An Intelligent Interface for Automatic Grading of Sketched Free Body Diagrams

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ABSTRACT

Sketching free body diagrams is an important skill that students learn in introductory physics and engineering classes; however, university class sizes are growing and often have hundreds of students in a single class. This creates a grading challenge for instructors as there is simply not enough time nor resources to provide adequate feedback on every problem. We have developed an intelligent user interface called Mechanix to provide automated, real-time feedback on hand-drawn free body diagrams for students. The system is driven by novel sketch recognition algorithms developed for recognizing and comparing trusses, general shapes, and arrows in diagrams. We have also discovered trends in how the students utilize extra submissions for learning through deployment to five universities with 350 students completing homework on the system over the 2018 and 2019 school year. A study with 57 students showed the system allowed for homework scores similar to other homework mediums while requiring and automatically grading the free body diagrams in addition to answers.

CCS CONCEPTS

• **Human-centered computing** → **Web-based interaction**; • **Computing methodologies** → **Artificial intelligence**; • **Applied computing** → **Interactive learning environments**; Engineering.

KEYWORDS

sketch recognition, engineering education, intelligent tutoring system

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1 INTRODUCTION

Free body diagrams are an integral part of problem solving in many fields of engineering. These diagrams are illustrations used to visualize how forces and reactions occur on a given body. They are often taught to students in the first physics or statics courses due to the prevalence of free body diagrams in engineering problem solving. Students should have thorough feedback about free body diagrams in entry classes so that they do not form misconceptions and unnecessarily struggle with future classes; however, many university courses can be quite large, especially in the introductory courses. The increased number of students results in an increased number of homework submissions for an instructor or teaching assistant to grade which carries a large time burden [1].

We propose a solution to the feedback and time constraint problems in the form of a web application called *Mechanix* that utilizes novel sketch-recognition algorithms to assess a sketched free body diagram and automatically grade a student's response to homework questions.

2 RELATED WORK

Existing Commercial Systems

There are several online homework systems such as *Mastering Engineering*, *WileyPlus*, and *McGraw-Hill Connect* offered by three major textbook publishers. These systems typically require only the final answer for a problem. This can result in students struggling with some concepts if they do not draw their free body diagram on their own since it is not required.

Sketch-based Systems

There are systems such as *Newton's Pen* [3], *Newton's Pen II* [2], and a previous version of *Mechanix* [4] which utilize early digital stylus computers to allow students to sketch diagrams and equations in physics problems while providing some feedback about their diagrams; however, these systems rely on older technologies that can limit the systems and make system usage more difficult. These systems are most similar to our system which utilizes modern hardware and technologies in addition to expanding on the system capabilities.

3 SYSTEM

Mechanix was designed with ease of use for the education space in mind. From prior work in the area, we determined a web-based platform would be easiest for the majority of use-cases. For example, most schools have strict software and firewall restrictions, so a desktop application would make it difficult for students to use *Mechanix* on school resources.

Mechanix must be able to recognize the sketched free body diagrams of students as well as determine if their answers are correct or incorrect. Both of these tasks are non-trivial given the messy nature of sketched data and the fact that there are multiple acceptable answers for a single problem. The sketch recognition occurs in the following order.

(1) Segmentation and corner finding
(2) Truss or main body recognition
(3) Arrow recognition

Segmentation is performed every time the user lifts their pen or mouse. Then the unrecognized segments are checked against the answer truss or shape for a match. After the answer body has been recognized, every time a user lifts their pen or mouse the unrecognized segments are checked to see if they form an arrow.

The user answer is checked against a solution provided by the instructor. *Mechanix* accounts for variants in the answer such as the student drawing an arrow in the opposite direction resulting in the opposite sign for the answer. Summation of force answers are entered in terms of the variables that the student used to label their force arrows.

Mechanix also supports a creative design mode where students are given constraints and asked to create a planar truss bridge satisfying the constraints. The students sketch the truss and then fill in the dimensions of their bridge which is analyzed to see if it satisfies the requirements.

4 RESULTS

Mechanix has been deployed to five universities in intro statics courses as well as an intro dynamics course. Data collection is currently in progress, but preliminary results indicate that using *Mechanix* results in similar homework scores as other online systems; however, *Mechanix* has the added benefit of requiring and grading hand-drawn free body diagrams. A two sample t-test on homework scores for 56 students in the same class (35 control, 21 experimental) yielded $\mathbf{p = 0.47}$. Students in the control group used *WileyPlus* and students in the experimental group used *Mechanix*. Both groups were given 3 graded attempts on the same problems.

A new truss algorithm was developed for *Mechanix* which was tested against 1500 trusses and 1500 non-trusses from a previously collected dataset. The new algorithm correctly labeled 1482 trusses and rejected all non-trusses for an f-score of **0.994**. Student usage was analyzed and the new algorithm recognized a truss without any erasing in 83.7% of problems with a truss. The remaining cases could be analyzed to see if there is a problem with the algorithm or if they were user mistakes.

5 FUTURE WORK AND CONCLUSION

We are currently working on adding different problem types for *Mechanix* including multi-body problems, problems with distributed loads, and problems with applied moments. Additional types of feedback are being explored in an attempt to increase student grades. We are also prototyping a new input modality where students use their phone screen as a drawing surface and computer for answer input.

The preliminary results showing *Mechanix* yields similar scores to other systems is a good start given that the students are required to draw the diagrams on *Mechanix*. *Mechanix* reduces grading burden on the instructors while still requiring the students draw the correct free body diagram.

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REFERENCES

[1] Ceilidh Barlow Cash, Jessa Letargo, Steffen P Graether, and Shoshanah R Jacobs. 2017. An Analysis of the Perceptions and Resources of Large University Classes. *CBE—Life Sciences Education* 16, 2 (2017), ar33.

[2] C Lee, Josiah Jordan, Thomas F Stahovich, and James Herold. 2012. Newtons pen ii: an intelligent, sketch-based tutoring system and its sketch processing techniques. In *Proceedings of the International Symposium on Sketch-Based Interfaces and Modeling*. Eurographics Association, Eurographics Association, Goslar, DEU, 57–65.

[3] WeeSan Lee, Ruwanee de Silva, Eric J Peterson, Robert C Calfee, and Thomas F Stahovich. 2008. Newton's Pen: A Pen-Based Tutoring System for Statics. *Computers & Graphics* 32, 5 (2008), 511–524.

[4] Stephanie Valentine, Francisco Vides, George Lucchese, David Turner, Hong-Hoe (Ayden) Kim, Wenzhe Li, Julie Linsey, and Tracy Hammond. 2012. Mechanix: A Sketch-Based Tutoring System for Statics Courses. In *Proceedings of the Twenty-Fourth Innovative Applications of Artificial Intelligence Conference (IAAI)*. AAAI, Toronto, Canada, 2253–2260.