

**DEVELOPMENT OF SMART DIABETIC FOOT WALKER – PROOF OF
PRINCIPLE PHASE**

A PROJECT REPORT

submitted by

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TKM21MECI04

to

the APJ Abdul Kalam Technological University

in partial fulfillment of the requirements for the award of the Degree

of

Master of Technology

In

Computer Integrated Manufacturing.



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DECLARATION

I, Anverlal A N, hereby declare that the project report “Development of smart diabetic foot walker – proof of principle Phase.” submitted for partial fulfilment of the requirements for the award of the degree of Master of Technology of the APJ Abdul Kalam Technological University, Kerala is a bonafide work done by me under supervision of Subhash N N, Scientist/Engineer Department of Medical Device Engineering SCTIMST Govt of India, Faizal N S, Assistant Professor, Department of Mechanical Engineering, TKM College of Engineering, Kollam. This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources. I also declare that I have adhered to the ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed as the basis for the award of any degree, diploma or similar title of any other University.

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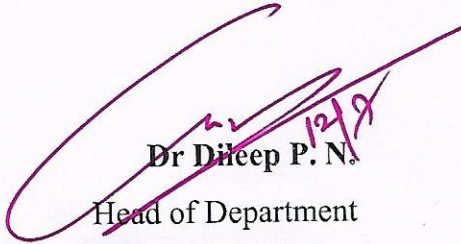
CERTIFICATE

This is to certify that the report entitled '**Development of smart diabetic foot walker – proof of principle phase**' submitted by '**ANVERLAL. A. N.**' '**(TKM20MECI04)**' to the APJ Abdul Kalam Technological University in partial fulfilment of the requirements for the award of the Degree of Master of Technology in Computer Integrated Manufacturing, Mechanical Engineering is a bonafide record of the project work carried out by him under my guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.


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ABSTRACT

Biomechanics studies usually limited to resource intensive laboratory with relevant technical expertise. The biomechanical assessments help to identify, understand and give treatments for disorders and diseases affecting movement. There is societal need to develop digital tools which enable the biomechanical assessments at a big scale. Advancements in mHealth and digital tools enable remote biomechanical measurements leading to the advent of home-based technologies for rehabilitation which may help people manage their health. The study was undertaken to develop smartphone based biomechanical gait assessment of diabetic walkers. With the aid of a smartphone IMU, this study suggests a new technique for determining the changes in shank angle that occur while using diabetic foot walkers. An application measures the angle changes that occur during heel strikes and toe-offs, and the motion analysis was carried out and verified using Kinovea. It can be concluded that the use of smartphone IMU is a convenient method for measuring shank angle during gait and real-time monitoring of gait parameters.

Keywords: mHealth, Gait analysis, real-time monitoring, Smartphone IMU, Kinovea

CONTENTS

Title	Page No.
ACKNOWLEDGEMENT	i
ABSTRACT	ii
LIST OF FIGURES	v
LIST OF TABLES	vi
ABBREVIATIONS	vii
Chapter 1. INTRODUCTION	1
1.1 Pathophysiology	2
1.1.1 Ischemia	2
1.1.2 Neuropathy	3
1.2 Risk Factors of DFU	4
1.3 Complications of DFU	5
1.3.1 Soft tissue abnormalities	5
1.3.2 Osteomyelitis	5
1.3.3 Amputation	6
1.3.4 Death	6
1.3.5 Treatment	6
1.3.6 Debridement	6
1.3.7 Wound Dressing	7
1.3.8 Pressure Offloading	7
1.4 Offloading Devices	7
1.4.1 Total Contact Casting	7
1.4.2 Removable Cast Walker	8
1.4.3 Irremovable Cast Walker	8
1.4.4 Half Shoes	9
1.4.5 Healing Sandal	9
1.4.6 Felted Foam	9
1.4.7 Crutches, canes, walkers, wheelchairs	9
1.4.8 Surgical	10

Chapter 2. LITERATURE REVIEW	11
2.1 Objectives	19
Chapter 3. METHODOLOGY	20
3.1 Introduction	20
3.2 System Architecture	21
3.3 Angle Estimation	22
3.4 Algorithm development Gait Parameter extraction	25
3.5 Smartphone calibration	27
3.6 Gait Parameter Extraction	29
3.7 Integration of IoT	32
3.8 Comparison in Benchmarked Devices	33
Chapter 4. RESULTS & DISCUSSIONS	36
Chapter 5. CONCLUSION	40
REFERENCES	41

LIST OF FIGURES

Title	Page Number
Fig.1.1 Pathway of DFU.	2
Fig.3.2 Smartphone attached to Diabetic foot walker	23
Fig.3.3.1 Plan model of shank angle application	24
Fig.3.3.2 Interface view the shank angle variation	26
Fig.3.4.1 Gait parameter estimation algorithm	27
Fig.3.5.1 Mechanical test system for calibration	29
Fig.3.5.2 Smartphone in Upright position.	30
Fig.3.5.3 Calibration – clockwise & anti-clockwise.	31
Fig.3.6.1 Gait phases	32
Fig.3.6.2 Step vs Stride	33
Fig.3.6.3 Walking area	34
Fig.3.8.1 Tynor Air Walker	36
Fig.3.8.2 Ottobock Infinity Air Walker	36
Fig.3.8.3 Ottobock Malleo Walker	37
Fig.3.8.4 Concept Model	37
Fig 4.1 UI of shank angle application	39
Fig 4.2 UI of shank angle application with gait parameters	40
Fig.4.3 Thingspeak Dashboard	40

LIST OF TABLES

Title	Page Number
Table 1.1 Ulcers	12
Table 4.1 Shank angle variation	51

ABBREVIATIONS

DFU – Diabetic Foot Ulcer

DPN – Diabetic Peripheral Neuropathy

TCC – Total Contact Casting

RCW – Removable Cast Walker

ICW – Irremovable Cast Walker

PAD – Peripheral Arterial Disease

IDF – International Diabetes Federation

IoT – Internet of Things

IMU – Inertial Measurement Unit

CIM – Computer Integrated Manufacturing

CHAPTER 1

INTRODUCTION

Diabetes is a chronic medical condition caused by high levels of sugar in the blood. It happens when the body either doesn't produce enough insulin or doesn't use the produced insulin properly. Diabetes comes in three basic varieties. diabetes of type 1, type 2, and gestational. Type 1 diabetes normally develops in childhood but can occur at any age, Type 2 diabetes is the most popular kind and typically develops in maturity, and Gestational diabetes is a condition that develops during pregnancy and typically goes away after giving delivery. Diabetic foot neuropathy (DPN), which is most frequent in the feet and legs, is caused by uncontrolled hyperglycemia. Pain, numbness, loss of feeling, and nerve degeneration are just a few of the symptoms that DPN can bring on. These symptoms can make it delay to recognize Diabetic foot ulcers (DFU). Vascular disease, which can affect blood flow and nutrition delivery and cause ischemia, is associated with diabetes. Ulcer risk is increased by ischemia, a condition in which tissues receive insufficient oxygen. Diabetic patients are unable to react to repeated stress and trauma on their plantar tissues efficiently because of reduced sensitivity and a lessened metabolic response. Skin damage and sores could result from this. Furthermore, the increased burden on the wound site in obese diabetic individuals may cause additional stress and compromise the healing process.

Typically, a multidisciplinary approach is used in a comprehensive care plan for the treatment of DFUs, which includes wound debridement, wound dressings, pressure offloading, infection control, vascular intervention, negative pressure wound therapy, hyperbaric oxygen therapy, blood glucose management, patient education, and self-care. Offloading devices are used to increase therapeutic success and healing by reducing external pressure, hindering skin pressure,

and covering the wound site to reduce repeated harm. As alternatives to offloading devices, total contact casting (TCC), removable cast walker (RCW), irremovable cast walker (ICW), half-shoe, healing sandals, therapeutic footwear, felted foam, and mobility aids are also available.

1.1 Pathophysiology

In addition to neuropathy, ischemia, foot deformity, and greater foot pressures, there are numerous other variables that contribute to the pathogenesis of diabetic foot ulcers (Figure 1.1). However, neuropathy, ischemia, or a combination of the two are the key etiological causes.

