College of Engineering

Innovation, Technology, Design Degree

ITD 410 Senior Capstone I Report
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RealRehab

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Contents

1 Abstract

RealRehab is a rehabilitation system that is designed to improve the accuracy, engagement, and outcomes of at-home physical therapy for ACL injuries. The product integrates a custom sensor-equipped knee brace with a mobile application that delivers real-time visual feedback, personalized rehabilitation plans, and secure data storage. The brace uses a flex sensor and two IMUs to measure knee flexion, extension, and medial-lateral drift, while an Arduino collects and transmits these measurements to the mobile app via Bluetooth. The app enables physical therapists to create custom plans that are automatically reflected on the patient's dashboard where they can complete lessons, view feedback, and have their results uploaded to the cloud. To evaluate feasibility, we developed a minimum viable product that included a functioning user interface, authenticated account system, working ACL rehab plan, and a brace capable of stable real-time feedback. We conducted a killer experiment to validate our product goals, which was to complete a full knee extension lesson using live sensor data. The experiment confirmed calibration transfer, accurate angle and drift detection, correct error messaging, and consistent latency averaging approximately 120 milliseconds. Across 15 trials, all calibration data transferred correctly, error-detection logic performed at 100 percent accuracy, and both sensors showed high stability. These results confirm that RealRehab's combined hardware-software system can reliably guide correct movement during rehabilitation, providing a strong foundation for future expansion of lesson types, hardware refinement, and enhanced clinical use.

2 The team

2.1 Team mission statement

Our mission is to create a wearable brace that tracks leg movements and provides real-time visual feedback on an app to help users perform physical therapy (PT) exercises correctly.

2.2 Team strengths and weakness

Our team brings a diverse set of strengths across both hardware and software domains. We have experience with physical computing, more specifically, Arduino circuitry and programming. We know all the fundamentals of UI/UX design and can prototype solutions from conceptualization. Apart from that, we have knowledge of medical, physiological, and applied exercise concepts as well as connections with healthcare professionals through first-hand experience with studies on rehabilitation. Beyond our technical skills, we excel in soft skills such as public speaking, critical thinking, problem-solving, and human-centered design. We also have strong creative abilities, including pitch deck design and 3D modeling using CAD, Rhino, and other modeling software. Our team also hones the ability to plan goals and events accordingly and manage multiple parts of a project at once.

One of our main weaknesses is app development. While we all have some coding experience, the languages used in app development differ, and none of us have direct experience building mobile applications.

2.3 Project's acceptance criteria

Upon simple flexion and extension leg movements, our brace will be able to detect leg acceleration, flexion, and positioning within space and accurately display real-time visual feedback on our mobile app. The specific steps our product will accomplish include:

- The internal IMU within the Arduino and the external IMU will use the accelerometers for measuring velocity of movement and gyroscopes for measuring positioning and orientation of the leg during movement.
- The flex sensor will measure the angle of the leg in degrees, by converting the values of resistance within the sensor to the appropriate degree values it translates to. During flexion, the sensor gains resistance, or drops the electricity amount flowing within it, but while straight it has more electricity. More resistance in the sensor will be treated as the leg flexing, while less resistance will be treated as the leg extending.
- The Arduino will accurately compare the exercise data collected by the sensors to our "control" data, or what will eventually be the "correct" movements assigned by the physical therapist and the initial and final leg angles collected during the calibration step.
- The mobile app will display visual feedback based on the Arduino's calculations.

3 Need discovery and screening

3.1 Discovery

Our first step in choosing a problem was to determine the industry we wanted to focus on. We selected the healthcare field, specifically the health and wellness sector, because it is an area we are all passionate about and felt motivated to innovate in. We then each individually chose initial product concepts we wanted to explore, which included:

1. A microbiome tracker like an Apple Watch but designed to monitor gut health

2. A mobile app that creates personalized vitamin and supplement plans based on individual health goals
3. A device in the disability tech space designed to address a specific unmet need

3.2 Information gathering

1. Microbiome Tracker

To better understand gut health and its market potential, we conducted secondary research. Gut health has become an increasingly popular focus among Gen Z and Millennial populations, and we sought to leverage this trend by designing a product that enables users to actively track and monitor their gut health [1]. Our research revealed several reasons why this issue is worth addressing. For example, recent studies have underscored the gut's significant role in neurodegenerative diseases like Parkinson's and Alzheimer's, as well as in certain cancers [2]. Additionally, the rise of gut health-oriented companies such as Poppi and Olipop highlights the growing consumer demand in this space. We also explored existing technologies that could make microbiome monitoring feasible and found that the only noninvasive approach would involve analyzing gas samples from one's breath to detect microbial activity. However, this method presents challenges due to numerous confounding variables that could influence the accuracy of results.

2. Personalized Vitamin and Supplement App

As the market for wellness and fitness solutions steadily increases each year, the area for diet and supplementation is also something people take seriously. However, most people today only take supplements, not specific deficiencies like they were originally intended for, but out of vague belief that their current diet isn't enough. This leaves many people's reasoning and intention behind taking certain supplements to be uncertain and misunderstood. To try and learn more about the habits of Americans in this area, we conducted secondary research. We found that around 86% of U.S. adults take dietary supplements or vitamins, but only around 24% of them have received test results indicating they have a nutritional deficiency [3]. Furthermore, 92% of supplement users in a separate survey agree that they are essential to maintaining their health [4]. This survey included a nationally representative sample of 3,192 U.S. adults age 18+, including 2,328 adults who reported taking supplements occasionally or regularly. A supplement user even reported that, "It makes me feel less guilty for eating like crap… And I think it boosts my immune system?" [3].

This research helped us narrow down the problem occurring with supplements. Millions of adults take supplements without knowing which ones they truly need, how much to take, or if they are even effective! As a result, they often spend money out of vague habits rather than clear benefits. What these users need is a simple, personalized way to know what to take, when, and why, without the hassle of constant testing or confusion. For our path forward, we conceptualized the idea of a digital app or simple tool that identifies which supplements a person's needs, suggests dosage, timing, and safe product options while tracking the benefits over time without clinical testing. Additionally, we visualized the addition of a device or dispenser that synchronized the app to dispense the exact dose at the right time, making following through effortless.

We came to the conclusion that this idea would not be feasible moving forward because creating clinically reliable supplement recommendations requires too much medical expertise. We also would have to consider regulatory compliance and validate our testing methods which would go way beyond an academic capstone project's scope. Something like this would also take too long to receive verification for user testing and tracking biological changes in personalized dosage.

3. Disability Technology

To understand the current landscape of rehabilitation solutions, we conducted secondary research on accessibility and technology in this field. Rehabilitation services remain underdeveloped, underfunded, and often inaccessible, particularly for individuals with paralysis, limb differences, visual impairments, and mental health conditions [5]. Studies indicate that over 50% of people in low- and middle-income countries do not receive the rehabilitation care they require, and emergencies such as conflicts, natural disasters, and outbreaks further exacerbate these gaps [5]. While existing rehabilitation technology addresses some user needs, there is significant room to innovate solutions that improve effectiveness, comfort, and engagement. Our research highlighted an opportunity to design empathetic, user-centered technology that enhances rehabilitation outcomes.

3.3 Feasibility

Our original sense of feasibility for the ideas was based largely on our own interests and assumptions. For the supplementation concept, we mainly considered our personal usage with supplements and thought it could be an appealing space to explore given our shared interest in health. We initially believed it would not be too difficult to design an app for tracking pills or even creating a dispenser. However, when we began thinking more deeply about the application, we realized that determining what supplements a person actually needs would require significant lab work, which contradicted our goal of creating a seamless and easily accessible solution.

For gut health, we originally found the concept intriguing because we were curious about how the gut affects the brain. We thought an app centered around understanding gut health rather than improving it might be feasible. But through information gathering, it became clear that actually knowing the state of someone's gut microbiome would require ingestion of a product or laboratory testing, which was not practical for our MVP or the timeframe of a year-long senior design project.

After evaluating the feasibility of each idea, we agreed that the microbiome tracker would be the least practical. To obtain accurate data on the specific microbiota in a person's gut, an invasive device or lab-based testing would be required, making the idea unrealistic and heavily constrained by regulation. This left us with the vitamin and supplement app and the disability tech concept. Both were initially feasible, with the supplement app seeming slightly more achievable. However, further research revealed numerous comparable products on the market, such as SupTrack and Supplify, making innovation difficult in an already crowded space. This influenced our understanding of feasibility and pushed us toward the disability tech idea. One team member's prior experience in this field gave us additional confidence, and we felt that creating a product in this space would be more meaningful and have the potential to make a real difference in people's lives.

