Review

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Review

The future of Footwear: A Survey on Smart Shoe

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Abstract: Machine Intelligence and its Learning (MIL) are completely changed the working of modern industries starting from the raw material acquisition (RAM), designing and manufacturing of products (DMA), transportation and marketing. MIL have significantly impacted the consumer goods market, including the smart footwear industry. There is a big change in footwear manufacturing from craftsman to mass production, mass production to customization and from customization to mass customization. MIL are extensively utilized in the design and production of smart and agile footwear using augmented and virtual reality (AVR). There are various methods for manufacturing smart footwear, which can be categorized based on their applications. These include medical and healthcare smart footwear, assistive footwear for individuals with impairments, footwear designed for navigation in unfamiliar areas, footwear for studying foot movements and gait analysis, safety footwear, anti-skid footwear, footwear for the elderly, army shoes, and energy-harvesting footwear, among others. These smart shoes enable real-time patient monitoring and provide appropriate suggestions for their care. Additionally, smart footwear can be classified based on the tools and techniques used in their production, the sensors IoTs used, data transfer and storage. This paper reviews the various tools and techniques used in the creation of smart footwear for different applications. It also describes the various types of sensors/IoTs used in smart footwear.

Keywords: artificial intelligence; machine learning; smart shoes; sensors; IoTs

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1. Introduction

"Education, more education and education is the only panacea for all country's ills and evils". Most Revered Sir Sahab ji Maharaj 5th Revered Leader of Ra Dha Sva Aah Mi Faith Dayalbagh, Agra, India

Any change in the society is mainly dependent on the literacy level of that society. Due to the high literacy level of people, they are more conscious about their health, keep themselves fit and good looking. It leads to increase in demand of different types shoes, which are smart and intelligent. It can not only measure your health parameters such as blood pressure, oxygen level, diabetic level and calories intake and burn etc., but also give consultation to keep yourself fit and healthy. The domestic sports shoe market in India is covered chiefly by four internationals brands REEBOK, ADIDAS, PUMA and NIKE [1–3]. These companies are actively involved in manufacturing the smart shoes. The NIKE has technological collaboration with Intel chip manufacturing company to incorporate intelligence in shoes. Now there is a paradigm shift from conventional mass produced shoe manufacturing to customer centred customized production to accommodate life style, fashion and moreover their health and comforts.

This paper is divided in following sections – introduction and history,

i. Globally Smart shoe manufacturing companies
ii. Different functions of smart footwear
iii. Smart footwear and its components
iv. Different AI and ML techniques
v. Applications of smart footwear
vi. Smart shoe manufacturing
vii. Issues and challenges

viii. Conclusion and future scope.

2. Historical Prospective

Smart footwear is an exciting area where the quality footwear integrated with the latest technology/technologies. The first commercial smart footwear is Altra Torin IQ. It has pressure sensors, power supplying battery, and a microchip that connects sensor data to mobile phone through Bluetooth. The data generated by pressure sensor are impact force, the footfall location, contact time and cadence. The prime objective of this smart footwear was to improve running performance, efficiency and prevent injuries. The data received from the performer shoe has many important information which may not be known earlier and it can completely change the performance of a sport's person.

Figure 1. Altra Torin smart running shoes [edgeservices.bing.com].

PUMA international sneaker manufacturing companies started working on smart footwear in the early 1980s [https://www.techbriefs.com/component/content/article/34453-the-story-behind-the-first-smart-shoe-puma-s-rs-computer-shoe].

After this many footwear companies globally started working on smart shoe and manufactured them. Some smart footwear manufacturing companies are shown in Figure 2.

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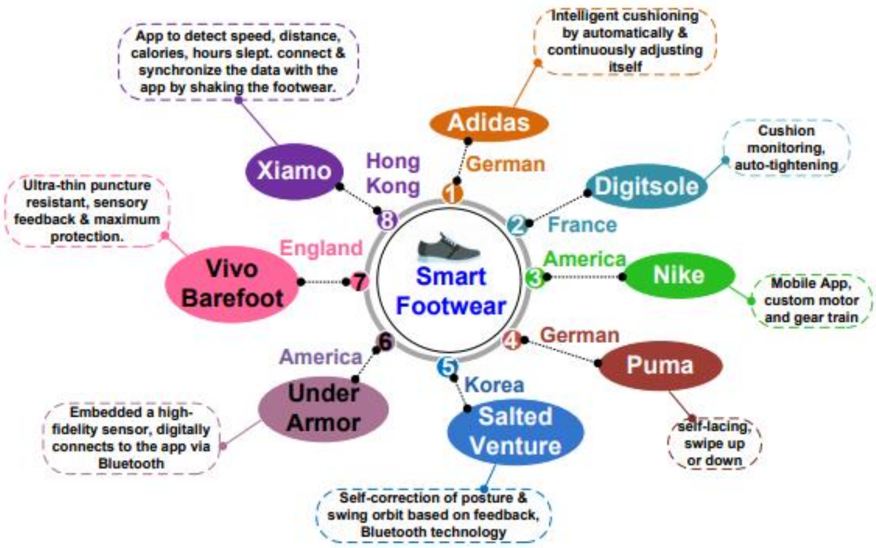

Figure 2. Smart shoe manufacturing companies globally [2402.01645v2 (arxiv.org)].

