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SMART SHIRT AND CARPET FOR MONITORING EYE-CONTACT IN AUTISM RESEARCH

Master of Science Thesis
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ABSTRACT

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The advancements in the field of textile electronics have revolutionized all aspects of daily life from medical technology to industrial automation. The biggest advantages of the textile electronics are that it leverages flexibility and adds-on smart feature to the applications.

The psychologist needs to monitor and analyse the duration and counts for each eye-contact made with the child. Previously, this is done through recording various physical gestures indicating the eye-contact establishment and the duration. However, this work provides an advance solution to monitor eye-contact in autism research by integrating the textile electronics into the laboratory equipment i.e., smart shirt and carpet. This is achieved by designing and fabricating textile electronics i.e., indicators such as infrared light emitting diodes (IR LEDs) to the shirt and the carpet. The turn-on counts and the turn-on time for the IR LED indicators on the smart shirt are meant for the number of times and duration of the eye-contact made with the child, respectively. In addition to above mentioned features, the IR LED indicator that are integrated into the carpet also indicates the beginning of the autism session with the child. After the selection of the shirt and carpet by the psychologists, based on various criterions i.e., wearability, colour and stretchability, the author has made the selection of the electronics components based on the form factor, efficiency, and power consumption of the textile electronics. Moreover, the feasibility of use for various semiconductor electronics in perspective of the experimental validation of the solution is made by testing the textile electronics on respective measurement tools. The smart shirt operation is synchronized with that of the smart carpet through a wireless module operating at 433 MHz frequency and is integrated into the smart shirt and the carpet. Infrared LEDs are used as an indicator for every eye-contact established, which will be captured via camera. While monitoring through the recorded video, they can detect the eye-contact duration and the number of times it happened with the help of infrared LEDs when they turned ON.

The prototyping of two smart shirts and three smart carpets of different colour schemes equipped with IR LEDs at various locations with different vision angles are designed. IR LED placements and the vision angles are significant in fabrication of the prototypes. Therefore, after rigorous testing and measurement, best of the prototypes are selected to present the promising results. The testing workbench is created, using laboratory measurement to verify the efficiencies of IR LEDs under numerous operating conditions, having various power ratings and fabricated through different connection topologies and distance dependent measurement techniques.

After rigorous testing in the laboratory, the performance of the prototypes is tested with psychologists which involves the real time environment. The analysis includes visualization of the IR LEDs on the smart shirt and carpet from various angles of visions, their light intensity, and synchronization of e-textile and RF switch with IR LEDs. The field testing further verified feasibility of use in real-time environments for autistic disorder treatments and the promising results of the developed prototypes. The study depicts that the utilization of smart shirts and carpets helped to compare and choose the optimized designs for both. However, further improvement in the designs can be made to the smart shirt and the smart carpet for future studies to enhance the effectiveness and reliability of proposed work.

Keywords: Autism Spectrum Disorder, E-textile, Eye-Contact, Infrared LED, Psychologist, RF, Smart Carpet, Smart Shirt, Surveillance, Textile Electronics, Wearable Electronics

PREFACE

The work Master Thesis “Smart Shirt and Carpet for Monitoring Eye-Contact in Autism Research” was completed in “Intelligent Clothing Research Group” at the Faculty of Medicine and Health Technology, Tampere University, Finland. During this work, I have learned many things which expands my knowledge towards flexible electronics, e-textile, and intelligent clothing, which were my key areas of interest in the past.

All praise to Almighty Allah, who showed ways and helped me through thick and thin to complete my degree. First, I would like to thank and dedicate my work to my parents, especially my father, Mr. Muhammad Nadeem Akram, who helped me to complete my thesis. Without his continuing support it wouldn’t have been possible. Then, I am grateful to my supervisors, Johanna Virkki and Karri Palovuori, for their guidance and encouragement. They provided suitable environment for my research and offered me the opportunity to learn and polish my skills.

Tampere, 27 September 2021

Ali Nadeem

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LIST OF SYMBOLS AND ABBREVIATIONS

ASD	Autism Spectrum Disorder
DC	Direct Current
E-Textile	Electronic Textile
EMG	Electromyograph
FM	Frequency Modulation
IC	Integrated Circuit
IR	Infrared
LED	Light Emitting Diode
PCB	Printed Circuit Board
PWM	Pulse Width Modulation
RFID	Radio Frequency Identification
RF	Radiofrequency
SMD	Surface Mount Device

cm	*centimetre*
g	*gram*
m	*metre*
mA	*milliampere*
nm	*nanometre*
v	*voltage*
Ω	*ohm*

1. INTRODUCTION

Autism Spectrum Disorder (ASD) is a complex evolution disorder that concerns lesser interpersonal interactions, shyness in communication, deficiency in certain acts and naturally restricted behaviour. ASD is quite common in children with age ranging less than five years and remains unnoticed by most of the parents and patients themselves. However, psychologists are finding ways to help those children struggling to overcome the ASD in its early phases. One of the key parameters to observe ASD is through monitoring the eye-contact of the child. Physiologically, eye-contact is the initialization of every conversation, either verbal or nonverbal, and it define person's attributes upon their response.

Nowadays, textile electronics are manufactured on a very broader level for various purposes in the medical field for monitoring human physiological parameters i.e., human well-being, body fitness, live event recorders, and surveillance applications. The textile electronics are developed under different shapes and sizes as per the desired requirements like textile watches, rings, wrist bands, hand gloves, head cap and smart clothes etc. The psychologists are eying such integrated electronics that can be employed on a shirt for monitoring eye-contact of the child suffering from ASD. Integrated electronics are embedded in the shirt in such a way that the diagnosis technique remains unnoticeable to the patient and depicts the required characteristics for the monitoring application. In addition, a smart carpet is also introduced and embedded with the integrated electronics to assist the smart shirt during eye-contact surveillance.

This research work focuses on the design and fabrication of textile electronics which can facilitate the psychologist in the diagnosis and treatment of the ASD. The study involves different designs of the smart shirt and the smart carpet that can be implemented for the surveillance of the eye-contact between the child and the psychologist. In Chapter 2, the background of autism spectrum disorder and ways of its treatment are discussed. Chapter 3 explains the need and utilization of textile electronics, the materials and manufacturing methods used for fabrication of the e-textiles, conductive yarns and embedding electronics to the textiles. Chapter 4 includes the selection and testing methods of integrated electronics, smart shirt and carpet while, Chapter 5 elucidates the results attained after the performance testing of textile electronics in real-time operating conditions and provides the feedback from the psychologists whereas Chapter 6 concludes the thesis and presents future research work.

2. AUTISM SPECTRUM DISORDER (ASD)

The Chapter will provide an introduction to psychology and how it is related to the work.

2.1 Introduction to Psychology

Human mind being a very complex organ tends to make this study of psychology tough since there is a wide diversity in human nature and brain works different for different people. Psychology is therefore a multifaceted field that addresses the sentimental study of human behaviour and cognition systems and their interactions [1]. Psychology in terms of scientific hunts for the laws and protocols that oversees the affective, behaviour and the cognitive system of human body. However, such scientific studies are not bounded to humans only, but they involve infra humans as well and other mammals [1]. Scientific psychology is however performed on academic level having a goal of elucidating the psychological systems and interactions. On the other hand, professional psychology emphasis entirely on how to apply the psychological knowledge. Scientific and professional psychology is therefore related to each other very tightly. Given that psychology without practical application can cause literalism and sophistry. However, psychology without research and academic findings will result in insignificant output and destructive results that could even affect the humanity and communities [1].

The main branches of psychology involve abnormal, behavioural, biological, comparative, cognitive, developmental, physiological, and social psychology [2]. As per William James, psychology is entirely regarding human mind and brain and effusive understanding it is not possible which is why in the psychology domain the behaviour of humans is observed and studied using scientific methods and tools thus deducing what lies within the living human brain [2].

2.2 Introduction to Autism Spectrum Disorder

This section will introduce the basics of autism spectrum disorder.

2.2.1 Background

Autism as a word is a meaningful combination of two Greek words where the first half ‘Aut’ means self and the other half ‘ism’ stands for condition or situation, that ultimately states that it is a condition in which the individual is ‘self-state’ means stay within him/herself and is unable to socialize. However, the specific word lacks the other characteristics of such individuals [3].

The history of autistic spectrum disorder (ASD) is quite old. For the very first time ASD was diagnosed and renowned as a psychological disorder by Kanner in 1943 [4]. He diagnosed that certain children have innate incapability to be social. He believed that children with ASD have exhibits two types of feature that dominates their personality, one being the autism disorder itself where the child has the incapability to be social thus dumping oneself in isolation socially and the other being the inability to amend this behaviour. In the older naive times, it was highly believed by the people that ASD has a connection with wrong and irresponsible parenting, however it was not the case at all in-fact as per the collected research-based evidence it was shown that ASD is linked with genetic factors [4]. At the beginning of early 1952, ASD was not an identified disorder although quite many people and children were affected from it [4]. Later in 1980 autism disorder was categorized as pervasive development disorder [4]. With the advent of time, considering the research and evidence-based data the concept and definition of autism disorder changed. Diagnostic and the statistical manual of mental disorder (DSM-5), a book written by American psychiatric association, was published that revised the diagnostic criterion for autism disorder from the prior version. A broader term of ‘spectrum’ was introduced in 2013 and replaced the term autism disorder with autism spectrum disorder [4]. This wide novelty in DSM-5 focuses more on being accurate in diagnosis and its main focal point is to aid the early detection of ASD [5].

Criterion of sensory symptoms was also introduced in this fifth edition that comes within the sub-category of symptoms like repetitive behaviour, activities, and actions [5]. In the previous edition it was suggested that the age for the beginning of ASD is nearly 3 years or even earlier [5]. However, in the fifth edition it was updated that the onset of ASD might be present since the early stages of life but is more apparent when the social requirements are way more demanding for the individual [5]. Sub-criteria were also minimized from three to two in the fifth version containing social communication disability that remains constant and provided repetitive actions and signs of autism [5].

Autism spectrum disorder is very common, complex, and baffling psychological disorder that is affecting a wide range of the world. ASD tend to manifest the person since birth or first few years of life of a child and have the tendency to persevere till adulthood as well thus making the life of such individual difficult [5]. An individual with ASD exhibits discrepancy in being social with other people; they limit themselves and their interaction with other people consequently making it hard for others to understand them. Their activities and body movements are also unusual so their interests as well. In the US approximately 1 out of 59 children are reported being affected with ASD [5]. The ASD develops in the child at the time of birth and even before the birth but the symptom does not appear to the extent that enables parents to identify the disorder. Initially, the parent may think that child being flaccid and interactive is somehow his personality and presumes that the child has introverted nature. However, when the ASD child reaches the age of two to three years when normally children begin to interact with other people and explore their surrounds, ASD children stay antisocial, non-interactive, starts to exhibit repetitive movements, their vocals repeat, becomes very complicated to understand, easy irritable and depicts odd gesticulation [6].

Even at the age of pre-schooling, they are very hard to cope with due to their different gestures and off vocalizations. Since they are unable to interact with other children thus making them an easy target to be bullied. It is not that they don’t have disliking and liking, they have but their way of interaction and interest in certain objects and things makes it difficult to socialize [6]. ASD children can even have anxiety attacks if they are forced to be socialized in contact with other children [6]. In ASD children, part of the brain lacks development that triggers the mind of the child to observe, evaluate and learn. ASD in short, makes it harder for the child to learn and explore [6].

ASD can be triggered in any child regardless of their gender, race, and ethnicity. However, it was observed as per the available data that males are more prone to have ASD than girls [5]. Also, Caucasian children are more likely to be diagnosed way more than children of any other race [7]. This difference in diagnosis might also be due to the availability of proper experts, heath care organizations facility, social stigma and even language barrier [7].

Normally, children communicate in one way or another. They can be a part of active conversation with their care givers by responding in a certain way. They smirk, laugh, and respond even by body movements and facial expressions. However, an infant with ASD might not be able to show or communicate via all these stated expressions. Such babies might be responding to the actions of their caregivers or they tend to respond with delays and strange body movements. A child in its younger age has a lot of sense to figure out their surroundings, they observe, ask questions, navigate the possibilities, and learn about their bodies etc. but an autistic child has the tendency to withdraw him or herself from such exploration and they do not usually communicate with other people around their profound curiosity [4].

2.2.2 Treatment

Diagnoses of ASD children are a crucial phase since improper diagnosis might lead to wrong treatment. There are three primarily domains through the impairment of ASD can be diagnosed. Those three factors containing the communication factor, language, and social behaviour of the child [4]. Communication of such individual consists of both verbal and nonverbal communication and any activity that consists of interaction with any other person via either by gestures or linguistics. Psychologists have to look for many options to treat such children. They first have to figure out what is wrong with the child and possible symptoms and what triggers them.

Certain times psychologist tries to treat the autism not by just treating the child but by changing the environment of such child and how other people interact with the child [6]. Contrarily, life of autistic child can be made better by seeking medical attention and giving them such medicine that could regulate the abnormality in the chemical and neural regulation of their brain and neural pathway [6]. However, few naive and old specialists still believe in the power of healing by developing positivity in the attitudes of such autistic individuals since they believe that ASD is an emotional imbalance rather than psychological disorder [6]. Specialist also focuses on improving the diet of ASD children to alleviate their symptoms. It is preferred to have amino acid in the diet in order to enhance both metabolisms, the neurotransmitters, digestion, and behaviour symptoms [6]. Apart from balanced diet, vitamins and biological active substances are also given to ASD children to control and treat the brain affecting autism [6]. Treatment of autism is deployed on many factors; however the most important ones on which the treatment of ASD is espoused are either to treat the underlying pathophysiology of disorder to directly aim the cause depending on the research based evidence and by doing so, the overall condition of the autistic child can be improved or another method of treatment is to only alleviate any particular symptom of autism i.e. behaviour, the attitude, mood swings, hyper-ness etc. [6].

2.3 Eye-Contact and Autism Spectrum Disorder

Eye-contact plays a vital role in the everyday lives of humans and non-humans. Perhaps the eye-contact provide messages of different kind, like getting friendly or panicking [8] [9] [10]. In a few examples, a direct gaze or looking directly to someone can provide a positive response like a sign of happiness or a smile. While, in some cases, it can be the opposite depending upon the person attributes [8].

There are numerous methods of delivering words in a social circle using verbal messaging, communication on a phone call, online meetings etc. However, voiceless communication is another mean to deliver your information involving hand gestures, body signs and head movement and sometimes eye-contact will do the needful [11]. To attract attention, adults [11] [12] and newly born child's choose direct eye-contact to initiate conversation [11]. Direct eye-contact is not restricted, and it also corresponds that a person is completely inattentive while he is being stared [11] [13]. This way of gazing to each other is automatically developed in a human being and is the easiest method of elucidating your message. However, a person or child having autism spectrum disorder will provide untypical response and in practice will fight shy of in making the eye-contact [11]. With reference to [14] [15], restriction in staring or making an eye-contact with other person has become similar to ASD and communal disablement, which makes it a universal aim of interventions for child's suffering from ASD.

As in [16] [17] [18], the new-born children give a longer gaze at faces as in comparison to preventing or looking away. However, babies approaching the age of 1, signals untypical responses of looking towards faces or another person eyes, and in the future, they are diagnosed with Autism Spectrum Disorder [16] [19].

To study the behaviour of autism in individuals, numerous methods were applied and implemented in previous studies by the psychologists using techniques involving medical imaging, eye surveillance, tracking and facial reactions etc. In [8], they explored variety of emotive behaviours via electromyograph (EMG), when another person made an eye-contact with the person suffering with ASD, by recording the results of EMG. Taking readings or measuring EMG recordings of the body reactions is an extensively used method of analysing reactions [20] [21]. However, in [16], the research was carried out on Autism and the direct gaze. They analysed the eye-contact behaviour of different age groups of children suffering from ASD and investigated them with their past history of ASD. The start of this study came from the psychologists, as they executed to track the eye-contact physically in a meet-up session with the child. They are arranging sessions with the child suffering from this condition with the involvement of child's parents and psychologists themselves. The psychologists try to engage the child in different activities i.e., playing with toys, communicating different things, asking questions etc. During these, they monitor the eye-contact by displaying their thumb in the camera. The aim was to find how many times the eye-contact was made and for how long each eye-contact lasted. So, whenever the child makes the eye-contact, the psychologist shows their thumb up to the camera. The display of the thumb continues till the eye-contact breaks. In this way, they examine the video recordings and analyse the results.

Although, they were able to examine the recordings and gathered the information they needed, but as the situation was on-going all the time during the sessions and this type of technique distract the child of acting normally, they found it very difficult to implement and they themselves needed to always turn so that their thumb is visible to the camera, which was challenging. The critical situation needs to be tackled as they also sometimes tried to only monitor the eye-contact with the camera, and it gets extremely difficult to record the eye movement of the child as they continue to play and move around in the room. To facilitate and improve the eye-contact monitoring, the research is implemented where, there will be no need to turn and show the thumb to the camera, the psychologists can fully focus on interacting with the child and the child will not be distracted from the psychologists unwanted movements while under surveillance.