3.4 Screening

To screen and sort the three unmet needs, we began by discussing each idea in depth and brainstorming multiple different ways they could work. We also grouped the ideas according to broader categories within the health industry, physical, mental, and nutritional health, to ensure we were exploring different subdomains rather than repeating similar problem areas. We then needed to determine which of the three spaces had the most reasonable and attainable path toward a concept solution given the limited time available during the semester. That direction was disability tech, which we identified as both impactful and realistically achievable.

Next, we conducted another round of screening specifically to determine which concepts were the least logical or feasible to pursue. We quickly eliminated the supplement concept because we were unable to find convincing research demonstrating that supplement misuse or confusion was a pressing unmet need. Although some evidence exists that people overspend on supplements, most users simply do not care enough to justify the creation of a new system. Additionally, any product related to supplements or nutrition would carry substantial regulatory burdens, which further reduced feasibility.

We found similar issues with the gut health idea. Any meaningful solution would require navigating significant regulatory barriers, and we did not find strong enough research demonstrating that a personalized gut-health tool was genuinely needed. Many improvements in gut health can already be achieved through proper nutrition and general wellness practices. Thus, through this structured screening process, we ultimately decided to look deeper into disability tech as the unmet need most appropriate for continued development.

3.5 Need selection

After deciding to focus on the disability tech space, we wanted to identify a specific area where technology could make a meaningful impact. As we began exploring different problems within this space, we found that many people with disabilities struggle with recovery and rehabilitation after injury or surgery, particularly when it comes to maintaining motivation during physical therapy [6]. This insight led us to consider physical therapy as a potential focus area, since it plays a crucial role in improving mobility and independence for many individuals with disabilities.

Drawing from our own experiences with physical therapy, we all agreed that the exercises often felt repetitive and unengaging. We wanted to find a way to make the process more interactive and enjoyable. During our secondary research, we came across an interesting project from UT Dallas, where a professor was developing a gamified approach to enhance neuroplasticity using vagus nerve stimulation for neurological disorders [7]. This discovery inspired us to explore how gamification could be used to improve the physical therapy experience. However, we realized that committing to a gamified solution before fully understanding the root challenges in the physical therapy space would be premature, as it felt like we were searching for a problem to fit a given solution. To avoid that, we conducted a survey to better understand the specific frustrations and barriers people face during physical therapy.

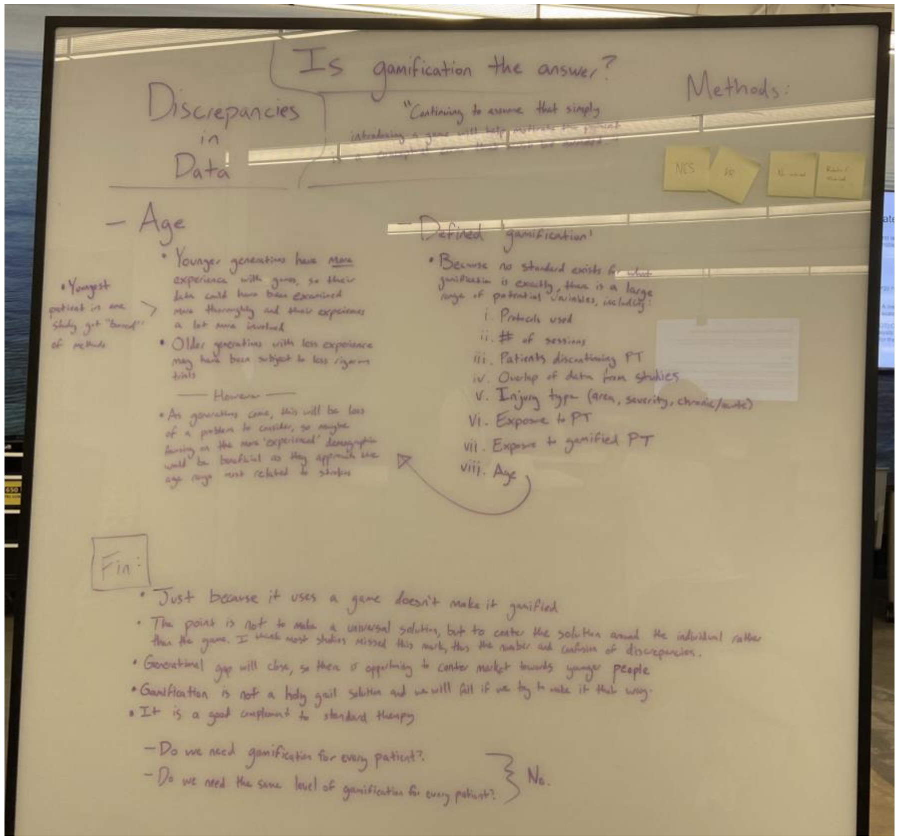

Figure 1. Exploring gamified solutions in rehab

From this survey, we found that nearly one-third (29.5%) of respondents identified *visible progress tracking* as a key factor in their physical therapy success, while 41.1% reported benefiting from *personalized plans*. Additionally, in a survey sent to physical therapists, we found that 75% of respondents believe real-time feedback would improve patient compliance with home exercises. Therefore, it was evident that we needed to develop a product that allowed users to monitor their physical therapy progress, in real time and through periodic updates, and receive customized exercise plans curated by their physical therapists. Additionally, survey responses indicated that incorporating gamification would be beneficial, as it would make physical therapy more fun and engaging for users.

4 Understanding the opportunities

4.1 Selected unmet need

4.1.1 Problem and fundamental background

The goal of any physical-therapy-based product is to ensure full patient recovery. While there are many companies in the rehabilitation space that deploy similar methodologies to achieve this, our product, RealRehab, will stand out through its five key features. The product's primary value lies in its real-time feedback and progress tracking capabilities; however, it also offers personalized lesson plans, engaging gamification elements (e.g., streaks), and precise sensor-based data collection. While several products provide some of these individual features, there is currently no single solution that combines them all into one comprehensive product. By integrating these components into a single product, RealRehab will help patients recover more quickly by boosting motivation through gamified elements and ensuring correct movement via data-driven feedback. Without such a comprehensive solution, users lack access to reliable, continuous monitoring and engagement tools which can lead to suboptimal adherence, less accurate exercise execution, and increased risk of re-injury.

4.1.2 Existing solutions

Currently, three companies create similar products to our RealRehab brace: Reev, Hinge Health, and Sensoria Health, with Sensoria Health being the most similar. Reev focuses on restoring mobility in patients with neurological gait impairments following a stroke. Although the company does not work directly with patients in traditional physical therapy, their solutions still support the rehabilitation process, making them a competitor. Their ReevSense product enables healthcare professionals involved in recovery to monitor patient progress in real time [8]. The product consists of a wearable sensor placed on the thigh, calf, ankle, or shoe, paired with a mobile app that generates detailed gait and mobility reports. Clinicians can use these reports to tailor individualized rehabilitation plans based on the patient's progress. The system uses inertial measurement units (IMUs) to capture metrics such as walking speed, cadence, stride length, balance, and joint movement (e.g., knee and ankle flexion) and all data is collected in real time and transmitted to the app via Bluetooth for analysis.

Hinghealth is a company dedicated to helping people reduce joint and muscle pain [9]. Through its mobile app, users receive a personalized exercise plan designed to target their discomfort. They can choose to work with a professional coach, follow routines created by their physical therapist, and communicate with them directly through online calls. After downloading the app, users complete a baseline assessment so their program can be customized to their starting level. During each exercise, the app uses the device's camera to track movement and provide real-time feedback.

Sensoria Health's Smart Knee Brace is the most similar to RealRehab. It is specifically designed for patients undergoing rehabilitation after knee surgery [10]. The device integrates with standard physical therapy exercise protocols, and clinicians can adjust exercises and develop individualized plans through the platform. The product stands out through its AI-driven system which generates optimized exercise recommendations and provides insights on the patient's progress. Like ReevSense, it uses IMU sensors to track movement and communicate with the mobile app via Bluetooth.