In every smart/intelligent footwear learning has an important role. The performance of smart footwear depends on how efficiently it will learn from the environment or past experience. The learning is shown in Figure 3.

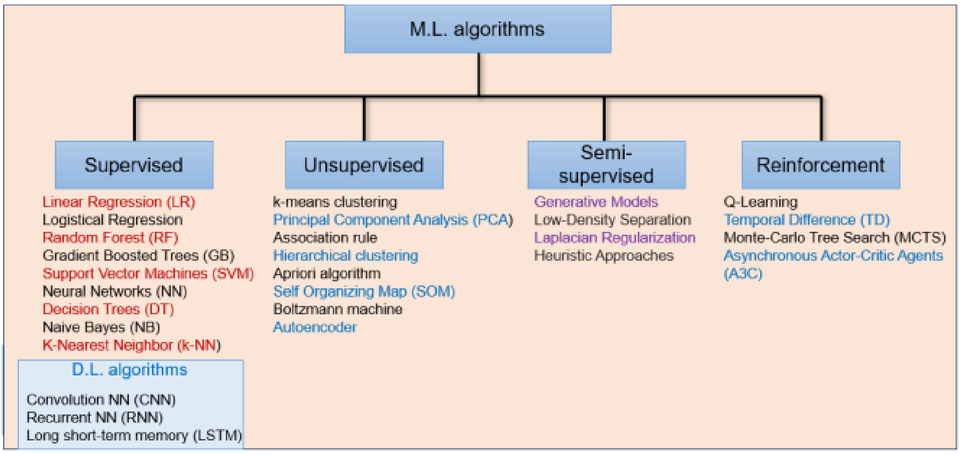

Figure 3. Different Learning algorithms [2402.01645v2 (arxiv.org)].

3. Smart Footwear and Its Functioning

The smart footwear is normally consisting of different functional blocks as shown in Figure 5.

1. Sensor and communication

Every smart footwear has some sensors or Internet of Things (IoTs) depending on the application of that footwear. For example, the motion analysis of a person for different purposes must have some pressure sensors, accelerometer and gyroscope on the footwear insole. Similarly, piezo electric sensors for energy harvesting smart shoes. In medical and health care applications temperature sensor, heart rate, blood pressure measuring sensor, step counter etc. All these sensors measure different quantities and then send them to some remote location or local memory device. Communication may be through internet or through some physical or virtual channels. The commonly used sensors/IoTs are summarised in Table 1. Different parameters tracked by sensors are also tabulated in Table 2.

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Table 1. Sensors/IoTs employed in smart footwear.

Quantity to measure	Sensor/IoT	How to measure
1. Foot Pressure	Force Sensor Resistor (FSR)	physical pressure and weight distribution and magnitude
	Capacitive sensor (CS)	Measure change in capacitance due to pressure applied
	Piezo-electric sensor (PES)	Generate electric charge when pressure applied
	Piezo-resistance sensor (PRS)	Resistance change due to applied pressure
	Load cell	Measure force and weight distribution
	Strain gauge	To measure deformation due to pressure
	Pressure Sensitive Conductive Rubber (PSCR)	Changes conductivity when pressure applied.
	Flexible sensor	Thin and flexible sensors that can't discomfort to foot.
	Micro-Electro-Mechanical sensor (MEMS)	Tiny sensor to measure pressure and acceleration
	Optical sensors	To measure pressure-induced changes
	Ultrasonic sensors	It uses high frequency sound waves to measure pressure.
	Resistive sensor	To measure changes in resistance due to pressure.
2 – Heart activity (Heart rate, its variability, R-R interval, Blood oxygen level), cardiac output, stroke volume)	ECG sensor	measure the electrical activity of the heart
	Photo plethysmography (PPG)	Detect change in blood flow and oxygenation.
	Ballisto-cardiogram (BCG)	Measure mechanical movement of the heart
	Seismo-cardiogram (SCG)	Detect the vibrations produced by heart
	Impedance-cardiogram (ICG)	Measure changes in electrical impedance due to heart activity
	PES	Detect the mechanical movement of heart.
	Capacitive sensor	Measure change in capacitance due to heart activity.
	Bio-impedance sensor	Measure electrical impedance of body

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3 - Measure orientation, acceleration, rotation and the inclination of the foot	Mechanical Gyroscope	Uses spinning wheel or rotor to detect changes in orientation.
	Optical Gyroscope	Uses light to measure changes in orientation and rotation
	MEMS Gyroscopes	Tiny, low power sensors to detect changes in orientation and rotation
	Piezo-electric Gyroscopes	Use piezo-electric material to detect changes in orientation and rotation.
	Vibrating structure Gyroscopes	Uses vibrating elements to detect changes in orientation and rotation.
	Laser Gyroscopes	Uses laser light to measure changes in orientation and rotation.
	Fiber optic Gyroscopes	Uses fiber optic cables to detect changes in orientation and rotation.
	Quartz crystal Gyroscopes	Uses quartz crystal to detect changes in orientation and rotation.
	Solid state Gyroscopes	Uses solid state sensors to detect changes in orientation and rotation.
	3-axis Gyroscopes	Measure movements and orientations in 3-D.
4- To measure acceleration of the foot, allowing the smart footwear to detect steps, pace and distance.	Piezo-electric Accelerometer	Use piezo-electric material to detect changes in acceleration
	Capacitive accelerometer	Measure changes in capacitance due to acceleration
	Piezo-resistive accelerometer	Use piezo-resistive material to detect changes in acceleration
	MEMS Accelerometer	Low Power sensor to detect acceleration
	Strain gauge accelerometer	Measure change in strain due to acceleration.
	Quartz Crystal accelerometer	Use quartz crystal to detect changes in acceleration
	Surface Acoustic Wave (SAW) accelerometer	Use surface acoustic waves to detect changes in acceleration
	Optical accelerometer	Uses light to measure changes in acceleration.
	Inertial measurement Unit (IMU) accelerometer	Combine multiple sensors to measure acceleration, orientation and rotation.

