Human Balance Models for Engineering Education: An Innovative Graduate Co-Creation Project

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At Bell Laboratories Dr. Thompson created with the Vice President of Research and Nobel laureate, Arno Penizas, the W. Lincoln Hawkins Mentoring Excellence Award (1994). This award is given to a member of the research staff for fostering the career growth of Bell Labs students and associates. This award is

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His awards include the US Presidential Award for Excellence in Mentoring; Tau Beta Pi Eminent Engineer; James E. Blackwell Scholar; AT&T Bell Laboratories Cooperative Research Fellowship. He is cited in WhoÄôs Who among African Americans, Education, and Technology Today; American Men and Women of Science, West Babylon Alumni Hall of Fame; He is a Fellow of the Acoustical Society of America and cited for his fundamental contributions to theoretical and computational acoustics. He is senior member of IEEE, and a member of the American Physical Society and Sigma Xi. He has published reesearch in acoustics, control theory, fluid mechanics, heat transfer, linear and nonlinear systems, and telecommunications.

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Abstract

Balance problems affect more than eight million adults, and the percentage of balance problems increases with age. Globally, the population is aging, making balance problems a relevant topic of investigation. Balance impairments are the primary cause of falls, which result in debilitating injuries, especially for the elderly population. There is a significant opportunity for students in engineering and other disciplines to explore and contribute to research and education in this area. In this work, a group of graduate students from electrical, industrial, and mechanical engineering present research that will be mapped into an educational module on this topic. This module is co-created with faculty and domain experts. Sensors of various types are being investigated for monitoring gait and identifying the propensity for losing balance. A survey of the state of the art of sensor technology pertaining to balance is conducted. Models of human balance during quiet standing are investigated. An interactive simulation tool is developed to allow students to vary the model parameters and gain an intuitive understanding of the engineering principles involved. For engineering students, this offers many opportunities to better understand how topics they study in engineering courses relate to a significant societal problem. For students in courses such as statics, dynamics, and control systems, the concepts of change in the center of mass, the center of pressure, the inverted pendulum, and stability can be reinforced in relation to the balance dynamics problem. This paper describes the framework that will be used in an educational module that will improve undergraduate engineering concepts through balance dynamics experiments and simulations, and present interdisciplinary research problems to graduate students. This study contributes to an Innovations in Graduate Education National Science Foundation research project.

Index Terms

Human Balance System, Co-creation, Graduate Education, Interdisciplinary, Sensor, Simulation

I. Introduction

In recent years, the limitations of traditional learning, such as instructor driven lecture style teaching, have been widely recognized, and there has been a growing interest in alternate approaches that emphasize active engagement and collaboration. Research has shown that incorporating active learning strategies such as group work, problem-solving, and hands-on projects can lead to improved student motivation, engagement, and performance [1]. To benefit from these strategies, it is important for graduate students to develop a sense of self-authorship and to take an active role in their own learning and research. This can involve seeking out opportunities for independent study and project work, working collaboratively with peers and mentors, and taking advantage of professional development workshops and training programs.

Similarly, in upcoming years, the engineering workforce will require particular skill sets that involve the combination of discipline-specific knowledge and technology to address complex problems with the involvement of diverse field experts. Thus, co-creation is being proposed as an alternative learning and teaching method. This refers to the joint and collaborative effort between educators and students to design and implement curriculum components, pedagogical approaches, and other educational initiatives. This approach will prepare students for these changing demands in the post-Covid era. In the case of the NSF Innovations in Graduate Education project that was the basis for this research, co-creation is studied in a case study at the University of Massachusetts Lowell. Students and mentors co-created this paper and will continue this work in developing an online educational module on the topic of the human balance system.

The human balance system was chosen as the theme due to the interdisciplinary issues it presents and its relevance to society. Balance problems are easy for students to connect with, as many students have aging relatives. The multi-faceted issue of balance presents a problem for the interdisciplinary group of graduate students to bring their unique perspectives to, and also provides a problem that can easily be implemented into an educational module that can be used in a variety of undergraduate engineering courses. The study of balance problems necessitates a multidisciplinary approach involving expertise from fields such as physics, engineering, neuroscience, and rehabilitation sciences.

In this paper, we present an overview of the human balance system, its sensors, and models, emphasizing the complexity of the reflex system that processes input cues to maintain balance stability. The inverted pendulum model is selected as the balance system model due to its simplicity and flexibility for implementation into more complex models. Outcomes of the co-creation experience in engineering education are outlined. In conclusion, the paper aims to be a resource for those seeking an introduction to the human balance system, its sensors, and models and also a case study for the co-creation method in graduate education.

II. **Innovations in Graduate Education**

The "Innovations in Graduate Education (IGE) in Cyber-Physical Systems Engineering" NSF project is a collaborative effort across the University of Massachusetts Lowell, the University of Massachusetts Dartmouth, and the University of the District of Columbia. This effort focuses on interdisciplinary collaboration, inclusivity, and co-creation of educational modules. It involves graduate students from underrepresented groups, participants from various disciplines and industries, and employs an iterative improvement process to evaluate knowledge gained and promote effective communication and collaboration. The primary goal is to equip graduate students with interdisciplinary skills and knowledge to prepare them for a diverse and dynamic workforce.