	Real-Time Feedback	Engaging Gamification	Personalized Lesson Plans	Progress Tracking	Sensor Based Hardware
Our Concept	✓	✓	✓	✓	✓
Reev Sense	✓	✗	✓	✓	✓
Sensoria	✓	✗	✓	✓	✓
Hinge Health	✓	✓	✓	✓	✗

Figure 2. Competitor Analysis

4.1.3 Stakeholder analysis (one page maximum)

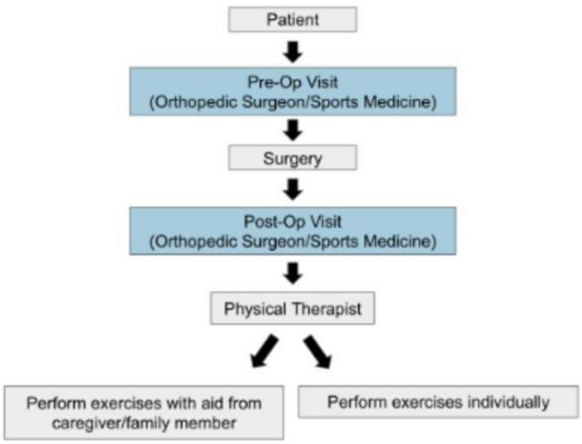

Figure 3. Workflow Analysis

The typical recovery process for a patient with a knee injury, such as an ACL tear, begins with a visit to a specialist. Depending on the severity of the injury, the patient will usually first see an orthopedic surgeon or sports medicine physician, though in more urgent cases they may go to the emergency room. After diagnosis, the patient schedules surgery with their specialist and undergoes the procedure. A post-operative visit follows, during which the specialist provides a referral for physical therapy. From that point forward, recovery takes place through a physical therapy program that includes both in-clinic sessions and prescribed exercises to be completed at home. From this process it is clear that patients undergoing physical therapy and clinical professionals such as orthopedic surgeons, sports medicine doctors, and physical therapists are our primary stakeholders. However, we do have additional secondary stakeholders.

Primary Stakeholders	**Secondary Stakeholders**
Core Users 1. Patients who have undergone physical therapy 2. Patients who are currently undergoing physical therapy	Manufacturing 1. UX/UI Designers 2. Software Developers 3. Hardware Manufacturers 4. Suppliers (Sensors, circuitry, etc.)
Clinical Professionals 1. Physical Therapists 2. Sports Medicine Doctors 3. Orthopedic Surgeons 4. Athletic Trainers	Operations 1. Product Manager 2. Logistics and Distribution 3. Marketing and Sales
Other 1. Caregivers/Family Members	Regulatory 1. Legal and Compliance Teams 2. Medical Device Regulatory Bodies

Figure 4. Stakeholder Groups

Our three most important stakeholder groups are patients, physical therapists, and physicians. Each group will experience the innovation differently, and their support or resistance will depend on how the product affects their goals, workflows, and outcomes.

Patients are our central stakeholders, as they are the individuals recovering from injury and performing the rehabilitation exercises. For our MVP, we are primarily targeting younger adults (ages 18–35), who tend to be more tech-savvy and more receptive to adopting digital health tools. This age group is also disproportionately affected by ACL injuries, making them a natural early user base [8]. Their support will be driven by the ability to receive real-time feedback on exercise form without a therapist present, increased flexibility to complete rehabilitation on their own schedule, and greater confidence and motivation from measurable, reassuring progress. These three components (convenience, accurate guidance, and confidence during their rehabilitation) are what we will need to address in our product. Additionally, addressing concerns about whether the device is easy and safe to use is critical.

Physical therapists are likely to be supportive of this product because it can save them time and effort by reducing the need for frequent in-person check-ins while still allowing them to monitor patient progress effectively. Their behavior will be driven by whether the system genuinely streamlines, not complicates, their workflow, so it is essential that creating and adjusting rehabilitation plans is simple, intuitive, and allows therapists to add new exercises beyond those already included in the app. We also need to address any concerns about job displacement by clearly positioning the product as a tool that enhances the quality of their care rather than replacing their expertise. Maintaining a strong relationship with therapists is critical, as they must feel confident that the technology supports their ability to track and guide patients' recovery. Overall, when these needs are met, their support for our product will be strongly positive.

Physicians will likely be neutral toward this product, as they will have little to no direct involvement with its use. We will need to ensure that the product's role is clearly communicated as a tool used solely by patients and physical therapists, with no added responsibilities placed on the physicians. Maintaining a positive relationship with them is still important, however, as they still recommend rehabilitation options to patients, but their day-to-day engagement with the product will be minimal. To summarize:

Stakeholder	**Level of Power/Control**	**Unique Characteristics**	**Key Issues**
Patients	High	Tech-savvy early adopters (ages 18–35), highly motivated to recover efficiently, value flexibility and real-time guidance during rehab.	Need accurate real-time feedback, desire for flexible scheduling, varying levels of comfort with technology, require reassurance that at-home exercises are safe and effective.
Physical Therapists	High	Responsible for creating and adjusting rehab plans; oversee patient progress; rely on efficient workflows and clear data.	Rehab-plan creation must be simple, ability to add custom exercises is essential, must feel the product supports

			and does not replace their role
Physicians	Low	Diagnose injuries and refer patients but have little to no involvement in day-to-day rehab	Need assurance that the tool supports patient recovery to promote it to patients

Figure 5. Data for 3 Most Important Stakeholder Groups

4.1.4 Market analysis

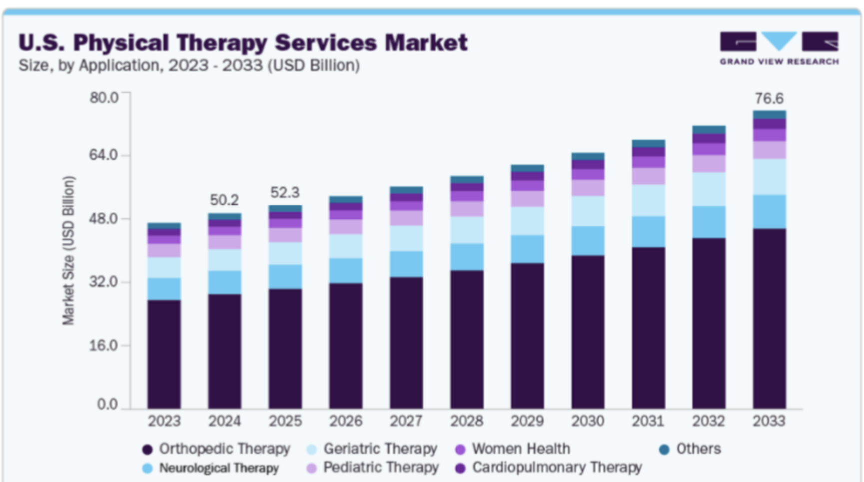

Figure 6. Data for physical therapy service market

The U.S. physical therapy market is large and expanding, driven by increasing musculoskeletal (MSK) injuries, post-surgical rehabilitation, sports participation, and an aging population. In 2024, physical and occupational therapy providers generated roughly $53 billion in revenue, and the overall PT market is projected to reach $76.6 billion by 2033 [11,12]. Within this space, knee rehabilitation represents one of the largest subcategories because ACL tears alone exceed 200,000 cases annually, and knee injuries account for a significant share of orthopedic PT visits [13]. Digital MSK solutions, which include motion-tracking devices, remote rehabilitation platforms, and sensor-based monitoring systems, represent a rapidly growing subsector, as providers continually shift toward hybrid and home-based PT models. As previously stated, three companies currently dominate technology-enabled PT: Hinge Health, Sensoria Health, and Reev. Their costs vary widely but remain high across the board. Hinge Health typically charges employers and payers several hundred to over a thousand dollars per enrolled patient through multi-year contracts. Sensoria's Smart Knee Brace is sold to clinics at a premium due to its hardware and software licensing costs. Reev focuses on neurorehabilitation and uses specialized, clinic-oriented pricing. Overall, existing solutions are expensive and generally inaccessible for many patients and smaller clinics.

Across this landscape, three major market segments emerge. Post-surgical knee rehabilitation patients (Group A) perform large volumes of home exercises and need accurate form correction and measurable progress tracking. Their current options range from paper instructions to devices like Sensoria's brace. Conservative-treatment knee injury patients (Group B) which includes those with chronic pain, ligament strains, patellofemoral issues, or overuse injuries often lack consistent guidance and motivation, making digital programs like Hinge Health appealing but still limited in objective feedback. Physical therapy clinics and rehabilitation networks (Group C) need solutions that improve workflow efficiency and patient adherence, yet their existing options include EMR-linked systems, manual assessments, and high-cost platforms like Hinge Health, Sensoria, and Reev. Across all segments, unmet needs consistently include real-time corrective feedback, clear progress tracking, improved motivation and adherence, and seamless integration into clinical workflows. Willingness to pay varies across segments. Post-surgical patients are highly motivated and may accept moderate out-of-pocket costs or insurer-covered fees if a device reduces re-injury risk. Conservative-treatment patients are more price-sensitive but may pay for guidance that prevents further injury or surgery. PT clinics and rehabilitation networks are willing to invest in higher per-unit or licensing costs when a system improves workflow efficiency, boosts adherence, and provides billable or reportable outcomes data. Ultimately, identifying the optimal target market depends on where need, willingness to pay, market accessibility, and openness to new technology align.

Our MVP is best positioned for adoption by Groups A and C, as it is designed to support patients recovering from ACL surgery while enabling physical therapists to monitor progress and easily adjust treatment plans. Our primary target audience will consist of individuals aged 18–35, who represent the population most prone to ACL injuries [14]. This group is highly motivated to recover fully to avoid long-term complications and is generally tech-savvy, making them well-suited for digital rehabilitation solutions.