	3-axis accelerometer	Measure acceleration in 3-D
5 – location and tracking	GPS	Provide location, track distance, pace and route.
6 - Temperature	Thermistor	Resistive sensor changes resistance with temperature.
	Thermocouple	Generate voltage proportional to temperature
	IR sensor	Measure thermal radiation to detect temperature
	Thermopiles	Uses multiple thermos couples to detect temperature
	RTDs	Measure changes in resistance due to temperature
	Thermistor based sensor	Use thermistors to detect temperature
	MEMS	Small size sensor to measure temperature
	Fiber optic temperature sensor	Uses fiber optic cables to measure temperature
	Piezo-electric	Use piezo – electric materials to detect temperature
	Calorimetric sensor	Measure heat transfer to detect temperature
7- Measurement of sweat rate, its composition, Electrolyte level, hydration level, stress level, physical exertion, and heat stress	Electro-dermal activity (EDA) sensor	Measure electrical conductivity of sweat.
	Galvanic Skin Resistance (GSR) sensor	Measure change in skin conductivity due to sweat.
	Capacitive sensor	Measure change in capacitance due to sweat.
	Resistive sensor	Measure change in resistance due to sweat.
	Hygrometer	Measuring relative humidity, including sweat levels
	pH sensor	Detect change in skin pH due to sweat
	Conductive sensor	Measure electrical conductivity of sweat
	Impedance sensor	Measure change in impedance due to sweat
	Optical sensor	Uses light absorbance or reflectance due to sweat
	Bio-impedance sensor	Measure change in skin impedance due to sweat.
8- Measurement of BP, Pulse transit time,	Piezo – electric sensor	Measure change in pressure
	Capacitive sensor	Measure change in capacitance due to blood flow

Pulse wave velocity, oxygen level	Resistive sensor	Measure change in resistance due to blood flow
	Optical sensor	Use light for detecting blood flow
	Bio-impedance sensor	Measure impedance change due to blood flow
	BCG sensor	Measure mechanical movement of the heart
	SCG sensor	Detect vibrations produced by heart.
	PPG sensors	Measure change in light absorption due to blood flow

Table 2. Different sensors and their working principles.

S.No.	Sensor type and working principles
1	Ultrasonic sensor for assistive smart footwear- measures the distance to an object using ultrasonic sound waves with the help of a sender and receiver. It can be classified based on – 1. Frequency range – Low (20-1000kHz), High (100 kHz – 1Mhz) 2. Operating principle – pulse-echo, continuous wave, phase shift 3. Transduce type – piezo-electric, capacitive, electromagnetic 4. Beam Pattern – narrow, wide, focused 5. Housing type – plastic, metal, stainless steel
2	LiDAR Sensor – means laser imaging, detection, and ranging. It measures the time of laser light to travel and return back to receiver after striking with target.
3	Pressure sensor i. Capacitive Type – When pressure applied the gap between the plates of capacitor changes and potential changes. ii. Resistive type – It is made by conductive polymer. When pressure applied the resistance decreases. iii. Piezo-resistive – the electrical resistance of PRS changes when strectched iv. Piezoelectric type – The pressure is transformed into electrical charge in PES. v. Optoelectronics – It is consisting of a pair of transmitter and receiver, when a force is applied the output voltage will be generated.
4	Accelerometer and Gyroscope- used to measure movement. Accelerometer is used to measure linear acceleration, while gyro is used to track rotation or twists.
5	Sweat Sensor – It is a flexible sensor for sweat analyte detection. Some of the most commonly sweat sensors measure various parameters such as i. electrolyte levels, such as sodium, potassium and chloride. ii. Glucose level iii. Lactate Level iv. pH indicator v. Hydration level vi. Sweat biosensor use optical, impedance-based and piezoelectric sensors.
6	Temperature sensor- Measure temperatures in different ranges. Different types of Temperature sensors are: i. Thermocouples (K-type, J-type) ii. Resistance Temperature Detectors (RDTs) iii. Thermistors (eg. NTC, PTC) iv. Infra Red (IR) type