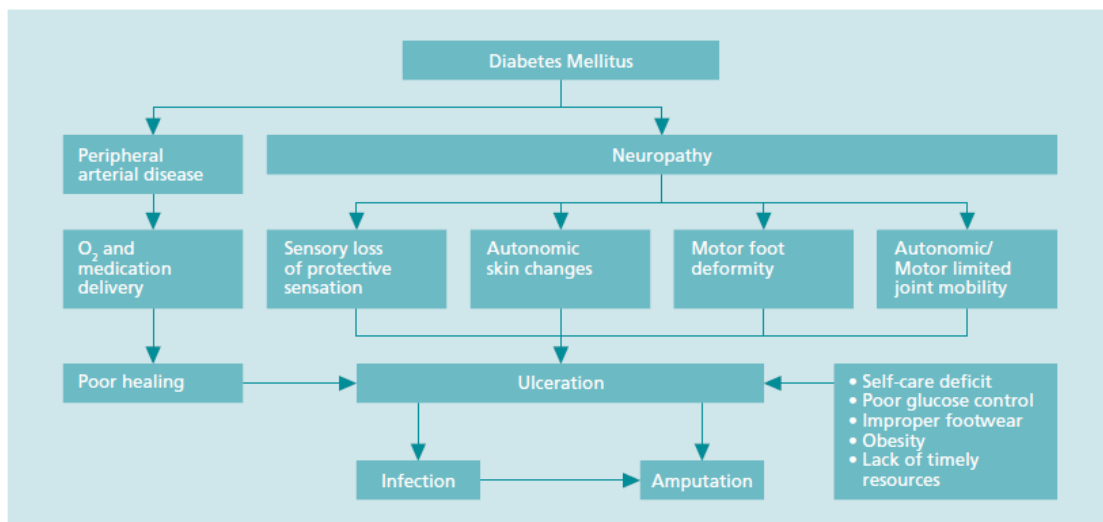


Figure 1.1 Pathway to diabetic foot ulcers

1.1.1 Ischemia

30% of people with diabetes have peripheral arterial disease (PAD), which is a prevalent problem among diabetic patients. Patients with PAD make up about half of those with diabetic foot ulcers (DFUs). A significant feature of PAD in the lower extremities is ischemia, which is brought on by decreased blood flow. Although only around 15% of DFUs are entirely ischemic ulcers, the presence of ischemia considerably slows down the healing of foot ulcers. Insufficient blood flow prevents the transfer of essentials like oxygen, nutrients, and blood to the wound, resulting in ulcers that do not heal. As a result, the environment is favourable for

the spread of infections and the destruction of tissue. Additionally, PAD prolongs the time that DFUs tend for healing and raises the possibility of recurrence. Furthermore, the reduced blood flow associated with PAD increases the risk of infection-related problems and increases the possibility of amputation due to diminished tissue viability. To maximize wound healing, lower the risk of negative consequences, and enhance patient outcomes, PAD must be managed properly.

1.1.2 Neuropathy

The Maillard reaction and the inhibition of nitric oxide generation are thought to be the two primary mechanisms involved in the pathophysiology of diabetic neuropathy, a frequent consequence of diabetes. Increased non-enzymatic glycation of intracellular proteins occurs as a result of the Maillard process, producing advanced glycation end products. Peripheral nerves' structural proteins may change as a result of these end products, leading to nerve degeneration and a reduction in their capacity to regenerate.

The second method, nitric oxide blockade, prevents endothelial nitric oxide synthase from being activated, which lowers the amount of nitric oxide produced. In the tiny arteries that feed the peripheral nerves, particularly those in the foot, nitric oxide plays a critical role as a vasodilator, preventing platelet aggregation and controlling protein expression involved in atherogenesis..

Peripheral sensory neuropathy, the most prevalent type of neuropathy, causes a decrease of pain sensibility. Since patients are no longer able to feel pain, there are no longer any warning signs of tissue trauma. As a result, the foot is subjected to increased and constant pressure, which causes tissue damage and the development of ulcers. Due to poor sweat and oil gland function, autonomic neuropathy can further raise the risk of foot issues like dryness, fissuring, and infection. The intrinsic muscles of the foot are impacted by motor neuropathy, leading to atrophy and weakening. Deformities including claw toes, plantar flexion of the metatarsal

heads, and other structural abnormalities can be caused by this. These anatomical deformities lead to areas of increased pressure and calluses on the sole of the foot, particularly in the forefoot and bony prominences, as well as restricted joint mobility brought on by motor neuropathy or other foot deformities like Charcot neuroarthropathy, flatfoot, hallux valgus, and hammer foot. Trauma is required for tissue breakdown and the emergence of ulcers. Trauma can be extrinsic from poorly fitted shoes or intrinsic from repetitive pressure sores and calluses.

1.2 Risk Factors for Diabetic Foot Ulcers

Risk factors associated with DFU are :

- Combination of deformity, callus, higher peak skin pressure, and diabetic neuropathy
- Critical limb ischemia due to PAD
- Penetrating trauma
- ill-fitting footwear or skin injuries brought on by friction
- prior ulcer history
- inadequate glucose regulation
- Smoking Cigarettes
- Social influences such low socioeconomic level, limited access to healthcare, and inadequate education

Table 1.1 Ulcers

Feature	Neuropathic	Ischemic	Neuroischemic
Sensation	Sensory loss	Pain	Degree of sensory loss
Callus/necrosis	Callus present and often thick	Necrosis common	Minimal callus; prone to necrosis
Wound bed	Pink and granulating, surrounded by callus	Pale and sloughy with Poor granulation	Poor granulation
Foot temperature and pulses	Warm with bounding pulses	Cool with absent pulses	Cool with absent pulses
Other	Dry skin and fissuring	Delayed healing	High risk of infection
Typical location	Weight-bearing areas of the foot, such as metatarsal heads, the heel and over the dorsum of clawed toes	Tips of toes, nail edges and between the toes and lateral borders of the foot	Margins of the foot and toes
Prevalence	35%	15%	50%

1.3 Complications of Diabetic Foot Ulcers

1.3.1 Soft tissue abnormalities

Various soft tissue consequences, including edema, cellulitis, abscesses, sinus tracts, tenosynovitis, and joint effusions/arthritis, can result from infections in diabetic foot ulcers (DFUs). Edema, cellulitis, and abscesses require immediate antibiotic treatment. Specialised treatments are needed for sinus tracts, while immobilisation and antibiotic therapy may be necessary for tenosynovitis. Joint suction, antibiotics, and rehabilitation are necessary for joint effusions and arthritis, which cause discomfort and functional impairment. To stop the progression of these problems and encourage healing in DFUs, effective care is crucial.

1.3.2 Osteomyelitis

Osteomyelitis is a problem that develops from ulcers that don't heal, where a soft tissue infection spreads into bone, first affecting the cortex and then moving on to the marrow. It can affect any bone, however it most frequently affects the forefoot (90%) followed by the midfoot

(5%), and the hindfoot (5%). All ulcers expose bone, and a large percentage (82%) of deep ulcers have osteomyelitis symptoms following bone biopsy. To address this illness and prevent subsequent complications, prompt detection and adequate treatment are necessary.

1.3.3 Amputation

Major consequences of improper DFU management include amputation. Patients with osteomyelitis, soft tissue necrosis, unmanageable infection, or unrelenting agony may require it. These problems can affect patients' general health and quality of life and present significant obstacles to proper wound healing.

1.3.4 Death

Amputations performed on patients with DFUs cause higher fatality rates.

1.3.5 Treatment

Comprehensive treatment should be used for DFU. A comprehensive care plan should include pressure offloading, wound debridement, infection therapy, and, if necessary, revascularization treatments. Debridement of a wound aids healing by removing infected or dead tissues. The blood flow in the affected region is improved through revascularization techniques. Last but not least, pressure unloading facilitates healing by reducing stress on foot.

1.3.6 Debridement

In order to promote healing, necrotic and non-viable tissues are removed during debridement, a crucial procedure in the management of DFU. Various techniques, including surgical, enzymatic, mechanical, biological, and autolytic ones, can be used to accomplish this. The quickest and most effective way to remove necrotic tissue is through surgical debridement, which uses a scalpel. A healthy, actively bleeding ulcer bed that promotes the development of granular tissues and accelerates wound healing is a sign of successful debridement.

1.3.7 Wound dressing

Clinicians should choose dressings for wounds based on their location, size, depth, exudate, presence of infection or necrosis, and surrounding tissue condition in order to maintain a moist wound bed after debridement.

1.3.8 Pressure offloading

Plantar ulcers are relieved of prolonged pressure using off-loading techniques like total contact casting (TCC), cast walkers, half shoes, and felted foam dressing, which aids in the healing process.

1.4 Offloading Devices

Offloading tools are essential for facilitating therapeutic success and accelerating wound healing. These gadgets are made to lessen external pressure on the ulcer-affected region, which lessens the strain on the wound and the tissues around it. Offloading devices delay skin pressure, preventing excessive strain on the wound site, and allowing it to heal more quickly. These tools also offer a barrier of defence that protects the wound from repeated trauma, aiding in the healing process even more. The right offloading device should be chosen based on a number of considerations, such as the need for mechanical protection, the unique needs of each patient, and the necessity of maintaining consistent adherence to the device in order to maximise healing rates.

1.4.1 Total Contact Casting

Total Contact Casting (TCC) uses a non-removable, custom-made cast to evenly distribute direct forces along its length, shielding the wound from damage and halting the growth of ulcers. TCC needs to be applied consistently and changed every one to two weeks to stop skin lesions from getting worse, more tissue from being damaged, and soft tissue from becoming infected. As it restricts wound inspections and dressing changes, it is contraindicated in cases

of significant wound seepage, untreated ischemia, infection or osteomyelitis, and severe peripheral arterial disease (PAD).

1.4.2 Removable Cast Walkers

Removable cast walkers (RCW) are light, semi-rigid casts that keep the ankle at a 90-degree angle by having a rocker bottom sole and a protective inner sole. They allow for dressings while offering support and security. RCWs have the benefit of being removable, allowing for quick application and removal as well as simple wound care. Some RCWs have features like additional foam layers for complete contact and overlapping air cells for intermittent pneumatic compression. RCWs, however, are not made to order and might not fit people with short legs, wide feet, or severe deformities. For the device to be effective, the patient must wear it consistently. The Scotchcast boot, a lighter alternative to plaster casts, is one example of an RCW. By removing the cast covering the foot's dorsum, the Scotchcast boot can be made removable or non-removable and is well-padded. It has a closure system with fabric hook and loop fastener straps, tape, and padding. As required, windows are cut to cover the ulcers, and removable fibreglass heel caps are added for severe heel ulcers. The boot is worn with a cast sandal to increase patient mobility while still shielding the ulcer from pressure.

