- 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. Extrinsic factors are related to the individual's surroundings, and some of these are controllable, for example, footwear and features of the home environment, including secure floor coverings and non-slip surfaces. Other factors are, however, uncontrollable, such as features of the outdoor environment, including uneven footpaths, obstacles, surface–height negotiation, and slippery surfaces. Intrinsic factors include age, gender, medical conditions, and fall history. Controllable intrinsic factors can be medications, visual abilities, cardiovascular status, gait, and balance.

- 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 the first heel contact to the next heel contact. This cycle can be divided into two major stages: stance and swing. Stance is the period in which the limb is in contact with the ground, and it takes ~60% of the gait cycle time. Swing is the phase where the limb is moving without having contact with the walking surface, and it takes ~40% of the time.
- 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). These three categories can be sub-divided by the methods used to obtain the data, e.g., 3D motion capture, digital video recording, accelerometers, and radar.
- 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.
- WEARABLE: Movement sensors, force sensors, and muscular activity sensors.
- NON-WEARABLE: Image processing, floor sensors, clinical tests.
- Motion Capture Sensors Systems (MCSs) use an array of high-speed cameras to determine the position of reflective markers attached to the subject's body through image processing. Later, by tracking the position of these markers, it is possible to obtain gait parameters with submillimeter accuracy.

- With further work to address the challenges in fall prevention, wearable sensor devices offer significant opportunities for gait analysis by providing quantitative data for reliable patient monitoring and the accurate prediction of falls. Wearables can be used in two different contexts, in-lab and free-living. In the laboratory, wearables are used when performing predetermined tasks, such as walking on a treadmill, often combined with non-wearable methods such as motion capture, force plates, and video recording. The second and most interesting use of wearables is in uncontrolled free-living gait analysis.

- Numerous studies have focused on sensors to characterize foot motion for the determination of gait parameters. Although each sensor type has its strength, significant weaknesses affect each sensor's utility. Some of these are: Inertia measurement unit (IMU), Force-sensitive resistors (FSR), Pressure sensors, Optical Time of Flight (OToF), Ultra-sonic, Radar and RF, and Piezo-electric Bend.

- **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. Inertia measurement units are often combined with other sensors to improve accuracy or estimate parameters that cannot be obtained from accelerometry. A further drawback of IMUs is drift, which can present a major problem when extracting data over long periods of time.

- **Force Sensitive Resistors (FSRs)**, which are used to measure ground reaction forces by installing them inside or below the soles of footwear. FSRs are inexpensive and provide good estimates of temporal parameters such as step time, stride time and stance time.

- **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. They have good accuracy and are inexpensive but are oversized for the application (40 mm × 20 mm × 20 mm) and must be externally mounted on the shoe. Another 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.

- **OTOF sensors** are accurate, lightweight, and very small (5 mm × 3 mm × 2 mm), making them highly suitable for embedding in shoes. They operate well under most conditions, including black surfaces, which cause only a loss of precision due to their low reflectivity of light for this sensor type.

- **Radar sensors** have also been explored 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.

- **Radar in Gait Analysis and Fall Prevention**
  The term RADAR was an acronym for **Radio Detection And Ranging**. Radar detects objects by emitting radiofrequency waves and analyzing 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.
  <u>Non-Wearable Radar Systems:</u>
  Many researchers have studied non-wearable radars to provide alternatives to Motion Capture Systems (MCSs), given that 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 its low price. Radars can also track objects from long to short range and estimate some gait parameters from 120 m. Other works combining radar, wireless communications, and data-processing techniques reported up to a 94.3% success rate in detecting fall-like events.

Wearable Radar Systems:
Radar systems can be adapted to a wearable form using System-on-Chip (SoC) devices, particularly ones operating in millimeter wave domains due to their small size. This technology could be used for many applications, such as calculating foot clearance, either by measuring the return time of flight of the radar signal, using DFCW (dual frequency continuous wave) techniques, or measuring the distance from shoe to shoe to estimate stride length.

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.

- A number of research challenges remain for achieving reliable obstacle detection and measurement of gait parameters. One of these challenges is the detectability of everyday objects that are likely to act as obstacles. The detectability of an object is proportional to its radar cross-section (RCS), which depends on its shape, size, and material composition. Conductive objects are the easiest to detect; however, everyday objects are usually made of plastics, wood, and other non-conductive materials presenting lower RCSs, making detection more difficult. RCS also depends on the operating frequencies used: the higher the frequency the more sensitive the radar can be to non-conductive materials, as well as the higher the BW that can be used.

- **Wearable Radar for Fall Prevention: Proof of Concept:**

  HARDWARE: A prototype was built based on evaluation boards from Texas Instruments. This radar system was selected due to its operating frequency of 60 GHz. The IWR6843 instrument has a bandwidth of 4 GHz, achieving a range resolution of 3.4 cm, and has three transmitters (Tx) and four receivers (Rx), enabling MIMO through multiplexing transmitters in time. The Tx antenna array has one odd antenna in the line to enable elevation angle estimation, and the Rx array enables azimuth angle estimation. This MIMO configuration enables not only obstacle detection but a 3D location with respect to the shoe. 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.

  SOFTWARE: The four receivers' intermediate frequency (IF) output is digitized by four analogs to digital converters (ADCs) and then filtered to reduce interference. The signals are then processed by a chain of FFTs to find the range, elevation, and azimuth angles and, finally, they are converted to a point cloud by a Constant-False-Alarm-Rate (CFAR) block.

These data are then serially passed on to the datalogger and then parsed, post-processed, and displayed in MATLAB.

<u>CONCLUSION:</u> The successful detection and location of obstacles could allow for fall prevention to be carried out by feeding predicted foot trajectories calculated from the secondary sensors, such as the IMUs, and the location of objects detected by the radar to a machine learning algorithm that can classify the high-risk obstacles, then this output can be used to give timely feedback to the user to avoid tripping, for example by means of haptic feedback (vibrating device in the shoe) or a beeping sound.