<u>Demographics and Communities Answers</u>

1. The design is intended for patients recovering from knee injuries, especially post-surgical patients, and for physical therapists who monitor rehabilitation. It has the potential to serve thousands of knee injury patients annually in the U.S. alone.
2. Patients will use the product during their prescribed home exercises while physical therapists will review the recorded data to adjust treatment plans. The amount of time spent per day varies based on the severity of the patient's injury and their specific treatment plan.
3. Clinics and rehab centers will be the direct purchasers, but the final users are the patients and therapists.
4. The device primarily benefits individuals undergoing knee rehabilitation, regardless of demographic group, and does not inherently disadvantage or harm any specific community. However, this could change once we determine a price to sell the product at. (e.g., smaller clinics may have trouble purchasing it)
5. The design follows medical device regulations and data privacy standards. The system handles patient data using encrypted communication and secure authentication, which aligns with HIPAA-aligned practices. Also, there are no invasive sensors or force applied to the limb that pose physical risk to the patient. It supports monitoring but does not diagnose medical conditions or replace clinical judgement. Data stored in the database has RLS policies and secure schema architecture, meaning only authenticated physical therapists and corresponding patients can view or upload rehabilitation data.
6. Benefits include faster recovery and improved adherence to prescribed exercises, while potential risks involve data privacy issues and safety concerns related to the brace's wires and sensors

<u>Business Competitor Answers</u>

1. Yes, our design competes fairly with other existing products and businesses.
2. The device can serve as the foundation of a new rehab-technology company by differentiating itself through real-time corrective feedback, gamified motivation, accurate

sensor-based hardware, comprehensive progress tracking, and personalized rehabilitation that will all be integrated into a single, unified product.

3. Certain elements, such as sensor calibration algorithms, data-processing methods, or app software, will function as trade secrets accessible only to the internal engineering and leadership team.
4. It is unlikely to threaten local businesses because it supports rather than replaces physical therapy services, strengthening clinical care rather than competing against it.

4.1.5 Scientific, technical and financial a-priori feasibility

Our concept appears scientifically, technically, and financially feasible for multiple successful iterations. The brace itself uses reliable sensing technologies, such as IMUs and flex sensors, to capture knee joint movement, acceleration, and positioning during rehabilitation exercises. These components integrate into a simple hardware configuration involving a knee sleeve, a microcontroller, and basic wiring, keeping prototyping costs under $100 per unit and allowing for frequent refinement. On the software side, the mobile application is highly adaptable: adding new features and adjusting feedback logic can be done quickly, and incorporating additional exercises into the app is relatively straightforward. The more challenging aspect will be determining which biomechanical variables (e.g., acceleration) must be captured for entirely new exercises, which may require modifying the brace or adding new sensing elements. Even with these considerations, however, the combination of low-cost hardware and the ability to rapidly change the app's features, supports strong feasibility for creating more advanced versions in the future.

4.1.6 Need statement

Patients need real-time feedback when performing their home-based exercises. The current problem is that individuals recovering from injury often complete their rehabilitation exercises without knowing whether their form is correct. This issue primarily affects younger, active patients undergoing ACL tear recovery. The desired outcome is to improve adherence, accuracy, and confidence during at-home exercises, ultimately leading to quicker recovery.

4.1.7 Critical (a.k.a., Heilmeier) questions

1. We are developing a product that allows users undergoing physical therapy to accurately monitor their form in real time while performing their rehabilitation exercises. Users will also be able to track their progress over time and engage with gamified elements that make the rehab process more enjoyable and motivating.

2. Today, patients rely heavily on in-person sessions with physical therapists to assess their movement quality. When completing exercises at home, most patients have no real-time feedback on form. Digital rehabilitation tools do exist, but are limited as they either lack precise motion-tracking capabilities or are too expensive. As a result, when patients perform exercises at home, they lack reassurance that they are performing movements correctly.

3. The new aspect of our product is that it brings together all the existing solutions for improving compliance with home-based exercises into one integrated system. It provides real-time feedback, progress tracking, gamified features to boost motivation, and hardware that delivers accurate motion-tracking capabilities. No current product does all of this.

4. Mainly patients undergoing physical therapy and physical therapists. Patients benefit directly from better form, faster recovery, and increased motivation. Physical therapists benefit from being able to monitor patients more efficiently and improve outcomes without increasing workload.

5. If we are successful, patient adherence to rehabilitation plans will significantly improve, addressing one of the biggest challenges in the space. Additionally, we will make the traditional monotonous recovery process more engaging through the gamified features integrated into our product.

6. Risks include physical therapist adoption and the technical challenge of achieving precise motion tracking. Payoffs include a more advanced rehabilitation system that benefits both patients and physical therapists.

7. The cost to build our MVP is relatively low, totaling just under $85. Most of the expenses come from materials, including one Adafruit IMU, one Adafruit flex sensor, one Arduino Nano 33 BLE Sense Rev2, and a knee sleeve.

8. Developing the mobile application for our MVP required roughly two months, while building and testing the knee brace took about one month. The time needed to create additional braces will likely decrease as the process becomes more efficient.

9. Midterm exam

- Working wearable sensor that accurately detects knee movement
- Functional real-time feedback prototype
- Basic app interface with simple progress tracking
- Initial testing to show reliable movement detection

10. Final exam:

- Fully functional product where patients can complete full exercise routines with accurate feedback
- Therapist dashboard that allows plan customization and progress monitoring
- Testing to validate that the product works consistently in real-world rehab scenarios

5 Design specifications and constraints

5.1 Design specifications

<u>Performance</u>

The product must accurately collect movement data during prescribed exercises and provide real-time visual feedback in the mobile app indicating whether the user is performing the exercise correctly. Initial "heartbeat" functionality includes reliable sensor readings, data transmission, and clear feedback. Additional features include progress tracking, therapist dashboards, and customization of exercises.

<u>Product Size and Shape</u>

The brace size and shape are flexible during prototyping if it functions reliably and securely holds the sensors in place. For the final product, however, the brace should be streamlined and minimalist, lightweight, low-profile, and easy to wear, while still maintaining full functionality and stability. The product size is about 10” x 6” measuring in at about 5 ounces.

Aesthetics

The brace must be visually appealing and user-friendly, with all sensors and wiring concealed in internal pockets or sleeves so that nothing protrudes or irritates the user. The color scheme should match the app’s design for a cohesive experience, and the brace material must feel smooth, comfortable, and be easy to slide on. Sizing may involve multiple brace sizes or an adjustable one-size-fits-all option.

Ergonomics

The brace should fit comfortably around the knee, prevent skin irritation, and allow unrestricted range of motion. It must be easy to put on and remove, safe for repeated use, and designed so that components do not poke, scratch, or create pressure points.

Operating Environment

The mobile app must run smoothly on both iOS and Android and be freely downloadable from the Apple App Store and Google Play Store. The brace materials must withstand typical home exercise conditions, including sweat, varying temperatures, and repeated tension without poor performance.

Life Cycle

The brace should remain functional for at least 12–18 months of regular rehabilitation use, with durable materials that withstand daily stretching and movement. The electronics should support repeated charging cycles without significant wear, and the software ecosystem should allow the device to remain relevant through app updates rather than requiring frequent hardware replacement.

Maintenance

The product should require minimal maintenance. Firmware and app updates should be limited to minor performance improvements or small feature additions and should not disrupt regular use. The brace itself should only require simple cleaning and basic care. All technology in the brace should be easily removed so it can be washed.

Design Parameter	**Acceptable (Minimum Requirement)**	**Desired (Preferred Specifications)**
Performance	Detects basic knee flexion and extension movements and provides real-time feedback on the correct form.	Detects movement for any given exercise and provides real-time feedback on the correct form.
Product Size and Shape	The brace can be as large as needed, provided it securely holds all sensors, ensures they function properly, and can fit on a knee.	The brace is designed to fit any leg size or width from the foot to the knee.
Aesthetics	The app and brace can have any design as long as they both function properly.	The brace has a clean look with concealed wiring. The app has a consistent style.
Ergonomics	The brace is designed to fit on one’s leg for testing.	The brace is designed to fit any leg size and withstand stretching.

Compatibility	The app can function and be tested on an Apple iPhone.	The app can function on both IOS and Android devices.
Durability	The brace can function for a leg extension and flexion exercise.	The brace can function for the duration of any given rehab plan.

Figure 7. Product parameters and requirements

5.2 Design constraints

Resources

The team is limited by the number of members available for hardware prototyping, software development, testing, and user research, as well as the equipment accessible through the University of Miami

Budget

The project must remain within a modest student-level budget; meaning materials, sensors, and microcontrollers must be low-cost and commercially available. Large-scale fabrication or specialty manufacturing processes are not feasible at this stage.