1.4.3 Irremovable Cast Walkers/Instant Total Contact Cast

A removable cast walker's (RCW) frame and a total contact cast's (TCC) semi-permanent binding are combined in irremovable cast walkers (ICW), also known as immediate total contact casts (iTCC). The ICW has the advantages of better offloading capacity than a TCC while still allowing for simple removal and reapplication by encircling an RCW with cohesive tape or composite fibres. For patients with severe ischemia, this gadget allows for regular wound checks. The ICW offers the best wound management and unloading by striking a balance between the RCW's practicality and the TCC's adherence.

1.4.4 Half shoe

Half-shoes are made to relieve forefoot stress while preserving heel, midfoot, and toe-off functionality while walking. They are made of a firm sole with a rocker-bottom shape and an above-ankle brace that has been specially shaped. Only the heel and midfoot remain as weight-bearing surfaces because the anterior portion of the shoe has been removed. Although it takes skill and time to create a unique half-shoe, these tools are inexpensive and simple to use. Half-shoes are excellent for controlling diabetic foot ulcers and fostering the best possible recovery since they allow focused unloading and maintain normal gait mechanics.

1.4.5 Healing Sandal

A hard rocker sole can be added to a sandal for offloading reasons to distribute pressure on the metatarsal heads. It takes skill to create the rigid-sole rocker and make the appropriate adjustments for different patients with this portable, reusable gadget. Another choice is the Mabal shoe, which combines the advantages of a cast walker and a healing sandal. The Mabal cast shoe has a solid sole, little cushioning, and complete contact with the entire plantar area. It includes a flexible soft cast that reaches below the ankle, which is worn with a plastic roller sandal to aid with walking.

1.4.6 Felted foam

When other biomechanical choices are not accessible, a bilayered felted foam pad is applied across the plantar area corresponding to the ulcer site as an unloading technique. For best results, it's crucial to combine this technique with the appropriate footwear.

1.4.7 Crutches, canes, walkers, wheelchairs

Although helpful for unloading diabetic wounds, assistive devices have their limitations. They need force and strength in the upper body to be used successfully. Offloading is successful only when it is used consistently and frequently because there is no requirement to do so. These devices may also raise pressure on the unaffected side, raising the possibility of ulceration on

the limb on the opposite side. These devices are used by some patients to immobilise ambulatory modalities, such as a TCC. However, they can also support the gradual return to normal activities and weight-bearing as a necessary component of the healing process.

1.4.8 Surgical

When non-surgical therapy for diabetic foot problems is ineffective, surgical offloading is an alternative. Joint arthroplasty, single- or pan-metatarsal head excision, and osteotomies are all procedures that can enhance the healing process and help prevent recurrent foot ulcers. Additionally, by lowering forefoot pressure and enhancing alignment from the ankle and rear foot to the midfoot and forefoot, exostectomy combined with tendon lengthening can successfully relieve bone pressure. These surgical procedures seek to correct the underlying biomechanical problems and enhance foot performance, thereby lowering the chance of developing ulcers in the future.

CHAPTER 2

LITERATURE REVIEW

Kharroubi AT, Darwish HM ,2015 in the paper titled Diabetes Mellitus: The Epidemic of Century [1] discuss the molecular genetics, categorization, diagnosis, and aetiology of diabetes. The numerous causes of diabetes are also covered in the essay, including hereditary issues, endocrine disorders, and viral infections. The study also emphasises the link between specific genes and diabetes-related comorbidities such nephropathy, retinopathy, and cardiovascular disorders. Overall, the study offers a thorough analysis of diabetes, including all of its origins and complications.

Williams R et al 2020 [2] discuss gives forecasts for the prevalence of diabetes and impaired glucose tolerance (IGT) as well as estimations of the prevalence of diabetes, undiagnosed diabetes, and IGT for the years 2030 and 2045. This document contributes to the International Diabetes Federation's (IDF) effort by offering up-to-date estimates and projections for the national, regional, and worldwide prevalence of diabetes. In 2019, 463 million individuals worldwide are predicted to have diabetes, according to the paper's conclusion. This figure equals 9.3%. By 2030, there will be a 10.2% prevalence (578 million people), and by 2045, there will be a 10.9% prevalence (700 million people). Urban locations and nations with high incomes have a higher occurrence. The study also emphasises that one in two diabetes sufferers are not aware of their illness. In order to combat diabetes, the authors emphasise the necessity for quick and multi-sectoral interventions.

Yazdanpanah L et al 2015 [3] concentrate on treating diabetic foot ulcers (DFUs), a frequent and expensive consequence of diabetes mellitus. It emphasises how crucial early and efficient DFU management is for lowering serious consequences including needless amputations and probable mortality while improving the general quality of life. The review contends that effective DFU management requires a comprehensive strategy comprising a multidisciplinary team. Controlling blood sugar levels, wound debridement, advanced dressings, offloading techniques, and additional therapies like hyperbaric oxygen therapy, electrical stimulation, negative pressure wound therapy, bio-engineered skin, and growth factors are just a few of the strategies for DFU management that are covered. Patient education is also emphasised as being essential for encouraging proper foot care to stop DFUs and the issues they cause. The review emphasises that a multidisciplinary approach is essential for achieving speedy recovery and that prompt and thorough therapy are required for DFUs. It emphasises the value of education, blood sugar management, wound care, cutting-edge dressings, unloading, surgery, and cutting-edge therapies in the management of DFU. The review emphasises the possibility to lessen the significant morbidity and serious consequences linked to DFUs by using a thorough and interdisciplinary approach. In the end, the review offers insightful perspectives on DFU management and emphasises the need for prompt and efficient interventions to improve patient outcomes.

Cavanagh PR et al 2005 [4] offers an overview of the current state of medical and surgical treatment for diabetic foot ulcers (DFUs). It highlights the escalating public health problem posed by foot ulcers due to the high prevalence of diabetes worldwide. DFUs lead to significant

morbidity, impair quality of life, result in high treatment costs, and are the primary risk factor for lower-extremity amputations. Unfortunately, the provided treatment for foot ulcers often falls short, leading to avoidable complications and prolonged healing times. The paper discusses various off-loading techniques and preventive measures for non-plantar ulcers. It also explores recent advancements in DFU treatment, such as bone marrow-derived stem cells, negative pressure dressings, bioengineered skin substitutes, and growth-factor therapy. However, many of these treatments lack controlled or comparative studies to establish their efficacy. Maggot biotherapy shows promise in debridement, expediting healing, and potentially reducing antibiotic usage and amputation risk. The paper concludes that utilizing the assessment and treatment approaches outlined can contribute to successful and prompt healing of DFUs. Implementing these strategies, whenever possible, can help mitigate the high morbidity and serious complications associated with foot ulcers. However, there is still ample room for improvement in both the techniques employed and ensuring clinicians adhere to the highest standards of care. The paper suggests that multidisciplinary speciality foot clinics, leveraging the expertise of diverse healthcare providers, are likely to enhance outcomes for diabetic individuals with foot ulcers.

Singh S et al 2015 [5] discuss that diabetic foot ulcers, a serious consequence of diabetes, can be treated using a variety of unloading strategies. The merits and downsides of unique offloading mechanisms are discussed in the paper. The necessity of early detection and care of foot ulcers and amputations in diabetes patients is emphasised in the paper. The interdisciplinary approach necessary for the best therapy of diabetic foot ulcers is also

highlighted in the research. Overall, the publication advances knowledge regarding the treatment of diabetic foot ulcers and offers information that is beneficial to medical practitioners.

Fagalia E et al 2010 [6] examine the efficacy of a removable cast walker in treating diabetic plantar foot ulcers in comparison to a nonremovable fiberglass off-bearing cast. The Stabil-D cast walker, though removable, was proven to be just as effective as the TCC in terms of shrinking ulcer size and overall healing pace. With Stabil-D's simpler application, off-loading devices may be used more frequently to treat plantar neuropathic diabetic foot ulcers. The study makes additional inferences about how better glucose management may have positively impacted patient compliance generally and, possibly, the rate of ulcer healing in patients wearing the detachable device. The study adds to our understanding of how well various off-loading devices work to treat diabetic plantar foot ulcers.

Basatneh R et al 2018 [7] explore the potential application of IoT devices, smart home devices, and health sensors in preventing and managing diabetic foot ulcers (DFUs). It highlights the significant prevalence and cost of DFUs and their complications. The paper discusses the potential benefits of IoT devices in this context and outlines recent advancements in the Internet of Medical Things (IoMT). It provides examples of how voice-enabled smart speakers can assist DFU patients by offering reminders, educational information, and connectivity to healthcare professionals. The paper also emphasizes the importance of addressing challenges related to patient compliance, battery life, and security and privacy issues associated with the use of IoT. Overall, the paper contributes valuable insights into the role of IoT technologies in

preventing and managing DFUs while addressing critical considerations for their implementation. The conclusion of the paper is that the IoMT has opened new avenues and opportunities in health care from remote monitoring to smart sensors and medical device integration, and has the potential to not only keep patients safe and healthy but also improve how physicians deliver personalized and timely care. Recent market research indicates the "sensor market in consumer healthcare" will be worth \$47.40 billion by 2020, and with DFU care nearly doubling the costs of diabetes in the United States, there is hope that a new era in the development of medical sensors and their integration with IoMT can help alleviate the economic burden of this disease.