3. TEXTILE ELECTRONICS

Textile electronics have influenced major attention because of its employment in the medical health technology, human well-being, automation, robotics, and smart clothing industry [22]. Moreover, textile electronics are in their supreme spot to transform the field of wearable electronics with their wide-ranging of applications [23]. Textile electronics advances its implementation in smart clothing like shirts, hat, pants, gloves etc. and other textile practices like carpet, blanket, pillow etc. Smart clothing consists of the unified pieces or assemblies of thread or yarn that have the ability to transfer or generate signals after measuring any physical input, electrical signal, and active communication [24]. Smart clothing reaches all the requirements for the modern up-to-date technology and they are rich in their flexibility, quality, manufacturing on a larger scale and research [25].

3.1 Introduction to Wearable Electronics

Wearable electronics is a rapidly spreading discipline of modern technology that has principal function in the areas of medical field and human well-being. It was recorded in 2015, that wearable electronics earned a business of $20 billion and is predicted to expand further for an estimate of around $70 billion by 2025 [26]. The key objective of wearable electronics is to integrate electronics with a person’s day to day life via smart clothing or as required [26]. Wearable electronics plays an important role in smart textile clothing and in related industries to perform and provide results. The electronics are embedded in materials like textile, metallic rings, wrist watches, eyeglasses, flexible printed circuit boards for sensing and displaying the analysed outcomes. The electronics are micro-embedded and are specifically designed for these kinds of applications. They are used and planted anywhere, subject to data collection, and to analyse the results. A simple overview of wearable electronics can be seen in Figure 1. Numerous electronics are placed at different places on the human body according to the shape, size, and design requirement [24]. Every electronics has its own unique feature in Figure 1. They are integrated with each other but will not alter the results while the data is being collected. Wearable electronics are worn in such a way that it should not unsettle the person and without any human intention they remain hidden.

Figure 1. *Different types of wearable electronics [24]*

The word Intelligent corresponds to something that can react on its own from any physical input. The input can be the atmospheric, surrounding environment, or any electrical, thermal, and mechanical signal. So, perhaps, that the material or a cloth that has the ability to sense from its surrounding and respond to the action and can adjust itself as per the situation is termed as intelligent clothing [25]. Due to the unique features and adaptability of smart intelligent clothing, they are widely being used in many applications of medical industry as discussed above in this Chapter. There are quite many sensors that are manufactured using textile materials to sense human physiological parameters and convert the property into the electrical signal to study the behaviour. Besides these, there are applications including smart shoes, smart work clothes, smart sleepwear, smart active wear, smart casual wear, and smart socks [27]. However, different types of smart electronic wearables and intelligent clothing are shown in Figure 2.

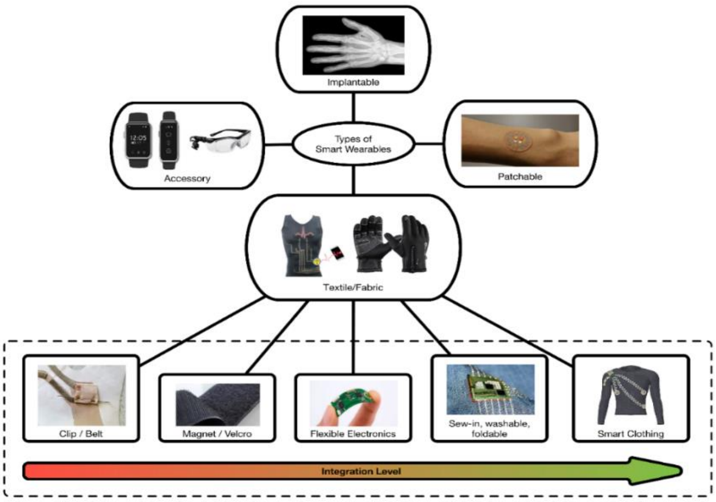


Figure 2. *Types of smart wearable and intelligent clothing [28]*

The study now introduces with a few examples of wearable electronics. The wearable electronic device named OURA smart ring was presented in [29], where they have classified different ways to tackle and prevent Covid-19. The ring consisting of sensors like inertial measurement units, temperature sensors and infrared LED's which help in monitoring the individual physiological parameter including body temperature, rest taken after work, and variation in the pulse etc.

Figure 3. *The OURA wearable ring [29]*

Figure 3 depicts the design of OURA ring. The physiological parameter monitoring screen can be viewed on the smart phone, displaying different channels using OURA ring app. However, some new features were also developed using the latest AI algorithms which detect the walking distance between individuals and provide safety measures to retain the distance of 6 feet to prevent Covid-19 [29]. Applications like sleep tracking during normal human sleep routine is included in the AI algorithm to extend the detection technology [30].

On the other hand, the use of wearable electronics on the human wrist is very common and the easiest way to implement applications. Most of the human wrist practices lead towards wearable RFID (Radio Frequency Identification) implementation. The work [31], shows design of intelligent wearable wristband using conductive thread and 3D printing pen. The wearable wristband was designed for wireless identifications and gaining access through RFID doors etc. An overview of the band can be viewed in Figure 4.

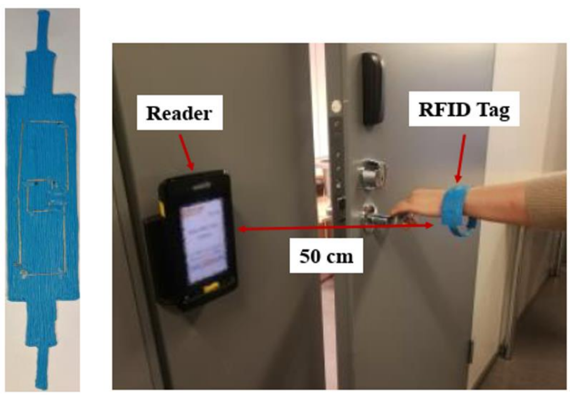


Figure 4. *Wearable wireless intelligent wristband [31]*

Similarly, a wearable smart watch was designed in [32] and can be seen in Figure 5. The aim was to facilitate crew members and allow them to utilize the wearable device by displaying and monitoring the plane seating map and other staff team location during the flight. The map defines the locations of staff members with different colours on the watch. Wireless Bluetooth detection technology was implemented inside the smart device.

Figure 5. *Wearable smart watch for location tracking [32]*

3.2 Materials and Manufacturing Methods

Like other technologies, textile electronics are prepared using standard materials and different manufacturing methods. Conductive materials are needed naturally in e-textile. This property of a material helps to connect electronics, which are embedded inside the textile. It depends on the applications and the utilization, that we manage integrated conductive materials inside the textile materials, or we can sew or merge them afterwards. Similarly, there are several other techniques to manufacture e-textiles i.e., different printing methods, weaving, coating etc. but only those methods are further discussed which are relevant to the thesis work [33].

3.2.1 Manufacturing Methods of Textile Electronics

This section includes manufacturing methods of conductive thread and e-textile.

3.2.1.1 Conductive Thread

A lengthy thin thread having aligned constant filaments or wrapped textiles is defined as a Yarn. These parallel fiber compositions can be interweaved, interthread into 2D or even 3D textile structures which further can be intermeshed to form thread, ropes, or strap [34]. Yarn is the most widely used textile, that is implemented in every fiber product which are applied in clothes, home decoration curtains, shoes, office chairs, automobile seats, gloves, winter jackets and caps etc. Constant thread can be transformed or shaped into different systematic copies using planned enmeshment and or spatial reconfiguration, to produce flexible, stretchable, and sizeable yarns. The whole process is carried out using texturizing [34]. However, spun yarns are prepared using principal strand from pure or artificial origins. The method is processed via successive mixing, washing, extracting, and twirling to orient the threads and synthesizing them into a yarn by meshing, and revolving methods [34] [35]. The processing technique of Continuous filament yarn and spun yarn can be viewed in Figure 6.

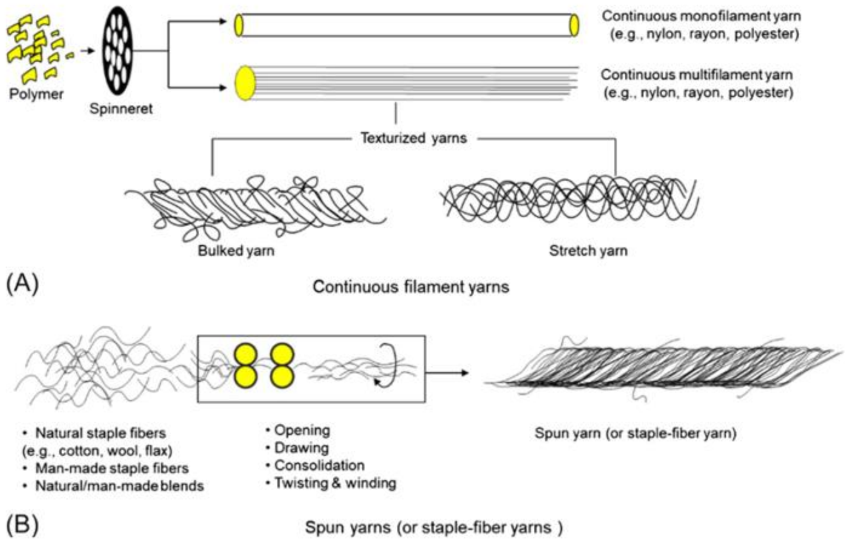


Figure 6. *Yarn processing methods [34]*

The keynote of characterizing yarn into numerous classifications is to highlight the reality that there are limitless diversities of yarn compositions which tend towards in the formation of various product options and lies on the required physical parameters and behaviour features [34]. Moreover, special types of yarns can be manufactured to fill the particular needs, functions, and structures of the end product.

Discussing various applications of yarns, now-a-days conductive yarns are introduced, which has the capability to conduct electricity between two points. These conductive yarns are produced from sources like metals including silver, gold, copper etc. [36]. As in [37], conductive yarns and threads are being used in several applications and assist purposes like flexible electronics, electronic textile (E-textile), electromagnetic compatibility or shielding, and antistatic purposes etc. The textile material provides insulation shielding to the conductive material and helps to utilize it during different processes. According to [36] and [38], a ply or folded yarns are produced using rotor revolving equipment. Afterwards, metal materials are included with the addition of polypropylene to prepare synthesized folded yarns that are used to protect electromagnetic interference and static current. In [36], they used bamboo charcoal (BC), high-strength polyester (HS-

PET) and some stainless steel (SS) filaments. The parameter values of all individual materials can be seen in table 1.

Table 1. *Physical properties of individual materials [36]*

	Diameter (mm)	Denier (D)	Tensile strength (cN)	Elongation (%)
BC	–	5846.5	–	–
SS	0.08	–	414.85	37.07
HS-PET	–	500D/96f	3020.81	119.63

As in Figure 7, the preparation process of conductive yarn includes the filaments of stainless steel, high-speed polyester, and roving bamboo charcoal. All these materials are advanced and fed into a rotating round assembly and rotated at 8, 9, 10, 11, 12, 13 and 14 twist per inch to obtain the final product [36].

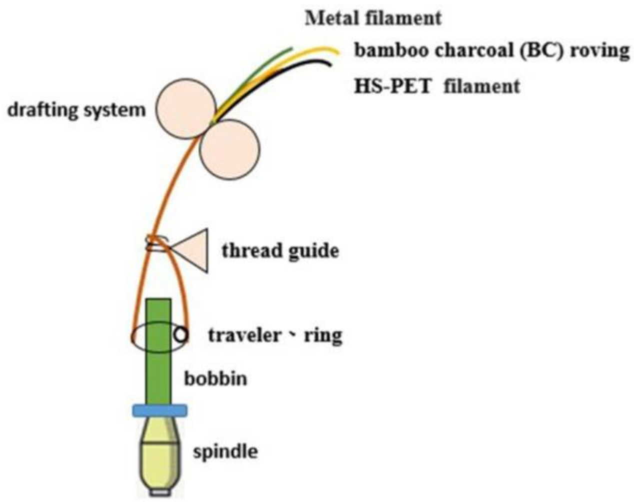


Figure 7. *Conductive yarn production [36]*

In producing conductive yarn [39], the materials applied are stainless steel (SS), polysulfonamide fiber (PSA), and waterproof 2P which consists of amalgam fluorine-polymer, mixed liquid, and a frail ion which is bio-degradable. The equipment as in Figure 8, conductive core yarn, has the ability to enfold stainless steel, which is particularly assembled with a rotating frame, in the polysulfonamide peregrinate process. This will help in uncovering metallic cables and eliminating oxidation out of them. Conductive core yarns are formed by regulating the metallic wires. Though, the wires (metallic) are being utilized as the inner core materials, the polysulfonamide circumambulator having the properties of 4 g/10 m is executed. The procedure of twisted counts is followed to manufacture conductive yarns having 50, 60, 80, 100, and 120 turns/10 cm [39].

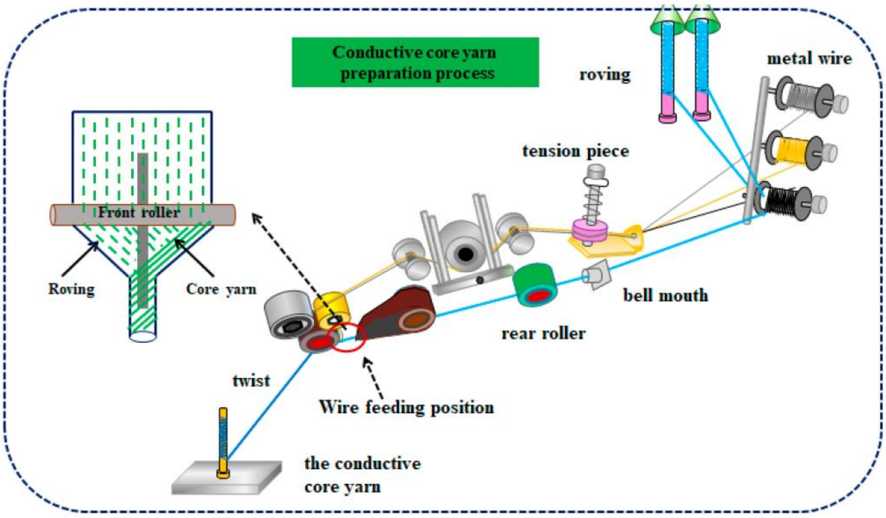


Figure 8. *Manufacturing process of conductive wrapped yarn [39]*

3.2.1.2 E-Textiles

E-textiles which, can also be termed as electronic textiles and or smart clothing, are textile materials of a kind which have integrated semiconductor devices into them to be utilized for desired applications in medical healthcare, fitness, and sports etc. E-textiles are efficient enough to communicate with its surroundings, can monitor and provide information for other electronics via implementation of integrated transducer and its wireless connectivity. Due to their wide range of applications, they are utilized in the domains of military, human well-being, and civil security [40]. According to [40], the business development of e-textile market size is expected to reach $5.55 billion in US by 2025. Some common examples of e-textile materials are copper, silver, nickel, and nickel carbonate and they are illustrated in Figure 9. Moreover, Table 2 depicts the characteristics of these e-textile materials as shown in Figure 9. It is also highlighted that according to past studies, the conductive textile or fabric like Lycra implemented in [41], Cat. # 321 conductive fabrics having reduced electric and magnetic fields implemented in [42], and Cordura yarn implemented in [43], have shown that e-textiles are lesser in weight, they are adjustable and uncomplicated to work with [44]. e-Textile can be easily cut into pieces using scissors or laser cutters, to work according to the desired application.