Co-creation has been explored as a means of enhancing educational outcomes [2]. This approach aims to transform the traditional view of students as passive consumers of education to active participants in the learning and decision-making process [3]. The key features of this concept are collaboration in both the process and output, transformative interaction, learner empowerment, a sense of community and partnership in learning, and value. These findings are supported by various researchers such as [1], [4]–[8].

This co-creation project was structured around the project-based learning framework known as the gold standard, which involves seven stages that start with a challenging problem or question and end with generating a public product [9]. Through this structure, graduate students aim to create effective educational models and promote interdisciplinary collaboration, while learning to adapt to changing situations in a dynamic and diverse workforce.

The study includes evaluations of the technical and humanistic knowledge gained by the students who co-create content, focusing on effective communication and collaboration practices between students and experts from different fields. This study is noteworthy for its use of disciplinary structures and techniques from various fields, including engineering, computing, education, business, psychology, and sociology. Graduate student researchers in different majors collaborate in designing educational modules, and the project emphasizes creating a supportive environment for student participants to express their opinions and address concerns using a participatory action research framework. The project follows an iterative improvement process, utilizing both qualitative and quantitative data from students and facilitators to achieve project goals.

The faculty mentors in this project who are a multidisciplinary group from electrical and mechanical engineering, sociology, and psychology, presented a research topic on human balance to the group of graduate students from electrical, industrial, and mechanical engineering majors. This topic posed multi-faceted challenges, allowing students from these disciplines to contribute their unique expertise. The topic was introduced within a societal context to emphasize its relevance and encourage students to bring authenticity to their work. Interdisciplinary collaboration is driven by the students' interests and ownership of the topic. The IGE project's focus on promoting interdisciplinary collaboration and agility in responding to changing situations is applied to the development of solutions for balance-related problems.

III. **Human Balance System**

To become more knowledgeable about the topic, students conducted background research and literature reviews on the human balance system, focusing on its relation to sensors and principles of engineering. This step is an integral part of the research process. Students attended a literature review workshop with the mentors who provided ideas and resources for the students to start. The students determined what were the most important features to be searching for and discussed their ideas with the mentors. Over the weeks, mentors and students shared the literature they found relevant, and the students would critically analyze it and categorize important details. General findings from the initial search showed that the human balance system and its complexities have been studied for over a century; various balance tests, measurement devices, and models have been made to create a deeper understanding of this system. The simplest model of the human balance system is considered for the educational purposes of this project. A summary of the initial findings is as follows.

The human balance system is a complex and dynamic reflex system that processes visual, vestibular, and somatosensory (touch and proprioception) input cues to maintain equilibrium stability. Special biological sensors in the human body process these inputs, which are sent to the brain, and in turn, signals are sent to the parts of the body responsible for postural control [10]. Elderly individuals or those with disabilities may have several sensory impairments and face muscle weaknesses, making balance more difficult, and therefore increase the risk of falls. This study surveys models developed to describe postural dynamics. A dynamic model is developed as a simulation tool that can be used to further understand balance, and be implemented as a multi-disciplinary educational module.

A general understanding of the human balance system must be attained before exploring models and sensors. The human body's state of equilibrium is determined by the center of pressure, center of mass, and center of gravity, as shown in Fig. 1. The center of pressure (CoP) is a point representing the average pressures applied on the surface of the area, with a constraint referred to as the base of support (BoS), in contact with the ground [11], [12]. The center of mass (CoM) is a position representing the total body mass whereas the center of gravity (CoG) is concerned with the weight. The human body is characteristically unstable and must rely on a constant-acting balance control system due to its top-heavy composition consisting of two-thirds of the human body mass being located two-thirds of the height of the body above the ground [11]. Even when standing still, the human body is not static. It is constantly swaying, and the central nervous system acts as the controller trying to maintain the CoG within specified limits of the BoS [13]. In general, postural sway increases with age, and more sway means that the system is less stable [13]. Changes in postural sway or abnormal balance strategies can indicate underlying conditions [14]. For example, an abnormally small postural sway is indicative of Parkinson's disease, while an abnormally large sway is often seen in multiple sclerosis patients [14].

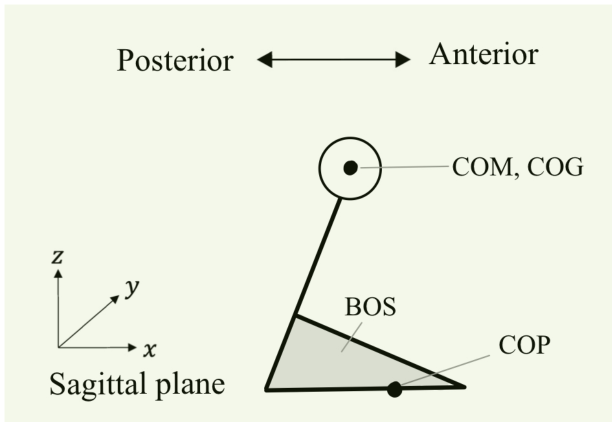


Fig. 1. CLocations of the center of mass (CoM), center of gravity (CoG), and center of pressure (CoP) with the base of support (BoS) for a human body model.