Najafi B et al 2020 [8] discuss the use of wearable and mobile health technologies to improve the management and prevention of diabetic foot ulcers (DFUs). Exploring how smart sensors and communication technologies can be used to identify high-risk patients for timely intervention, personalize prescription of offloading, and improve adherence to protective footwear. Highlighting the need to shift the focus from just healing open wounds to maximizing ulcer-free days for patients in diabetic foot remission. Emphasizing the potential of technology to extend remission and improve the quality of life for patients with DFUs. Providing insights into recent promising technology developments that could assist in the effective prevention of DFUs. The conclusion of the paper is that next-generation technologies should be geared towards the long-term monitoring of people both with tissue loss and after healing in remission. This will likely consist of a multitude of epidermal, wearable, and implantable sensors. Long-term success in assisting individuals in maintaining their active lifestyles while optimising

DFU management and supporting DFU prevention programmes will depend on the development of uniform ways of communication and assessment of these technologies that transcend the private nature of particular devices.

Raviglione A et al 2017 [9] presents the development of a real-time smart textile-based system designed to monitor pressure offloading in diabetic foot ulcers (DFUs). The system comprises a textile pressure sensor attached to a stretchable band, hardware for data collection and Bluetooth transmission to a smartphone, an accompanying app for data aggregation and cloud storage, and a web dashboard for displaying the data to clinicians. The study demonstrates the feasibility of creating a simple and modular wearable system that enables real-time monitoring of pressure beneath DFUs. The authors conclude that this system represents a significant innovation in mHealth for DFU care. Remote pressure monitoring provides an opportunity to ensure and promote optimal offloading in community settings. The web dashboard enables doctors to track multiple patients simultaneously and quickly identify high-risk individuals with inadequate offloading. Overall, this technology has the potential to enhance DFU care by enabling proactive monitoring and intervention.

Kang G A et al 2022 [10] perform a mini-review that outlines the most recent research on the use of wearable IMUs to assess gait and balance in individuals with diabetic feet. The authors discovered early indications of digital biomarkers, such as sluggish gait speed, high gait variability, unstable gait beginning, and significant body sway, in persons with diabetic feet. However, more research is advised to corroborate this preliminary finding due to the heterogeneities in included publications regarding study design, movement tasks, and small

sample size. The authors also noted a number of difficulties and limitations with the included studies and proposed future lines of research that could address these concerns and make improvements in the care of diabetic feet.

Finco MG et al 2023 [11] explore user perspectives of irremovable, removable, and sensorized offloading walkers to provide insight on ways to help promote adherence among older adults with diabetic foot ulcers (DFUs). In order to determine whether smart offloading with real-time feedback is acceptable to persons with DFUs, the study is the first to examine participants' attitudes towards it. The purpose of the article was to learn more about the variables that affect whether a smart offloading device with remote patient monitoring will be adopted. The conclusion of the paper is that smart offloading with a remote patient monitoring solution may help promote adherence among older adults to wear offloading boots prescribed for DFUs. The design of the particular walker that was used in this study, regardless of being irremovable or removable, was better accepted among people who identified as Hispanic or Latino. Further, findings suggest clinicians could provide additional patient education for people who report experiencing at least one fall over the previous 12 months, particularly in putting on and taking off the walker. Manufacturers could also consider designs that improve perceptions of the stability and appearance of the walker.

Gujarathi T, and Bhole K 2019 [12] provide a wearable IMU sensor-based device and its related gait analysis algorithm in order to collect quantitative measurements of a person's gait parameters to track patient improvement in orthopaedics and rehabilitation. The following are the paper's contributions: The article explains an IMU-based gait analysis technique that

employs angles from the accelerometer and gyroscope sensor in the MPU6050 to pinpoint the various phases of each gait cycle when a person is walking. The paper proposes a gait phase detection algorithm on gait signals collected from IMU sensors mounted on the shank. The paper demonstrates that the chosen sensor is effective for data acquisition and improves the accuracy of gait analysis. The paper explores the functionality of a system that is totally based on an IMU sensor, including the use of two MPU6050 sensors. The paper provides a low-cost effective and simple technique by considering a person's comfort to walk which can be used for gait analysis. The following is the paper's conclusions: The experiment's findings show that the suggested approach works well for gait analysis and can extract metrics including gait speed and cadence as well as stance time, stride time, swing time, step time, stride length, and step time. The appropriate methodology of analysis can serve as an appropriate rehabilitation process for a patient with gait malfunction.

Hisham N A et al 2022 [13] explores the capability of HD VideoCam-Kinovea as an alternative software method to perform motion analysis. The study clarifies the reliability of Kinovea in performing motion analysis, particularly in the gait phases of human's walking activity by focusing on the ankle. The study shows that Kinovea can provide output as good as a more established motion capture system such as Cortex, thus making it a good alternative in motion analysis. Kinovea is relatively more economical and easier to be used. The conclusions of this paper are: The HD VideoCam-Kinovea has the potential to become a reliable motion capture and analysis system. From the eight sets of angles analyzed by Kinovea, six of them have a percentage difference of just between 0.82% to 4.07% when compared to Cortex's, thus

demonstrating the reliability of the analysis Kinovea is capable of. Only two of the eight data exceeded 10%, which are the toe off and initial swing phases.

2.1 OBJECTIVES

The following are the objectives of this investigative experimental study:

1. To perform gait assessment for determining gait parameters and analyse gait pattern
2. To ensure remote assessment, track and monitor gait performance, improvement
3. Provide patient engagement and education
4. Comparison of shank angle variations in motion analysis tool Kinovea and developed smartphone hardware on benchmarked devices.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This research aims to develop a smartphone application capable of measuring shank angle variation and determining gait parameters in patients wearing diabetic foot walkers. Analysis and monitoring of gait are significantly hampered by diabetic foot problems such as diabetic neuropathy and foot ulcers. Gait analysis is essential for diagnosing and treating these problems because it offers insightful information about the biomechanics of walking and aids in treatment and rehabilitation planning. However, the unique characteristics of diabetic foot walkers require specialized techniques for accurate gait analysis. By leveraging smartphone technology and wearable sensors, this research seeks to address these challenges and improve gait analysis and monitoring techniques for individuals with diabetic foot conditions.

The significance of this study lies in its potential to revolutionize the assessment and management of diabetic foot conditions through the development of a smartphone application. Current gait analysis methods often involve expensive and specialized equipment, limiting their accessibility in routine clinical practice. This research intends to offer a more practical and affordable alternative for monitoring gait in patients using diabetic foot walkers by utilising the capabilities of smartphones, which are widely available and contain built-in sensors. Using the programme, healthcare providers can precisely gauge shank angle variation, a key factor in determining whether a person has a gait disorder, and calculate gait characteristics including stride, step duration, and cadence. These variables give healthcare professionals useful quantitative data regarding gait patterns that they can use to monitor patient progress, personalise treatment regimens, and assess the efficacy of diabetic foot walkers in practical situations.

This methodology section's goal is to provide an overview of the methods and steps used to create the smartphone application. It will provide detailed explanations of the system architecture design, sensor calibration, data acquisition, gait parameter determination algorithms, integration with the ThingSpeak cloud platform, system validation, and ethical considerations.

Additionally, the research aims to compare the shank angle values measured using the smartphone application with those obtained through the kinematic motion analysis tool Kinovea for different diabetic foot walkers. To validate the accuracy and reliability of the smartphone application, a comparison will be made between the shank angle values obtained from the application and those measured using Kinovea. This comparison will involve a participant wearing different diabetic foot walkers, allowing for a comprehensive evaluation of the application's performance across various walker types. Ultimately, this research has the potential to revolutionize the monitoring and assessment of diabetic foot walkers, contributing to better care for individuals with diabetic foot complications.

3.2 System Architecture

The smartphone application for measuring shank angle variation and determining gait parameters in individuals wearing diabetic foot walkers will have a comprehensive architecture comprised of both hardware and software.

Hardware components

1. Smartphone: The application will utilize built-in sensors of smartphones, such as an accelerometer and gyroscope, to capture necessary data for gait analysis.
2. Diabetic foot walker: For capturing the shank angle variation the smartphone should be attached securely to the diabetic foot walker with the help of Velcrow as shown in

Figure 3.2



Figure 3.2 Smartphone attached to diabetic foot walker

Software Components

1. Mobile Application: The core component of the system architecture is a mobile application developed on the Android platform. The application facilitates data acquisition, data processing, gait feature extraction and visualisation.

In order to upgrade to a smart diabetic foot walker, smartphones must be integrated into walkers using Velcro. To achieve this, in this study, IMU sensors in the smartphone are preferred to determine the shank angle.

3.3 Angle Estimation

For the measurement of the shank angle, an application on the Android platform named “shank angle” is developed with the help of the MATLAB Simulink model as shown in Figure 3.3.1

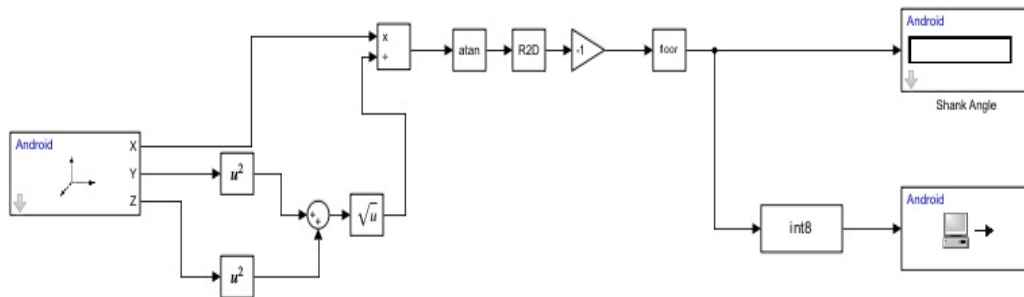


Figure 3.3.1 Plan model of shank angle application

From the planning model, acceleration data of smartphones IMU, while the participant is wearing the walker and walking, is taken as the main data. The smartphone is placed on the walker vertically as shown in Figure 3.2. in the sagittal plane. Simulink model that processes accelerometer data from a smartphone's inertial measurement unit (IMU) to calculate and display the shank angle. The model uses various Simulink blocks from different libraries to perform the required calculations and visualize the angle value.