Time

All functional prototypes and testing iterations must be completed by April 2026, placing strict constraints on development cycles, user testing, and refinement of both hardware and software.

Materials

All brace materials must be safe for prolonged skin contact, sweat-resistant, and comfortable, while also being affordable and easy to source. Electronic components must be compact and durable.

Manufacturability

The design must be simple enough to fabricate consistently.

Environmental Factors / Sustainability

The product should minimize waste by using durable materials and standard electronic components that can be replaced individually rather than disposing of the entire brace. At end-of-life, fabric components should be recyclable or easily separated from electronics for proper disposal.

Biomedical / Regulatory (IRB, FDA, Liability

Because the product provides corrective feedback during physical therapy exercises, it may eventually fall under FDA Class I or II guidelines if commercialized. While clinical trials are not required for early prototypes, the design must avoid making medical claims that trigger regulatory scrutiny and must prioritize user safety to minimize liability.

6 Concept generation and screening

6.1 Information gathering

When deciding how we were going to build the brace and app we followed this process. Our first step was to define exactly what movement variables we wanted to capture during the leg extension and flexion exercise and then identify the components required to measure them. To guide this process, we reviewed motion-capture research to understand how previous studies recorded human movement and what technologies were used. One article we identified noted that inertial sensors, such as accelerometers and gyroscopes, provide an accurate and reliable method for studying human motion. These sensors are especially appealing because they are small, portable, and can be used outside of a traditional motion-capture laboratory [15]. We also reviewed studies focused specifically on leg extension and flexion exercises and the tools used to capture movement data. One study showed that by combining acceleration and angular velocity data from IMUs placed on adjacent limb segments, it is possible to accurately compute flexion and extension joint angles [16]. For the app, we consulted with our teaching assistant, Alex, to determine the best development approach, and collaborated closely with James from the Untethered group to learn the basics of using Cursor and GitHub, the platforms we used to build our application.

When selecting the sensors to measure leg acceleration and position during the exercise, we drew on both prior knowledge and the research we reviewed. IMU sensors were a strong choice because they contain both accelerometers and gyroscopes. Additionally, one of our team members had previous experience working with IMUs and Arduinos, which made this approach practical for analyzing the data and comparing the brace's recorded movement to the "correct" movement patterns provided by a physical therapist. To measure knee flexion specifically, we incorporated a simple flex sensor.

6.2 Generation of alternatives

During brainstorming, we evaluated several additional sensing approaches before selecting our final design (IMUs + flex sensor). Our initial idea was to use electromyography (EMG) sensors to measure electrical activation of the quadriceps and hamstrings during leg extension and flexion. However, we realized muscle activation did not directly translate to joint angle, and EMG signals are highly sensitive to noise and user variability. We also explored an elastic technology concept, where a stretchable band integrated into the brace would use conductive ink or a resistive polymer to detect strain as the knee bends. This idea was appealing because it would be a lightweight design, but it came with major limitations. For example, stretch-based sensors drift over time, leading to inaccurate data collection and vary depending on how tightly the brace is worn. Our third alternative was a three-sensor kinematic system, which involved placing small sensors on three anatomical points of the leg such as the kneecap, upper leg, and tibia to compute joint angle using multi-point motion tracking. We believed this idea would produce the most precise data, but mounting three sensors consistently on different locations of the leg added significant mechanical complexity. For example, each sensor would have to be positioned at the exact same location every time an exercise is performed to ensure accurate angle calculations. Minute shifts, caused by the brace slipping or by users tightening the straps differently, would change the relative angles between sensors and produce incorrect kinematic data.

Figure 8. Concept sketch of our EMG sensor knee brace

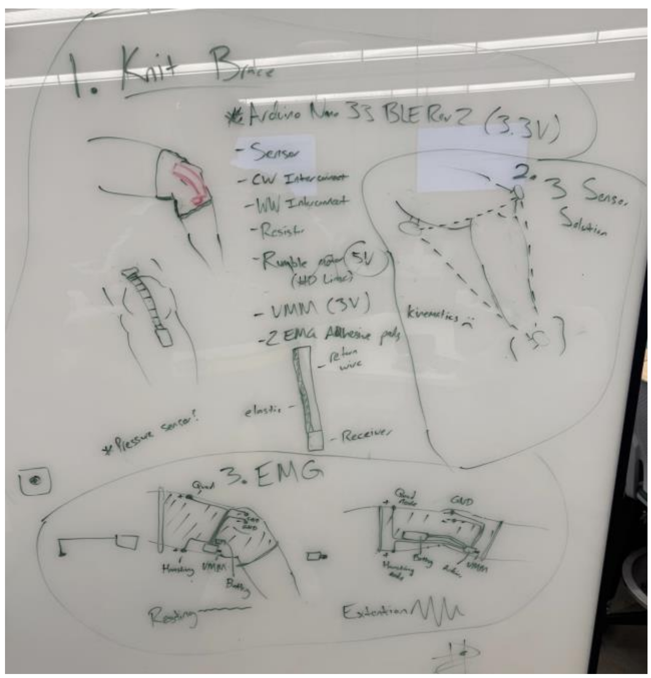

Figure 9. Concept sketches of different sensor approaches

6.3 Alternative selection

To compare the four sensing concepts, we evaluated each one across the following four metrics:

Precision: How accurately can the sensing method measure the true movement or joint angle.
Reliability: How consistently the sensing method produces correct, repeatable data across different conditions.
Setup Complexity: How difficult the system is to assemble, position, and calibrate each time it is used

Mechanical Difficulty: How challenging it is to physically mount the sensors on the brace so they function correctly.

In the figure below, green boxes indicate strong performance on that metric, while red boxes indicate weak performance.

	Precision	Reliability	Setup Complexity	Mechanical Difficulty
IMUs + Flex Sensor	**Medium/High** – IMUs + flex sensor together give stable joint-angle estimates.	**High** – Secured directly on the brace, minimal signal variability.	**Low/Medium** – Only two sensors placed once	**Medium** – Requires some integration work, but mounting is repeatable and stable.
EMG Sensors	**Low** – Muscle activation doesn't directly map to joint angle.	**Low** – Highly sensitive to sweat, skin prep, and electrode placement.	**High** – Requires exact skin placement + calibration for each use.	**Medium** – Electrodes are easy to attach but fragile and shift easily.
Elastic Technology	**Low** – Stretch readings drift and vary with brace tightness.	**Low** – Elastic materials lose tension and change baseline over time.	**Low** – Simply pull on the brace; no precise placement needed.	**Low/Medium** – Easy to embed but difficult to keep consistent tension.
Three-Sensor System	**High** – Multi-point IMUs produce very accurate angles.	**Medium/Low** – Small shifts in sensor position ruin calculations.	**High** – Must align 3 separate sensors at exact anatomical points.	**High** – Hard to secure sensors so none of them move independently.

Figure 10. Comparison of Sensing Methods

7 Concept

7.1 Concept

The functionality of our product can be shown through journey flows from both the patient's and the physical therapist's perspectives. The movement of data throughout the system can be illustrated in a technical flow.