A. Survey of Models

In the survey of models of postural control, the goal was to choose a model that could be explained to undergraduates in engineering and be implemented into a simulation to support experiential learning of the topic. For this reason, it was decided to limit the models to static standing balance for this paper and the corresponding educational module before introducing advanced motion like walking in subsequent work. Modeling walking balance results in more complex math that requires a solid understanding of the more introductory concepts outlined here.

Quiet standing is a static standing balance postural stance used to evaluate human balance. This is also the standardized balance stance used in understanding human balance in fields of physiology and engineering alike [15], [16]. In this stance, the subject is asked to stand barefoot with their feet parallel, a 6-cm distance between their heels, eyes open, head looking forward in a natural position, and arms hanging at their sides [17]. As aforementioned, although the body appears to be still in quiet standing, it is constantly moving and receiving biological signals to readjust in order to maintain balance [18].

The human body has been modeled in a variety of ways that range in complexity to represent the human balance system. Multi-segment models are more advanced. For example, a three-dimensional thirteen segment model is described by lengthy Newton-Euler equations and is used to model balance in a balanced reach test [19]. This is beyond the scope of quiet standing, and fundamental principles of engineering and math must be explained to undergraduates before complex models are developed.

An inverted pendulum model has been widely used to represent human balance systems and solve balance-related problems. The model is used to study key principles in human balance, which are to understand how the human balance is maintained and how it is affected by external forces. Some well-known papers that utilize the inverted pendulum model for a human balance system study include [11], [12], [20]–[23]. This literature utilizes an inverted pendulum model on the sagittal plane or the side view, which sways in the anterior-posterior direction [11] as shown in Fig. 1. Their models are classified as a single inverted pendulum, which uses the ankle as a pivot point, called the ankle strategy, and assume a rigid pole with both feet in contact with the ground. An alternative strategy is called the hip strategy which is represented using the double or 2-link inverted pendulum model that uses both ankle and hip as pivot points of the inverted pendulum [11], [24]. To further analyze human balance systems considering multiple joints to represent more realistic human standing, an N-link inverted pendulum model is used [25]. Combined strategy, such as ankle-hip, is also considered in literature such as [11].

Control system models with proportional-integral-derivative controllers are another common representation of the human balance system. The human balance system can be represented by a control system, as the central nervous system acts as the controller tuning the body movements to maintain balance. The inverted pendulum model is often incorporated into the transfer functions used in control models [26]. Therefore, it is best to introduce the inverted pendulum model alone to undergraduate students, and later the model could be applied to control theory for an added layer of complexity. Similarly, more complexity can be added later on by incorporating N-link inverted pendulum models into the control system.

The single inverted pendulum model is chosen for this paper, as it is the most commonly used balance system model and because it can be adapted into more complex models in the future.

B. Survey of Sensors

In this section, a survey of the state-of-the-art of sensors is provided. The ultimate goal of the literature review is to identify what type of sensor could be used in fall prevention and collect the data necessary for the inverted pendulum model.

In the field of fall prevention, various types of sensors are utilized to detect and prevent falls in individuals who are at risk. These sensors can include pressure sensors, motion sensors, accelerometers, infrared sensors, and image recognition sensors. Pressure sensors are placed on the floor or integrated into footwear to detect changes in weight distribution that may indicate a fall. Motion sensors are designed to detect sudden changes in movement, and can trigger an alarm if a fall is detected. Accelerometers measure acceleration and deceleration and can be used to identify a fall and activate an alarm. Infrared sensors detect body heat and can be used to monitor changes in posture that may indicate a fall. Image recognition sensors, utilizing cameras and computer vision algorithms, can detect falls and trigger an alarm. These sensors are commonly incorporated into wearable devices, such as smartwatches, or fixed systems installed in homes or care facilities. They are essential components in fall prevention systems for elderly individuals, people with disabilities, and anyone who is at risk of falling [27]–[29].

1) Force plate: The force plate is considered the gold standard of balance testing and used to measure the CoP, CoG, and postural sway [13]. However, its size and cost may impose limits on its versatility [30].

2) Inertial Measurement Units: Inertial measurements units are the sensors consisting of accelerometers, gyroscopes, and magnetometers that measure three-dimensional movements of the body, making them a reliable evaluation tool for physical function during functional tasks such as gait, stair climbing, or sit-to-stand [31]. In recent years, these sensors have gained popularity for their ability to be integrated into wearable devices, providing a non-invasive and cost-effective method for measuring and monitoring balance. Studies have shown that these wearable sensors can provide accurate information and have demonstrated effectiveness in detecting falls in older adults and balance problems in individuals with neurological conditions [32]. They have also been used in the development of balance training programs and to monitor the progress of individuals undergoing physical therapy [33].

