Wheelchair In-seat Monitoring Design Considerations Cliff Notes

Wheelchair in-seat activity trackers are developed to monitor and provide feedback about the pressure redistributing movements of wheelchair users, including weight shifts and other postural shifts that redistribute buttocks pressures.

From a design perspective, in-seat activity trackers reflect myriad design decisions that impact performance, function, and usability. Many, if not all, of these decisions involve interconnections across system components, and can have significant impact on tracker operation and user-experience. Technology developers will have to manage many benefits and trade-offs that accompany design of each subsystem. This document was created based upon real-world use of in-seat trackers to briefly identify design criteria and constraints that should be considered. This document offers a short summary and was based upon a more thorough document of design considerations which is publicly available in SMARTech at https://smartech.gatech.edu/handle/1853/54079.

To provide users with information about their sitting behavior, in-seat activity trackers generally consist of 3 subsystems operating together:

Hardware

A Seat Sensor mat which is comprised of an array of force or pressure sensors. The mat is placed below the wheelchair user, either above or below the wheelchair cushion.

A data acquisition & communication module that is connected to the seat sensor mat to collect sensor readings and transmit them to the mobile phone, either directly via Bluetooth or other wireless communications, or via a cloud-based system.

Classification algorithms

A computational process, using Machine Learning or other logic-based systems to classify seat occupancy and pressure redistributing movements using readings from the seat sensor array.

Mobile phone app

The user-interface that serves as the primary feedback and control mechanism for the tracker system. The app performs background functions such as managing communication with the module, monitoring hardware status, receiving data from the communication module and processing it into usable information. Foreground functions consist of leading user through any set-up or initialization process needed to configure the system, providing an interface to manage settings and report the module's status, such as battery level and connectivity, and presenting the in-seat activity to the user.

Hardware

- Seat Sensor Mat
  - Design:
    - Typically comprised of an array of individual pressure or force sensors; The number and spatial arrangement of the sensors impacts the ability to calculate the parameters used to reflect pressure redistribution activities.
    - Stay secure under the user
    - Be unobtrusive and not interfere with user's wheelchair setup or operation (e.g., use of powered seating functions)
    - Robust: no damage from movement, fluids, handling, etc.
    - Localized loading on certain sensors may be very high or very low. Factors that can lead to erroneous values include a sling seat, rigid seat base, hardware on a seat base, wheelchair cushion with a soft base or a rigid base with a discontinuous surface, or excessive seat dump. Erroneous values under these situations are influenced by sensor size, spatial layout, and characteristics and should be evaluated during seat sensor mat design.
  - Placement:
    - Regular postural movements should change loading on sensors
    - Sensor location must be consistent; if it changes with respect to the cushion, the measurement and classification of weight shifts will be impacted
    - The mat should be accessible to the user
    - Placement inside the cover results in a more portable system, but access to the module may be challenging.
    - If the seat sensor is attached to the chair, it may impact a folding chair; also consider if the module must also be attached to the chair.

- Data Acquisition and Communication Module
  - Physical connection to the seat sensor mat should be reliable and user friendly to a population with limited hand function
  - Be easily accessible for charging and visual feedback about system status
  - Consider ease of charging
    - If it is difficult to remove from the wheelchair, can the module be charged while still on the wheelchair? This has advantages, but the wheelchair must be easy to bring near an outlet.
    - Alternatively, the module should be easily removed for charging.
    - Users suggested wireless charging after removal from the wheelchair to eliminate the need to manage connections.
  - Loss of communication between the module and mobile will occur. Consider how this will impact system operations and usability. Some onboard data processing offers the advantage of transmitting processed in-seat activity metrics versus transmission of all seat sensor mat data.

Classification Algorithms

- Trackers can use a variety of methods to classify weight shifts. Because the seat sensor is placed below the cushion, these algorithms must manage force measurements that are impacted by the occupant, the type of cushion, and the wheelchair seat. A major design decision for the algorithm is how the classification algorithm defines changes in the force measurement will count as a weight shift. For example, an algorithm can consider a sustained reduction in magnitude of readings on one side of the mat versus the other in combination with overall movement of the center of pressure to classify a weight shift. Alternatively, an algorithm can define a minimum amount of the mat's center of pressure displacement to classify a weight shift.
- The chosen method will define the sensitivity and specificity of the system in accurately classifying weight shifts. As such, trackers should clearly describe the approach to the user within the system's documentation.
- Consider if algorithm will be implemented on board the data acquisition and communication module, on the mobile app, or in the cloud. Continuous Wi-Fi availability should not be assumed.
- Common Metrics: Occupancy, weight shift or pressure relief.
- Alternative Metrics: In-Seat Movement Score
- Occupancy is required in order to normalize the weight shift events to the amount of sitting time. Relatedly, goal attainment should accommodate the varying durations of sitting bouts which vary over a day.
- Provide clear description of the metrics that are reported to users because it will assist users in configuring the system and understanding the information being provided.

Mobile Phone App

- The mobile phone app performs multiple functions and has many requirements, including to 1) use the phone's communications features to find and connect to the module, 2) receive data and interpret status reports from the module 3) receive metrics from the algorithm and convert them into final display metrics, 4) Display useful information to the user about their activity and provide feedback, 5) receive input from the user to change criteria for identifying their activity, 6) receive input from the user to change criteria for feedback about their activity, and 7) guide the user through troubleshooting such as reconnecting to the module.

- Initialization:
  - To validly classify the seated environment, the use of an initialization routine is required to inform the classification algorithms. Typically, this requires the user to adopt a self-selected static posture as well as sequencing through a series of postural changes (i.e., reaches and leans) that mimic pressure-redistributing activities. This, in effect, 'individualizes' the tracker's response to the user's unique postural changes within the particular user-cushion-wheelchair configuration.
  - The tracker system can be designed for independent or assisted set-up (either in-person or remotely). Both have advantages and disadvantages. Regardless of the decision, real world use resulted in many instances that required users to set up the system again for varying reasons (new wheelchair equipment, new phone, etc.), so the design should always allow for independent user setup after the initial setup.
- Feedback
  - Passive: apps should allow users to visualize occupancy and weight shift activity on-demand, and both parameters should be normalized by occupancy. Comparison to user's goals is also useful.
  - Active: Notifies the users about their activity in relationship to their goals. Notifications can be done every time an expected event is missed, or as feedback (positive or negative) over a longer timeframe. Optimizing the frequency of active notifications is challenging and should be carefully considered. More than half of the participants found the notifications of every missed event (and continued notifications until event completion) were too frequent, and multiple users reduced their in-seat activity goals in order to reduce the frequency of notifications.
  - Data from user trials indicated that active notifications are effective at increasing the frequency of weight-shifting activities. All trackers should include the option for active notifications.
- Connectivity
  - Connectivity can be lost due to myriad factors, some of which are user factors. Many users struggled with the requirement to keep the app open in the background to maintain app functionality. Users should be clearly informed that the app cannot be exited if they want to receive accurate data and notifications. In addition, a system that does not experience data loss when the app is closed is preferable.
  - If the connection between the app and data acquisition and communication module is lost (due to proximity, low battery, Bluetooth connectivity, etc.), automatic reconnection is preferred to requiring user action. However, if user action is required to prevent data loss, thoughtful user notification is critical. When the disconnect first occurs, the problem may not be immediately solvable (i.e., the module might still be charging).