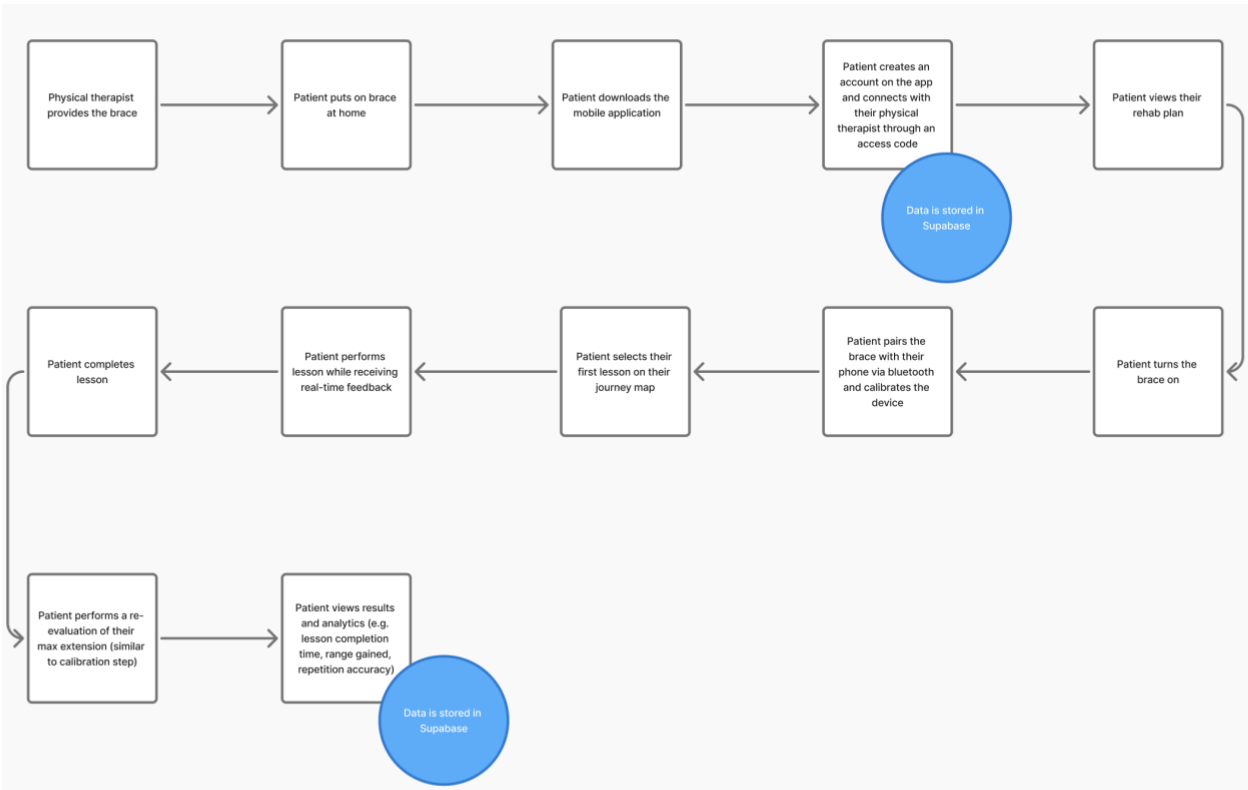

Figure 11. Patient's journey flow

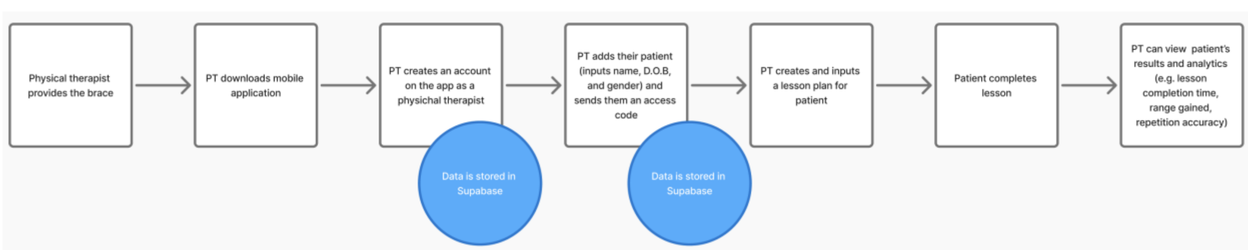

Figure 12. Physical therapist's journey flow

To summarize, physical therapists create personalized rehabilitation plans in the app, and patients complete the assigned exercises while wearing the brace. As they move, patients receive real-time feedback and can view their progress through the data and statistics provided after each exercise.

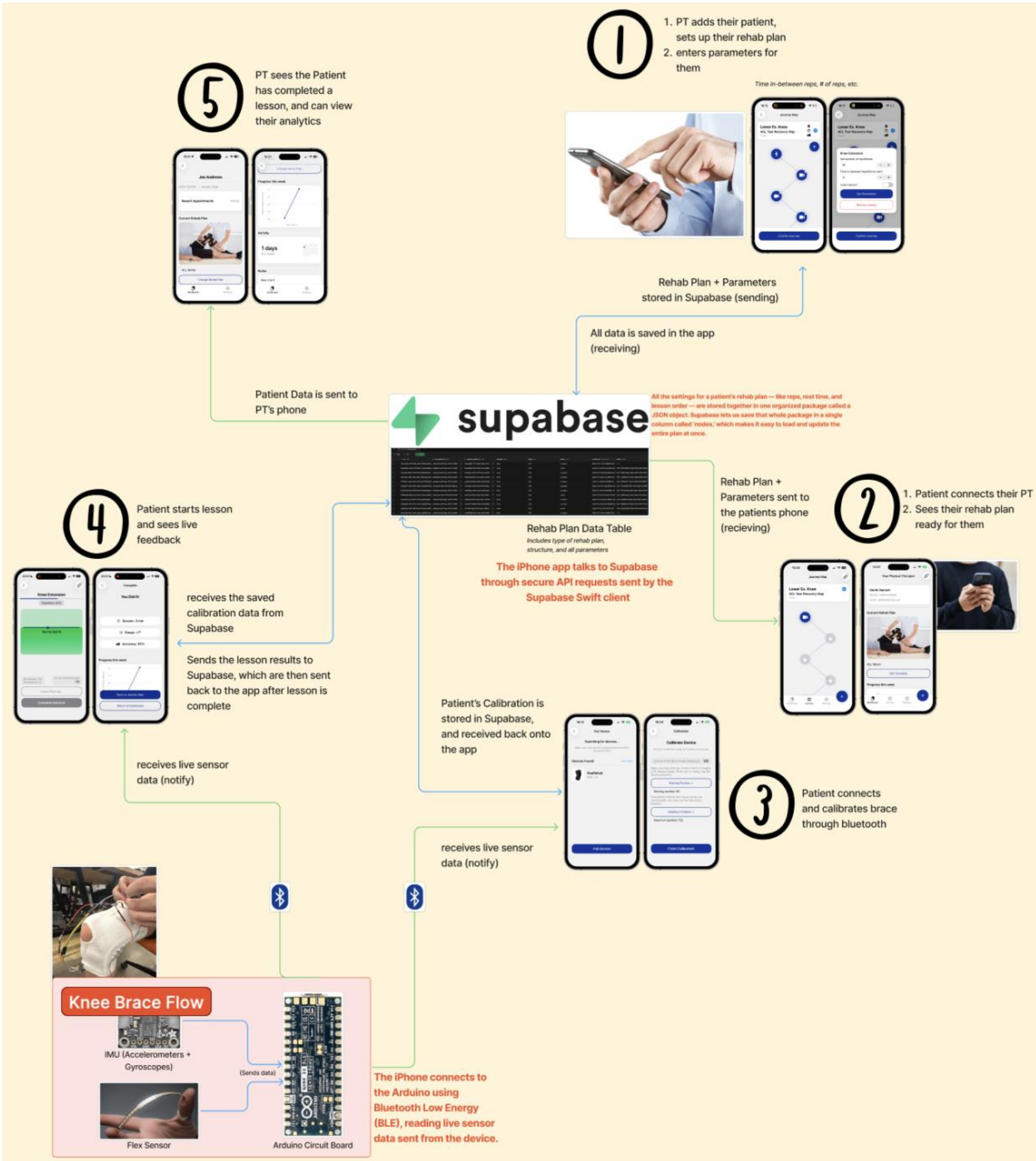

Figure 13. Full technical flow

7.2 Production feasibility

Most existing models are simplified versions of our product, often using a single sensing modality such as a flex sensor or a basic IMU. We used one such model from prior research as inspiration for our current brace design [17]. Our version incorporates both a flex sensor and IMUs to capture knee flexion and extension more accurately by combining bending-angle data with acceleration and angular-velocity measurements. Existing open-source IMU libraries (such as Adafruit AHRS, Madgwick, and Kalman filter implementations) allow us to process and fuse sensor data without developing these algorithms from scratch. Our team's experience also strengthened the feasibility of this project. One team member had prior experience working with IMU sensors, Arduinos, and Bluetooth communication, which streamlined the process of assembling the electronics and troubleshooting any issues. Another team member contributed design experience, allowing us to adapt existing knee brace templates to ensure proper fit, comfort, and sensor placement. These combined skill sets enabled us to focus on building only the components necessary for our prototype while relying on established algorithms, open-source code, and widely available hardware.

8 Proof of concept (killer experiment)

8.1 Requirements

Our killer experiment was completing one full lesson in the rehab journey plan created by the physical therapist. This test required that the live feedback from the flex sensor, which measured leg angle in degrees, and the IMUs, which measured leg positioning, be displayed accurately on the lesson screen so the patient could visualize their movement in real time. We knew this feature worked because we conducted several trial runs using the brace on each of our own legs and performed the movements displayed on the app to follow the animation.

To validate the system, we set up four different error scenarios. The first was if the patient moved too slowly compared to what the physical therapist prescribed, in which case the app displayed an error telling them to go faster. The second was if they moved too fast, where the screen flashed red and told them to slow down. In both cases, the patient had about a 10-degree grace range to stay within. Since the user records their maximum extension during calibration, they are expected to reach that maximum during the lesson, and if they did not reach it within a 5-degree grace zone, the app flashed red. If they exceeded their maximum extension, the rep was counted. Lastly, if the patient shifted their thigh more than about 5 inches to the left or right, the app instructed them to straighten their leg.

