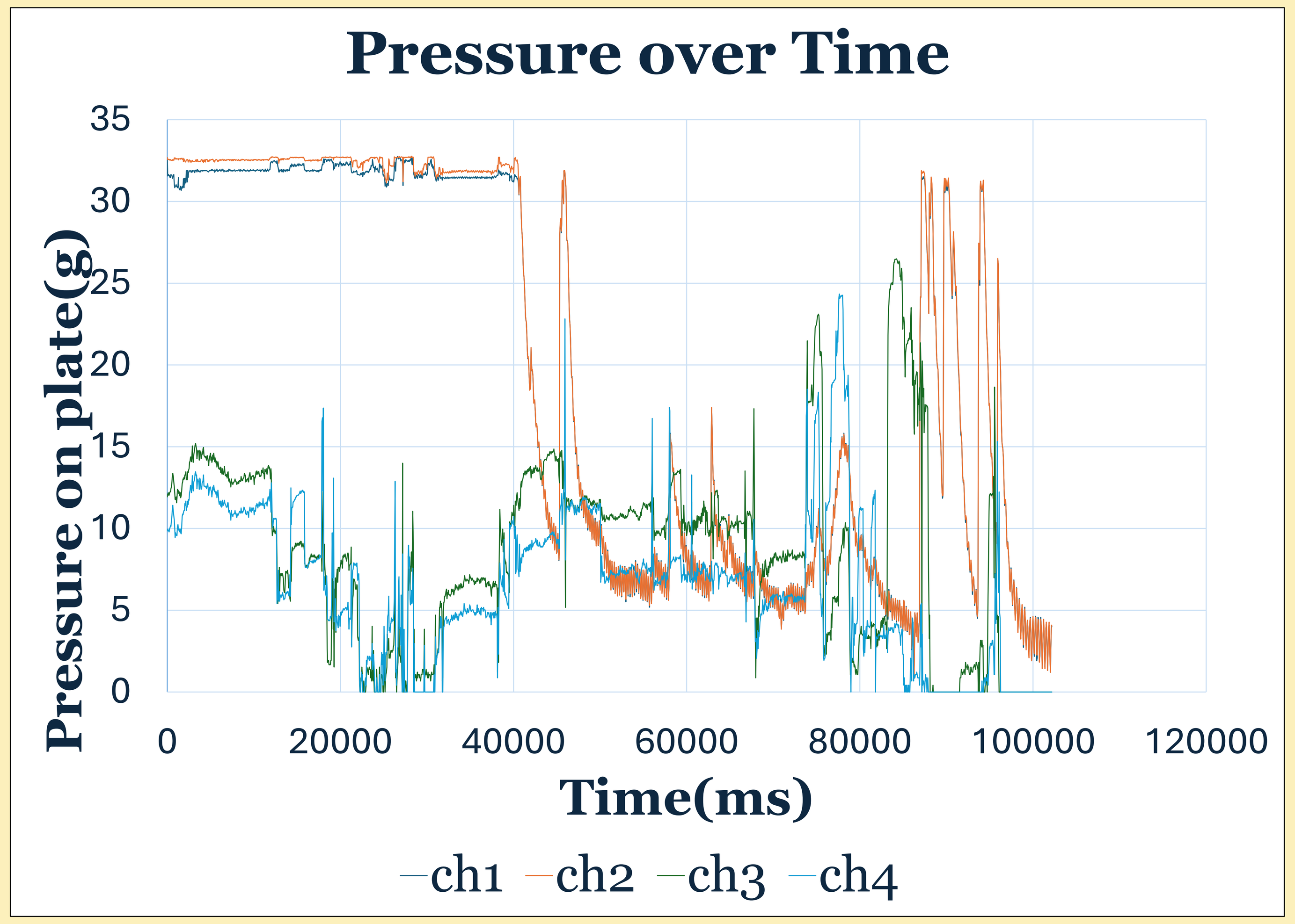


Figure 1: UA-R4-W30 bucket tested. Sensors (CH1, CH2, CH3, CH4) were attached to the top left, top right, bottom left, and bottom right corners of the plate, respectively.

