STATE OF THE ART WEARABLE SENSORS

- Radar technology is constantly evolving, and new applications are arising, particularly for the millimetre wave bands. A novel application for radar is gait monitoring for fall prevention, which may play a key role in maintaining the quality of life of people as they age.
- Fall prevention research focuses on identifying and controlling risk factors for falls. These risk factors can be broadly grouped into extrinsic and intrinsic factors, and both groups feature both controllable and uncontrollable factors.
- While external and uncontrollable risk factors are beyond the scope of patients and clinicians to exhaustively anticipate and manage, intrinsic and controllable factors represent a strategic target for interventions that can optimize patient awareness.
- **GAIT ANALYSIS**: Gait analysis is the systematic study of human movement during locomotion. . The gait cycle is defined as the interval on which one limb goes from a first heel contact to the next heel contact. Systems for gait analysis can be divided into three major groups: Non-Wearable Systems or context-aware systems (NWS), Wearable Systems (WS) and Combined Systems or fusion systems (CS).

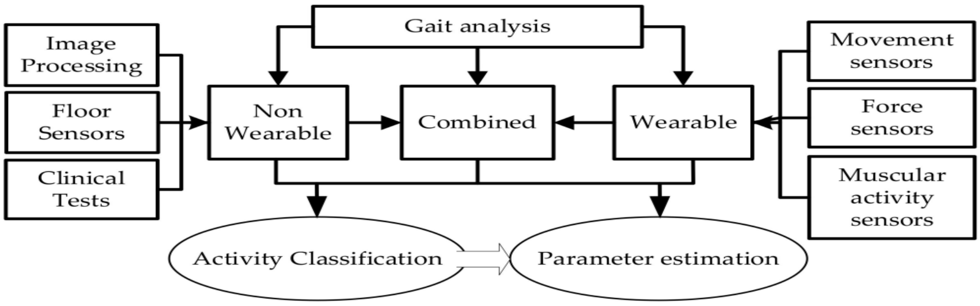

Figure 1. Classification of gait analysis systems. Gait analysis can be achieved using non-wearable and/or wearable systems. Both systems can achieve similar types of results but with significant differences in price, usability, resolution and accuracy.

- **PREVIOUS ATTEMPTS OF QUANTIFYING AND CLASSIFYING RISK OF FALL:**
  For example, Begg et al. focused on minimum foot-ground clearance during the swing phase to predict the risk of falling. Di et al. developed a motorized robot cane to provide guidance and obstacle avoidance using a laser range finder, and fall detection and prevention by means of an algorithm that combines the estimation of the user's centre of gravity with the position of the cane. Majumder et al. predicted falls using smartphone accelerometers and smart shoe insole pressure sensors. The combination of data from these two sensors triggered an alarm when gait abnormalities were detected. Several studies have investigated the subjects' functional ability and behaviour with different technologies, such as RFID and nonlinear classification, to prevent falls in constrained environments such as acute care facilities.

- **WEARABLE DEVICES:**

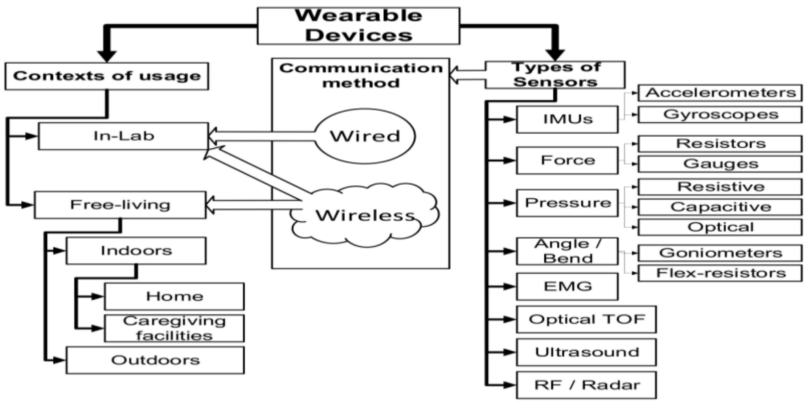

Figure 3. Classification of Wearable Devices. This classification shows how the different types of sensors can be used in different contexts depending on the communication method. TOF stands for time-of-flight, EMG for electromyography and IMUs for inertia measurement units.

- Inertia Measurement Units (IMUs) are the most popular sensor, given that they are easy to work with and inexpensive. They are comprised of accelerometers and gyroscopes packaged into small chips (3 mm × 3 mm × 1 mm), making them an excellent device for embedding into shoes.

- The second most common sensor type comprises Force Sensitive Resistors (FSRs), which are used to measure ground reaction forces by installing them inside or below the soles of footwear.
- Pressure sensors are often used in place of FSRs for similar purposes and they also provide heatmaps of the user's footprint
- Ultrasonic sensors act as sonars and they can be used for estimating the distance between the floor and the subject's foot, disadvantage of ultrasonic sensors is that they usually consume more DC power than RF sensors, since they have to physically push–pull, or vibrate a structure to generate the ultrasonic waves.
- Radar sensors have also been explored [71–73] and provide a good method for measuring foot clearance. These sensors have the additional capability of scanning the environment, which will allow significant advances in fall prevention by enabling obstacle detection.

- **<u>RADAR IN GAIT ANALYSIS AND FALL PREVENTION</u>**: The term RADAR was coined in the early 1940s as an acronym for Radio Detection And Ranging. Radar detects objects by emitting radiofrequency waves and analysing the reflected signals. It can also determine the position and velocity of objects depending on the type of signal emitted, e.g., pulsed or continuous-wave, and on the processing applied to the return, e.g., moving-target indicator, constant false-alarm rate and/or Doppler.