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	v. Digital temperature sensors (eg. DS18B20, TMP36) vi. Fiber-optics sensor
7	Humidity sensors – to measure relative or absolute humidity. Different types of humidity sensors are: i. Capacitive ii. Resistive iii. Thermal iv. IR v. Ultrasonic vi. Piezoelectric vii. Digital (eg. DHT11, HIH6130)
8	Gas sensors – detect and measure the presence of specific gases in ppm or ppb, gas flow rate, gas temperature or gas pressure. Different types of sensors: i. Electrochemical ii. Catalytic iii. IR iv. Metal oxide semiconductor (MOS sensor) v. Photoionization detector (PIDs) vi. Solid state sensors vii. Optical sensors.
9	Piezo-electric sensor- It is sensor uses piezoelectric materials to measure physical parameters such as pressure, acceleration, vibration, force, strain and torque. The mechanical stress is converted into electric charge in PES. Different types of piezoelectric sensors are: i. Piezoelectric ceramic (i.e. lead zirconate titanate) ii. Piezoelectric polymers (i.e. polyvinylidene flouride) iii. Piezoelectric composite (i.e. combining ceramics and polymers)
10	PRS – PRS is useful to measure pressure, strain, force, acceleration, acceleration and vibration. It converts physical parameters into electric signal. Different types of piezo-resistive sensors are: i. Silicon based ii. Polymer based iii. Metal based
11	EMG sensor

Table 2. Parameters tracked by Sensors in smart footwear.

1	Parameters to track
2	Foot pressure and its distribution
3	Foot temperature
4	Humidity and sweat level
5	Motion and acceleration (includes step count, distance, speed, etc.)
6	Orientation and balance
7	GPS location and tracking
8	Biomechanical data (e.g. pronation, supination)
9	Muscle activity (e.g. EMG sensors)
10	Health parameters (e.g, Blood pressure, oxygen level, heart rate, diabetic level)
11	Obstacles in the path
12	Monitoring Centre of Gravity of body

There are certain issues related to senors/IoTs used in smart footwear as mentioned below:

- Scalability – increase the number of sensors/IoTs
- Standardization issues– which sensors/IoTs/technology is to use
- Inter-dependency
- Programming complexity
- Handling of big data
- Battery backup and power issues
- Communication problems
- Robustness
- Customer Data security

The working of Smart insoles (SIs) of a footwear depends on sensors/IoTs, their real time data transfer to decision module such as smartphone App developed for a particular application. It is also called the brain of smart shoe, because intelligence lies there.

The data collection mdule from sensor/IoT is the key components of smart footwear. The customer data is collected in this module and used by other modules of smart footwear to optimize the behavior for taking real time decision.

2. Data Storage

The data received in the above step can be stored at suitable place, so that it can be quickly retrieved and used for further action. The amount of data generated is depending on the following five Vs:

- Velocity –Data generated per unit time.
- Volume – Amount of Data generated from different sensors/IoTs
- Variety – structure, source, and format of data
- Value – valuable proposition added to raw data to make it useful.
- Veracity – High fidelity and reliability

The smart footwear sensors/IoTs generate high speed, large volume data needs sufficient and fast memory to store and retrieve data (sometimes cloud storage is used). This big data is used for further action. The variety of sensors/IoTs used in smart insole/footwear, summarized in Table 1. These sensors/IoTs have their own merits and demerits. The selection of suitable sensors/IoTs mainly depends on the problem in hand, their speed, shape and size, accuracy, range of variable to measure, cost, and power consumption.

The perfect position for the placement of Planter pressure sensors in the smart footwear/insole as shown in Figure 4. The sensor/IoT is located at

Low pressure area - Heel,
High pressure areas –
Lateral Forefoot,
Medial Forefoot, and
Hallux.

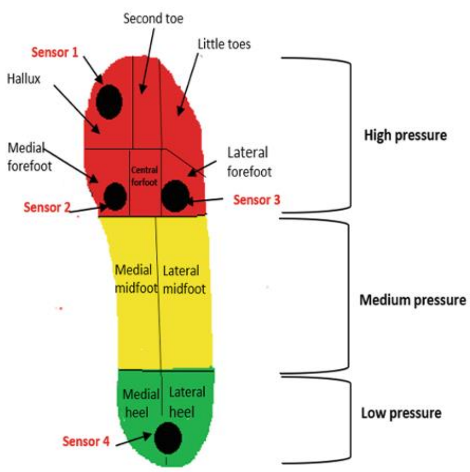

Figure 4. Pressure sensor locations at smart insole.

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4. Data processing and information extraction

The data is pre-processed before using it. Mainly in pre-processing of data, the missing data is completed or removed, remove noise from the data, and also check the erroneous data. The pre-processed data is then used for information/feature extraction.

5. Data Analysis

Different soft computing techniques such as neural network, fuzzy information processing system, optimization based on nature inspired techniques, etc. are used to analyse the pre-processed collected data for some inferencing.

6. Decision making

The appropriate decision is to be taken based on the analysis.

7. Control

Once the appropriate decision has been taken using some intelligent tools, then suitable control action is initiated.