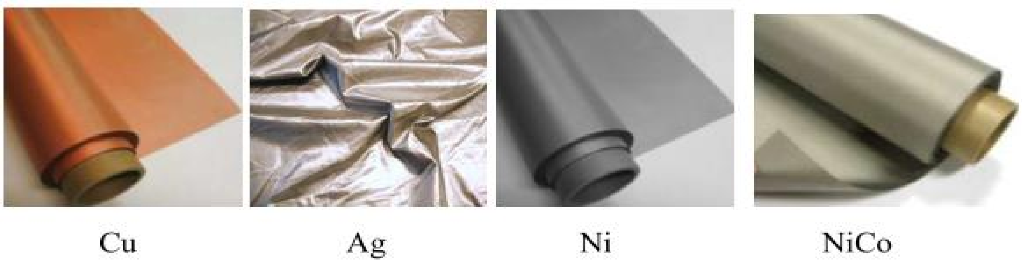


Figure 9. *Numerous types of e-textile fabrics [40]*

Table 2. *Illustration of e-textile fabrics [40]*

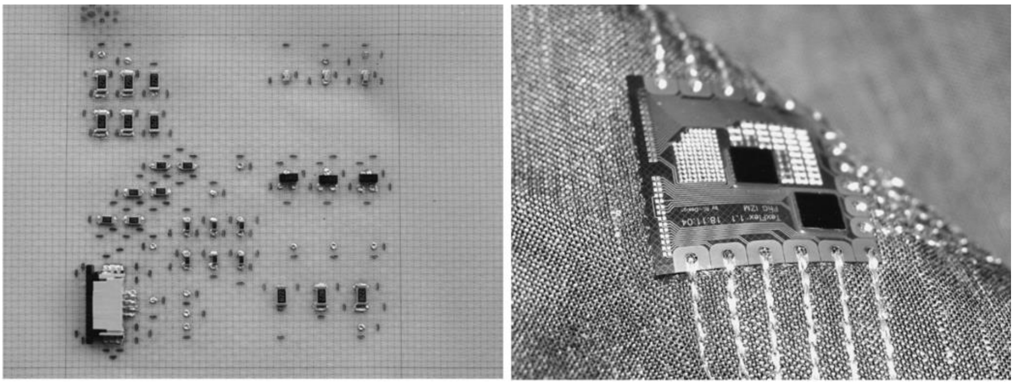
Sample	Cu	Ag	Ni	NiCo
Fabric	Polyester	Nylon	Polyester	Polyester
Out layer metal coating	Copper	Nylon	Nickel/Copper	Nickel-Cobalt
Sheet resistance (Ohm/sq)	0.05	<0.25	0.03	<0.1
Thickness (um)	3.44	0.49	2.43	2.64

Figure 9 depicts different types of e-textile materials that can be utilized in applications as discussed above to acquire results. Having good conductive properties, they are also integrated to provide healthy amount of current and voltages from source to the destination. Metals like silver, gold or copper which have good electrical properties are used as conductive materials in between the textile fabrics [45]. Moreover, e-textile has a great advantage of contacting more transducers attached to the body in a wearable application [46]. Although despite such advantages with e-textile we might face some challenges while using the fabric especially in wearable electronics. The process of combining two different industries i.e., the textile and electronics may introduce difficulties related to prototyping, production, marketing, and product reliability. An e-textile possesses the ability to fulfil the needs of modern technology comprising stretchability, launderability and reassurance in order to facilitate the demanded electronic features. However, to achieve these tasks, many elementary standards and dependable concerns needs to be described [40]. For example, the launderability of e-textiles is a difficult problem of handling especially in wearable electronics. Because, during the entire lifecycle of e-textile, they will go through the process of cleaning and drying periods which can limit the working efficiency of embedded electronics like micro-controller units, power sources and integrated sensors. To address this issue, in [40], they evaluated different conductive materials to illustrate their degradation functioning during laundry cycles.

3.3 Embedding of Electronics to Clothing

The embedding of electronics into textile materials was first attempted in 1998 using a wearable main processor unit of GeorgiaTech. Similarly, Infineon produced MP3 player in wearable jackets, the earliest product of its own in the smart textile field. However, the availability of micro and nano sized electronics in the present industry, resulted in the previous research becoming redundant due to oversize components [47].

The primary aim in smart fabrics is to integrate electronics with textiles while retaining the working efficiency of electronics and adaptability of textile materials. Currently, to accomplish this task one need to compromise on each side [47]. Some examples of embedding electronics to textile materials using electrical wires, conductive thread and its electrical traces are illustrated in Figure 10. Figure 10 a) illustrates the placement of electronic components in the textile fabric which are traced together using electrical copper wires. The electronic components are connected with the wires using conductive paste. Similarly, in Figure 10 b) a micro-controller unit is placed on a textile material which is interconnected using conductive thread traces to build the circuit. The conductive thread is traced using the sewing needle [47]. Both the processes carry varying methods but attain the same results.



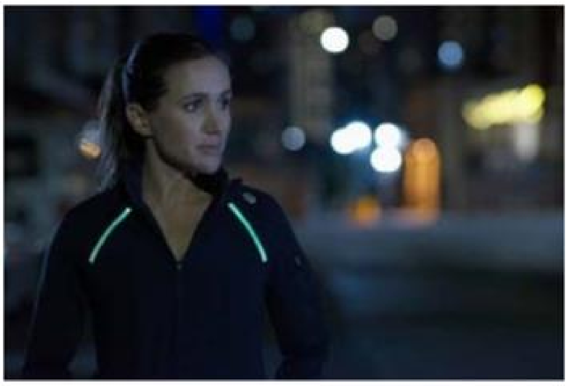
a) b)

Figure 10. *Integration of electronics and textiles [47]*

Figure 11 shows the implementation of e-textile into clothing. Figure 11 a) illustrates a wearable shirt consisting of e-textile sensors which are integrated on the shirt to monitor the electrical activity of heart from the body. Likewise, Figure 11 b) demonstrates an e-textile based LED jacket that is used by pedestrians and individuals using the bicycle during dark hours of the day for their safety [46].

Beside using handheld methods to integrate electronics into textiles, the software controlled sewing machine is another approach for the same purpose. In [48], they have discussed different methods of designing flexible antennas. One of the techniques, the fabric based embroidered antenna, which implements a microstrip patch on one end of the antenna and a ground plane on the other are embroidered on a textile fabric. They are embroidered using the software controlled sewing machine to sew the connections automatically upon design selection. In the embroidery process, it should be noticed that the connections sewed have precision and are conductive enough to allow the flow of current [48].

a)



b)

Figure 11. *Combining textile and electronics [46]. a) Cardio skin measurement wearable shirt. b) LED embedded jacket.*

However, there are some challenges which occur during and after embedding electronics to textile materials. In some cases, during the embroidery procedure, there are chances that the material will unravel unless precise needle position, applicable speed, and right force is exerted [48]. Another challenge that arises is the deterioration of conductive thread and e-textiles due to mechanical stress, change in environment and during regular laundry cycles which affects the conductivity of the material [46] [48]. Moreover, a possible issue can introduce a stretch in the textile circuit which happens due to the weight of electronic components [49]. This can unstitch the component and dysfunction its purpose.

4. SELECTION AND INTEGRATION OF TEXTILE ELECTRONICS

The Chapter introduces the selection of textile materials and electronics for the study and their integration to execute them in the real time situation with the psychologist.

4.1 Research Background

The psychologists want to investigate, the number of times eye-contact has been made and the time duration of each eye-contact lasted with the child. Eye-contact or a direct gaze is the key source of determining autism spectrum disorder in the early stage of a child especially with the age of three years or even below [5]. In one of the previous studies, the psychologists were monitoring the eye-contact by displaying their thumb in the camera during a regular meetup with the child. Whenever, the child makes an eye-contact, they display their thumb in the camera otherwise not. They were able to monitor the eye-contact but, the technique was quite hectic due to the live on-going situation and it also disturb the child of behaving naturally which resulted in imprecision.

However, the thesis simplifies the eye-contact monitoring and reveals a new methodology to keep track on the eye-contact made by the disorder child with the psychologist. In the thesis, a smart shirt and carpet are designed and fabricated with integrated electronics to fulfil the need and applicability in the research. The smart shirt, which is wearable, will be worn by the psychologists to track the eye-contact of the child and monitor it afterwards with the recorded session. As the session with the child also includes their parents in the same room, a smart carpet is introduced and placed in the room which will provide indication, that the session is started with the child sitting on the carpet with the psychologist, which is being monitored. This technique eases the psychologists to study and examine the eye-contact in the recorded video of the session. The smart carpet is wirelessly integrated with the smart shirt, and the person wearing it can control both, the shirt, and the carpet indications.

Infrared Light Emitting Diodes (LED’s) are used as indicators on the smart shirt and on the carpet. The reason of implementing infrared LEDs on the smart shirt is the low power consumption it requires and the invisible light that cannot be seen with the normal human naked eye. As, the session is recorded using cameras in the room so, the infrared LED’s will only be visible while sighting it on the camera when they will turn ON and OFF. This will improve the precision of tracking the eye-contact due to the invisible surveillance which will allow the child to act normally without any interference. Moreover, the infrared LEDs are deployed using LED driving module circuit to maintain LED operation on high or low voltages. The detailed description of the smart shirt and carpet, and integrated electronics designing, and fabrication used in the study are discussed in following sub-chapters.

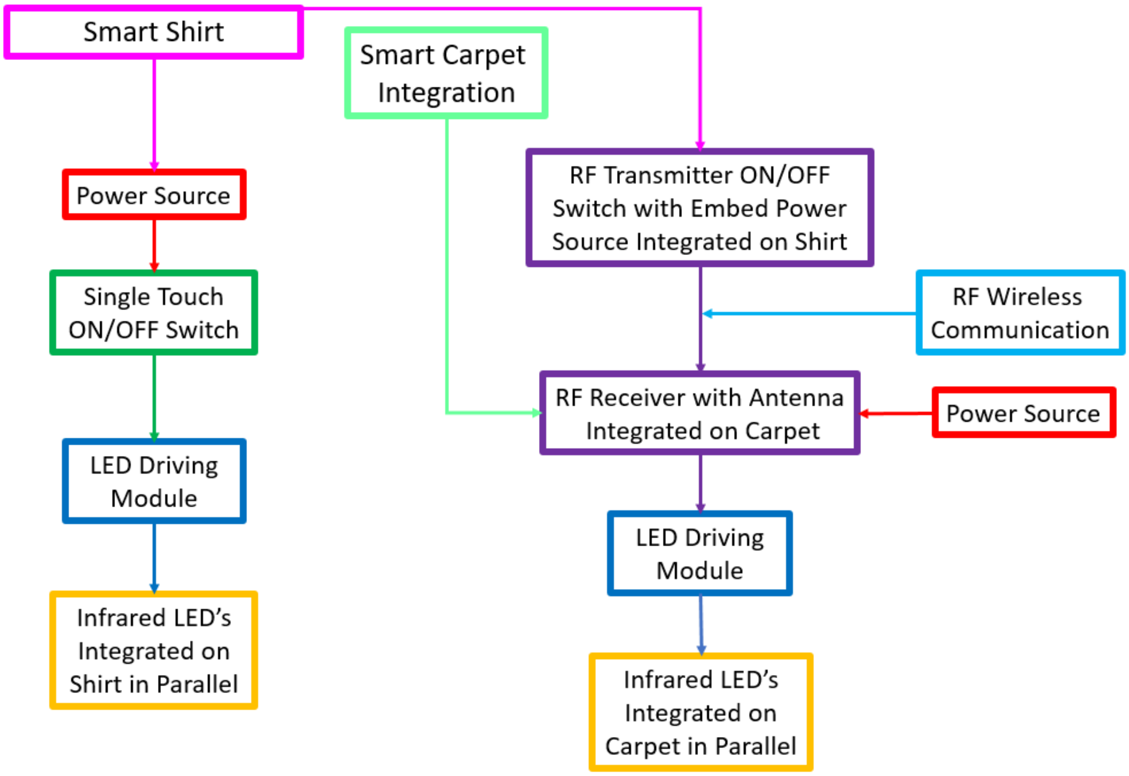


Figure 12. *Flow chart illustration of smart shirt and smart carpet*

Figure 12 represents the working principle of the smart shirt and carpet. The smart carpet is connected wirelessly with the smart shirt. The wireless communication is carried out via Frequency Modulation (FM) technique, having an RF Transmitter and an RF Receiver Antenna. The RF transmitter has embedded power supply and upon switching it will wake up the RF receiver through wireless communication. The RF receiver will open the gate of power source provided and supply it to LED driver module to operate the infrared LED's.

4.2 Smart Shirt and Smart Carpet

The main idea is to introduce a shirt and a carpet as the ideal textile material for the thesis. The psychologist selected the shirt and the carpet for the study in terms of colour, stretchability, and their wearable profile. The shirts of two different sizes i.e., Large and Medium, having dark grey colour and carpet of two different colours having the same size i.e., 195 cm in length, 133 cm in width and 2.59 m^2 of surface, were introduced to accomplish the task. Colour of the textile product is the important aspect because most of the infrared LED's produces purple and blue light and it becomes difficult to observe any with lighter colour in the background. The chosen shirt will provide an advantage in the actual practical implementation while monitoring autism disorder children, as the shirt does not appear to be a dress code of a doctor or a nurse. As most of the child are afraid of visiting doctor or a nurse, so due to the dress code colour they will remain calm and act normally. It will help the psychologists to feature natural results from the child reactions, as the child will not think of being monitored under any clinical staff.

The shirt comprises 55 % polyester, 43 % cotton and 2% XLA stretch material. It is stretchable and very flexible to fit. It also contains a chest pocket with two lower hand pockets and closing strip buttons on the front side [50]. Shirt used in the work can be seen in Figure 13 below.

Figure 13. *Front and back view of shirt*

The carpets are produced from 100 % polypropylene with a bottom layer of synthetic latex and 100 % polyester with a bottom layer of synthetic rubber. Both the carpets are quite durable and have anti-slip under the carpet, which is the bottom layer [51] [52]. The carpets used in the study can be viewed in Figure 14 and 15 respectively.

As the Figures 13, 14 and 15 are illustrated, the electronics will be integrated with the textile material in such a way, that they remain hidden, not alter any operation results, easy to use for the wearable application, and the output can clearly be observed. The placements of electronics on the smart shirt and carpet are discussed in detail in further sub-chapters. However, it is to be kept in mind that textile and electronics are two different industries and while integrating them, it can bring some difficulties which may cause error in working situations. Those errors can be reduced or terminated by re-designing, re-evaluating, and re-thinking the integration between the two technologies.

Figure 14. *Carpet 1 produced from 100 % polypropylene [51]*

Figure 15. *Carpet 2 produced from 100 % polyester [52]*

4.3 Integrated Electronics

The Chapter discusses electronic components implemented in the study for integration with the clothing.

4.3.1 Infrared Light Emitting Diodes (IR LEDs)

Infrared, which is electromagnetic radiation and normally termed as IR, having wavelength longer than those present in normal light and is visible to humans [53]. Wavelength of infrared light normally operates between 760 nm to 1 million nm and are produced majorly from the heating components. The infrared light on the spectrum analysis typically lies in between the wavelengths of the microwave and visible light. As it is produced particularly by heating components and in results make thermographs. Thermographs produces different colours due to variance in temperatures for the infrared light i.e., blue, purple, red, orange, and yellow [54].

Figure 16 shows the electromagnetic spectrum of different lights having wavelengths starting from cosmic rays of 0.0001 nm and ending at the radio waves of 100 km. The infrared light is distributed in near, middle, and far wavelengths. The infrared light is invisible to the human eye as the wavelength it possesses is far beyond the visual capacity of a normal person which lasts at around 750 nm i.e., visible light.

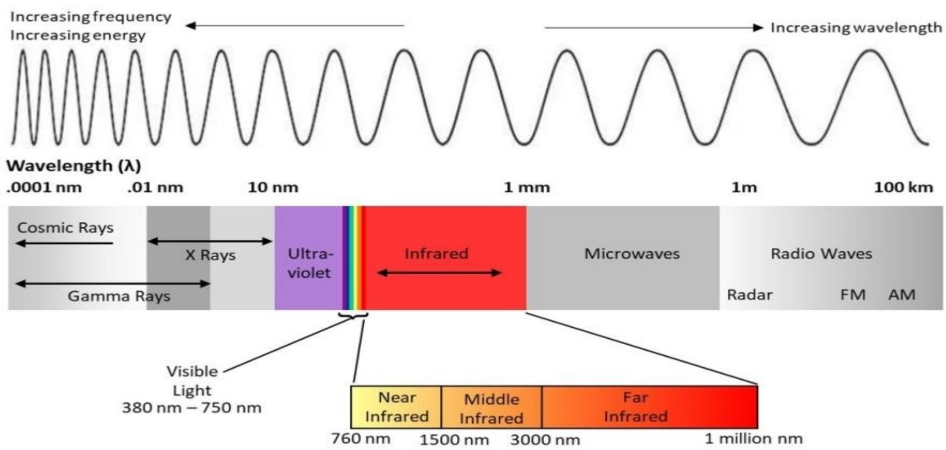


Figure 16. *Electromagnetic spectrum of infrared light [55]*

The infrared LEDs are used as key electronic components in the thesis. They are important in delivering indication to the psychologists that the eye-contact has been made with the child or not. The infrared LEDs are integrated on the smart shirt and carpet to indicate a sign in the camera during the session with the child.

Most of the infrared LED's are very small in size and it is very important to realize how they actually produces light. The light emitting diode is a kind of a diode that convert electrical energy into light energy and is designed to emit light. The LEDs are made from compound semi-conductor-based silicon materials like gallium arsenide, gallium phosphide and other related semi-conductor materials that can emit light. As LED is a diode, where a diode can be a forward biased or a reverse biased. However, LED only emits light when it is in a forward biased condition. In forward biasing, a voltage is delivered in between the P-N junction, where a P-side of the LED or a diode is attached to positive terminal and the N-side is attached to the negative side of the diode terminal, as can be seen in Figure 17 a). However, when the voltage supply is delivered, the free electrons in the n-region will cross the P-N junction and combine with free holes in p-region. After each free electron combines with each free hole, they will release energy in a form of light as can be viewed in Figure 17 b). That light, depending upon the silicon material, can be visible and or infrared etc.