1. Accelerometer Data Block: This block is selected from the Simulink model for the Android Sensors library. It represents the accelerometer sensor in the smartphone's IMU and provides raw acceleration data.
2. Calculation of Shank Angle: The raw acceleration data (x, y, and z components) from the accelerometer is used to calculate the shank angle (θ) using the equation provided. The arctangent function (\tan^{-1}) is applied to the ratio of x and the square root of the sum of the squares of y and z[14].

$$\text{Shank angle, } \theta = \tan^{-1}\left(\frac{x}{\sqrt{y^2+z^2}}\right)$$

3. Conversion to Degrees: The shank angle calculated in radians is then converted to

degrees using the Radians to Degree block from the Simulink extras library. This block performs the conversion from radians to degrees.

4. Rounding the Angle: The angle value obtained in degrees is rounded to the nearest integer using the Rounding function block from the Math Operations library. This ensures that the angle value is a whole number.
5. Positive/Negative Display: To represent the angle value during heel strike as positive and toe-off as negative, a constant gain is applied to the angle value using the Gain function block from the Math Operations library. Multiplying the angle value by a negative constant would flip the sign of the angle, representing toe-off as negative.
6. Displaying the Angle: The processed shank angle value is then displayed as numerical data on the "shank angle" application. This is achieved using the Data Display block from the Simulink Support Package for Android Sensors library. The block allows the angle value to be visualized and monitored in the application.
7. Remote monitoring of Angle: For visualizing the shank angle measurements on a separate interface developed on a personal computer or laptop, the UDP send block from the Simulink support package for Android devices is employed. This block sends the angle data over a UDP (User Datagram Protocol) connection to the computer or laptop, where it can be received and displayed in a custom interface.

Overall, the Simulink model takes raw accelerometer data, performs the necessary calculations to obtain the shank angle, converts it to degrees, rounds it, adjusts the sign for heel strike and toe-off, and finally displays the processed angle value on the "shank angle" application and sending it to a separate interface developed on MATLAB Simulink as shown in Figure 3.3.2 for visualization in a laptop or computer.

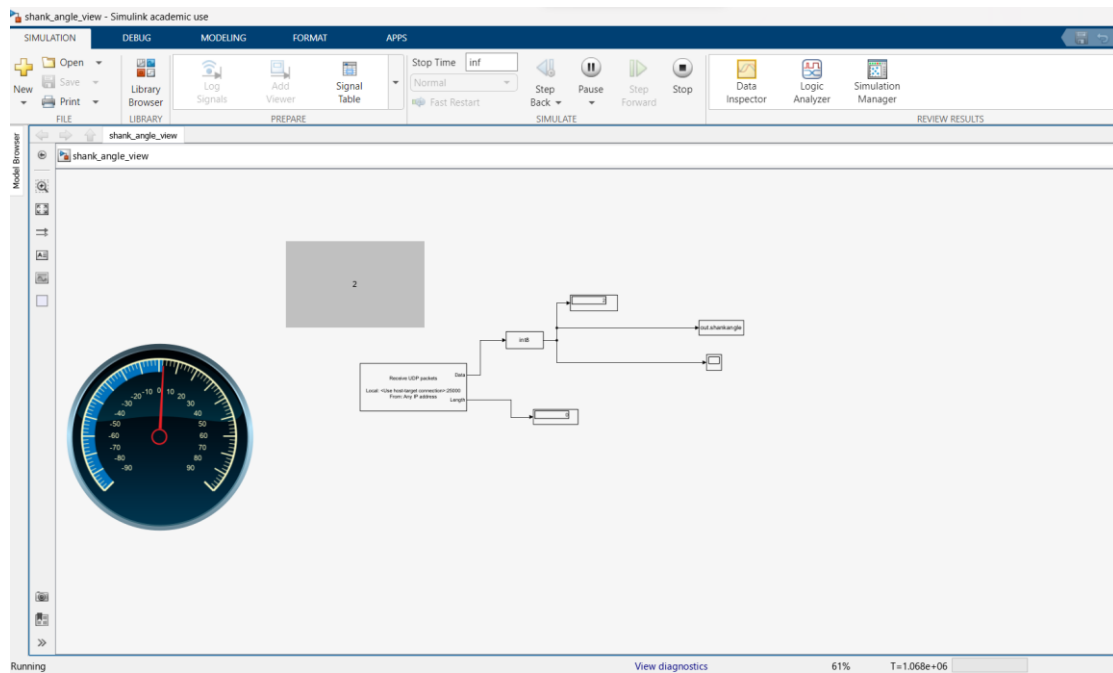


Figure 3.3.2 Interface view the shank angle variation

Now the planned model is deployed as an application on Smartphones in the Android platform.

3.4 Algorithm development for Gait Parameter estimation

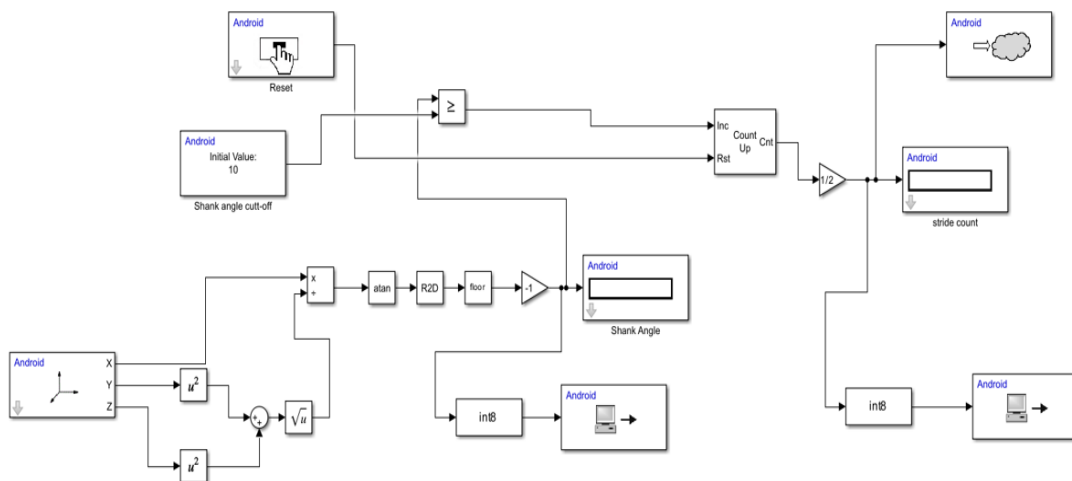


Figure3.4.1 Gait parameter estimation Algorithm

The algorithm described in Figure3.4.1 monitors and calculates strides based on the shank angle value during the heel strike. Here is a step-by-step breakdown of the algorithm's

operation:

1. Real-time Shank Angle Value: The algorithm inputs a real-time shank angle value. This value represents the angle of the shank (lower leg) during the heel strike phase of walking.
2. Predetermined Cut-Off Value: There is a predetermined cut-off value (x_c) that serves as a threshold. The real-time shank angle value (x_i) is compared with this cut-off value.
3. Data Input Block: The Simulink support package for Android sensors provides a data input block that allows the algorithm to receive the real-time shank angle value.
4. Relational Operator Block: The algorithm uses a relational operator block from the logic and bit operations blocks in Simulink. It compares the current shank angle value (x_i) with the predetermined cut-off value (x_c) to determine whether the shank angle is greater than or equal to the cut-off value.
5. Counter Logic: Counter Logic: The counter logic is set to 1 if the shank angle (x_i) exceeds or equals the cut-off value (x_c). It is set to 0 if not.
6. Counter Block: The DSP System Toolbox provides a counter block that is used to initiate the counter logic. When the counter logic transitions from 0 to 1, it indicates a count occurred and it repeats .
7. Stride Calculation: The counter value is multiplied by 0.5 using a gain block from the Math Operations library to calculate the number of strides. This division by 2 is based on the assumption that each stride consists of two heel strikes.
8. Data Display: The numerical values representing the stride numbers are displayed on an application named "shank angle." The Simulink Support Packages for Android Sensors library provides a data display block that enables the visualization of numerical values on the application.
9. Cloud Storage: The stride numbers are also stored in a cloud platform called Thingspeak, developed by MathWorks, to allow interventions from clinicians. The Thingspeak Write block

is used to publish the data to the Internet of Things (IoT) using the Thingspeak block from the Simulink Support Packages for Android Devices/Communication.

By following this algorithm, the system continuously monitors the shank angle during the heel strike, calculates the number of strides based on the predetermined cut-off value, and displays the stride numbers on an application while also storing them in the Thingspeak cloud platform for further analysis or interventions from clinicians.

3.5 Smartphone calibration

The process described below is the calibration procedure for the "Shank Angle" smartphone application, which is designed to measure the angle of tilt or inclination of the smartphone using its internal IMU (Inertial Measurement Unit) sensor.

To calibrate the application, a mechanical test system is developed. This system consists of angle markings similar to a protractor, drawn on a vertical surface as shown in Figure 3.5.1.

The smartphone is placed in an upright position against this vertical surface.