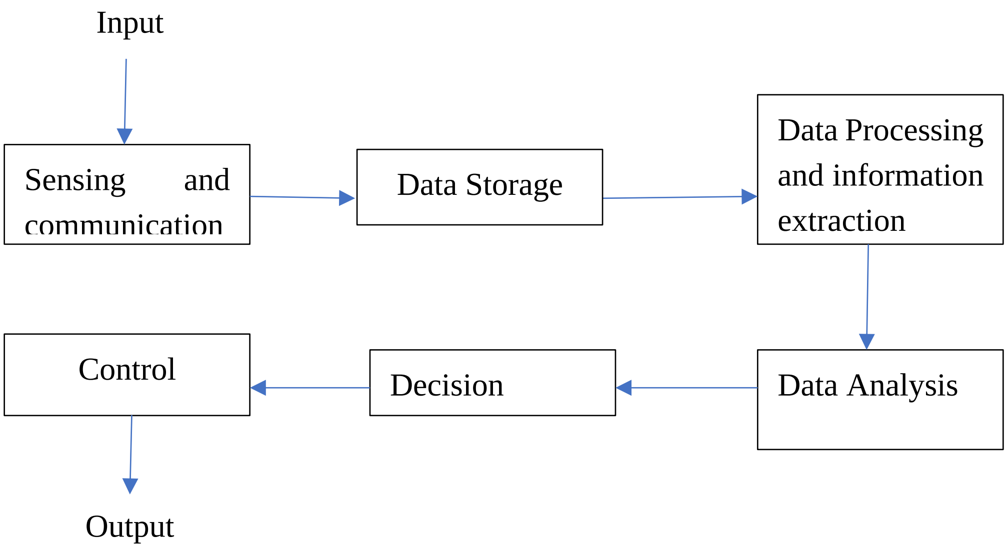

Figure 5. Functional Block Diagram of Smart Footwear / Smart Insole.

Different components of Smart footwear

Smart Footwear has many components depending on their applications, but some commonly used components (Figure 6) are mentioned below:

1. Sensors/IoTs – To measure different variables such as pressure, temperature, humidity, acceleration, speed, location etc. There are variety of sensors/IoTs available in the market based on their cost, accuracy, range, shape and size, working principle etc.
2. Micro-controllers- To process data obtained from sensors/IoTs and control other components.
3. Storage Module – To store data received from sensors/IoTs, suitable place and fast memory is needed. It also needs suitable transmission channel and software.
4. Communication module – it enables connectivity of smart footwear to smart phones, smart home devices or other systems via blue tooth, wi-Fi, or NFC.
5. Power supply module: Battery, charging (through USB, wireless or other charging methods such as energy harvesting devices) and discharging circuitry, battery management system.
6. User Interface – Display of results, buttons or touch sensors for user interface.
7. Footwear Material to protect electronic circuits.
8. Software and applications – It is required for data analysis, feedback and customization.
9. Integration module - Integration with other devices and its compatibility. Actuators, motors, alert systems and other safety mechanism.

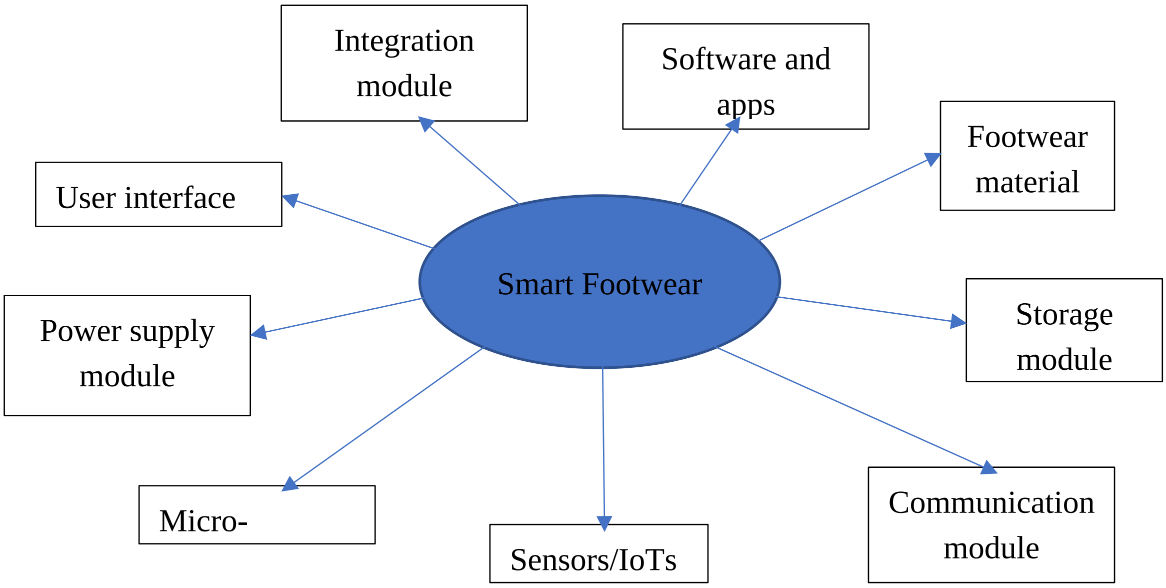

Figure 6. Smart Footwear Components.