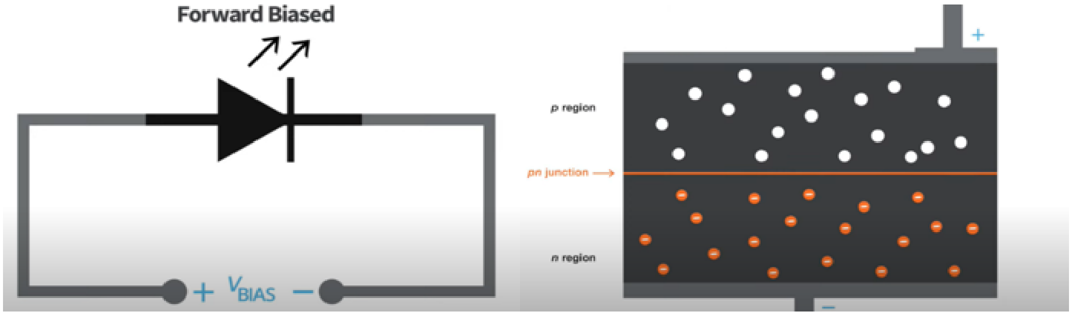


Figure 17. *Light emitting diode working principle [56]. a) Forward biased light emitting diode. b) Flow of n-region electrons into p-region holes.*

The infrared LED used in the thesis, consisting of the wavelength of 940 nm and can be viewed from an angle of 130°. It has an operating voltage rating of 1.4 V, the current rating of 350 mA, and flux of 225 mW. This infrared LED is a surface mount device (SMD), embedded on a metal board, having two positive and two negative terminals which make it easier to use. It is typically a near infrared wavelength LED which is not visible to the human eye. The infrared LED is superior in performance, operates using industry standards, and is flexible [57].

Figure 18. *Infrared LED having wavelength 940 nm [57]*

Figure 18 shows the frontal view of the infrared LED utilized in the work. On the other hand, Figure 19 illustrates the dimension properties of infrared LED. The infrared LED can be used in different applications. In the thesis, it is particularly utilized to perform the surveillance of the autism spectrum disorder child. As the infrared LED intensity is quite good at low voltages and it is completely invisible to the human eye, it comes in handy for these practices. However, it can also perform functions like license plate scanning, automotive mobile sensing, machine vision for night visualities and eye tracking systems [57].

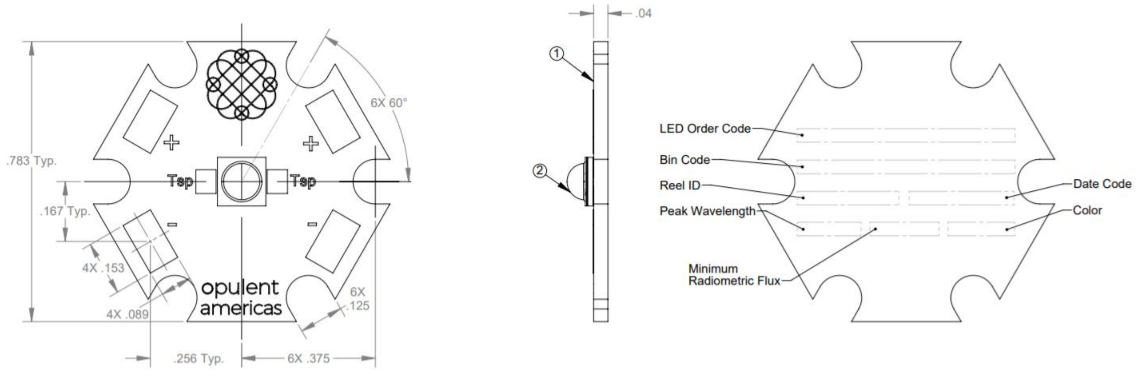


Figure 19. *Dimensions of infrared LED [58]*

4.3.2 Light Emitting Diode (LED) Driver

Now-a-days, it is getting important to operate a system using stabilized voltage and or constant current supply, in order to protect the system from over and under voltage sources. Like in the past, voltage stabilizer or regulator is extensively used in the areas where the voltage supply was inconsistent and user tend to face electrical jerks, which results in damaging home appliances. The voltage regulator provides consistent voltage for the product and saves the electrical equipment from low and high voltage surges.

In the study, to drive and provide regulated voltage for the infrared LED's, LED driver module is implemented to ensure, safe and guaranteed power supply. The LED driver module used is SPARKFUN PicoBuck LED driver [59]. The driver can be controlled manually by providing constant voltage, as executed in the thesis, or by regulating voltage through any microprocessor using pulse width modulation (PWM). The product has three output channels to operate. The PicoBuck driver consists of an embedded AL8805 integrated circuit (IC), which is a step-down DC-DC converter. The specific IC is operated to drive LEDs at the constant current and variable voltages. The IC operates in a wide range of voltages starting from 6 to 36 Volts with a constant current of 1 Ampere [60]. It has a capacity of driving 8 LEDs connected in series with a forward voltage of 1.4 Volts. The overall representation of AL8805 can be viewed is Figure 20. However, Table 3 shows pin representation of the IC and Table 4 illustrates the operating condition of LED driver module.

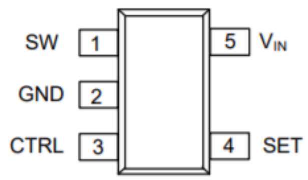


Figure 20. *Front view of AL8805 IC [60]*

Table 3. *Pin configuration of Al8805 IC [60]*

Pin Number	Pin Name	Function
1	SW	Switch Pin. Connect inductor/freewheeling diode here, minimizing track length at this pin to reduce EMI.
2	GND	GND Pin
3	CTRL	Dimming and On/Off Control Input. • Leave floating for normal operation. ($V_{CTRL} = V_{REF} = 2.5V$ giving nominal average output current $I_{OUTnom} = 0.1/R_S$) • Drive to voltage below 0.4V to turn off output current • Drive with DC voltage ($0.5V < V_{CTRL} < 2.5V$) to adjust output current from 20% to 100% of I_{OUTnom} • A PWM signal (low level ≤ 0.4V and high level > 2.6; transition times less than 1us) allows the output current to be adjusted below the level set by the resistor connected to SET input pin.
4	SET	Set Nominal Output Current Pin. Configure the output current of the device.
5	V_{IN}	Input Supply Pin. Must be locally decoupled to GND with ≥ 2.2µF X7R ceramic capacitor – see applications section for more information.

Table 4. *Operating conditions of Al8805 IC [60]*

Symbol	Parameter	Min	Max	Unit
V_{IN}	Operating Input Voltage relative to GND	6.0	36	V
V_{CTRLH}	Voltage High for PWM Dimming Relative to GND	2.6	5.5	V
V_{CTRLDC}	Voltage Range for 20% to 100% DC Dimming Relative to GND	0.5	2.5	V
V_{CTRLL}	Voltage Low for PWM Dimming Relative to GND	0	0.4	V
I_{SW}	Continuous Switch Current	—	1	A
T_J	Junction Temperature Range	-40	125	°C

As the PicoBuck driver module has 3 output channels to operate. It is very easy to connect a maximum of 8 LEDs in series to each output channel and control maximum of 32 LED's, having 1.4 forward voltage supply of single LED, from one LED driver module. In the thesis, the LED driver is operated using the voltage ratings of 9 and 12 Volts, which is higher than the infrared LED requirement. The LED driver will regulate the voltage and only provide the required power for the infrared LED. Three output channels have a common voltage input terminal and each channel have a separate voltage output terminal. For controlling via microprocessor, each channel has its own controlling pin i.e., IN1, IN2 and IN3. The chip board illustration of PicoBuck LED driver can be seen in Figure 21. In Figure 21, it can be noticed that every voltage power supply input and output terminals have conductive holes for power connections. So, for the connection through conductive yarns, it becomes very simple to sew the connection from the provided holes and provide it further to the destination component. In general, the driver module can be integrated with e-textiles and conductive yarns.

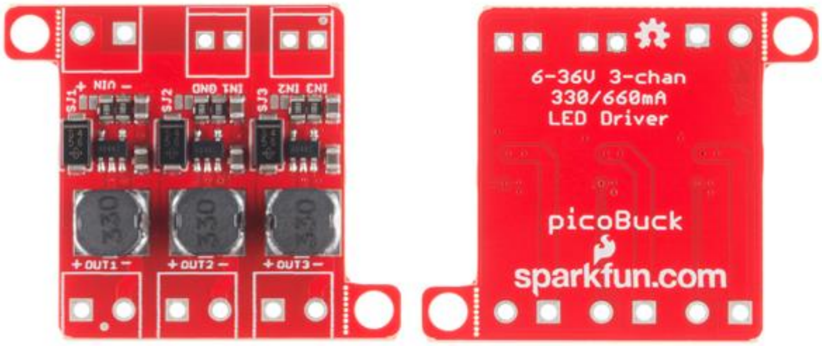


Figure 21. *Front and back view of PicoBuck LED driver [59]*

Despite the current ratings of AL8805 IC mentioned in PicoBuck LED driver in Table 4. It is recommended to operate the LED driver no more than 660 mA current, and by default all the three channels in the LED driver operate at 330 mA current [61]. The schematic representation of PicoBuck LED driver, provided each three channels, is illustrated in Figure 22 below.

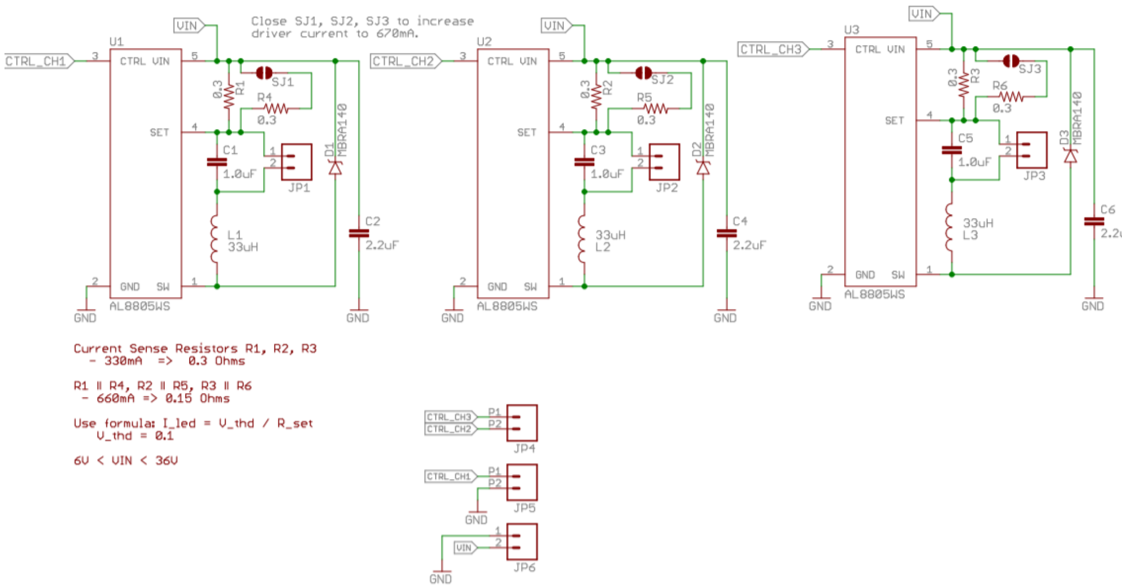


Figure 22. *Schematic diagram of SPARKFUN PicoBuck LED driver [62]*

4.3.3 Radiofrequency (RF) Remote Control System

During the signal, information is shared between the transmitter and receiver, the transmitter carries a carrier wave to manipulate useful data to the receiver. The process is called modulation. A modulation basically consists of Amplitude Modulation and Frequency Modulation. For the study, Frequency Modulation (FM) is used in RF remote control system to carry data from the transmitter to the receiver.

In FM, a modulator is attached to the transmitter side while a demodulation, which is opposite to modulation, is performed at the receiver end. The output obtained from the transmitter modulation is provided to the antenna attached to the demodulation receiver side. So, when the frequency of the carrier wave is changed in accordance with the intensity of the signal, the modulation is termed as FM. However, in FM the amplitude and phase of the carrier wave remains the same. Only, the frequency of the carrier wave is changed as per the signal. According to [63], the frequency of the carrier signal should be higher than the input signal provided from the transmitter. This will help to keep the antenna at a reachable limit. A simple form of modulation signal from transmitter to receiver is illustrated in Figure 23 below.

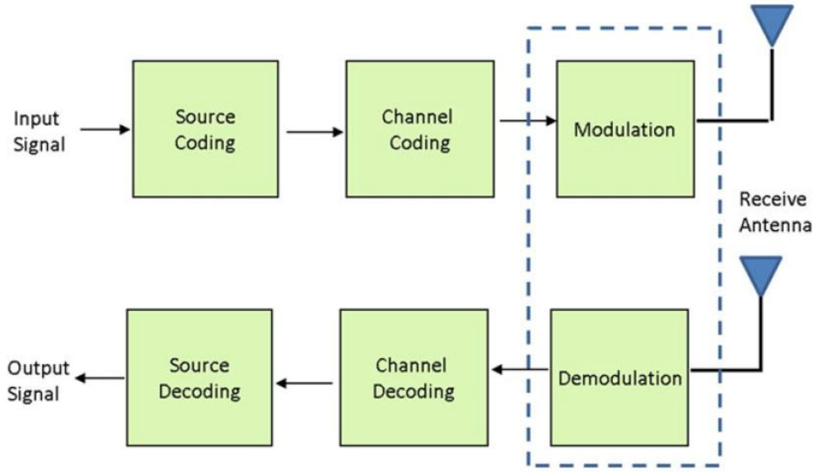


Figure 23. *Block diagram of frequency modulation [63]*

In the thesis, the RF remote control system is embedded on the smart shirt (transmitter side) and on the carpet (receiver side). It is used to wirelessly operate the infrared LEDs on the smart carpet to initiate the signal when the session begins with a specific child. The transmitter on the smart shirt will be operated by the psychologist and they will operate it by pressing the signal switch on the transmitter. The receiver will sense the signal due to the antenna attached and open the gate to power up the infrared LED's. The RF transmitter is operated by 3.3 volts built-in battery however, the RF receiver board consists of the relay-based circuit and needs a separate power source to be operated. According to the data sheet of RF remote control system [64], the receiver board requires 12 or 24 V DC supply as an input. The board is operated at 433.92 MHz frequency with a range of up to 150 meters. The RF transmitter remote provides either momentary or latching output and it can be programmed by one's demand. However, the relay circuit is used as a switch to turn ON/OFF the infrared LED's. The basic schematic of the relay switch is shown in Figure 24. A normal relay basically consists of five terminals. Two terminals are the power supply of the relay. The remaining three are Common (COM), Normally Open (NO) and Normally Closed (NC) terminals. The Common point is the terminal connected with the positive end of the input supply, connecting it to either Normally Open or Normally Closed points to generate an output. If there is no signal, then Common point remained connected to Normally Open point (by default), meaning no output. If a signal is generated, then the Common point will latch and connect with Normally Closed point to provide certain output. However, as per [64] the terminals points operation is opposite to what explained above, as can be seen in Figure 24. The Normally Open and Normally Closed points are swapped in functions i.e., output is provided when RF transmitter sends a signal, where Common point connects with Normally Open terminal otherwise if there is no RF transmitter signal then Common point remains intact with Normally Close point.

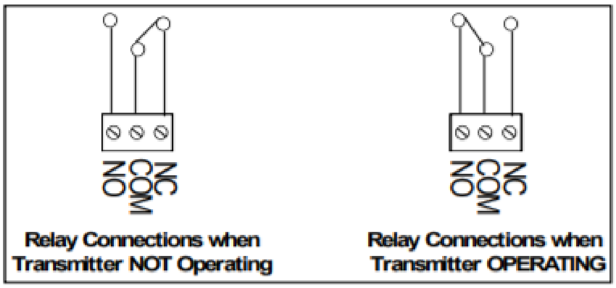


Figure 24. *Relay operation modes [64]*

The RF transmitter and RF receiver implemented in the thesis are shown in Figure 25.

