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Abstract

Background: Delivery of a hands-on laboratory experience is a real challenge in the present pandemic environment. Many instructors tend to acquire and record experimental data, and then instruct their students to analyze such data to produce results and lab reports in an online course mode. Such a process considerably diminishes students' motivation, engagement, and eagerness to explore further knowledge, as students appreciate more experimental data that they gather themselves. Such drawbacks are even more profound in a practical field such as biomechanics, where students need to feel the sense of kinematic and kinetic data of their own body motions and muscle forces.

Purpose: The aim of this paper is to communicate with engineering educators facing challenges in the current pandemic time, a new teaching method that allows students to remotely gain a hands-on knowledge by applying the principles of mechanics on their body motions using a computer vision kinematics laboratory module that can be easily applied at home.

Methods: In this research, students first capture their selected body motion with a webcam at home. They are provided a video tracking algorithm that calculate spatial locations of the body segment motion. Students then perform calculations to estimate further kinematic and kinetic data, plot them, and comment on their own estimated muscle forces. The students' perceived workload and effort in completing the lab requirements can also be evaluated. The proposed computer vision approach is utilized to calculate the participants' kinematic data in an interactive motion analysis problem.

Results: As a work in progress study, initial results showed that 97% of the participating students successfully applied the computer vision-based kinematics module, supported by the generation and submission of full laboratory reports including critical data analysis of their body motion experience.

Conclusions: The proposed computer vision experimental approach may enhance the learning experience of biomechanics students at home in such an isolating pandemic environment. The demonstrated methods can be applied to many teaching fields including biomechanics and robotics.

Keywords:
Remote learning, Laboratory data acquisition, Biomechanics, Video Tracking, COVID-19

Introduction

Kinematics is a subfield of biomechanics that describes body parts movements, while kinetics studies the motion causing forces and moments. The main goal of this remote biomechanics laboratory is to introduce biomedical engineering students to the profession of medical research where qualitative analysis of human movements is conducted to find clues of a certain injury, monitor recovery from injury, and to examine kinematic characteristics of a specific body movement. The original lab objectives were:

1- Students would be able to apply qualitative and quantitative analysis of human movements with biomechanical principles.
2- Students would learn how to calculate kinematic data for a specific joint movement.
3- Students would calculate kinetic data based on kinematic and anthropometric data.

Tools usually employed to measure biomechanical variables, vary in sophistication, complexity, and cost. Most motion measurement systems based on optical imaging principles are quite expensive [1]. Angular kinematic/kinetic calculations can be carried out using combined video and anthropometric data [2]. As all spring 2020 classes moved to the online mode, such tools were not accessible to the instructor neither the students. In such remote environment, active learning is not achievable. Active learning has repeatedly proven, across all STEM disciplines, to improve the retention of the content to be taught, level of achievement, and courses success in general [3, 4]. Therefore, a need exists to make an experiential and involving learning experience for the student to achieve remote active learning.

The author had to improvise a way of remote data collection that utilizes the students' own body movements data and achieve the goal of active learning in such a new pandemic environment. Therefore, this paper is considered as a work in progress study, as it includes some preliminary results of the success rates of students conducting the experiments and interpreting the lab results at home. The purpose of the paper is to introduce to the engineering education community a new method of capturing human movements (or more generally, objects in motion) and estimate parameters describing motion in an at-home setting.

Methods

The proposed kinematics biomechanics module is part of a combined laboratory course in the track of the Biomedical Engineering program that is offered to junior students in the third quarter of the academic year. The objective of this course is to provide introduction to specific system analysis methods used in physiological systems evaluation. Students are presented with real-world biomedical engineering problems and research ideas that overlap the fields of physiology, digital signal processing (DSP), and biomechanics demonstrated as multidisciplinary investigative experiments. The course's prerequisite is a comprehensive DSP course that covers sampling, digital filtering, and frequency analysis methods. The combined laboratory course also has two corequisites that are required to be taken by students at the same quarter, namely Biomechanics and physiology courses.

The motion experiment starts with placing two markers (such as white labels) on the two ends of the body part in motion (e.g. forearm motion). A webcam captures a short video (about 20-40 seconds) while the body part is in motion, so that all spatial positions of the body part would be captured. Video capturing was initiated using a small MATLAB script (MATLAB R2019b, MathWorks, Inc., Natick, MA, USA) which is provided to students by the author/instructor. This script starts the capturing process and saves the video file on the computer's drive. The recorded video is then fed (by browsing the video file location) to a video tracking software module implemented by the author/instructor. The tracking module has been implemented with a custom MATLAB script, using the computer vision toolbox utilizing the Kanade-Lucas-Tomasi point tracking algorithm [5]. The script generates two arrays of the estimated points displacements (in x and y coordinates) corresponding to the two ends of the body part in motion.