Applications of Smart Footwear

Smart footwear is used in the following areas [1,2]:

i. Games and Sports– Smart footwear is very commonly used in sports and games to enhance the players' performance [7–9].
ii. Fitness of an individual – It is used in different fitness activities such as walking, running, jogging, cycling or doing exercise.
iii. Health care and Medical – It is used for diagnosis of different disease or abnormality in the body. It is also used to maintain the history of different bio-physical parameters of an individual. Smart footwear for diabetes and rehabilitation [18–20,27,28].
iv. Industrial and work safety- This is also a prominent area where smart footwear is used to protect the industrial worker from hazardous environment or any safety issue.
v. Women and kids safety – To safeguard women and kids from any unforeseen situation.
vi. Gaming and virtual reality
vii. Fashion and life style.
viii. Assistive footwear for blind persons [4–6,10–14,21–26]
ix. Army shoes [15–17]

Smart shoe manufacturing and its challenges

i. Selection of suitable sensors
ii. Sensor accuracy and its reliability
iii. Power consumption and battery life
iv. Self-powered sensors
v. Comfort and wear ability
vi. Durability and water resistance
vii. Data transmission, storage and analysis and feedback mechanisms
viii. Suitable tools and techniques for decision making and control
ix. Integration with other devices and systems

Challenges and issues related to smart footwear

i. Reduction of power consumption and battery life
ii. Comforts and wear ability – Integration of sensors and electronic circuits can compromise comfort and wear ability.
iii. Withstand with environmental conditions- dust, dirt, water, mud, humidity and temperature variations.
iv. Data accuracy and reliability – This is mainly dependent on sensor selection and their limitations.

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v. User interface and feedback – Quality of smart footwear and customer satisfaction is also an important issue in its development.
vi. Seamless Integration is also an issue.
vii. Cost and affordability
viii. Privacy and data security
ix. Calibration issues related to sensors
x. Lack of national and international standards
xi. User adoption and awareness
xii. Balance between fashion and functionality
xiii. Sensor performance may be affected by humidity and sweat.
xiv. Weight of smart footwear
xv. Compatibility with different footwear types

Different research articles included here are summarized in the following Table 3.

Table 3. Different research papers on Smart footwear /insole.

S.No.	Authors	Number of sensors	Type of sensors	Location	Data Transfer
1	James B. Wendt and Miodrag Potkonjak., 2010[32]	Reduction from 99 to 12	Pressure sensors	Under the foot.	Data collected at 60 Hz
2	Lin Shu al.,2010[29]	6	PRS	At metatarsal areas and heel	Bluetooth
3	Biofoot 2012[30]	64	Piezo electric	Under foot	Wi-fi USB
4	Wiisel 2013l[32]	14	Resistive Accelerometer Gyroscope	insole	Bluetooth
5	E. Klimiec et al., 2014 [31]	8	PVDF sensors	Under foot.	Bluetooth 2.4 GHz
6	E.S. da Rocha et al.,2014[29]	NA	Pressure sensors	Distributed in the forefoot, midfoot (MF) and rear foot (RF).	Plantar pressure for obese and non-obese participants at Fs=100Hz .
7	Moticon 2015 [33]	13	Capacitive 3D Accelerometer	Under foot	wireless
8	Tek scan 2015 [41]	960	Resistive sensors	Under foot	USB

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9	Techno 2015 [35]	58	Resistive Accelerometer	Under foot	Bluetooth
10	Dyna-foot 2 [54]	58	Resistive Accelerometer	insole	Bluetooth
11	James Coates et all.,2016[37]	42	Multi-sensor (Accelero-meter, Rotation, Humidity, Temperature, GSR, Bioimpedance, Force, Temperature	Sensors used to measure temperature and force located at heel, great toe, 1st metatarsal (MT) joint at the base of the great toe 5th MT joint at the base of the small toe, force sensor with bio-impedance placed at mid foot, GSR sensor can be placed below 5th M .	Bluetooth and Wi-Fi with Fs= 20 Hz.
12	E Klimiec et al.,2017 [42]	8	Piezoelectric transducer made of polarized PVDF foil.	Transducer-1 on heel(H), transducer-2 on MF, transducer-3 on	Packet form Data is transmitted

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				MT, transducer-4 on great toe (GT), transducer-5 on lateral midfoot (LM), transducer -6 on MT1, transducer -7 on MT, transducer -8 on lesser toes(LT).	
13	Arion smart Insoles 2018 [39]	8	Accelerometer, Gyroscope and GPS.	Insole	Bluetooth
14	Paro-tech[40]	24 to 36	PRS Hydro-cell	insole	Memory Card
15	Andrei Drˇagulinescu, et.al. 2020 [44], Sazonova et.al 2011 [43]	As per need	a clip on accelerometer and force-sensitive resistors	insole	Bluetooth unit
16	Rescio, G.; [45], Najafi, B.; et.al. 2017 [46]	5	Optical fiber sensors	insole	N/A (LabVIEW interface only)
17	Bonafide, C.P.; et. al. 2018 [47]	As per need	Pulse oximeter		WiFi / Bluetooth
18	Pedar-X Insole [55]	99	PES	Smart insole	Bluetooth, Optical fiber, USB,

The smart soccer shoe developed by Bo Zhou and his team [50] is consisting of textile resistive pressure sensor and fitted in soccer shoe of Adidas. The sensors normally made up of 2- fabric layers with parallel metallic stripes. The sensors are placed in 3 areas; first -outside front, second-inside front and third - inside heel as shown in Figure 7. This sensors efficiently gather the football interaction parameters with smart shoe and results are shown in Figure 8

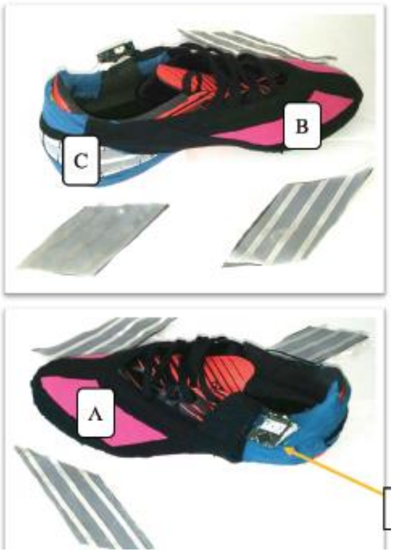

Figure 7. Smart Soccer shoe with three.