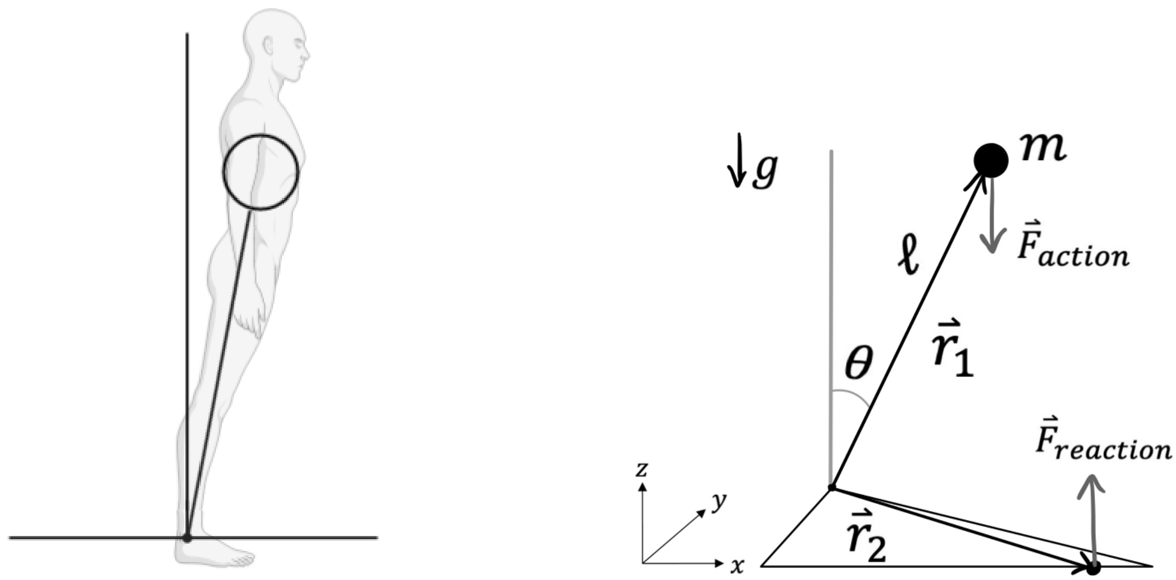
Moreover, wearable devices have been used to capture data about loss of balance events in older adults and analyze them to improve fall risk assessment and prevention. Investigators have developed systems that can accurately assess standing balance and body movements associated with real-world trips, making it possible to identify trips that lead to a loss of balance during daily activities. Machine learning models have been developed to detect loss-of-balance events in older adults using collected data [34].

Such sensors that are deployed in wearable devices offer a non-invasive and cost-effective way to measure and monitor balance. However, standardization is necessary to make it easier to choose and compare among the various available options for sensors, algorithms, tests, and parameters.

IV. **Models of Human Balance**

A human balance system during quiet standing (static stability) is considered using the inverted pendulum described by [20]. To represent a human body as an inverted pendulum model, the application Biorender [35] is used to create Fig. 2 (a) adapted from [36], which shows a human body overlaid with the system considered. The model consists of a rigid weightless pole on top of a fixed weightless block that models the base of support as shown in Fig. 2 (b). A ball is attached to the tip of the pole, which represents the mass of human body, or the CoM. The force is applied on the mass due to gravity. The bottom triangle represents feet, the BoS. The ankle muscular activity to prevent falling, which corresponds to the counterclockwise force, is denoted by the point CoP. The position of the CoP can be varied but physically limited by the BoS. The ankle strategy is used, which indicates that the moment is defined with respect to the ankle. Although the CoP can move back and forth, the primary concern in the model is falling forward. Three assumptions are integrated from [20] whose model uses the system described by [11], [36]: (i) the balance system is characterized by the movements of the CoM and CoP, (ii) the distance ℓ between the pivot point and the CoM remains constant, (iii) the movement of CoM is small with respect to ℓ.

The literature suggests that the condition for the stability of human balance is met when the CoM is within the BoS [11], [20], which is referred to as CoM-BoS relationship. [21] validates the performance of the inverted pendulum model by performing experiments on human subjects, which shows the agreement between the theoretical calculated CoM acceleration using the ankle strategy and true values. [37] suggests that the functional boundary, which is defined by the effective CoP movement, is more suitable as the limit of stability boundary instead of the BoS. When considering dynamic balance, such as walking, [12] and [20] propose a need to assess the velocity of CoM, which refers to the position-velocity of CoM and BoS relationship. The focus of this section is to present the basic balance system during quiet standing; thus, CoM-BoS criteria is implemented for the interactive simulation of the human balance. Given the CoM-BoS criteria, the stability of the human balance system in two cases are considered: (i) when the body has no motion (static) (ii) with the body has an initial velocity (dynamic).