Our killer experiment was successful because we confirmed that the live data was read with low latency, meaning the feedback was accurate. The parameters set by the physical therapist, such as total reps and the timing between reps, were also transferred correctly to the patient account and were fully reflected in the lesson. Not only did the real time feedback function accurately, but all intended error messages appeared correctly when lesson goals were not met. We repeated this test 15 times before recording the final iteration of the lesson to make sure it was consistent every time.

8.2 Implementation

We implemented a function in the swift app code to translate the flex sensor readings, where values around 300 were attributed to 180 degrees of leg angle and values around 185 were attributed to 90 degrees. The function used was degrees = 90 + ((sensor value – 185) / 115) x 90. We also confirmed that the degree values mapped to the flex sensor were accurate by holding the leg at known reference positions, including 90 degrees and 180 degrees, and verifying that the corresponding sensor values (185 and 300) remained consistent across all team members. When the user calibrated the device to their personal range of motion, the system took their maximum extension value, for example 160 degrees, and matched that to the top of the animation box on the lesson screen, while the bottom of the box represented their resting position, for example 90 degrees. We also mapped the IMU readings so that negative values represented moving the leg to the right and positive values represented moving the leg to the left. When moving the leg about 5 inches in either direction, that corresponded to about 7 numerical units on the IMU, meaning the range of negative seven to positive seven. When the user clicked "Begin Lesson" on the screen, the IMU values were zeroed out in case they had shifted their leg before the lesson began, to prevent inaccurate readings. Our proof-of-concept demonstration was to complete 15 of these lesson tests to validate whether the sensor readings were accurate, whether there was any latency, and whether the correct error messages would appear for each type of incorrect form.

After testing, we were pleased to find that in each of the five cases of incorrect movement, including not extending far enough, moving too quickly, moving too slowly, shifting the leg right, and shifting the leg left, the proper error messages appeared every single time to guide the user into proper form. In addition, the maximum and resting position values from calibration were successfully transferred from the database. The horizontal bar that represented the leg angle in degrees moved with low latency in relation to the real time leg movement, and the IMU accurately reflected the left or right leg positioning on screen using a blue dot that shifted with the user's movement.

8.3 Test protocols

To verify our killer experiment specifications, we designed a structured test protocol centered on real-time accuracy, error detection, and overall system responsiveness. Our evaluation was based on the following hypotheses:

Hypothesis 1: The most recent calibration data for rest and maximum extension stored in the database will translate accurately to the lesson screen. The calibration data will also transfer to the completion screen after the lesson is complete.
Hypothesis 2: The flex sensor will measure knee angle within an acceptable accuracy range during a full extension and flexion cycle.
Hypothesis 3: The IMU will correctly detect medial and lateral leg drift and map it accurately to the lesson screen.
Hypothesis 4: The real time feedback will have low enough latency that users can follow the animation without delay.
Hypothesis 5: The app will correctly deliver error messages for each type of incorrect movement.

Before the experiment, we noted the expected latency of the real-time data. The primary source of delay was the Bluetooth polling interval, which reads new sensor values every 100 ms. Additional BLE processing, parsing, state updates, and UI rendering introduced smaller delays. Altogether, the expected latency from sensor reading to animation ranged from 100-150 ms. Although this appeared in nearly real time during use, documenting the estimated timing was essential for validating Hypothesis 4. To reduce sensor noise and improve signal stability, we added an averaging function in the Arduino code that calculated the average of every 15 flex sensor readings and every 5 IMU readings. This reduced the static noise by approximately 95% during one-minute stillness tests. We also implemented a drop-correction filter that replaced any sudden drop greater than 70 value points with the previous value for the next three outputs, which prevented the horizontal bar from falling abruptly during leg raises. These modifications were validated by counting the total number of times the flex sensor value dropped unexpectedly during each lesson trial.

We conducted 15 total trials, five per team member. Before every trial, the user re-calibrated the brace to independently test calibration transfers for Hypothesis 1. The user completed a full knee-extension lesson while we observed whether the angle bar tracked movement smoothly, whether the IMU dot responded accurately to left-right drift, and whether latency remained within the expected range. To evaluate error detection for Hypothesis 5, the user intentionally performed each incorrect movement scenario: moving too slowly or quickly, failing to reach or exceeding full extension, and shifting the leg right and left. For Hypothesis 6, we verified that the lesson completion screen plotted a new max extension value in degrees on the graph and correctly displayed the range gained.

The values recorded in our tables corresponded to a specific hypothesis. Calibration Transfer (y/n) indicated if the most recent calibration values were carried correctly into the lesson and also if the range gained was plotted on the graph post-lesson. Flex Sensor Drop Count recorded how often the angle bar dropped unexpectedly. IMU Shake Count captured unintended jumps in IMU readings. Correct Error Messages (%) reflected if the app reflected the appropriate error message displayed over the total amount of errors performed. Latency (ms) was calculated by using an Xcode console output averaging function to record the time difference between each sensor update and the corresponding UI update. These readings were reported in the Xcode console after each lesson was complete.

The rationale behind these protocols was to simulate real use as closely as possible. Since our heartbeat and functional requirement involve real time feedback, accurate representation of motion, consistent calibration transfer, and reliable error pop-ups, testing a complete lesson under correct and incorrect movements allowed us to validate all critical scenarios in a repeatable format. To record our quantitative data, we developed a table that would be used for each team member:

Trial	Calibration Transfer (y/n)	Flex Sensor Drop Count	IMU Shake Count	Correct Error Messages (%)	Latency (ms)
1					
2					
3					
4					
5					

8.4 Results

<u>Qualitative Findings</u>

- The lesson showed low enough latency to provide stable and consistent real-time feedback from the sensors, allowing the user to watch the bar representing their movement on the screen and move accordingly. The bar moved with the user's leg movement smoothly and predictably.
- The calibration data was always saved correctly, and it was always transferred to the lesson screen accurately as new data was collected from each trial. The reassessment calibration data taken at the end of each lesson was also saved and correctly plotted on the graph at the completion screen.
- The readings from the flex sensor only dropped a few times throughout the entire experiment. This demonstrated that the averaging function we included to reduce noise, as well as the function that re-output the previous value for the next three outputs if the reading dropped by 70 points, worked considerably well.
- The amount of noise on the flex sensor overall was very low. We noticed only a few instances where, when the user's leg was completely still, the bar shifted slightly on the UI and the value changed a little. Overall, when the user's leg was still, the horizontal bar did not move most of the time.
- The readings from the IMU were very accurate in terms of the orientation of the user's leg. The dot on the lesson screen only moved when the user's leg moved, and it showed very little noise. Because the leg is never perfectly straight during the movement, the dot shifted slightly left and right, which accurately represented the user's positioning. The IMU never jumped value points or changed dramatically at any point during the experiment.

- The correct error messages were displayed for each intentional mistake made by the user during every experiment. There was not a single instance where an incorrect or unrelated error message appeared. After each error occurred, the test resumed after a three-second countdown, and the rep was never counted, as intended in the code. The errors appeared for four seconds unless the user drifted too far left or right, in which case the error disappeared once the user returned to the correct position.
- The latency varied slightly across different trials. This was due to changes in voltage flowing through the sensors on the brace or fluctuations in the Bluetooth connection between the Arduino and the app. Overall, the latency was never above 140 ms.
- Finally, the placement of the sensors and the Arduino was consistent throughout the testing. The flex sensor was securely held with Velcro tape and resistor wires, while the IMU and Arduino were held securely onto the brace by piercing the header pins into the fabric.

<u>Quantitative Findings:</u>

Table 1. Nikiel – 5 Trials

Trial	Calibration Transfer (y/n)	Flex Sensor Drop Count	IMU Shake Count	Correct Error Messages (%)	Latency (ms)
1	y	0	0	100%	112
2	y	0	0	100%	118
3	y	2	0	100%	105
4	y	0	0	100%	121
5	y	1	0	100%	127

Table 1. Sean – 5 Trials

Trial	Calibration Transfer (y/n)	Flex Sensor Drop Count	IMU Shake Count	Correct Error Messages (%)	Latency (ms)
1	y	0	0	100%	109
2	y	1	0	100%	131
3	y	0	0	100%	115
4	y	0	0	100%	136
5	y	0	0	100%	108

Table 1. Charlie – 5 Trials

Trial	Calibration Transfer (y/n)	Flex Sensor Drop Count	IMU Shake Count	Correct Error Messages (%)	Latency (ms)
1	y	0	0	100%	124
2	y	0	0	100%	119
3	y	0	0	100%	129
4	y	0	0	100%	111
5	y	0	0	100%	138

Based on the latency values recorded during the experiment, the average latency was approximately 120 milliseconds with a standard deviation of 11.2 milliseconds. This indicates the app paired with the device performed consistently with minimal variation between trials. The lowest observed latency was 105 milliseconds and the highest was 138 milliseconds, both within the expected 100-150 millisecond range. Across all trials, calibration transferred successfully 100 percent of the time, and the correct error messages appeared in 100 percent of the intentional error scenarios. The flex sensor drop counts totaled only 4 times across all 15 lesson iterations, while the IMU shake count was consistently 0. These quantitative results support our hypotheses that the MVP was stable, accurate, and repeatable for future knee extension lessons.