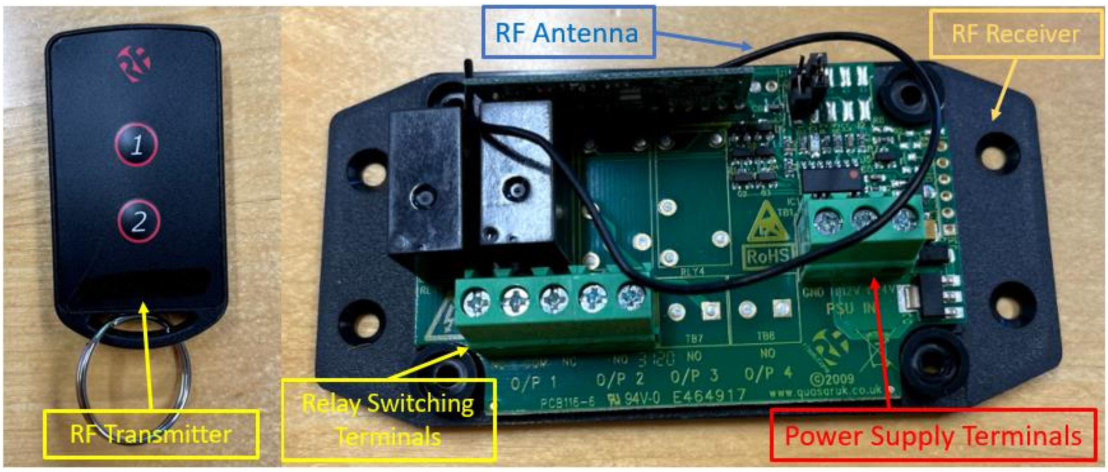


Figure 25. *RF transmitter and RF receiver board switch control system*

4.3.4 E-Textile based Single Touch Switch

Operation of infrared LED’s is the most important factor in this study. Despite the functionality, it also needs to be kept in mind that the infrared LED’s glow at the exact time and duration when the psychologists want to operate them during an eye-contact with the child. To turn infrared LED’s ON and OFF on the smart shirt, a switch is required which can handle this process. There are many switches available i.e., a traditional mechanical ON/OFF switch, which is difficult to implement in this case, because of the non-integrated property of the switch points with the smart shirt i.e., conductive yarn or e-textile, and it can be visible on the shirt due to oversize, voltage and current flow limitations, and small delay in operation, which is in milliseconds, but there is still quite a lot to mismatch the eye-contact made and infrared LED captured in the camera.

As per the above-mentioned factors, an e-textile based single touch switch was designed and integrated with the smart shirt for the desired requirements. The e-textile based switch is integrated easily with the smart shirt and possesses no delay in switching properties. The switch consists of three layers, top and the bottom layer made of e-textile material while they are separated with the middle layer containing normal soft textile material. The e-textile material is conductive while the soft textile material is non-conductive which forms a bridge between the upper and the bottom layer. The upper layer is connected to the positive or the negative terminal of the power supply i.e., the battery, and the connection is discontinued in between the upper and the bottom layer having the non-conductive middle layer. A small hole is made in the non-conductive textile, so that on pressing the upper and bottom layer it can be creating contact between upper and bottom layer and complete the circuit. In this way, the e-textile switch will complete either positive or negative terminal source and pass it to the destination component. The e-textile based switch can be viewed in Figure 26 below.

The switch is specifically designed to power up the infrared LED's only when the conductive e-textile contacts are made while pressing it. Otherwise, it will remain OFF. As in Figure 26 b), three layers are integrated via sewing using yarn. Each layer of e-textile is further extended with an e-textile connection. Both extended connection acts like a wire which is disconnected from the centre and while pressing the switch the two layers of e-textile will get in contact and provide the supply as needed. However, the resistance of the switch is also tested using the digital multimeter. While pressing the switch, it shows a resistance of 0.5 Ω while on slight contact it varies from 0.9 – 1.2 Ω. The result depicts that the resistance of e-textile switch is quite less which illustrates that this is a good material to conduct the flow of current.

a) b)

Figure 26. *E-textile based single touch switch. a) Layers of switch having two conductive e-textile material and one non-conductive soft textile material with a round hole. b) Combined e-textile switch via sewing with thread having two ends of the same power source.*

4.3.5 Power Source

In the thesis, the power source is required to operate LED driver module and infrared LEDs for the smart shirt and carpet. It is to be kept in mind, while implementing power supply to the smart shirt and carpet, it should be lighter in weight, easy to integrate with the e-textile, provides healthy voltage and current for a longer duration, and can be easily replaceable upon discharging or the breakdown. As discussed in previous sub-chapters, i.e., the infrared LEDs operates at 1.4 volts and 350 mA current and LED driver module operates at 6-36 volts with the maximum current rating of 1 Ampere. The power supply of 9 volts, PP3 type non-rechargeable Alkaline, having 500-700 mA current is found sufficient for the smart shirt. However, for the smart carpet, RF remote control system requires 12- or 24-volts power to operate. In the study, the RF transmitter has built in 3 volts supply while the RF receiver is provided with 12 volts having 500-700 mA current to operate the infrared LEDs on the carpet.

On the other hand, 12 volts supply is required to power the RF remote control system. To provide the required voltages, batteries of 9-volt alkaline PP3 non-rechargeable and 3 volts coin cell non-rechargeable, are connected in series. The voltages after the connection in series become 12 volts while the current rating remains constant i.e., 500-700 mA. The testing of 12 volts battery having 16 infrared LEDs on load and constantly regulated by LED driver module is executed. The result shows that the battery rating drops to 11.2 volts while on full load with the current draw reaching 500 mA. The experiment is repeated several times as a latching circuit which resulted in constant output in terms of the voltage drop, the current draw and intensity of infrared LEDs which is surprising especially when a coin cell battery is utilized with the non-identical battery in series connection.

4.4 Methods

The section elucidates methods of testing numerous electronic components at different voltage levels, the testing intensity of various infrared LEDs, current and voltage draw requirements, advantage of implementing e-textile, integrating electronics with e-textile and other alternative techniques that went wrong or provided incorrect readings while executing electronic components. The main purpose is to find the best electronic components for the study and integrate them with the textile that can behave correctly in the actual situation and can provide accurate readings. The methods of testing electronic components are discussed below.

4.4.1 Design Consideration of Smart Shirt and Smart Carpet

The initial task was to choose a design for the placement of infrared LEDs and other electronic components in the smart shirt. It was kept in mind, that the size of components, power supply, single touch switch and infrared LEDs should be aligned, managed, and easily removable while selecting and designing the circuit on the smart shirt. At first, 18 infrared LEDs were selected to be integrated on the smart shirt while keeping in mind, that they should be visible from all directions. For that purpose, 6 LEDs were placed on the front side of the smart shirt, 3 LEDs on the right and on the left arm, and 6 LEDs on the back side of the smart shirt as can be seen in Figure 27. In Figure 27, all the electronic components can be seen which are integrated on the smart shirt that were considered at the first place i.e., the battery, the magnetic switch, capacitive touch sensor pads, LED driver module, infrared LEDs, and touch switch for operating LEDs on the carpet (RF transmitter). Initially, it was considered that using two Single touch pads i.e., ON/OFF switch using the capacitive touch sensor, will be useful for the thesis. As it will ease the psychologists to turn ON/OFF the infrared LEDs from two different places on the smart shirt. One pad is integrated on the right arm and other on the lower right side of the belly.

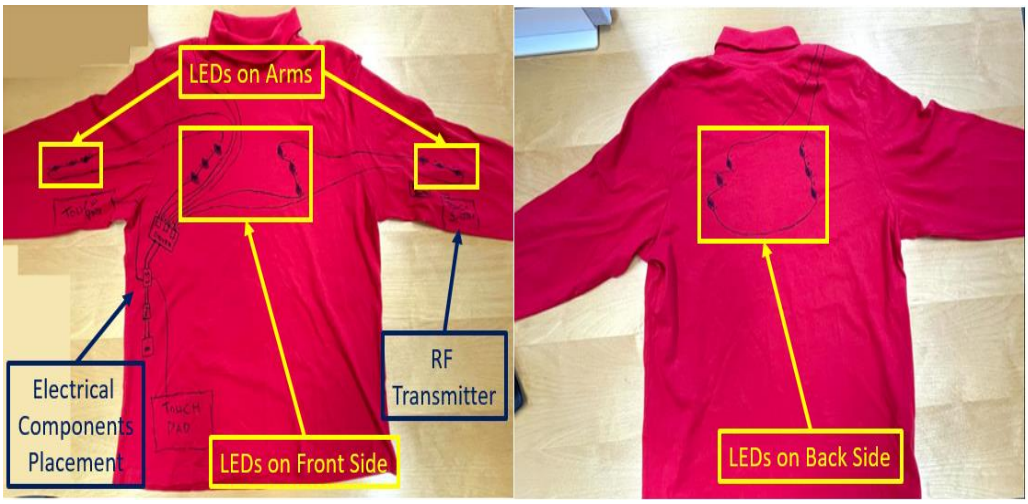


Figure 27. *Design consideration of smart shirt*

However, considering the infrared LEDs which will be monitored in the camera, if the psychologist moves their left arm to turn ON/OFF the infrared LEDs using the pad on the right arm, it will get difficult for the surveillance monitoring afterwards to view the infrared LEDs due to the moving left arm as it will cover most of the infrared LEDs. So, for that reason only one pad was finalized for the smart shirt which will be placed on the lower side of the belly. While approaching that pad, no LED will be hidden.

a) *b)*

Figure 28. *Alternative switching electronic components. a) Magnetic ON/OFF switch [65]. b) Capacitive touch sensor with pad (front and back side).*

On the other hand, the capacitive touch sensor pad and magnetic switch, which were the first choices to switch the LEDs ON/OFF, were also seems hard to implement. The magnetic switch was introduced to cut the power supply from the battery even if the battery remains intact. However, as the sensor and the switch operate at 5 volts and have a limited power of forwarding current. So, due to their limitations they were not considered in the electronic circuit. The magnetic switch and capacitive touch sensor are illustrated in Figure 28. To replace them, the thesis opted e-textile based single touch switch as discussed in Chapter 4.3.4.

Total of 18 LEDs were implemented on the subject design in Figure 30, they were divided according to 3 outputs terminals of LED driver module i.e., 6 LEDs per output terminal. 6 LEDs were connected in series and then connected with each output terminal of the LED driver module. Likewise, other LEDs were connected in series and attached with the remaining output terminals of the LED driver module. The purpose of attaching LEDs in series as a chain of 6 and attaching them separately with 3 outputs of LED driver, is to distribute the load equally through all output terminals so, that each output terminal provides the equal intensity of power supply to infrared LEDs.

Lastly, an RF transmitter switch is placed on the left arm of the smart shirt. The RF transmitter switch is used to operate the infrared LEDs on the smart carpet and while executing RF switch the infrared LEDs on the smart shirt will not be operating as discussed previously in Chapter 4.1 and 4.2.

Like the smart shirt, the design consideration of the smart carpet is reviewed for the placement of infrared LEDs. The initial design of the carpet is contemplated, infrared LEDs are placed in the middle of the carpet. In this pattern, total of 18 infrared LEDs is integrated to be viewed from all directions. They are controlled through LED driver module while switching facility is provided by RF remote control system. However, it is considered placing the LEDs on the edges of the carpet instead in the middle, because, during the session the psychologist and the child will sit on the carpet which will cover most of the middle area of the carpet. So, it is reviewed and finalized to place the infrared LEDs on the edges to view them clearly. The latest design also reduces the number of infrared LEDs from 18 to 16 which makes the prototype much better and visualizable.

4.4.2 Workbench Setup for Integrated Electronics

It is important to implement a test workbench and acquire outputs from electronic components used in the study in different conditions. This will assist in gaining precise measurements before the integration of electronic components in the smart shirt and carpet. The idea was to select most adequate electronics i.e., testing different infrared LEDs in terms of light intensity at varying distance and viewing angle, testing the LED driver module at the different voltage levels, RF remote control switch, and performance of conductive yarn. Before the battery performance being examined, the testing of electronic components is carried out with the help of variable direct current (DC) voltage supply as in Figure 29. Inclusion of DC voltage supply is to predict and find the actual behaviour of the components. The supply consists of two channels each can deliver voltage ratings from 0 – 30 volts with the current rating of 6 amperes. The device contains movable knobs that can vary voltage and current. It also provides attachable wire points to connect the deliverable component easily.

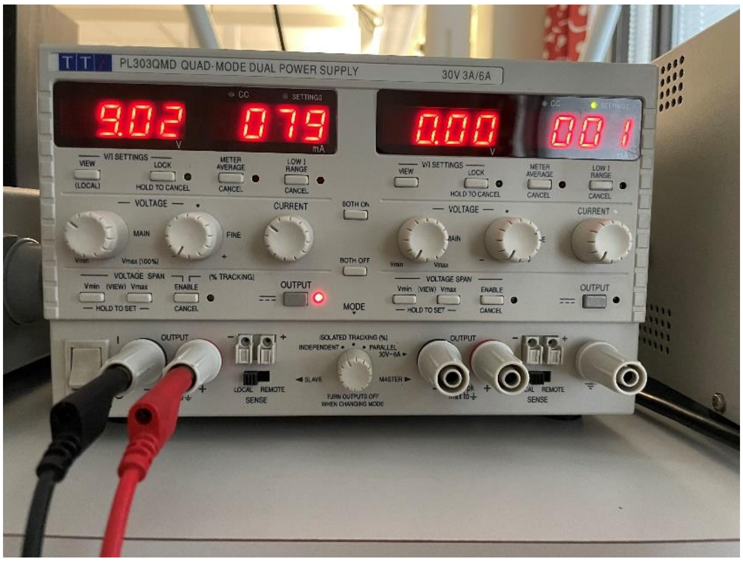


Figure 29. *Variable voltage direct current (DC) supply*

4.4.2.1 Testing Infrared LEDs and LED Driver Module

The testing of infrared LEDs is carried out from 6 – 24 volts at 500 mA current using LED driver module and DC voltage supply. Different infrared LEDs with dissimilarity in shape, size, power rating and wavelength varying from 880 and 940 nm are tested at different voltage levels to check the notable intensity and viewing angle. The LEDs consisting of the same wavelength are connected in series on a breadboard and provided power supply using DC voltage supply through LED driver module. The test setup workbench can be seen in Figure 30 consisting of breadboard, infrared LEDs, and LED driver module. A breadboard is a simple circuit board that is used to connect numerous electrical and electronic components having series and parallel electrical connections within. The board consists of small holes which are utilized to position components inside them and create a temporary circuit to verify schematic behaviour and result. In Figure 30, the DC voltage power supply is connected with LED driver module providing 9 volts and 500 mA current. The output terminals of LED driver module are connected with the breadboard where different infrared LEDs are connected in series for testing. Infrared LEDs with similar wavelength are connected in series and tested using the test workbench. While testing infrared LEDs the viewing angle is examined from different directions using the camera. The target is to visualize infrared LEDs from all positions irrespective to the positions of camera placement.

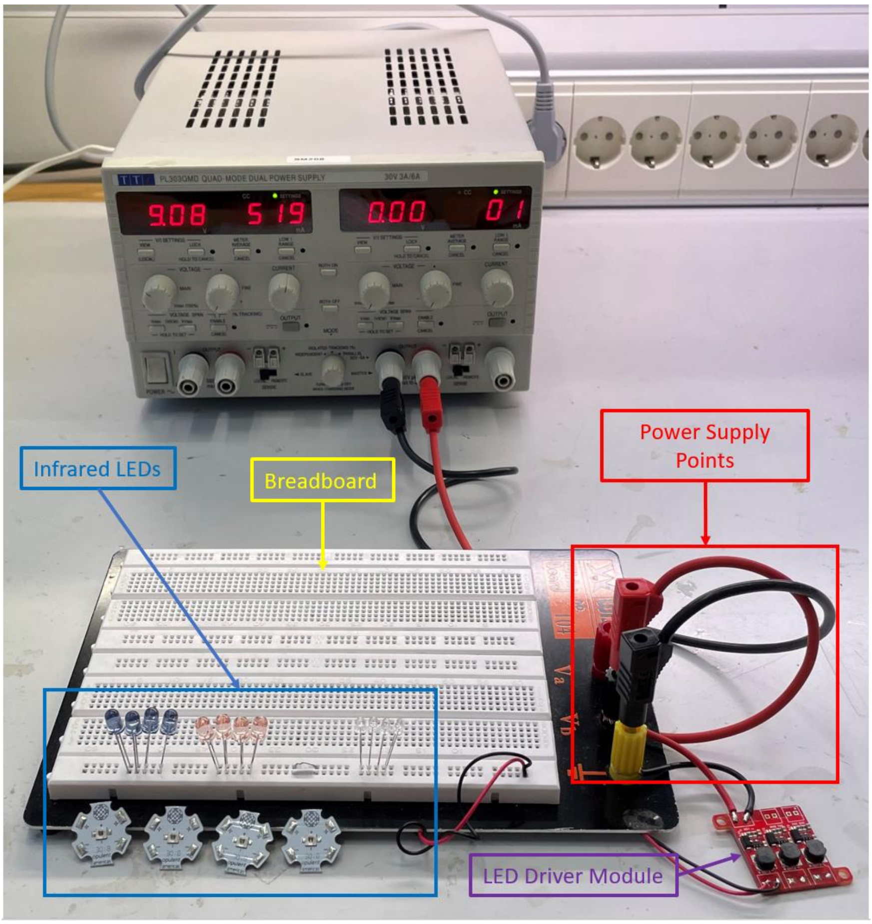


Figure 30. *Test setup workbench of infrared LEDs*

Initially, infrared LEDs with 880 nm wavelength having forward voltage of 1.7 volts and 100 mA current is tested. Power supply of 9 volts and 500 mA current is provided to the LED driver module. The LED driver module is connected with infrared LEDs which are attached in series on the breadboard. The power source is provided, and infrared LEDs intensity is visualized through the camera. The results suggest that the light intensity of the infrared LEDs is quite good and is noticeable very clearly. However, the viewing angle of the infrared light is dismal, as soon as the camera moves from the top view i.e., 90^{o} degrees and start to advance on the right or on the left side, the light of infrared LEDs began to disappear even within 10^{o} degrees of movement. This is due to the built-in viewing angle capability of the infrared LED, as it can only be viewed from 90^{o} degree angle. So, the subject infrared LED is not sufficient for the thesis implementation.