(a) (b)

Fig. 2. Free-Body Diagram of an inverted pendulum model

A. Statics and Dynamics

Statics is one of the first engineering courses that introduces students to fundamental concepts such as forces, moments, and interactions between bodies. The students' engineering problem-solving skills are also developed. The human balance system is introduced first to provide an introductory model that is accessible to a student who may be taking the Statics course.

Dynamics is taken after Statics and incorporates content from mathematics courses, including calculus and differential equations. Dynamics allows one to apply advanced motion concepts to the human balance model. Two types of systems are considered, namely a static and dynamic system. Since balance is an active process involving movement to maintain stability, a dynamic model is presented.

B. Balance Model

The mathematical model describing human balance is presented using the free body diagram as shown in Fig. 2 (b). $\vec{F}_{action}$ is the force of gravity. $\vec{r}$ is the position vector, $\vec{r} = x\,\hat{i} + y\,\hat{j} + z\,\hat{k}$. ℓ is the length of pendulum from the pivot point (ankle) to the CoM. θ is the anterior-posterior swing angle from the vertical. m is the mass of the pendulum, and g represents gravity.

$$\sum F = \vec{F}_{action} + \vec{F}_{reaction} = -m\,g\,\hat{k} + m\,g\,\hat{k} \tag{1}$$

Let x be the arc length or the trajectory of the CoM position in the 2 dimensional space,

$$x = \ell\,\theta \tag{2}$$

which can be the vertical projection of the CoM along the horizontal axis $\ell sin\theta \sim \ell\theta = x$ if small angle approximation is applied, which is used in [20]; thus, the moment with respect to the pivot point will be:

$$M_o = \vec{r}_1 \times \vec{F}_{action} + \vec{r}_2 \times \vec{F}_{reaction} = (x-u)\,m\,g\,\hat{j} \tag{3}$$

For the static case where the pole has no motion, the CoM and CoP are along each other:

$$\sum F = 0 \quad and \quad M_o = 0 \tag{4}$$

The sum of the forces and sum of the moments should always equal zero in statics. This denotes that the system is in static equilibrium.

For the dynamic situation, where the pole has motion, the acceleration is introduced:

$$M_o = J_o\,\ddot{\theta} = \ell^2\,m\,\ddot{\theta} \tag{5}$$

where J_o is the moment of inertia, and $\ddot{\theta}$ is the angular acceleration.

The second derivative of θ in Eq. 2 with respect to time will yield:

$$\ddot{\theta} = \frac{\ddot{x}}{\ell} \tag{6}$$

Substituting Eq. 6 into the moment equation for dynamic case will result in

$$\ddot{x} = \frac{g}{\ell}\,(x - u) \tag{7}$$

Let q be a non-dimensitonalized variable where $q = \sqrt{(\ell/g)}\,t$. This simplifies Eq. 7 into:

$$\ddot{x} = \,(x - u) \tag{8}$$

where x is differentiated with respect to q. Both Eq. 7 and 8 explain the same phenomena with different time scales. Thus, Eq. 8 is used to find the condition for falling and also will be used for simulation.

Eq. 8 can be solved using Laplace transform. Assuming the position of the CoP u is a constant, x(q) is found to be:

$$x(q) = u \;+\; (x_0 - u)\,cosh(q) \;+\; \dot{x}_o\,sinh(q) \tag{9}$$

The CoM-BoS relationship says the CoM position is within the CoP position [11]. Thus, to get the condition for a fall prevention given the initial conditions with a relation to u, Eq. 9 will be:

$$\dot{x}_o\;tanh(q) \;\leq\; u - x_o$$

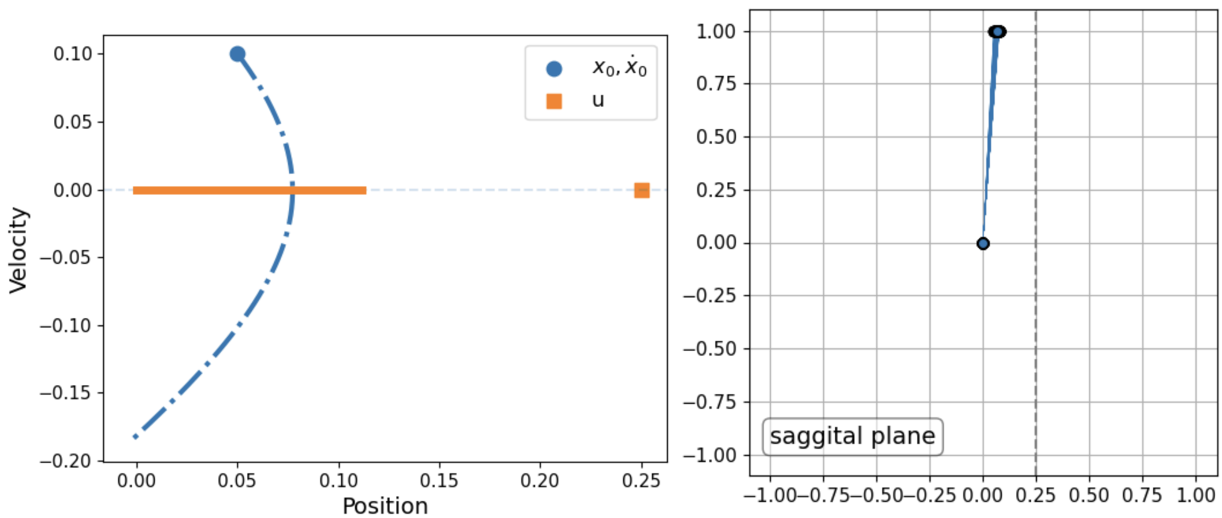
$tanh(q) = 1$ as $q \to \infty$ and the magnitude of $x_0 + \dot{x}_0$ is taken to compare the location of the CoM to u along the horizontal axis, which yields