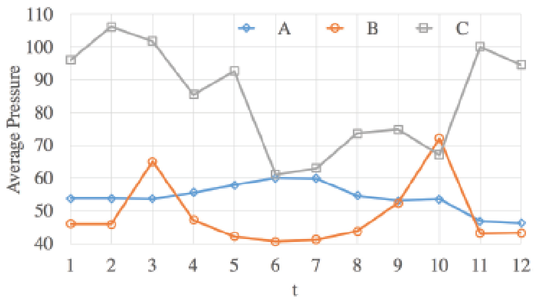

Figure 8. Mean Pressure from every sensor patch sensors (two on sides and one on heel) during the impact of ball.

In smart tracking shoe GPS system plays an important role. Fig 9. Shows the system architecture for smart tracking shoe. The important components of smart shoe are:

Micro-controller,
Sensors,
Bluetooth Device and
Smart phone.

The real-time foot parameter monitoring system using a smart insole/ footwear may have two applications. One is to monitor the patient/user data on mobile and second is to use at web application. In first application, all user data such as gate cycle data over time, plantar pressure data, medical parameters (i.e. Blood pressure, Temperature, blood oxygen level, diabetic level etc.) is stored on a mobile and also send them to a Web for the doctor's use. This application is quite useful for the doctor to analyse the situation of his patient and suggest suitable medicine.

Elderly people needs a reliable system for continuous monitoring and control all the time, while performing his/her routine works. To achieve this objective, it is necessary to use suitable sensors/IoTs of reasonable cost to ensure good, reliable and accurate monitoring of situation without an attendant. These elderly people normally face many physical, mental and health issues due to age factor such as the problem of dementia i.e. weakening of memory and delay in brain functions [51]. These challenges are real danger for them. They may fall down due to lack of attention [52] and can cause long term pain, sprained ligament, bruise, or sprained muscle, functional impairment or lead to disability or major injuries or bones fracture of joint fractures, deep cuts and head injuries, etc. Sometimes, these may cause to damage organs like kidney or liver and death also. The fall death rate

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is estimated about 43,000 in USA of age group 65years and above. In India, it is reported that around 95,000 deaths in 2018-19. [53].

The factors for falls in the elderly people include [56]:

Aging
Gender
Visual impairment
History of falls
Depression
Gait problems
Vertigo
Imbalance
Fear of falling
Chronic conditions
Use of antidepressants

There are various techniques for identifying the fall of elderly people. The most common technique is to use smart insole/footwear to measure different parameters with suitable sensors/IoTs to identify different routine activities.

The smart footwear architecture is shown in Figure 9 consisting of smart insole on which different sensors/IoTs are installed along with microcontroller, energy system and reliable data transfer unit to mobile and/or web.

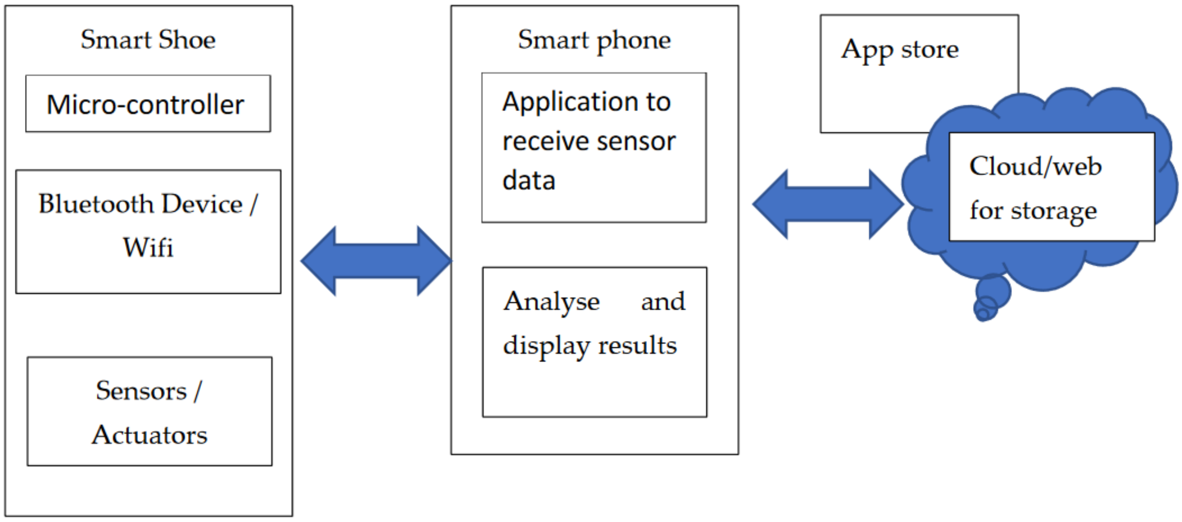

Figure 9. Smart shoe architecture.