Similarly, the testing of infrared LED having 940 nm wavelength and 60 mA current rating is completed. As the current rating is quite less and the wavelength is increased so, it is very clear that the intensity of light will not be as sharp as for the 880 nm infrared LED. However, the same experiment is concluded on the subject infrared LED. The testing shows that the intensity of infrared LED is quite poor with only 60 mA current rating and it is difficult to sight the light even with the closest angle. The viewing angle is also very inferior, and it disappears even moving the camera for less than 10^{o} degrees from its actual position i.e., 90^{o} degree.

On the other hand, when infrared LED with 940 nm wavelength and 100 mA current rating was examined, the results were quite different in terms of light intensity compared with infrared LED of 60 mA current rating. The intensity of light is fairly bright and can be seen clearly. However, the viewing angle is almost the same as experienced in the previous two testing of infrared LEDs. The light tends to disappear as soon as the camera shifts from 90^{o} degrees and moves to about 10^{o} – 15^{o} degrees.

Finally, infrared LED with 940 nm wavelength having 350 mA current rating was executed. This infrared LED is different in shape, as illustrated previously in Chapter 4.3.1, from the rest analysed before. The LED is SMD type component having two positive and two negative terminals, that are utilized for power supply connections. As its power rating suggests, it tends to produce good light intensity compared with the ones tested previously. Due to its non-compatibility with the breadboard, it cannot be tested on the breadboard and connected in series using wires with the help of the soldering iron machine. The testing is carried out, and it was noticed that the intensity of light is very bright and possesses viewing angle of 130^{o} degree from all sides. The viewing angle is enough for an infrared LED to be integrated on the smart shirt and observed from all directions.

However, it is analysed that the surface of these LEDs is very shiny and white in colour and whenever an overhead light hits the SMD component surface, it gets very difficult to observe the infrared LED, especially under the room light. To overcome this problem, the LED surface was sprayed with permanent black colour in order to observe the infrared LEDs more clearly and to provide dark background scheme to view infrared light more easily. Due to the infrared light intensity and broad viewing angle the infrared LED is selected as the indication electronic component for signal generation while monitoring child eye-contact in this study.

4.4.2.2 Testing RF Remote Control System

Infrared LEDs on the carpet requires a wireless communication source to operate them and the study have already discussed RF wireless protocol in Chapter 4.3.3. Although it still needs to be illustrated how the infrared LEDs will behave using the RF remote control system. To ensure the safe operation, the testing of RF remote control system is completed in this section.

The RF remote control system which operates at 12 or 24 volts is connected with the DC voltage variable source to provide power for the RF receiver system as can be observed in Figure 31. The LED driver module is connected with the RF remote control system to adjust variable supply and provide it for the infrared LEDs. The positive terminal of the LED driver module is connected with the Common relay point terminal on the RF remote control receiver board while the negative terminal is grounded on the same board where the power source is provided. The Normally Open relay point terminal is connected with the positive terminal of the power supply provided for the receiver board. The system is implemented using 12 volts power supply to the RF remote control system.

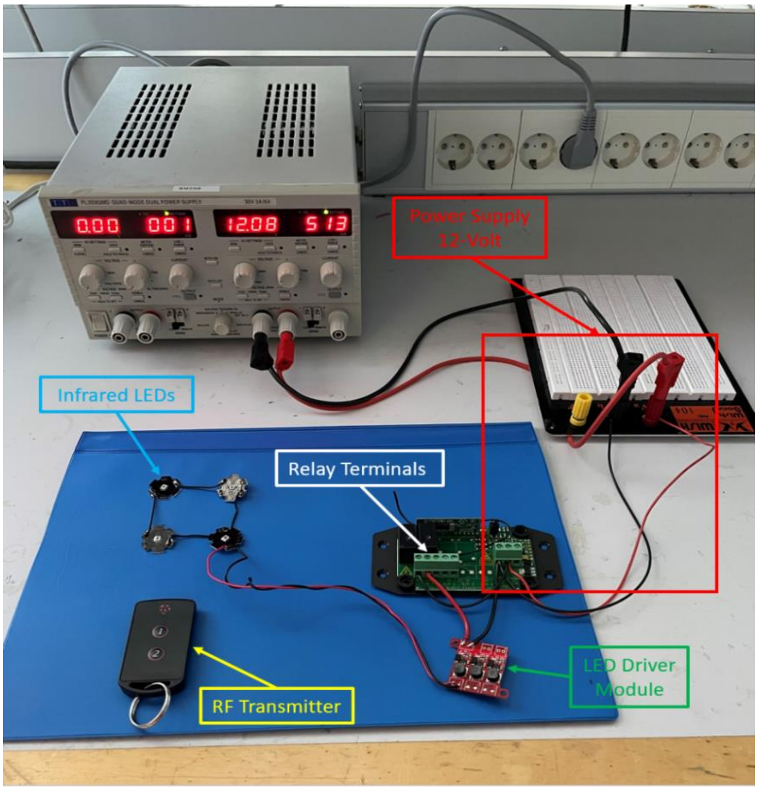


Figure 31. *Testing RF remote control system*

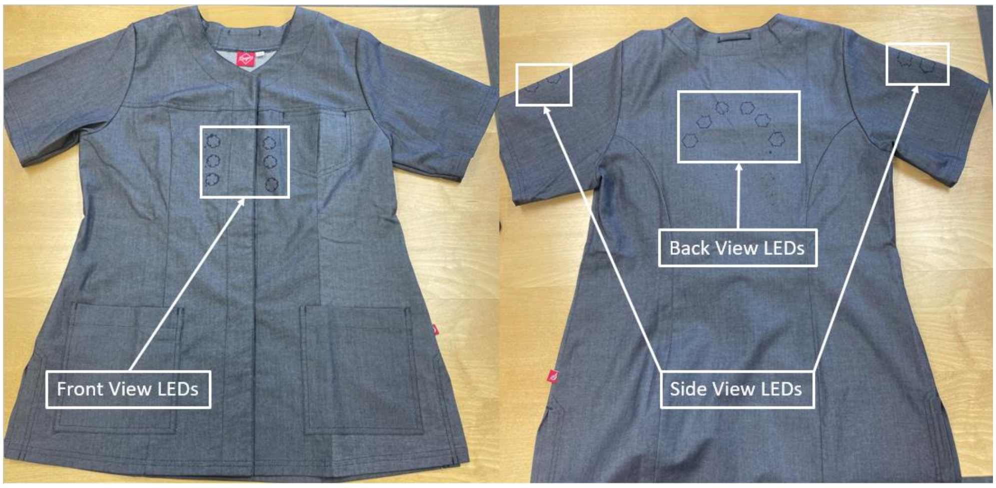
The testing includes efficiency and switching precision of RF remote control system on varying distance i.e., 3-5 meters. After executing the test setup, the efficiency of the RF remote control system appears satisfactory, and counterparts with infrared LED ON and OFF switch timings over a distance of 5 meters. The RF Transmitter will be integrated into the smart shirt and it will be used to operate the infrared LEDs on the carpet.

4.4.3 Design and Fabrication of Clothing Electronics

The study presents two designs for the smart shirts and three designs for the smart carpets, out of which I selected the ones for the actual practical testing. This section describes the designing and fabrication of these textiles and integration with electronics.

4.4.3.1 Smart Shirt

The placement of infrared LEDs on the smart shirt is selected on the basis of easy visualization from all directions as can be seen in Figure 32. The integration is carried out by sewing infrared LEDs using cotton yarn on the shirt, which can hold the LEDs firmly. However, before sewing the infrared LEDs, as they did not possess any sewing hole, the infrared LEDs is drilled using the Printed Circuit Board (PCB) drilling machine using a 0.90 mm drilling bit to acquire the task. It is assured that each LED contains two sewing holes which need to be placed on the smart shirt.



a)

b)

Figure 32. *Prototype layout of smart shirt. a) Design 1 prototype with frontal chest LEDs. b) Design 2 prototype with necklace type LEDs.*

After creating holes, each infrared LED is placed on the marked spots on the smart shirt and sewed using cotton yarn and sewing needle as illustrated in Figure 33. Total of 16 infrared LEDs is placed on Design 1 and 17 on Design 2 smart shirt. After the placement, the infrared LEDs are connected with LED driver module using e-textile, conductive yarn, and electrical wires. As the LED driver module consists of 3 output terminals, so to distribute the load equally, the output terminal contains 5, 5 and 6 infrared LEDs connected in series for Design 1 while 6, 6 and 5 infrared LEDs connected in series for Design 2. The infrared LEDs connected in series are attached using electrical wires. The electrical wires implemented for connecting infrared LEDs in series using the soldering iron machine. The series connection possesses, attachment of the negative terminal of the first LED with the positive terminal of the second LED and so on. However, the positive terminal of the first LED and negative terminal of the last LED are connected with the LED driver module output terminals to complete the series circuit.

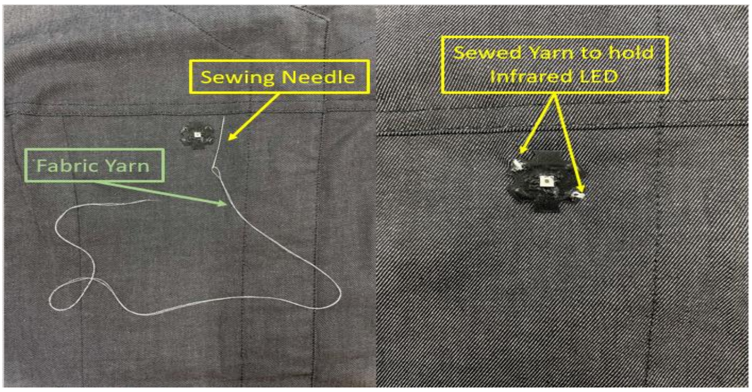


Figure 33. *Sewing infrared LED on smart shirt*

After the series connection of infrared LEDs, the LED driver module is placed, and e-textile is routed to provide the electrical connection between LED driver module and infrared LEDs and then power source to LED driver module. The e-textile material consists of two sides i.e., the conductive side which is the upper layer, and the bottom layer consists of iron-on material. Figure 34 depicts routing method of e-textile. Firstly, the e-textile is cut into desired length and size of the routing design using scissor, and then integrated on the smart shirt using iron pressing. For infrared LED input supply, the e-textile is routed from LED driver module output terminals to the infrared LEDs and for LED driver module input supply, the e-textile is routed from power source to LED driver module input terminals. Conductive yarn is sewed for attaching LED driver module and infrared LEDs terminals with e-textile. However, in Design 1 smart shirt, the conductive yarn is sewed from LED driver module terminals with the routed e-textile. While in Design 2 smart shirt, the electrical wires are first solder with LED driver module using iron soldering and then the electrical wires are sewed with routed e-textile using conductive yarn. The reason for designing two different patterns is to observe infrared LED intensity and choosing the best layout design for future studies. Conductive and cotton yarns used in the thesis are shown in Figure 35. However, the connection of infrared LEDs and power source in both designs are carried out using electrical wires sewed with routed e-textile using conductive yarn. Like infrared LEDs, the LED driver module is first sewed with cotton yarn to hold its position on the smart shirt. The routing connection of LED driver module is illustrated in Figure 36 below.

Figure 34. *E-textile implementation on smart shirt using iron machine*

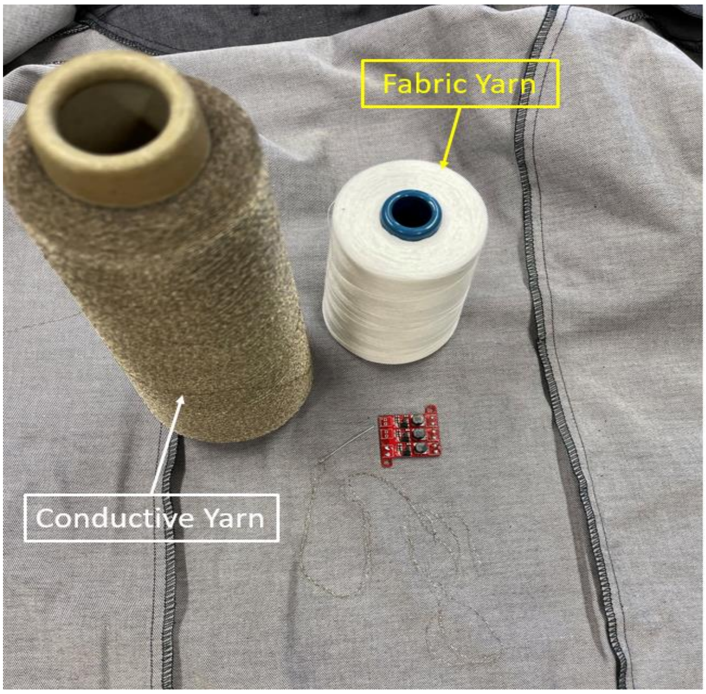


Figure 35. *Conductive and cotton yarns*

As per Figure 34, the e-textile is placed on the smart shirt according to the design requirement. Afterwards, the iron machine is carefully pressed on the e-textile to attach it firmly with the shirt. The iron-on material on the bottom layer of e-textile helps it to stick and remain intact with the shirt.

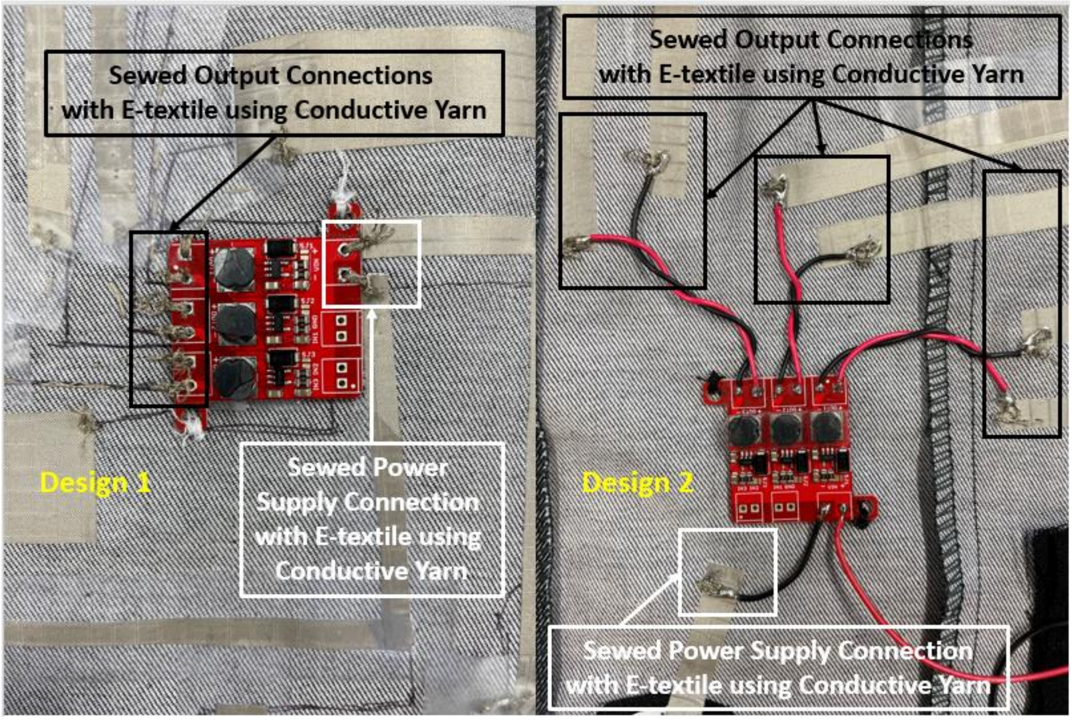


Figure 36. *Routed e-textile connection with LED driver module on smart shirts*

After the placement of LED driver module, e-textile switch is integrated on the shirt. As discussed in Chapter 4.3.4, the e-textile switch consists of three layers, two e-textile conductive layer and one non-conductive soft textile layer. The e-textile is placed on the bottom and on the upper layer while the soft textile material is placed in the middle. The bottom layer from the iron-on side of e-textile is iron-pressed on the shirt to fix its position close to LED driver module in both designs. Then the middle layer is placed, and e-textile layer is settled on the top, facing the conductive side towards the middle layer. The e-textile routed connection is extended, from the first and the third layer. One connection is provided to negative terminal of the battery and the other to the negative power supply input of LED driver module. Upon pressing e-textile switch, it will pass the negative supply of the battery to the LED driver module. The designing process of e-textile switch is illustrated in Figure 37. On the other hand, the routed connection of e-textile from the battery source to the e-textile switch and then its extension towards LED driver module is represented in Figure 38. Figure 38 demonstrates two different designs of the smart shirt which are connected via e-textile switch.