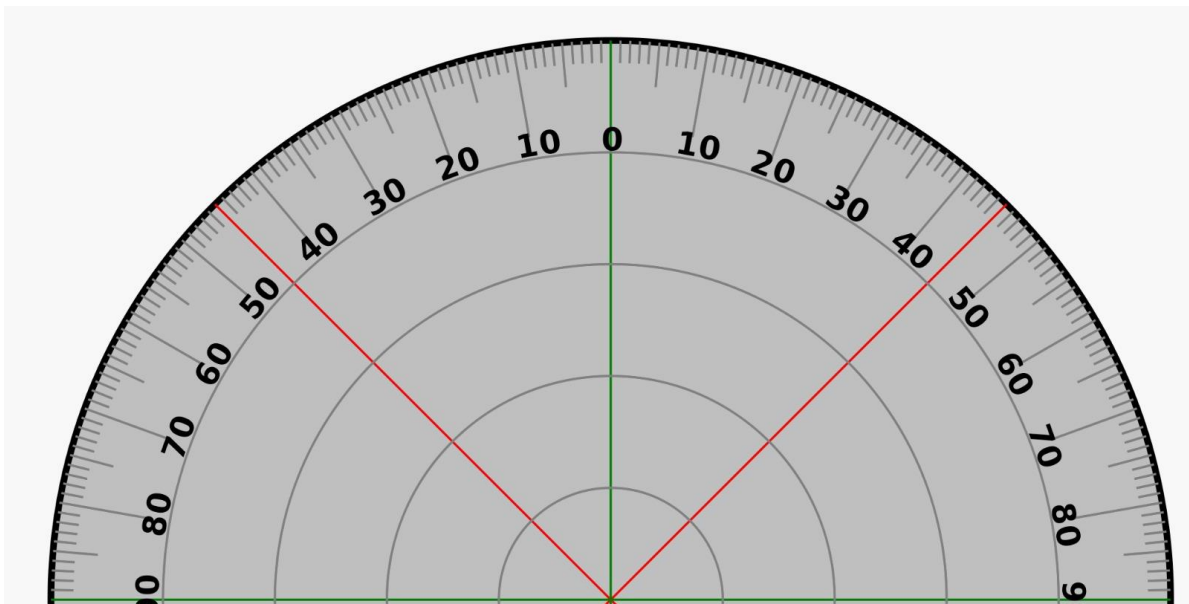


Figure 3.5.1 Mechanical test system for sensor calibration

In the upright position, the smartphone's IMU measures the values as zero. This means that when the smartphone is perfectly vertical, the application will display a zero-angle

measurement as in Figure 3.5.2.

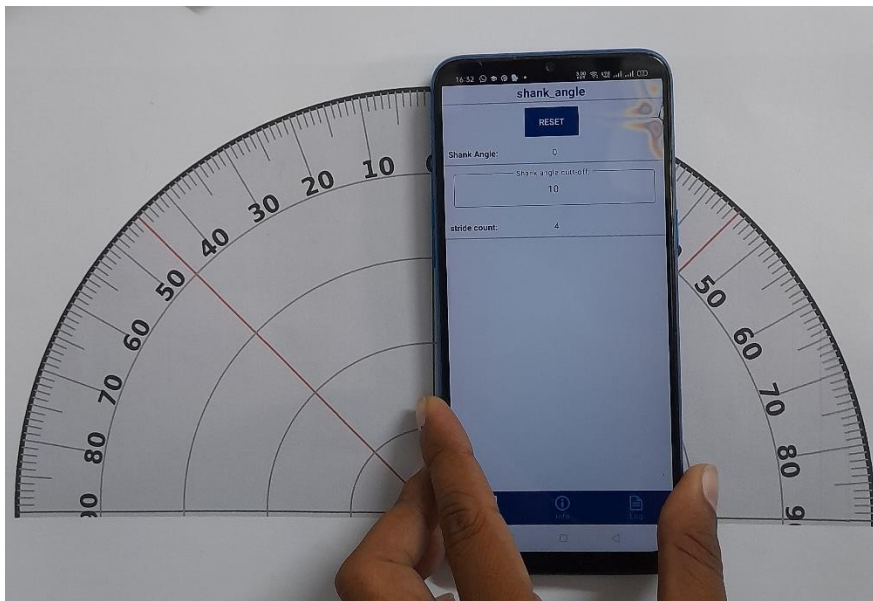


Figure3.5.2 Smartphone in Upright position

To determine positive and negative angles, the smartphone is tilted in a clockwise direction. As the user tilts the smartphone clockwise, the application will display the angle measured by the smartphone's IMU as a positive value. This means that the application is programmed to interpret clockwise tilting as positive angles.

Conversely, when the smartphone is tilted in a counterclockwise direction, the application will display the angle measured by the smartphone's IMU as a negative value. This means that counterclockwise tilting is interpreted as negative angles by the application.

The calibration process involves comparing the angles marked on the vertical surface with the angles displayed by the application. To match the angles marked on the surface, the user tilts the smartphone both clockwise and anticlockwise. The angle that appears in the application should match the angle indicated on the surface if the calibration is correct. The calibration in both directions is shown in Figure 3.5.3

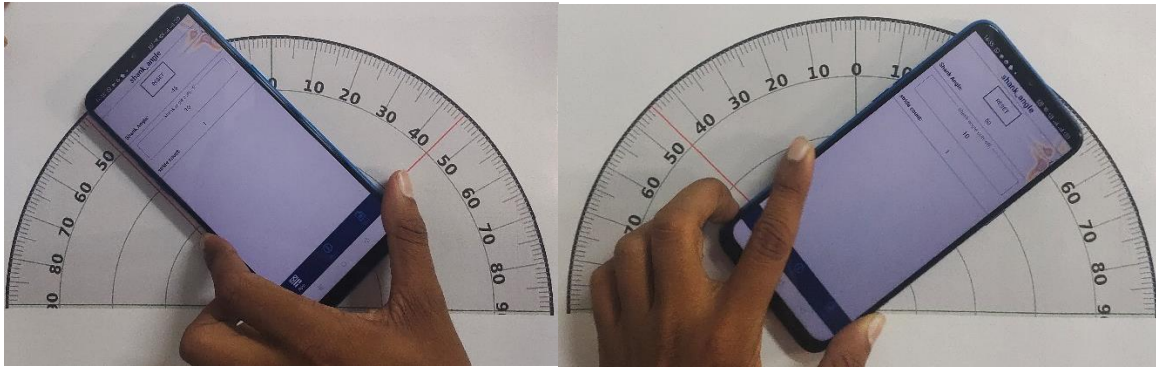


Figure3.5.3 Calibration in the clockwise direction (left) & counter-clockwise direction (right)

By performing this calibration procedure, the application aligns its measurements with the actual angles of tilt and provides accurate readings to the user. It ensures that the application's measurements correspond to the physical world and allows for reliable angle measurements using the smartphone's IMU.

3.6 Gait Parameters Extraction

Gait refers to the manner or pattern of walking. By adopting a series of well-coordinated actions and behaviours, people can go from one place to another. During the complex gait process, various body systems, including the musculoskeletal, neurological, and sensory systems, interact.

Important gait components include the following:

1. Stance phase: The first phase of the gait cycle, occurs when the foot makes contact with the ground. Heel strike is the first phase, then flat foot, midstance (when the entire foot is in touch with the ground), and toe-off are the final phases.
2. Swing Phase: This phase occurs when the foot is off the ground. It starts with toe-off, followed by initial swing (leg swinging forward), mid-swing (maximum knee flexion), and terminal swing (preparing for heel strike).

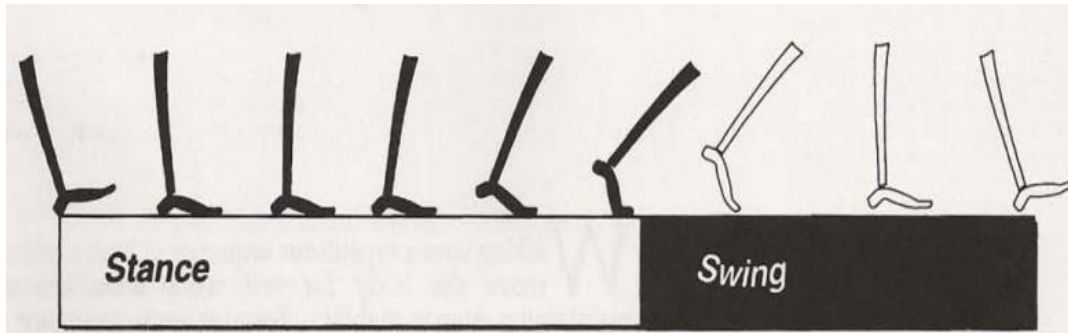


Figure 3.6.1 Gait phases

3. **Stride:** A stride is the complete gait cycle from heel strike to the subsequent heel strike of the same foot. It consists of one stance phase and one swing phase of the same leg.
4. **Step:** A step is a distance between the heel strike of one foot and the heel strike of the opposite foot. It involves two consecutive strides.
5. **Gait Cycle:** The gait cycle represents the complete sequence of events that occur during one stride of each leg, including both the stance and swing phases.
6. **Gait Parameters:** Gait parameters are quantitative measurements derived from gait analysis. They include step length, stride length, cadence, walking speed, stance time, swing time, and various other spatiotemporal and kinematic parameters.