$$|x_o \,+\, \dot{x}_o| \,\leq\, u \tag{10}$$

The key in the simulation is to identify whether the pendulum will fall or not given different values of the parameters. A speed of how fast it occurs is not a primary interest. Thus, a simulation is conducted using the non-dimensionalized unit q for a time index where $0 \leq q \leq 1.5$. This is found to be sufficient to capture the stability outcome.

Figs. 3 and 4 show the the movement of the CoM of the pendulum for different conditions. u and ℓ are set to 0.25 and 1.00, respectively, for both case and remain constant during the simulation. The relationship between the velocity and position of the CoM is shown in (a). (b) captures the movement of the pendulum where the horizontal and vertical axes correspond to x and z directions, respectively, on the saggital plane with the origin representing the pivot point, ankle. Fig. 3 shows the case where the

the pendulum will not fall. The solid line, $|x_o + \dot{x}_o|$, and the square marker, u position, along the horizontal line in Fig. 3 (a) clearly indicate that Eq. 10 is met. The pendulum in Fig. 3 (b) moves forwards while the velocity is greater than zero. At a certain time, the velocity reaches zero and causes the pendulum to stop. Then the pendulum will move backwards in (b) as the velocity goes negative values. On the other hand, Fig. 4 shows the situation where the pendulum will fall over although Eq. 10 is met. The velocity of the CoM does not reach zero as shown in Fig. 4 (a) and will increase eventually. The pendulum will keep moving forwards and pass the varticle projection of the CoP as shown in Fig. 4 (b). This is a case where the counterclockwise force is not sufficient enough to prevent from falling for the given parameters.



(a) (b)

Fig. 3. Simulation results when the pendulum does not fall. (a) Position x vs velocity $\dot{x}$ of the CoM. The dot is the initial condition where $x_0 = 0.05\,m$ and $\dot{x}_0 = 0.1\,m/s$. The solid line is $|x_o + \dot{x}_o|$ and the dashed dotted line is the movement of the CoM for $q > 0$. The square is the position of $u = 0.25\,m$. (b) The trajectory of the CoM. The dashed vertical line is the vertical projection of the CoP.

Eq. 10 itself is not sufficient for the condition for fall prevention. Additional constraint which the velocity of the CoM goes zero at some point given certain initial conditions is required. This indicates that the pendulum can reverse the movement, resulting in preventing the forward falling.

The inverted pendulum model presented can utilize data collected from the wearable sensors to determine the CoM and CoP, which are the key parameters for determining stability. The wearable sensors are equipped with an accelerometer, to measure the acceleration along an axis, a gyroscope to measure the angular velocity, and a magnetometer to give data about the direction to subject is moving [38]. The data from the wearable sensor must be processed including filtering, and the inverted pendulum model is used in an algorithm [38]. This algorithm can provide real-time feedback from the sensors to the users. In the case of this graduate education project, the scope is limited to creating an educational model; however, the goal was to find a sensor that could be used in fall prevention and successfully model the human balance system. This work could be extended to show fall prevention for subjects wearing sensors their real-time model projection and alerting them when the model predicts they are in a near-fall situation.