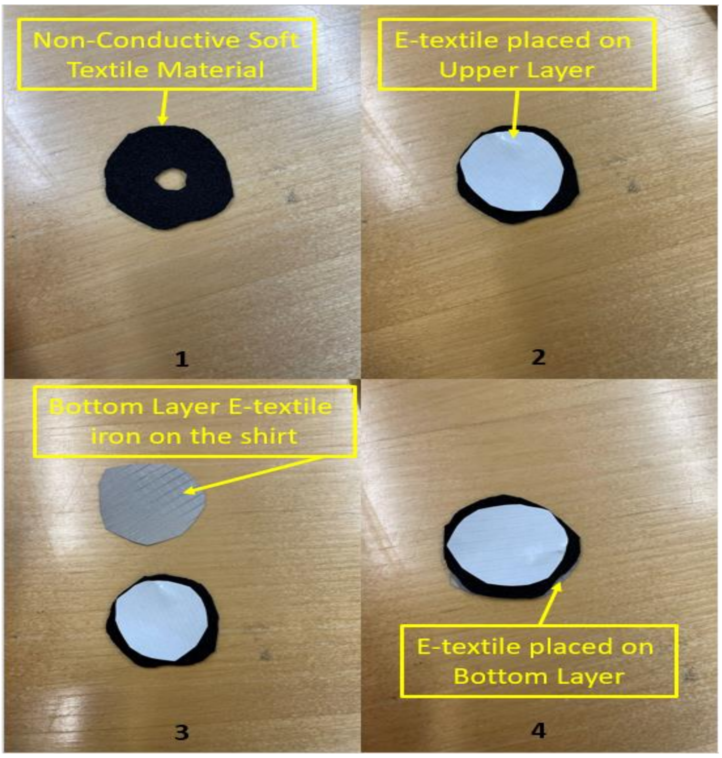


Figure 37. *E-textile based single touch switch*

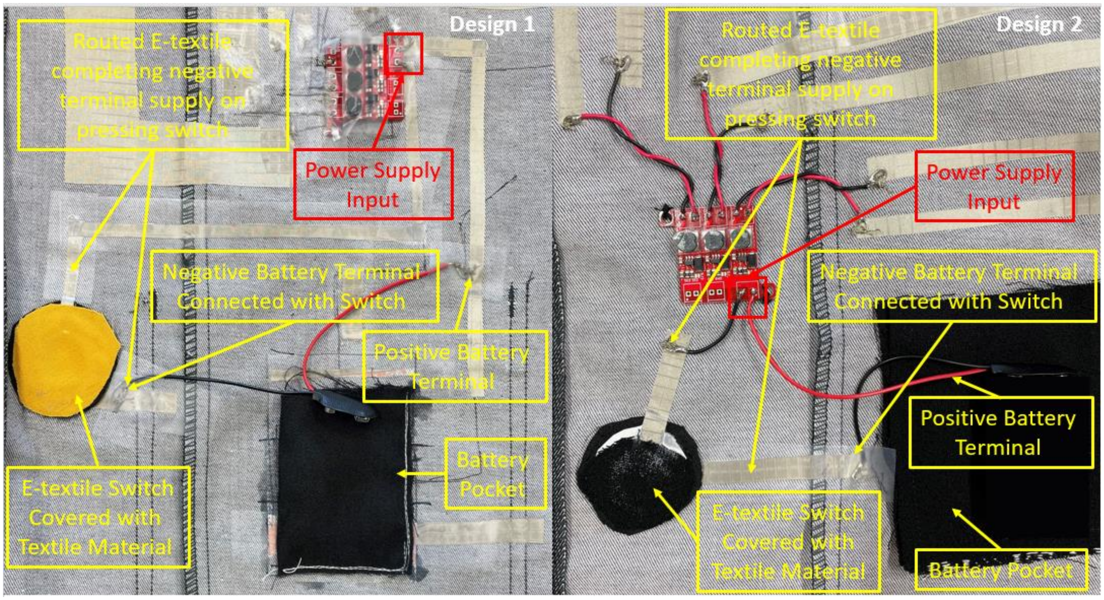
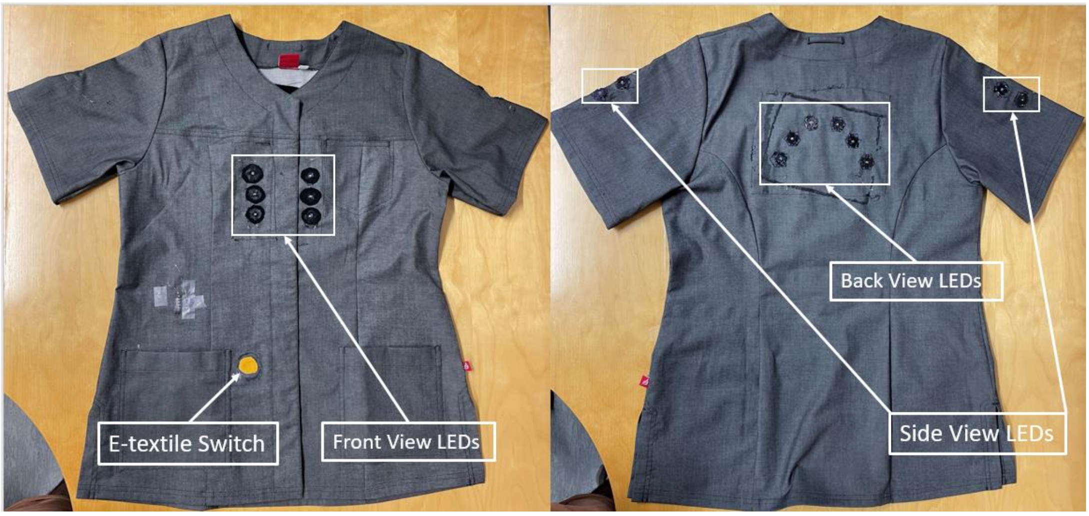


Figure 38. *Extended terminals of e-textile switch*

After succeeding with the placement of electronics and e-textile on the shirt, the integrated electronics and extended wire connections are internally covered with textile material to imply safe use in wearable applications. The textile material is sewed using the sewing machine. However, a pocket is also created on the smart shirt for the placement of the battery while using it. The battery is connected with the electronics using battery straps which make the design flexible and replaceable. Designed and fabricated smart shirts can be viewed in Figure 39. Each design includes integrated infrared LEDs, placed at different locations. However, the RF Transmitter remote, to operate infrared LEDs on the smart carpet, is not integrated permanently on the shirt, rather it is placed in the lower front pocket of the smart shirt. The working functionality and its implementation in real time situation are discussed in Chapter 5.



a)

b)

Figure 39. *Designed and fabricated smart shirts. a) Design 1 - smart shirt. b) Design 2 - smart shirt.*

4.4.3.2 Smart Carpet

As discussed previously is Chapter 4.2, two carpets of different colours having the same sizes i.e., 195 cm in length, 133 cm in width and 2.59 m^2 of surface are introduced to integrate with infrared LEDs. Initial prototype design of carpets is also discussed in Chapter 4.4.1, where infrared LEDs are embedded as per the layout. However, due to the colour schemes of carpets, the study implements three different designs of placing infrared LEDs on the carpets. The carpet 1 is lighter in colour compared with carpet 2, whereas it is quite obvious and illustrated that the infrared LEDs intensity is more visible with the darker background compared with the lighter background. So, the thesis executes two different approaches for the placement of infrared LEDs on carpet 1 due to its lighter background to analyse the infrared light intensity.

The first design is implemented on carpet 1, having the lighter background. Total of 18 infrared LEDs are placed on the carpet. The infrared LEDs are connected using electrical wires and the soldering iron station to solder the terminals between LEDs. Similar to the smart shirt, infrared LEDs will be controlled using LED driver module on the carpet. The infrared LEDs are connected in series and joined them with the LED driver module's output terminals i.e., 6 LEDs connected in series per output terminal of LED driver module. The RF receiver remote control system will provide voltage supply to LED driver module upon switching. The LED driver module is connected with relay points on RF receiver remote control system to establish power supply on activation. The power supply of 12 volts and 500-700 mA is provided to operate infrared LEDs on the carpet using two batteries in series connection.

Figure 40. *Infrared LEDs integrated on carpet 1 - design 1*

Figure 40 shows the LED placement on Carpet 1 - Design 1. LEDs are placed straight (laid down) at 0^{o} degree angle. 4 LEDs are placed on each corner of the carpet, while other LEDs are placed in between those 4 corners while maintaining good distance in between, so they can be viewed easily.

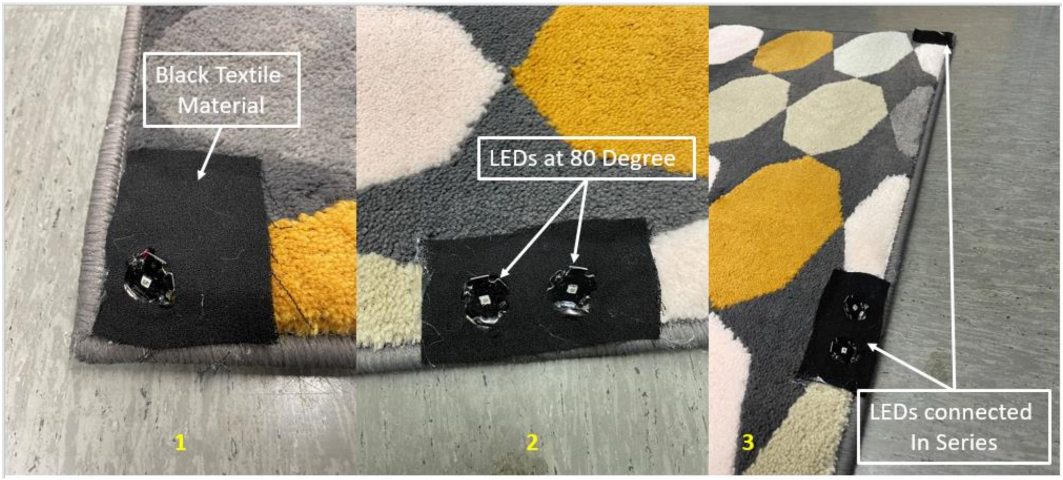


Figure 41. *Infrared LEDs integrated on carpet 1 - design 2. LEDs are fixed at 80° degrees with black textile material.*

On the other hand, due to the lighter background of carpet 1, another layout of placing infrared LEDs is implemented. The infrared LEDs are placed at an angle of 80° degrees on the carpet and a black textile material is placed around the infrared LEDs to provide a dark background. The infrared LEDs and the textile material are fixed using the silicon gun. In Carpet 1 - Design 2, total of 12 LEDs is integrated, making 4 LEDs per series connection. The series terminals of infrared LEDs are attached with LED driver module output terminals. The RF remote control system will control the LED driver module power supply. 4 LEDs are embedded on each corner and other LEDs are connected in between those LEDs with average and equal distances. The LEDs attached to each side of the carpet are facing opposite to each other, making it easy to view them easily from all sides of the carpet. This method is executed to analyse and compare the infrared light intensity with the former method. Figure 41 illustrates LED placement on Carpet 1 – Design 2.

The last prototype design is executed on carpet 2. The placement of infrared LEDs is similar as integrated on Carpet 1 - Design 1. To visualize light intensity with a darker background, carpet 2 is executed. Total of 15 infrared LEDs are attached to the carpet, making 5 LEDs per series connection which are connected with LED driver module. Like previous methods, the LED driver module is controlled via RF remote control system and is powered up using 12 volts battery supply. 4 LEDs are embedded on each corner of the carpet and other LEDs are placed in between them. The Carpet 2 - Design 3 represented in Figure 42.

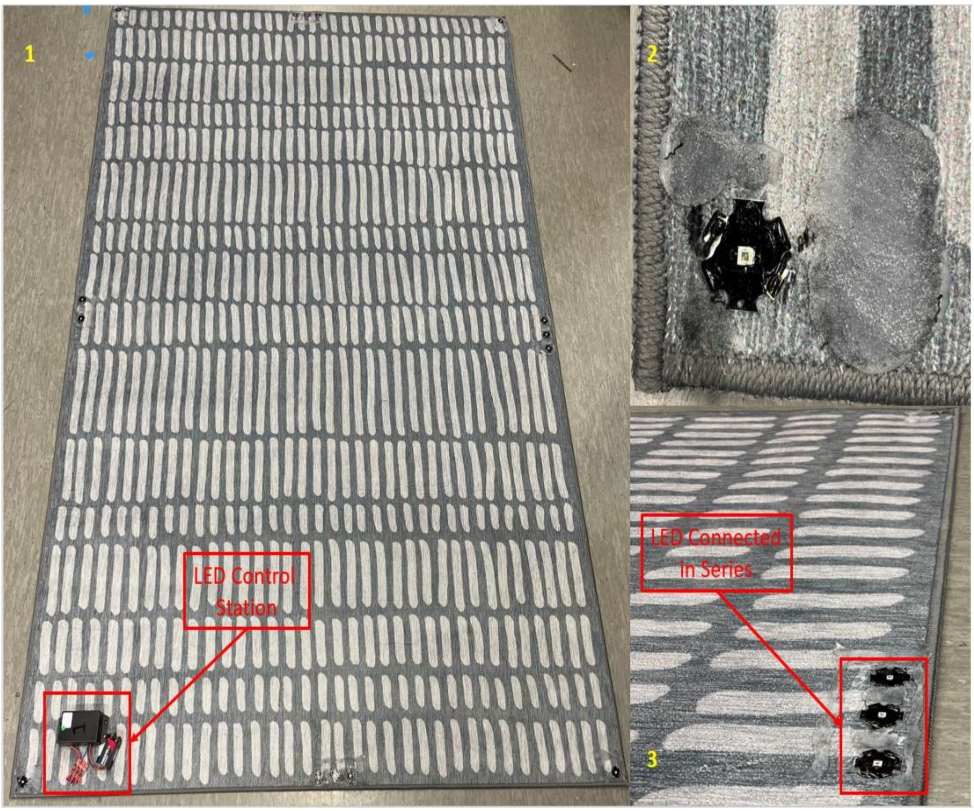


Figure 42. *Infrared LEDs integrated on carpet 2 - design 3*

However, the wiring connection of infrared LEDs is kept on the back side of each carpet and the wires are fixed using the hot silicon gun.

5. RESULTS AND DISCUSSIONS

This Chapter will introduce the performance testing of the designed and fabricated smart shirt and carpet. The performance will be examined in the laboratory and in the simulated practical use situation with the psychologists. The examination will provide the required conclusion regarding the accuracy and precision of smart shirt and smart carpet.

Initially, the performance testing will be carried out in the laboratory while creating a workbench for the performance test setup. Afterwards the testing will be completed in real time situation with the psychologists. Now-a-days, the cameras consist of embedded infrared filters, which filter out the infrared light and it becomes impossible to view any infrared light from a camera. In order to choose best viewing technique for the thesis, the testing includes usage of numerous cameras while monitoring infrared LEDs. Analysing and inspecting results in using various cameras will provide a broader image of utilizing the right hardware for the thesis.

5.1 Performance of Integrated Electronics

Performance of integrated electronics is tested after integration with the textile materials. It is the first proceeding, where they need to be examined and provide enough data that can be beneficial before the actual testing phase. In the performance testing workbench, three different cameras are utilized to analyse and monitor infrared light intensity behaviour in different situations.

a) b) c)

Figure 43. *Cameras examined for testing infrared LED light. a) Lenovo X390 laptop camera. b) Sony HD digital video recorder camera. c) iPhone 12 pro camera [66].*

The cameras used to execute the process includes the iPhone 12 pro camera, Lenovo X390 laptop camera, and Sony HD digital video recorder camera. The three cameras have varying properties in terms of infrared viewing intensity, hardware filters and infrared visualizing image quality. The cameras can be viewed in Figure 43.

In the first cycle of performance testing, the light intensity monitoring is initiated using all the cameras. The main aim is to survey and analyse, which camera suits better while viewing infrared LEDs through them. For studying the behaviour of light intensity under these cameras, design 1 smart shirt is selected as a subject. The infrared light of LEDs is monitored with 1 meter distance. The testing is completed under three different room environments as illustrated in Table 5. The three different room environments assisted in visualizing infrared LEDs using different cameras to examine and select the right method for the actual testing. The testing results of infrared LEDs using cameras can be seen in Table 5.