- Applications of radar are numerous, including air-traffic control, surveillance, weapons fire control, weather prediction and vehicle speed detection.

- **<u>NON WEARABLE RADAR SYSTEMS</u>** : they are simpler, less expensive and protect patient privacy by not capturing video, Simplicity comes from being comprised usually of just one device with two or more antennas, whereas motion capture systems require a fixed array of specialized cameras plus considerable processing power in the computer receiving the images from the cameras, In addition, the subject is required to wear reflective markers (passive or active) for motion capture systems, A further advantage of non-wearable system (NWS) radar over MCSs is price.

- **<u>WEARABLE RADAR SYSTEMS:</u>** Radar systems can be adapted to a wearable form using System-on-Chip (SoC) de vices, particularly ones operating in millimetre wave domains due to their small size.

- Even though wearable radar and wearable devices in general have advantages over non-wearable systems, user acceptance can be a barrier when the device is to be worn long-term. In the case of wearables for fall prevention, the mode by which information is presented to the user is key to the device's effectiveness. There is an exciting opportunity in wearable radar for fall prevention to develop embedded antenna systems, smaller form-factor radar systems and information extraction algorithms to inform the user in real time via an engaging user interface.

- **<u>WEARABLE RADAR FOR FALL PREVENTION: PROOF OF CONCEPT :</u>**
- **<u>HARDWARE:</u>**

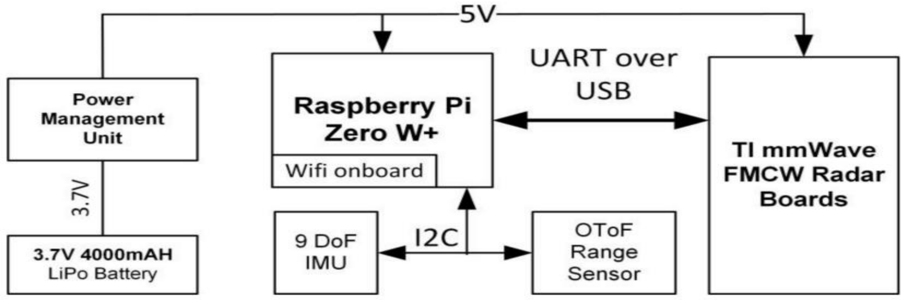

Figure 5. Hardware block diagram of smart-shoe prototype. The Raspberry Pi acts as the main command and control device, as well as a datalogger. The main sensor is the TI mm-wave radar, and the secondary sensors are a nine degree of freedom IMU and Optical Time-of-Flight range finder.

- A Raspberry Pi Zero W+ was selected as the control and data logging unit due to its reduced size and its Wi-Fi capability. Two additional sensors were included, an Inertia Measurement Unit with nine degrees of freedom (three accelerometers, three gyroscopes and three magnetometers) and an Optical Time-of-flight distance measurement sensor. The power supply unit consisted of a 4000 mA, 3.7 V Li-Po battery and a commercial USB battery managing circuit. All electronics were attached to a 3D-printed foot-mount shown in Figure above.
- **SOFTWARE:**

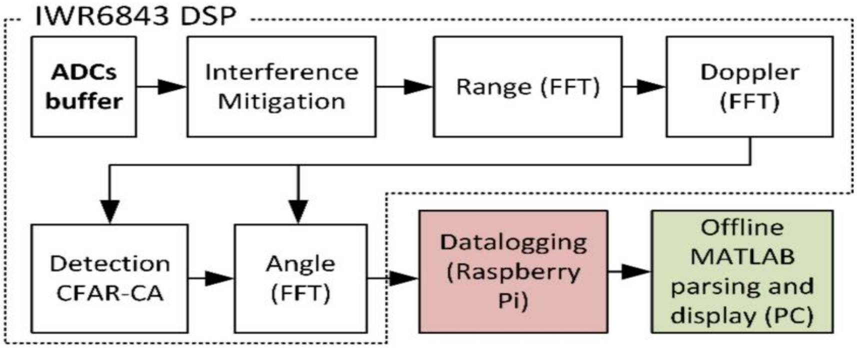

Figure 7. Software and digital signal processing chain block diagram. The four receivers' intermediate frequency (IF) output is digitized by four analog to digital converters (ADCs) and then filtered to reduce interference. The signals are then processed by a chain of FFTs to find range, elevation and azimuth angles and, finally, they are converted to a point cloud by a CFAR-CA block. These data are then serially passed on to the datalogger and then parsed, post-processed and displayed in MATLAB.

- The Raspberry Pi runs a suite of software developed in Python and PHP specifically for this application. The main python program is run upon power-up and is responsible for configuring and controlling the radar and receiving the data for storage in the file system within the SD card. This python program can spawn a series of independent python scripts that interact with the secondary sensors and store their data in a separate file in the same file system.
- The Raspberry Pi also runs an Apache Server with PHP for command and data control through HTTP. The smart-shoe can be controlled by accessing a simple PHP-developed interface on a web browser by typing the IP address of the system. The PHP interface interacts with the main Python program allowing the user to start and stop the sensors and initiate data logging by the click of a button. The data can then be extracted from the data directory via the web browser onto a PC that runs an offline MATLAB parsing script for data visualization.

- **CONCLUSION:**

  1. Fall prevention in everyday living conditions is still a largely unexplored area, and the development of new tools would be highly beneficial for researchers, clinicians and patients.
  2. A review of wearable and radar sensors for gait analysis and fall prevention reveals that, even though the utility of wearable sensor-based gait analysis is becoming widely recognized, we are only beginning to realize its potential.
  3. Experimental results suggest that fall prevention and gait analysis can be achieved; nevertheless, further research is necessary to advance the technology for commercial application. Future work should focus on improving the range and angle resolutions