Since the tracking module provides point coordinates in pixel units, students are required to develop their own MATLAB scripts to perform the necessary coordinate translations and trigonometric transformations to calculate motion displacements in the units of degrees rather than pixels, with respect to the non-moving joint end (the assumed origin of new coordinates). Students are then asked to apply their prior DSP knowledge to implement signal filtering and smoothing techniques (typically gaussian filters) in order to prepare the data for the differentiation step that follows. The smoothed signal consecutive differentiations provide estimates of the final kinematic data (from angular joint displacements to velocities and accelerations) which in turn are used to calculate kinetic data (muscle forces and moments) by solving biomechanical equilibrium equations. These tasks allow students to use their previous understanding of trigonometric transformations, DSP techniques, mechanical equilibrium analysis to solve the problem in hand and estimate many motion parameters. Students would plot the results and comment on their own estimated body motion parameters and how such results correlate with their own muscle forces.

Class Implementation

The laboratory module would be deployed as follows:

1- The module description is presented in a 50 minutes online lecture. Figure 1 shows the instructor demonstrating in at-home setting the video tracking estimates of his own elbow joint displacements during an extension/flexion movement.
2- Laboratory requirements are described in detail. To enhance the learning experience, students are given the opportunity to select a joint motion of their own choice, which adds to the module a motivation, curiosity, and ownership components to the overall learning experience.
3- Out of class student activity (typically at-home):
    - Students will develop their MATLAB scripts to perform all kinematic and kinetic calculations.
    - They will interpret kinematic/kinetic results, and drive conclusions.
    - Detailed Lab report will be the main deliverable that includes labeled displacement, velocity, acceleration, and muscle force plots. It is required to provide a description of the relationships between different events on the plots and the actual joint motion.
    - A reflection component in the lab report is also required in the form of a questions.

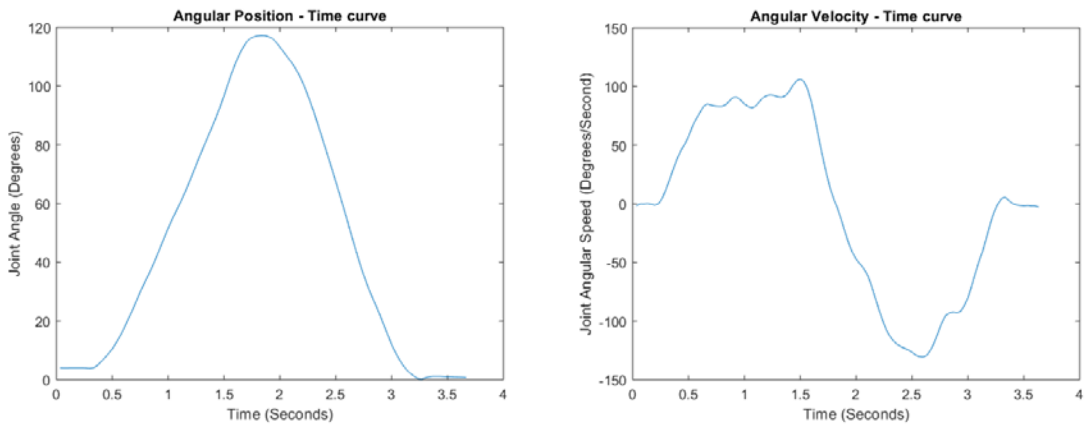
Figure 1. Captured image showing the author's experimentation with the computer vision tracking algorithm on his elbow joint at-home while describing the lab module to students in an online delivery mode.

Reflection component of the required report enables the student to think about the reason why we do such an activity and to whether they have gone as intended or not, and why we think they may have worked well (as part of the lab report critical analysis). Lab reports can be delivered online using platforms such as OneNote or via a Learning Management System (LMS) platform such as blackboard or Canvas. The report assessment would follow an announced rubric that takes into account: correctness of methods of calculations, clarity of presentation of results, appropriate use and number of significant digits, appropriate use of statics, appropriate use of graphs with complete and descriptive labels, interpretation of results, submission on time, and answers to the reflection questions. Student feedback can be sent via the same delivery method. The described methods have been tested in a class of 32 students in the biomechanics laboratory course in Biomedical engineering.