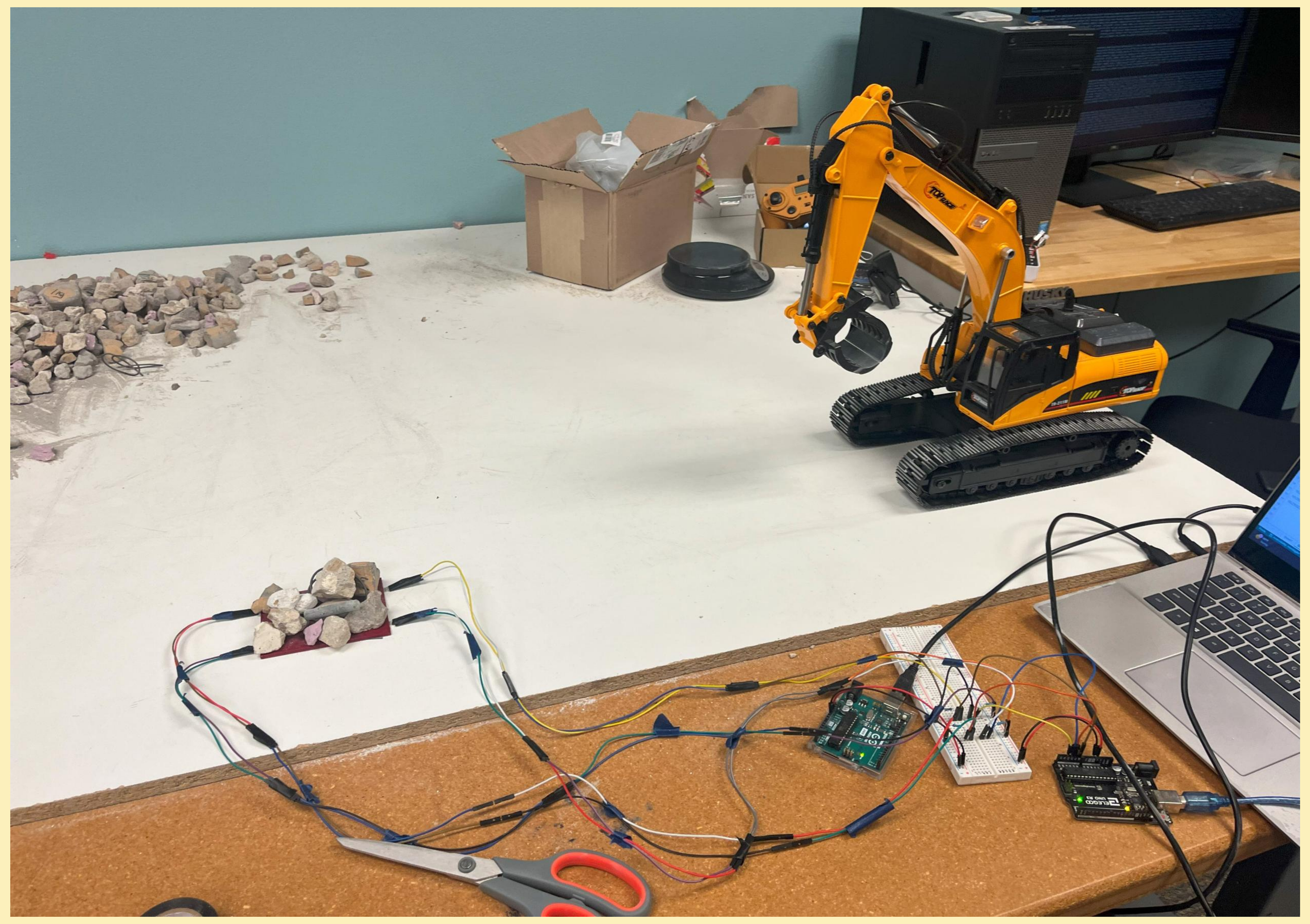
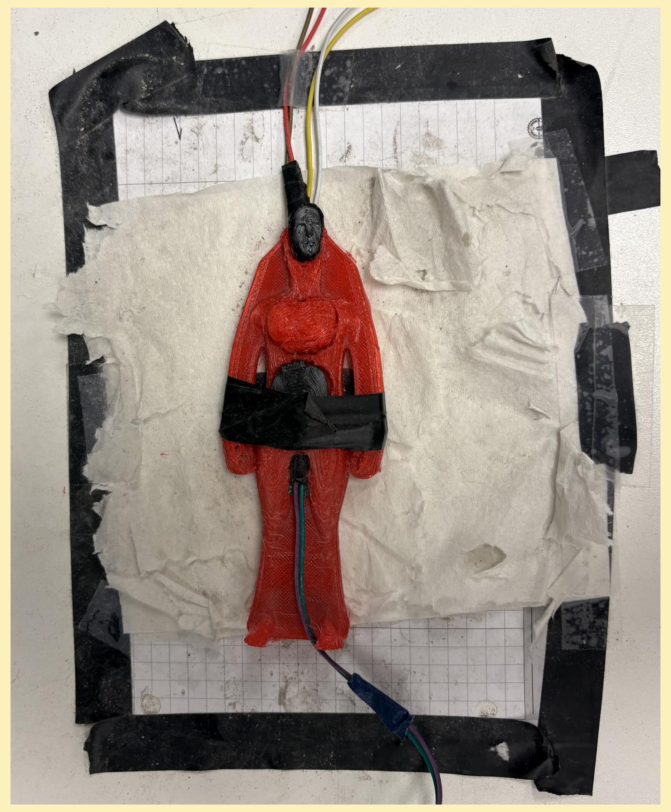


Figure 2: Picture of pilot study procedure with standard bucket.



Figures 3 (Left): Picture of 3-D printed human; sensors attached to critical parts of the human body (head, chest, & stomach).
Figure 4 (Right): Void zone set up.

Results & Discussion

(This project is still ongoing, and as such the results shown are mostly preliminary)

- Overall, claws with lower widths result in shorter rescue times
- Claws with radii higher up result in shorter rescue times and less pressure exerted on the human.
- Claws with both of these features allows for greater precision the removal of debris.

After comparing these two buckets, it will inform the rest of the experimental procedure. For example, as it's reported that the decreased bucket width allowed for greater precision, the width will be decreased again in future trials, to find the most optimal number.

Conclusion & Future Direction

Overall, while the specific parameters that are best for achieving our study's goal are inconclusive, the potential effects it'll have on the direction of further research is as presented:

Should this data support this method as an accurate simulation of the effect of bucket type on rescue efficiency we can turn our gaze to the effects of differing scenarios on our different bucket types, and their optimizations, using higher fidelity models and measurements. Some examples of this include:

- Changing debris material's density/mass to model different locations.
- Altering the size and position of faux human model.
- The effects of rust/weathering on excavator bucket efficiency
- Optimal methodology of excavator removal in dangerous areas

With the information from these experiments supporting this type of experiment's validity, we intend to dive into and explore the many possibilities which come with designing an excavator bucket for rescue operation.

Resources

Please scan the QR code to view the complete list of sources.

Special thanks to our mentors Dr. Juyeong Choi and Maral Nazemi.