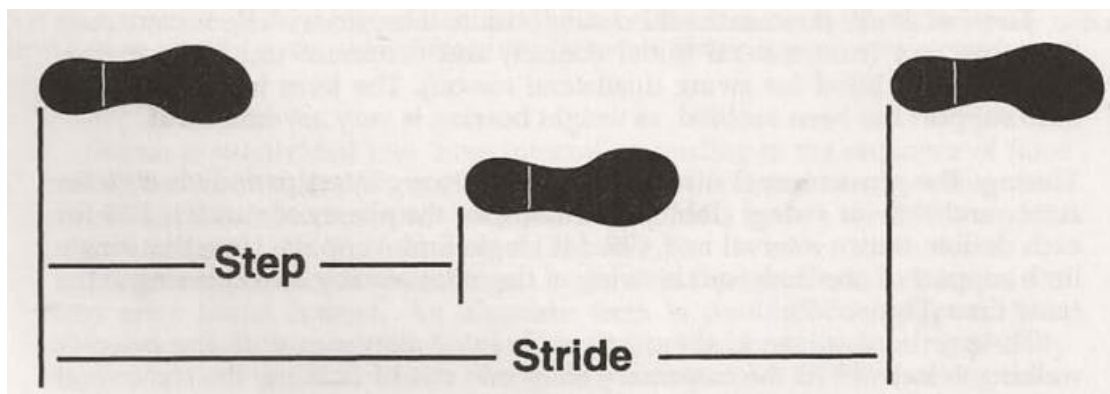


Figure 3.6.2 Step vs stride

Gait analysis plays a crucial role in various fields, including healthcare, biomechanics, sports performance, and rehabilitation. It can be conducted through different methods, such as visual observation, instrumented walkways, wearable sensors, and motion capture systems. Gait

analysis provides valuable information about an individual's walking pattern, gait abnormalities, symmetry, balance, and functional limitations. It can aid in diagnosing and monitoring conditions affecting gait, assessing the effectiveness of interventions, and designing personalized rehabilitation programs.

For the Gait component extraction participant wears a diabetic foot walker, to which a smartphone is attached using Velcro as shown in Figure 3.2. The smartphone has a shank angle application installed, which uses the smartphone's built-in Inertial Measurement Unit (IMU) to measure the shank angle during walking. The participant is instructed to walk in a straight line for a distance of 6 meters on a level surface while a walking video is recorded. The walking area of is shown in figure 3.6.3



Figure 3.6.3 Walking area

As the participant walks, the shank angle variations are captured by the smartphone's IMU and displayed on the interface developed for viewing the shank angle variation. The shank angle represents the angle between the shank (lower leg segment) and the vertical axis.

To estimate gait components like strides and steps, the angle values obtained from the smartphone's IMU at specific events during the gait cycle, namely heel strike and toe-off, are utilized.

Heel strike refers to the moment when the heel of the foot contacts the ground, typically at the

beginning of the stance phase of the gait cycle. Toe-off, on the other hand, occurs when the toes push off the ground, marking the end of the stance phase.

By analyzing the shank angle values at heel strike and toe-off, No of strides the participant is covered can be calculated.

3.7 Integration of Internet of Things

Integrating the "Shank Angle" smartphone application with the Thingspeak cloud platform by MathWorks can indeed provide a robust solution for real-time monitoring and data analysis of a smart diabetic foot walker. Here's how the integration can work:

1. **Data Transmission:** The "Shank Angle" application, running on a smartphone, collects data from the smart diabetic foot walker, specifically the shank angle measurements. The application establishes a connection with the foot walker's sensors and captures the real-time shank angle data.
2. **Cloud Storage:** The captured shank angle data is then transmitted from the smartphone application to the Thingspeak cloud platform. Thingspeak provides cloud storage capabilities, allowing the data to be securely stored and accessed for further analysis and intervention.
3. **Data Analytics:** Once the shank angle data is stored in the Thingspeak cloud platform, the platform's built-in data analytics features can be leveraged to gain insights. Thingspeak offers a user-friendly dashboard that enables clinicians and healthcare professionals to visualize and analyze the data effectively.
4. **Real-Time Monitoring:** The dashboard provided by Thingspeak can display the shank angle data in real-time, allowing clinicians to monitor the patient's gait and identify any irregularities or potential issues. Real-time monitoring empowers clinicians to intervene promptly and provide appropriate care and guidance to the patient.
5. **Data Visualization:** The Thingspeak dashboard offers various visualization tools, such as graphs, charts, and customizable widgets, to present the shank angle data in a clear and

meaningful manner. These visualizations can aid clinicians in understanding trends, patterns, and abnormalities in the patient's gait.

6. **Intervention and Treatment:** Based on the insights gained from the data analytics provided by Thingspeak, clinicians can make informed decisions regarding intervention and treatment plans. They can identify deviations from normal gait patterns, track progress over time, and adjust the treatment strategies accordingly.

7. **Collaboration and Communication:** The Thingspeak cloud platform facilitates collaboration and communication among healthcare professionals involved in the patient's care. Multiple stakeholders can access the dashboard simultaneously, enabling interdisciplinary collaboration and the exchange of information and insights.

8. **Data Security and Privacy:** Thingspeak ensures the security and privacy of the stored data, implementing industry-standard encryption and access control mechanisms. This protects the patient's sensitive health information and ensures compliance with data protection regulations. By integrating the "Shank Angle" application with the Thingspeak cloud platform, clinicians can leverage real-time monitoring, data analytics, and collaboration tools to provide personalized care for diabetic patients using smart diabetic foot walkers. This integration enables proactive intervention, data-driven decision-making, and improved patient outcomes.

3.8 Comparison of Shank angle variation in Benchmarked devices

Using a smartphone installed with the "Shank angle" application attached to benchmarked devices to measure and compare the shank angle variations. Here's a step-by-step explanation of the process:

1. **Walkers:** The walkers you have chosen for benchmarking are the Tynor Air Walker- Figure 3.8.1, Ottobock Infinity Walker- Figure 3.8.2, Ottobock Malleo Walker- Figure 3.8.3, and a concept model – Figure 3.8.4 developed. These walkers will be used to gather data on shank angle variations.



Figure 3.8.1 Tynor Air Walker



Figure 3.8.2 Ottobock Infinity



Figure 3.8.3 Ottobock Malleo walker



Figure 3.8.4 Concept model

2. Smartphone and "Shank angle" application: A smartphone with the "Shank angle" application installed will be attached to each walker. The application utilizes the smartphone's inertial measurement unit (IMU) to record data on shank angle variations during specific phases of the walking gait cycle.
3. Participant instructions: Participants who will wear the walkers are instructed to walk for a distance of 6 meters on a level surface in a straight line. The participants should walk naturally, replicating their normal walking pattern.
4. Video recording: As participants walk with each walker, videos of the walking motion are captured using the camera. These videos will be used for further analysis.
5. Shank angle measurement: The "Shank angle" application on the smartphone utilizes

the IMU to measure the shank angle variations during heel strike (when the heel touches the ground) and toe-off (when the toes leave the ground) phases of the gait cycle. The IMU records the orientation and movement of the walker, allowing for accurate measurement of shank angles.

6. Data analysis with Kinovea: To determine the accuracy of your method using the smartphone's IMU, the recorded videos are imported into a kinematic motion analysis tool called Kinovea. Kinovea allows you to analyze the shank angle variations captured in the videos and compare them to the measurements obtained from the smartphone's IMU.
7. Comparison and evaluation: By comparing the shank angle variations measured using the smartphone's IMU and the analysis conducted in Kinovea, can evaluate the accuracy and reliability of the method.

By the above-mentioned steps, can determine how the Value is measured using Smartphone IMU is closest to the motion analysis tool Kinovea,

CHAPTER 4

RESULTS & DISCUSSIONS

For the measurement of Gait components, a smartphone application named “shank angle” measures the inclination angles from smartphone IMU for the shank angle measurement. The User Interface (UI) of the shank angle application is shown in Figure 4.1.

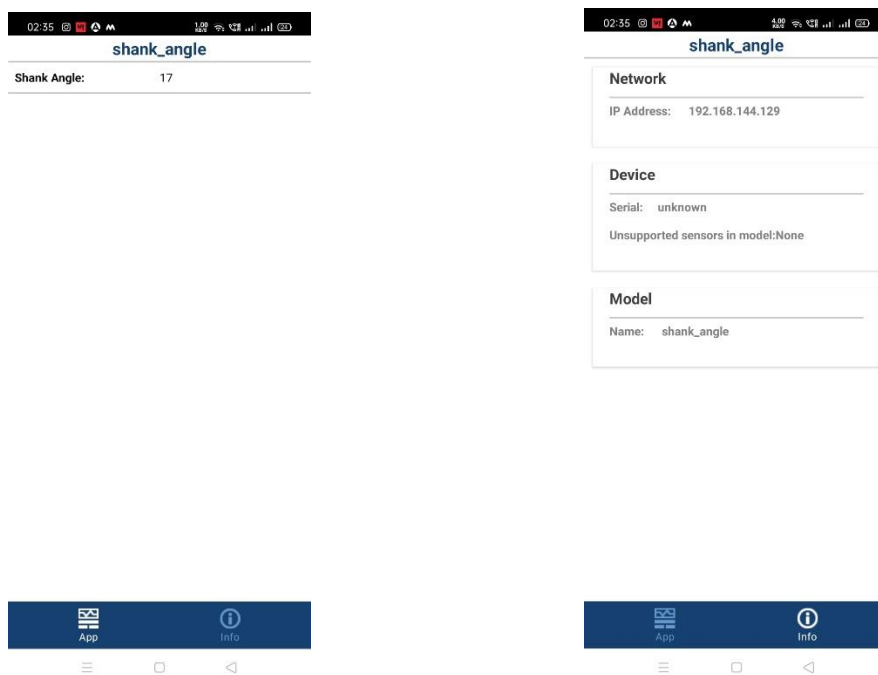


Figure 4.1 UI of the Shank angle application

According to the recorded video walking, the angle measured during the heel strike is the maximum positive value for the shank angle, and the angle measured during toe-off is the maximum negative value for the shank angle.