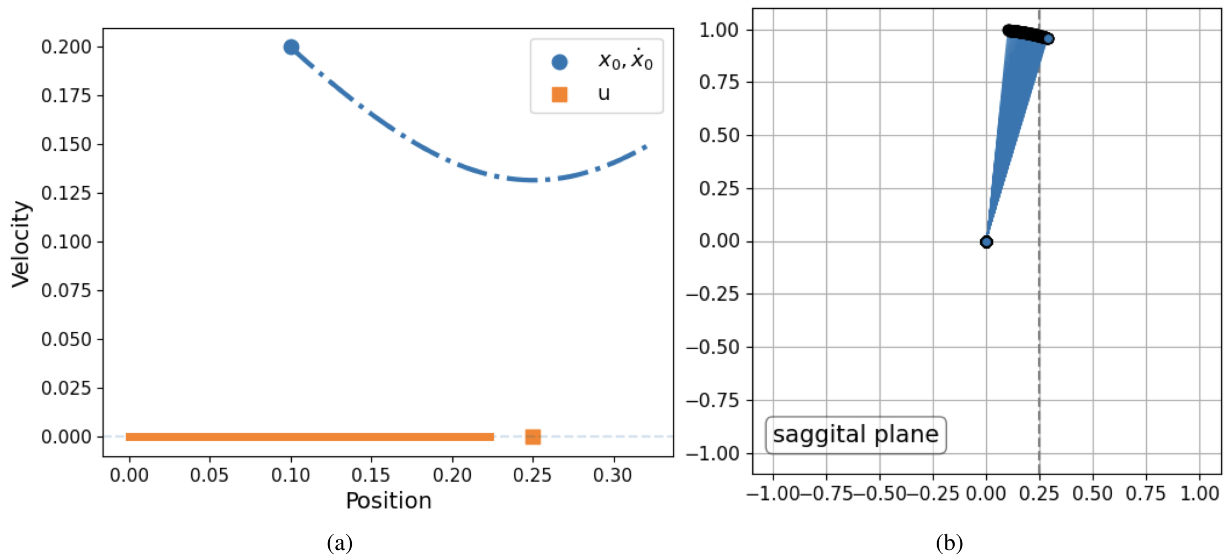


Fig. 4. Simulation results when the pendulum will fall. (a) Position x vs velocity $\dot{x}$ of the CoM. The dot is the initial condition where $x_0 = 0.1\,m$ and $\dot{x}_0 = 0.2\,m/s$. The solid line is $|x_o + \dot{x}_o|$ and the dashed dotted line is the movement of the CoM for $q > 0$. The square is the position of $u = 0.25\,m$. (b) The trajectory of the CoM. The dashed vertical line is the vertical projection of the CoP.

V. Proposed Educational Module

The main outcome of this research is developing an educational module that can be implemented in the existing University of Massachusetts Lowell Engineering courses and others at our partnering universities. This includes courses such as Dynamics Systems of Analysis, Physics, and Engineering Differential Equations. Fig. 5 shows the steps that were necessary to (1) understand the theory behind human balance, (2) choose adequate sensors, and (3) apply existing models. Understanding the theory and selecting proper sensors are essential to developing a well-rounded educational module in which students can understand the real-world phenomena of human balance and see the societal need. Thus, we developed a combined model that will inform creation of an interdisciplinary educational module geared towards undergraduate engineering students.

To create the understanding of human balance, this paper introduces the basic physiological concepts and outlines the need to find ways to better monitor and understand balance and creates the connection to fall prevention. This will be extended in the educational module, by allowing the students to practice observation. The balance problem will be introduced in a simple physical experiment to create the mental connection of the concept before any mathematical models are introduced. Such experiment could be, for example, pre-testing the students' knowledge by asking students if standing in the quiet position should be modeled statically or dynamically and then allowing them to experiment. One student could stand in the quiet standing position and ask the other students to look closely to observe their motion. Other variations could be asking the balancing student to close their eyes or stand on one leg and the other students to observe the changes. By the end of the experiment, they should understand that even though the person is standing still, they must be moving in order to maintain balance. A physical representation is often more memorable to students and aids in the learning process.

The next section includes introducing the dynamic formula. Students will be given a pre-test and post-test to understand their knowledge on free body diagrams. From the previous experiment, they can understand that the inverted pendulum is a simplified model of the human body in the quiet standing position, where the body sways to maintain balance at the ankle pivot point.