In an another study, the Pedar system the smart insole was partitioned into 10 areas (refer Figure 10): 1—heel; 2—LM; 3–7—first to fifth MT; 8—H; 9—second toe; 10—Toes 3–5. For better clarity in Figure 11, as compared to [48], LM, instead of MF.

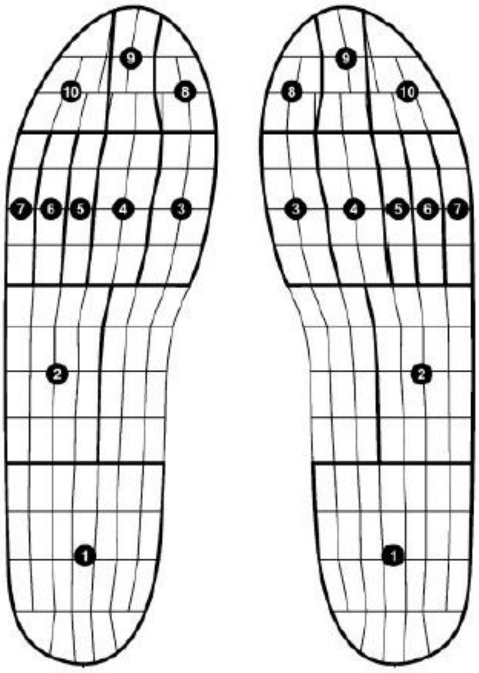

Figure 10. The L-foot and R-foot insoles of Pedar system divided in 10 areas [48].

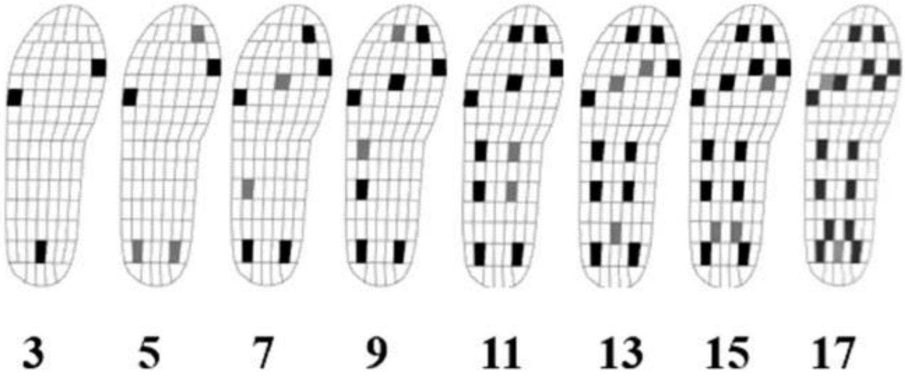

Figure 11. 8-layouts for L-foot insole, with 3-17 sensors/IoTs to measuring CoP [49].

To maintain the repeatability of experimental results, 6 out of 18 relevant parameters are considered for the Pedar system.

Table 4. Pedar parameters used in smart shoe [48].

Parameter	Measure Unit
Peak planter Pressure	Kilo-Pa
Cumulative Planter Pressure	Kilo-Pa • second
Area of Contact	Square cm
Cumulative Force	Nw • second
Contact Time	milli-second
Time of maximum Pressure	milli-second

Table 5. Comparative evaluation of smart shoe features [36,41,44,55].

Evaluating Parameter	Medilogic	OpenGo	Tekscan	Pedar

Pressure Sensor				
Model	Sohle Flex	Sport Moticon	F-Scan	Pedar-X
Type	R	C	R	C
# sensors/insole	size of insole decides number of sensors (up to 240)	13/16	size of insole decides number of sensors (up to 960)	99
Density	0.79 per sq.cm	0.1 per sq.cm	3.9 per sq.cm	0.57–0.78 per cm2
Other sensors	-	3-D accelerometer/gyroscope	-	-
Communication	Wi-Fi 2.4 GHz	ANT/BLE5.0 wired,	wireless Bluetooth,	fiber optic/TTL
Software	medilogic	Beaker/Moticon Science	F-Scan	Pedar
Thickness of Insole	1.6 mm	2–3 mm	0.2 mm	2.2 mm
Max. Sampling rate	300 c/s	50 /100 c/s	169 c/s	100 c/s
Range	6–640 kilo-Pa	0–400 kPa/0–500 kilo-Pa	345–862 kilo-Pa	20–600 kilo-Pa

Conclusion and Future Scope

The paper discusses the history of smart footwear and companies manufacturing globally. Different learning methods and the important blocks and their functionality of smart footwear, different sensors and their working principles, issues and challenges are also discussed. Smart footwear enables the medical practitioners to maintain the history of their patient's and analyse the present problem from current data and helps them. It can also assist people having blindness or dementia, enhance women and kids safety and security. Orthotic smart footwear can prevent the ortho problems well in time. The present paper, discusses different sensors/IoTs used in smart insole/footwear, their merits and demerits along with challenges.

The smart footwear is still evolving, and we can expect more exciting developments in the future. In future, sensors/IoTs may be self-powered and don't need external power supply or battery. The power consumption of sensors/IoTs may reduce and the batteries discharge time may increase. The smart footwear will go in a long way to help general people in every walk of life. Presently the cost of smart footwear is not affordable by a common people and it is a challenge. Further, the user characteristics and trades can accurately be analysed from the real time data received from sensors.

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