The valuable insight into shank angle variation during heel strike and toe-off is obtained from the recorded walking videos, an algorithm is developed for determining Gait parameters and is added to the Shank angle application. By adding the gait parameters the application interface shows the measured gait parameters strides, steps etc. The gait parameters data can be remotely

monitored from the Thingspeak cloud platform. The shank angle application and Thingspeak dashboard for analytics are shown in Figure 4.2 and Figure 4.3

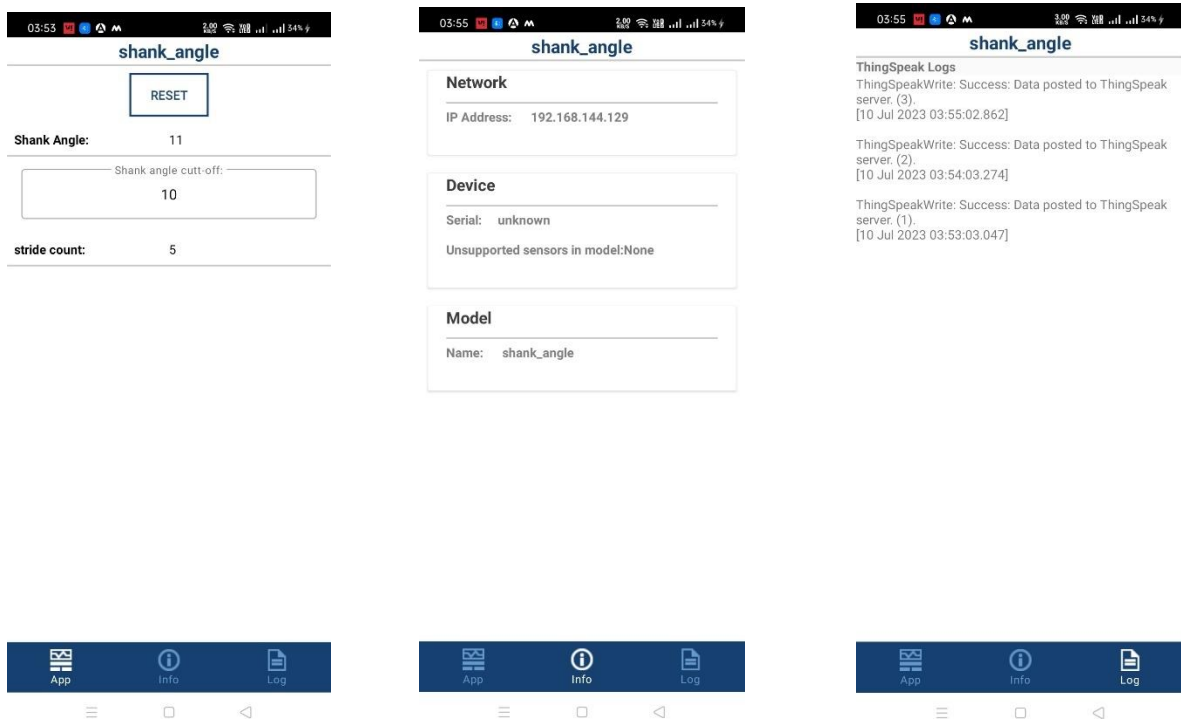


Figure 4.2 UI of shank angle application for gait parameters.

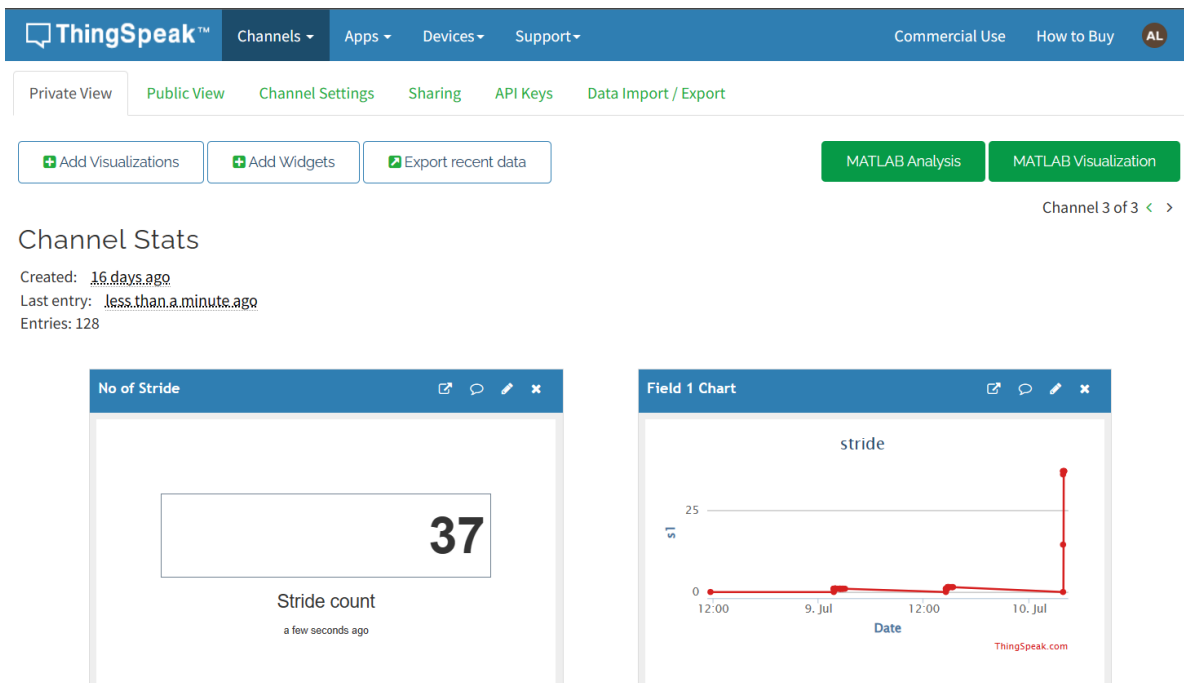


Figure 4.3 Thingspeak dashboard

Using benchmarked walkers, the variation in the shank angle of diabetic walkers during heel strike and toe-off measured by Smartphone IMU is compared with the shank angle variation measures using motion analysis tool Kinovea is shown in Table 4.1

		Ottobock Malleo		Ottobock Air Walker		Tynor Walker		Concept 1	
		Smart health using Smartphone IMU	Image motion analysis - Kinovea	Smart health using Smartphone IMU	Image motion analysis - Kinovea	Smart health using Smartphone IMU	Image motion analysis - Kinovea	Smart health using Smartphone IMU	Image motion analysis - Kinovea
How it effect	Product Angle & Specification								
	Gait angle	Shank angles during Heel Strikes	20	-	15	-	18	-	31
	Shank angles during Toe- off	12	22	9	22.3	12	20.9	19	24
		19	19.6	9	20.3	12	18.7	14	22
		22	18.7	9	16.6	9	13.4	14	15.2
		-25	-23.6	-24	-21.8	-30	-27.6	-19	-21.4
	Shank angles during Toe- off	-20	-20.2	-27	-28.9	-33	-26.2	-36	-30.1
		-21	-27	-26	-28.1	-32	-35.9	-22	-31.
		-37	-	-35	-	-39	-	-30	-

Table 4.1: Shank angle variations from Kinovea and Smartphone IMU

When using an Ottobock Malleo walker, the angle variations measured using a smartphone IMU are compared to the data obtained from the motion analysis programme Kinovea. Data for heel strikes and toe-offs show a minor difference between Smartphone IMU and Kinovea when compared. The angle of the heel strike can range between 0.6° and 10° . Toe-off variations range from 0.2° to 6° , in a similar vein. Small measurement errors made when walking, a smartphone held by Velcro tilting slightly, sensor drifts, bias, etc. are the main reasons of these variations.

The angle fluctuates similarly when using the Ottobock Infinity air walker, ranging from 2.9° to 14.6° during toe-offs and from 7.6° to 13.3° during heel strike. When using the Tynor Air Walker, the angle variations range from 4.4° to 8.9° for heel striking and 2.4° to 6.8° for toe-off. The angle variations for the idea Walker devised are 1.2° to 8° during heel strike and 2.4°

to 9° during toe-off. The reasons for these errors are mentioned above.

The shank angle value was measured using motion analysis software Kinovea for the benchmarked diabetic foot walkers, the Tynor Air walker has low values of angle during heel strike and higher angle values in toe-off[15], resulting smooth gait pattern.

CHAPTER 5

CONCLUSION

The smartphone application utilizing smartphone IMU provide an accessible and convenient method for measuring the shank angles during the gait. The recorded walking videos and the algorithm integrated into the application enable the determination of gait parameters, such as strides and steps. These gait parameters can be remotely monitored through the Thingspeak cloud platform, facilitating convenient data analysis and tracking.

When comparing the shank angle variations measured by the smartphone IMU with those obtained from the motion analysis tool Kinovea for benchmarked walkers, minor differences are observed. The differences in shank angle during heel strike and toe-off are attributed to small measurement errors, including smartphone tilting, sensor drift, bias, and other factors that can affect the accuracy of the measurements.

Despite these variations, the motion analysis software Kinovea reveals that the benchmarked diabetic foot walkers, particularly the Tynor Air walker, exhibit low angle values during heel strike and higher angle values during toe-off, indicating a smoother gait pattern.

Overall, the smartphone IMU-based measurement of shank angles in diabetic foot walkers, combined with remote monitoring capabilities, provides a promising approach for real-time gait analysis and assessment. Further improvements in accuracy and addressing the identified measurement errors can enhance the reliability of this technology for effective monitoring and management of diabetic foot ulcers.

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