Preliminary Results

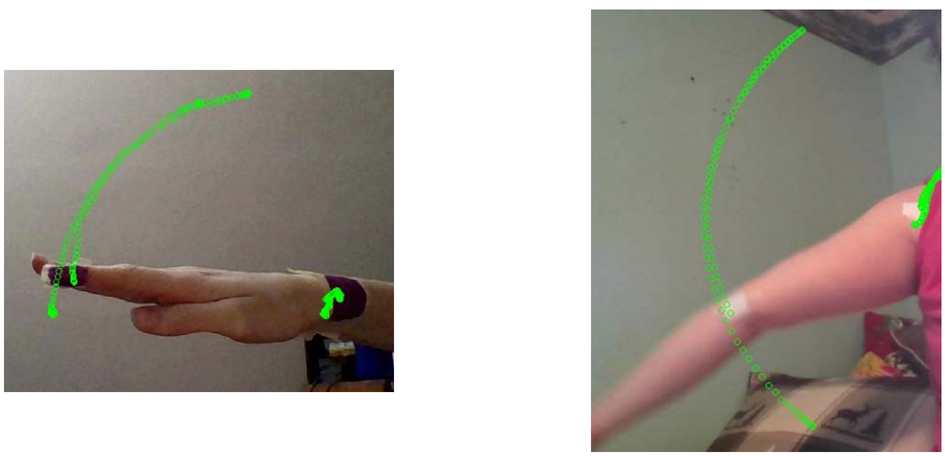
The preliminary application of the computer vision-based kinematics module revealed that 31 out of 32 students (97%) successfully applied and completed the required joint movement calculations. The only unsuccessful student had a low-resolution laptop webcam and did not reach the instructor to tune the tracking algorithm, but student was graded based on following the lab steps. Figure 2 demonstrates a successful example of the application of the computer vision module to produce kinematic data plots representing angular position and velocity of the elbow joint extension/flexion motion. Position data shows an elbow's joint range of motion of about 115 degrees, which is in agreement with the reported range of motion value for normal elbow joint movements [1]. Additionally, joint velocity data shows a maximum velocity of 130 degrees/sec in the flexion phase of the motion.

Furthermore, several students were so motivated and curious that they applied the module on different body part movements than the elbow joint movement described by the instructor in the lecture session. Figure 3 shows two examples of successful applications of the computer vision tracking of two different joints: the wrist joint and the shoulder joint.



A **B**

Figure 2. Examples of kinematics data graphical results produced the proposed computer vision laboratory MATLAB scripts as applied on the elbow joint extension/flexion motion: A) Angular joint position against time plot, showing a range of motion of about 115 degrees. B) Angular joint velocity against time plot, showing a maximum joint velocity of about 130 degrees/sec in the flexion phase of the motion.



A **B**

Figure 3. Examples of successful students' experimentation with the computer vision tracking software module on joint motions of their choice: A) An image showing Flexion and extension of the wrist joint. B) An image showing abduction and adduction motions of the shoulder joint. The green markers represent the video tracked joint angular displacement.

Some of the student comments were very positive of the at-home computer vision lab experiment: "overall this lab was very fun as we learnt more tools and it kept us engaged." and "The extension/toolbox was actually very interesting to see how it worked".

Discussion

In this paper, a low cost and accessible computer vision laboratory module was introduced. Preliminary application results of the module showed that it is highly applicable in at-home setting, and initial students' comments showed good acceptance of the new motion data acquisition method. The proposed lab module can help achieve the following skillset course objectives:

- To apply quantitative biomechanics of human movements with a computer vision, video tracking algorithm.
- To solve for a chosen joint kinematics.
- To relate kinetics to kinematics and anthropometric data.

The proposed lab module can also help achieve the following mindset objectives:

- Take ownership of the acquired kinematics data and express interest in the lab.
- Connect student's own joint movement parameters with theoretical biomechanics.
- Apply technical skills to the development of an accessible movement characterization technology.

Despite that this paper focused on the application and analysis in a biomechanics laboratory setup, the demonstrated module can be easily applied to other practical fields of engineering study. The computer vision algorithm requires markers on the moving parts to be tracked, even if they were more than two markers, in order to track the motion in video and then estimate the markers spatial location in pixel units. This principle can be applied on linear and rotational motions, which makes it very suitable for studying abstract mechanical motions (such as pendulum motion analysis). More advanced calculations can be performed as well for robotics applications and estimate the required motors specification to achieve a certain motion design requirement.

As mentioned earlier, this paper is considered as a work in progress study. It described some preliminary results of successful student conduction of the experiments. However, the study lacks detailed student survey data and its associated analysis, which is considered as future work that will be applied this academic year. A survey with statements using a Likert scale will be used in the next application of the module. Comprehensive graphical and statistical results can then be obtained. Also, the students' perceived workload and effort in completing the lab requirements will be evaluated. A literature review of similar engineering education studies will be made, and their results will be comprehensively compared with my research results.

Conclusions

The applied teaching module can allow students 1) to experience a motion analysis scenario that represents a simplified real-world engineering situation, 2) to develop their natural perceptive of the range of motion, velocity, and acceleration of a certain object motion, 3) to reduce the need for expensive motion analysis setups or equipment, and 4) to remotely be fully engaged. The proposed module was applied in a biomechanics laboratory setup, but it can be easily applied to other practical fields of engineering study, such as abstract mechanical motion analysis, and even more interestingly, robotics analysis.

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