8.5 Discussion

Using the results of the killer experiment, we were able to determine that all of the functions used to average the flex sensor and IMU values, reduce noise, translate flex sensor readings into appropriate degree values, and prevent sudden drops in the flex sensor output performed reliably enough to move forward with recording our final testing of the app paired with the device. The horizontal bar that mimicked the movement of the user's leg matched the physical movement as closely as possible within the limitations of the hardware. Although there was still latency within the app, it was not significant enough to require a change to the hardware or the code at this stage in the project.

The experiment also demonstrated that our chosen sensors were strong choices for calculating the range of the leg in degrees and determining its orientation in space. These findings also implied that other sensor options described earlier may not have been as accurate or practical for achieving our goal of providing real-time positional and angular feedback. Based on these results, we incorporated several adjustments into our final MVP implementation plan. We modified portions of the Swift UI code to remove unnecessary notifications and repetitive functions, which allowed us to improve latency by a small but meaningful amount. We also reviewed the averaging and stability functions within the Arduino code to ensure that everything was optimized to reduce the likelihood of value drops. After examining the hardware, we identified that the occasional flex sensor drops could be caused by inconsistent soldering, as well as splitting the 3.3V power output from the Arduino to power both the flex sensor and the IMU. This split likely contributed to small voltage fluctuations that caused occasional drops in the flex sensor readings.

Several qualitative insights from the experiment informed our next steps for the prototype. Because we occasionally noticed drops in the flex sensor readings, we may need to re-solder the sensor wiring and reconsider how the sensor is mounted on the brace. For next semester, the key considerations will include implementing more consistent sensors or improving the wiring and soldering to eliminate any current leakage. While the flex sensor remains a viable approach for measuring degrees of extension, we may also evaluate potential alternatives that could produce higher long-term stability. We will likely continue using IMUs, as they performed extremely well during testing.

We also plan to investigate whether a different Arduino board might provide advantages. Although we selected the Arduino Nano 33 BLE Sense for its built-in IMU and BLE capabilities, other microcontrollers may offer faster BLE performance and improved latency. Additionally, next semester could involve designing a more intuitive interface for the lesson itself. While the current representation of the flex sensor using a horizontal bar and the IMU using a dot worked effectively, we could explore more visually engaging or intuitive methods of presenting real-time movement feedback.

Beyond software changes, we will also focus on improving the brace's physical design to ensure sensor stability and consistent placement for all users. This will include creating a sleeker structure, sewing fitted pockets for the sensors, hiding and securing the wiring, refining solder joints, and implementing a proper rechargeable battery mounted on the brace. We also plan to incorporate haptic feedback using a coin motor so users can feel corrective cues during the lesson. This aligns with our broader goal of helping users "feel" their exercise performance rather than relying solely on visual feedback. Since we plan to add more lesson types to the ACL journey, such as squats, wall sits, or lunges, we will need to consider how the sensors will function with these movements, what the corresponding lesson screens should look like, and whether additional adaptations to the sensor code will be necessary. Overall, the results of our killer experiment strongly guided the refinement of our MVP and provided a clear direction for the enhancements we will pursue in the next phase of our prototype development.

9 Minimal Viable Product (MVP)

For our MVP, we aimed to create a functioning user interface for RealRehab in the form of a mobile application supported by a secure and fully operational backend database. The app includes essential authentication features that allow users to create accounts, store their information securely, and log in as either a physical therapist or a patient. Patients are able to sign in, view their connected PT account, and perform a rehabilitation lesson. Physical therapists can log in, add patients to their accounts, and create personalized rehab plans that are stored in the database and reflected on the patient's dashboard. Some components of the app are non-functional at this stage, such as the scheduling feature: patients can set up a schedule and save their preferences, but reminders, activity logging, and day-by-day tracking are not yet implemented. Additionally, for PTs, only the ACL rehabilitation plan is functional, while other injury pathways are placeholders for future development. Overall, the system's user interface contains the entire user journey flow needed and the backend functionality remains consistent and secure.

The second major component of the MVP is the physical knee brace. The brace incorporates three sensors: a flex sensor, an external IMU, and the IMU built into the Arduino. These work together to capture knee angle and leg positioning data. The Arduino receives all sensor inputs, processes them, and sends the translated values to the app using Bluetooth. The app connects to the brace reliably and delivers real-time feedback to the user during the lesson.

<u>The Heartbeat Feature</u>

The heartbeat of our MVP lies in completing the first lesson of the ACL rehabilitation journey map. The primary requirement for this heartbeat was ensuring that the patient could receive the rehab plan created on the linked PT account during authentication and begin the first lesson using the parameters the PT entered. Once the lesson parameters were correctly translated from the database into the app, the crucial functional requirement was determining whether the app could capture live sensor readings through the Arduino, display them accurately on the lesson screen, and save the results after the lesson was completed. The MVP successfully demonstrated this full flow: the PT creates the rehab plan, the patient receives it, the device pairs through Bluetooth, live data is displayed in real time during the lesson, and the results are saved to the database for the PT to review. The central heartbeat was the ability to display real-time data from the brace on the lesson screen, and this was achieved reliably in our MVP.

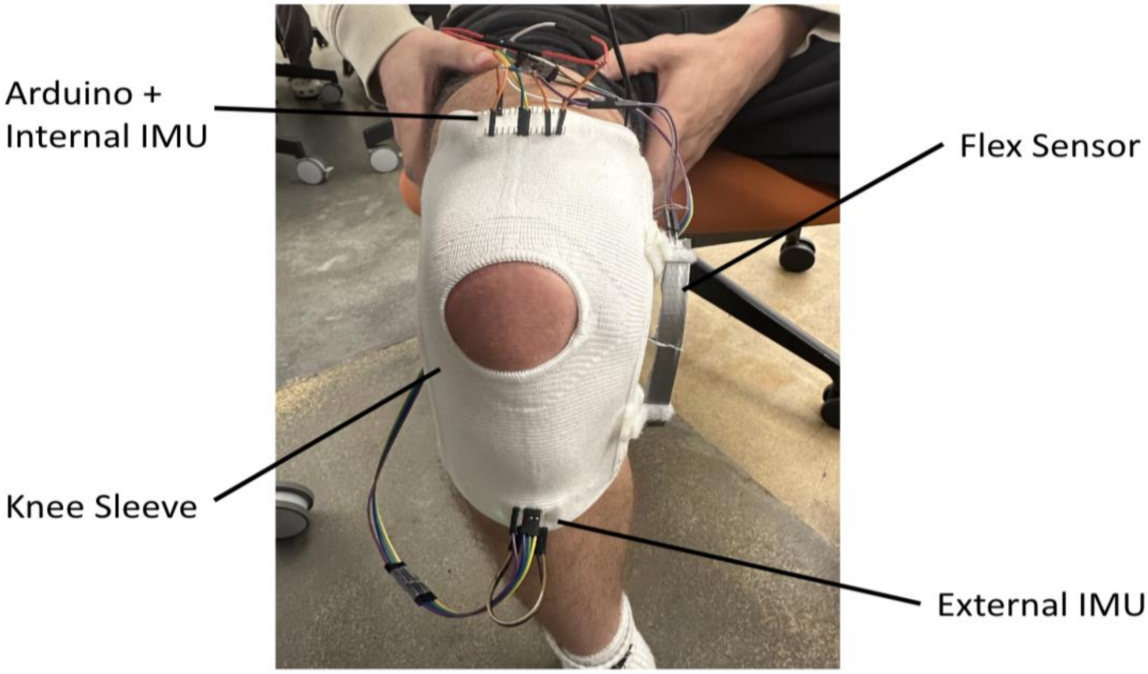

Figure 14. Minimum Viable Product

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11 Appendices

Documentation FigJam Link (click here)

This Figma documentation board is how our team kept track of all of our research, ideation, and stakeholder mapping. It contains the bulk of our project's organization and planning.

Materials

Item	Quantity	Supplier	Catalog #
Arduino Nano 33 BLE Sense Rev2 with Headers	1	Amazon	ABX00070
Adafruit 9-DOF Orientation IMU Fusion Breakout - BNO085	1	Adafruit	4754
Adafruit Long Flexor Sensor	1	Adafruit	182
Champion Knee Brace	1	Amazon	B00D6HDOOI

How Supabase Saves Rehab Plans

All the settings for a patient's rehab plan, like reps, rest time, and lesson order, are stored together in one organized package called a JSON object. Supabase lets us save that whole package in a single column called 'nodes,' which makes it easy to load and update the entire plan at once.

Acceleration and Positioning Equations For Kinematics