Table 5. *Infrared LEDs behaviour under different cameras*

Room condition	**Analysing infrared light intensity behaviour**		
	Iphone 12 pro camera	**Sony HD digital camera**	**Lenovo X390 laptop camera**
Room lights ON	IR LEDs not visible	IR LEDs not visible	IR LEDs visible
Overhead light OFF only	IR LEDs not visible	IR LEDs not visible	IR LEDs visible
Room lights OFF	IR LEDs not visible	IR LEDs not visible	IR LEDs visible

Table 5 depicts, that the infrared LEDs are only visible while using Lenovo X390 laptop camera with a distance of 1 meter. The reason behind the non-identical behaviour of cameras in viewing infrared light is due to the presence of infrared filter inside. The filter of the camera filters out the infrared light and offer visualization of all other visible lights. That is the reason why IR LEDs are not visible while using iPhone 12 pro and Sony HD digital camera due to the presence of the infrared filter in their system. On the other hand, the Lenovo X390 laptop camera does not contain such filter which makes it easy to view infrared light while using it. So, the performance testing results of the smart shirt and the carpets are carried out using Lenovo X390 laptop camera under full room light. However, to implement the camera possessing infrared filter, one can detach the filter from the hardware using precise laboratory tools.

Lenovo X390 laptop camera is utilized in further infrared LED monitoring on smart shirt and smart carpet. First of all, the Design 1 and Design 2 smart shirts are examined under full room light. The smart shirts are examined distance between 3 meters and 1 meter.

The idea is to analyse the behaviour of infrared LEDs from varying distance and examine their light intensity. The infrared LEDs on smart shirts are captured from all directions during the testing. The result of infrared LEDs on smart shirts is represented in Table 6.

Table 6. *Performance testing of smart shirt with varying distance*

Direction of monitoring	**Placement of infrared LEDs on smart shirt**	**IR LED testing on design 1 smart shirt**		**IR LED testing on design 2 smart shirt**	
		3 meters distance	**1 meter distance**	**3 meters distance**	**1 meter distance**
Front view	90^o angle	IR light inten-sity reduces	IR light intensity increases	IR light intensity reduces	IR light intensity increases
Back view	90^o angle	IR light inten-sity reduces	IR light intensity increases	IR light intensity reduces	IR light intensity increases
Side view	90^o angle	IR light inten-sity reduces	IR light intensity increases	IR light intensity reduces	IR light intensity increases

Table 6 shows the performance testing of smart shirts. It can be seen that the IR light intensity of LEDs increases on both designs when tested from a distance of 1 meter in a full bright room. However, as soon as the distance increases, the IR light intensity reduces. All the IR LEDs are attached to the smart shirt having 90^o degree angle.

On the other hand, the performance testing of smart carpets is also examined under full room light condition and utilizing the same camera. The testing includes distance measurement monitoring at 3 meters and then at 1 meter. As previously discussed in Chapter 4.4.3.2, the smart carpet possesses three designs. Each design is tested and analysed to examine infrared light intensity. The smart carpets are assessed with varying distances from all directions to examine infrared LEDs. The performance testing is illustrated in Table 7. Table 7 depicts the performance testing of infrared LED of smart carpets under full room light by varying distance. It shows that when the infrared LEDs are placed at 0^o degree angle on the carpet, it gets difficult to view them. As in design 1 and design 3, the light intensity of infrared LEDs is not visible from 3 meters distance whereas at 1 meter distance the light intensity is visible with fare intensity. However, in design 2 of smart carpet, the LEDs are placed at 80^o degree angle which makes it comfortable to be viewed from varying distance. The three different designs of the smart carpet conclude that, the background colour of the carpet for viewing infrared LEDs should be darker. This helps to view infrared LEDs more successfully. Similarly, to view infrared LEDs effectively, they should be placed at an angle of $80^o – 130^o$ degrees, depending on the design. However, to view infrared LEDs at longer distances i.e., more than 3 meters, infrared LEDs with higher power ratings could be utilized.

Table 7. *Performance testing of the smart carpets with varying distance*

Smart carpets	**Placement of infrared LEDs on the smart carpet**	**IR LED testing from all directions**	
		3 meters distance	**1 meter distance**
Carpet 1 – design 1	0^{o} angle	IR light not visible	IR light intensity reduces
Carpet 1 – design 2	80^{o} angle	IR light intensity reduces	IR light intensity increases
Carpet 2 – design 3	0^{o} angle	IR light not visible	IR light intensity reduces

5.2 Real Time Testing

The Chapter introduces testing in real time situation with the psychologists. The testing is held at Tampere University City Centre Campus in Pinni B Block, 3rd Floor. The session room inside the block is specifically prepared for the monitoring of autism spectrum disorder children. The overall look of the room can be seen in Figure 44.

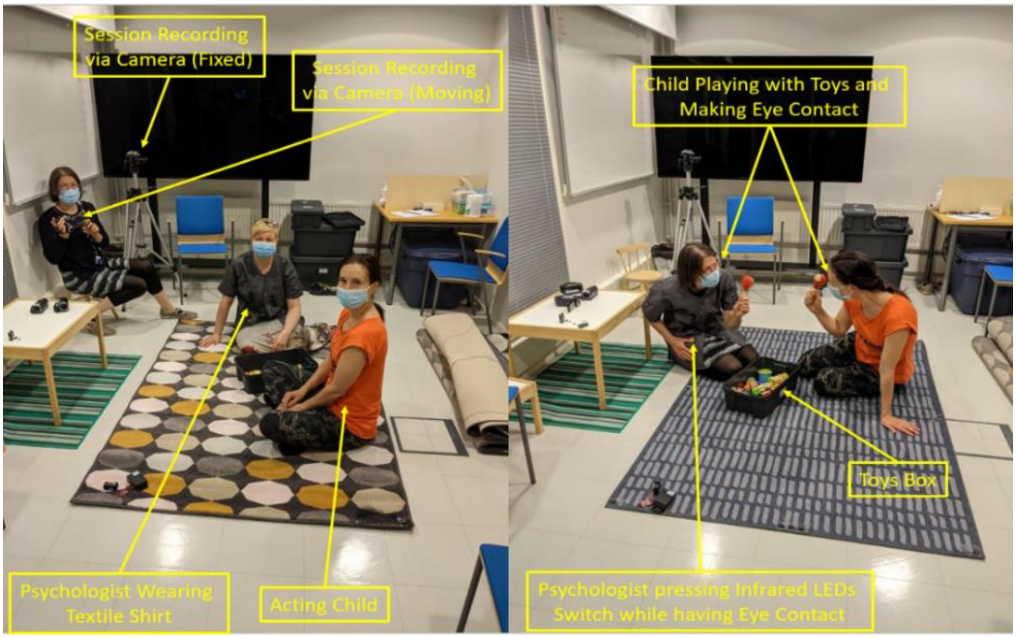


Figure 44. *Psychologist session room and real time test setup*

As can be observed in Figure 44, the room consists of boxes of toys for the children to engage them in different activities during a monitoring session. The video recording cameras, Lenovo X390 as in Figure 43 a) and Sony HD as shown in Figure 43 b), are utilized in the room to record the whole session. The two different cameras are executed to compare their results in terms of viewing and analysing IR light intensity on the smart shirt and carpet for monitoring the eye-contact of the child with the psychologist. The smart carpet is placed in the centre of the monitoring room. For monitoring eye-contact, the testing is performed under full bright room light. The smart shirts are utilized and worn by the psychologists. The smart carpets are also implemented and replaced during the session to record the performance of each carpet. Figure 44 also shows acting child and placement of camera to monitor eye-contact. The recording is carried out via two ways. One camera is fixed, which is Sony HD camera, on a tripod stand to record child behaviour from one permanent position while the other is moving, which is Lenovo X390 camera, around the carpet to monitor the eye-contact of the child and the infrared LEDs. The moving camera is held by another psychologist present in the room. The idea is to examine IR LEDs light intensity from all directions using two different cameras. To engage a child, different activities are performed i.e., playing with toys, talking with the child, using hand gestures etc. During these activities, the eye-contact is being monitored and as soon as the child makes an eye-contact the psychologists press the switch on the smart shirt to turn ON the infrared LEDs of the shirt and the light indication is recorded in both cameras. However, before the start of each session and as the monitoring room accommodates child’s parent as well. So, in order to ensure that the child is under surveillance, the smart carpet’s infrared LEDs are turned ON as an indication. The infrared LEDs of the smart carpet designates that the session with child sitting on the carpet is started. Table 8 shows how the indication of infrared LEDs on the manufactured smart shirts and carpets will be implemented. However, the result shows that the light intensities of IR LEDs are brightly visible using the Lenovo X390 camera as can be seen in Figure 45.

As discussed previously, the infrared LEDs on the carpet are controlled with RF control switch whereas infrared LEDs on the smart shirt are controlled using e-textile switch. Table 8 suggests when the session starts with the child, the psychologist will press the RF control switch to turn ON the LEDs on the smart carpet. This will give an indication that the session is started with the child sitting on the carpet. Whereas, whenever the child will make an eye-contact with the psychologist, the LEDs on the smart shirt will turn ON using the e-textile switch. However, in the remaining two states the LEDs will remain OFF, on the smart carpet and on the smart shirt.

***Table 8.** Indication states of infrared LEDs on smart shirt and smart carpet*

Indication states of IR LEDs for ASD child	IR LEDs switching method	Status of IR LEDs on smart shirt	Status of IR LEDs on the smart carpet
Session not started	OFF state	IR LEDs OFF	IR LEDs OFF
Session started	RF control switch	IR LEDs OFF	IR LEDs ON
Eye-contact not made	OFF state	IR LEDs OFF	IR LEDs OFF
Eye-contact made	E-textile switch	IR LEDs ON	IR LEDs OFF

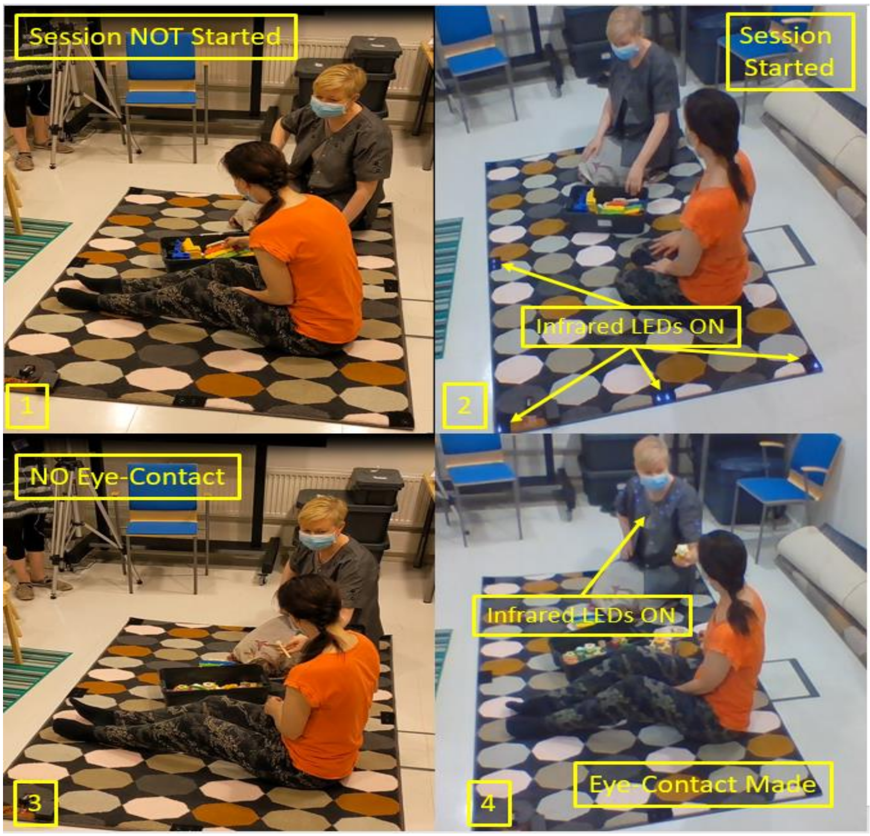


***Figure 45.** Real time infrared LEDs testing on smart shirt and smart carpet*

In Table 8, real time testing is carried out with the acting child. In the beginning, psychologist wears the smart shirt and asks the child to sit on the smart carpet before the beginning of the session. At this stage, the infrared LEDs of the smart carpet and smart shirt are OFF. However, when the psychologist thinks that the child is comfortable, they start the session by turning ON the infrared LEDs of the smart carpet. During the session, psychologists play with the child and try to gain child's attention. During all these situations, the child sometimes makes an eye-contact, and whenever, it happens the infrared

LEDs of the smart shirt turns ON otherwise they remain OFF. The overall view of the monitoring session can be observed in Figure 45.

5.3 Feedback of Psychologists

After successful real time testing trials with the psychologists, they had some feedback prior to their initial thoughts and previous research, regarding the manufactured and fabricated smart shirts and carpets. According to the psychologists, the below mentioned points could be considered improving the usability of the products and few things could be added for future applications purposes.

- Previously, the psychologists were monitoring the eye-contact of the child by showing their thumb in the camera. The exercise was quite hectic and not possible in all situations. Inclusion of the smart shirt and the smart carpet has provided them freedom and comfortability to monitor the eye-contact easily during the session. They can manage different activities during the session and can keep track on eye-contact of the child.
- In Current design, the placement of e-textile switch and RF control switch are embedded at different positions on the smart shirt. As the situation is on-going, the psychologist recommended to place both switches together on the same area of the smart shirt. However, the designing of e-textile switch could be made in such a way that it can be easily sensible with the hand without looking at it with significant difference while pressing either switch. While, the placement of the switch can be considered on the left side of the smart shirt, so that the left hand could be used to turn ON/OFF the LEDs. Currently, the switch is placed on the right side of the shirt and as the right hand is mostly busy while doing activities with the child it becomes difficult to press it.
- Initially, it was contemplated that only the smart shirt will be utilized to monitor and provide indication of the eye-contact. However, the addition of the smart carpet advances the surveillance methods of the psychologists. They can now monitor eye-contact when the child is sitting with their parents on the carpet. The infrared LEDs on the smart carpet is controlled via RF remote control and the psychologists can turn ON the indication whenever the child makes an eye-contact.
- The next version of smart shirt and carpet will be remodelled as per the psychologist's feedback. On the other hand, a hand glove can replace the current switching methods and embedded with the shirt for switching infrared LEDs. Whereas,

to make surveillance accurate, a live clock will be integrated on the smart shirt or on the carpet, to match and compare clock timings with the recording camera to gather eye-contact monitoring results easily. It will assist the psychologist's while monitoring exact timings of infrared LEDs turning ON and OFF.

As per the results and psychologists' feedback, the study highlights the importance of monitoring eye-contact and illuminates the significance of manufacturing smart shirt and smart carpet for autism disorder child. It also explicates the research on autism spectrum disorder.

6. CONCLUSION

Autism spectrum disorder is psychological disability that can remarkably reduce the communication effectiveness resulting in unconfident eye-contacts and shyness posing serious behavioural and socialization challenges for individuals. To overcome such disorders, the psychologists monitor frequency and duration of the eye-contacts made with the patient child to study their behaviour during different activities. The surveillance could help the early diagnosis of the disorder and improvement can be made for the well-being of the child.

The thesis work includes the prototype and design of the smart shirt and the smart carpet in monitoring eye-contact of a child struggling with ASD. Different layouts for the placement of infrared LEDs are proposed and implemented on the smart shirt and the smart carpet to record frequency and duration of the eye-contacts during a psychologist session through IR LED indicators. However, e-textiles are the most effective and simplistic ways to integrate electronics into the smart shirt. The integration of the e-textiles leverages the flexibility, wearability, cost effectiveness and reliability of the proposed solution. On the other hand, numerous IR LEDs with varying power ratings and vision angles are tested for the best outcome befitting the application challenging demands.

Two different designs of smart shirt and three designs for the smart carpet are included in the studies. Individual designs differ in the placement of infrared LEDs on the smart shirt and carpet. The focus is to compare and analyse befitting design for the study in terms of ease in monitoring the psychologist session. The results depict the productive integration of infrared LEDs on the smart shirt and on the carpet and they can significantly improve the psychologist's performance during a session. Infrared LEDs on the smart shirt and carpet, manifests systematic surveillance of the eye-contact of the child. However, for actual monitoring trials with the child, the integrated electronics can be scaled down on the smart shirt and carpet to enhance the ease of use. Miniaturized infrared LEDs can be integrated into the textile material to make it visible only to the camera. On the other hand, a transparent protective layer can be implemented on the infrared LEDs of the smart carpet to improve the robustness of the proposed solution. Similarly, the driving circuit and the battery could be miniaturized and placed on a single board to ensure less compactness of the electronic circuitry.

For future research work, a smart shirt can be fabricated for monitoring the various physiological parameters of the patient child under observation, upon eye-contact establishment, through means of the textile electrodes integrated into the clothes of the child and synchronised with that of the psychologist, as the physiological parameters vary with different activities of humans. The research will be beneficial in diagnosis of various psychological disorders through monitoring these parameters on different instances of a child suffering from ASD.

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