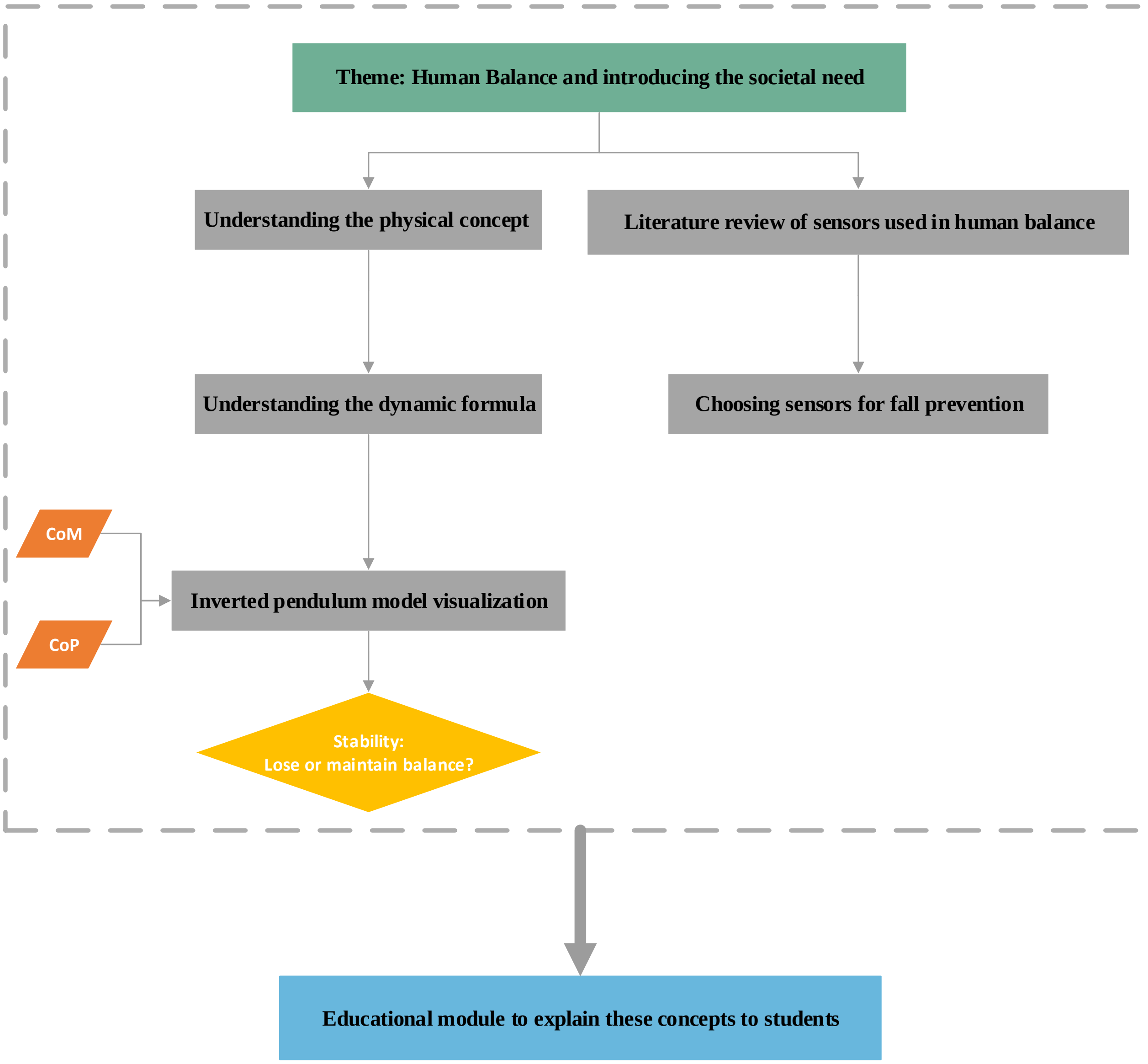


Fig. 5. Flowchart of this paper. The dotted lines are within the scope of the paper, and outside the dotted lines show that the work presented in this paper will be used to develop the educational module.

The dynamic model of the inverted pendulum is implemented into a Python visualization shown in Figs. 3 and 4. In the educational module, students will have access to a GUI and have the ability to modify the parameters and observe the changes in the stability outcome.

The other component of this paper was conducting a literature review to decide which types of sensors are best suited for monitoring fall prevention. In the educational module another experimental component can be explaining the concepts of inertial measurement units in the application of fall prevention and letting students conduct experiments to collect data that can be used in the Python model visualization.

This hands-on approach utilizing sensors integrated with the theory and dynamic model enhances students' understanding and problem-solving skills in real-world situations, like fall prevention and balance assessment. Overall, the module will encompass:

1) Theoretical background: Introducing human balance system fundamentals and models.
2) Sensor technologies: Presenting sensors, their principles, advantages, limitations, and applications.
3) Practical exercises: Providing hands-on experience with sensors, emphasizing real-world applications.
4) Data analysis and interpretation: Teaching data processing and analysis techniques.
5) Advanced topics and applications: Exploring complex concepts and applications.

Human balance is a physical concept, and utilizing experiments and allowing them to observe will help make the concepts more memorable. By integrating sensors, students bridge the gap between theory and practice, honing valuable engineering, data analysis, and problem-solving skills. The interactive simulation tool engages learners in understanding the human balance system's basic mechanism, allowing parameter adjustments and encouraging consideration of balance stability outcomes.

VI. Conclusions

The study emphasizes the importance of interdisciplinary collaboration and co-creation methods in addressing balance problems and their impact on falls in the aging population. Aligning with the Innovations in Graduate Education National Science Foundation program, the project aims to prepare graduate students for a diverse and dynamic workforce by providing interdisciplinary skills and knowledge.

The interdisciplinary collaboration among graduate students from various engineering disciplines provides unique expertise in addressing this issue. The study presents an educational module co-created with faculty and domain experts to help students understand engineering principles involved in balance dynamics. This module introduces the human balance system using an inverted pendulum model, static stability, and dynamic stability concepts.

Wearable sensors, inertial measurement units, are valuable tools for assessing and monitoring human balance. Data collected from these sensors help determine the center of mass (CoM) and center of pressure (CoP), key parameters for stability. Algorithms provide real-time feedback for fall prevention, and the model can visualize differences among age groups.

The end product of this project is the educational module, but it also opens up opportunities for future research to enhance and expand the co-creation approach. Students are required to have a certain level of knowledge in their domains to be successful in collaborative work for knowledge sharing and gaining an interdisciplinary perspective. Dedication to being part of the project is also vital. This includes being responsive, open-minded, and willing to learn. By integrating theory with hands-on practice, students can bridge the gap between traditional learning methods and real-world applications, better preparing them for the diverse and dynamic workforce.

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