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PHOTOVOLTAIC CELLS FOR DESIGNING ILLUMINATING SHIRT, BETWEEN ECO-DESIGN AND FUNCTIONALITY

HADJ TAIEB A.*, MSAHLI S. AND SAKLI F.
Laboratory of Genie Textile of ISET Ksar Hellal - Tunisia
B.P 68, Ksar Hellal 5070, Tunisia

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ABSTRACT

Photovoltaic cells offer significant perspectives for e-textiles applications. This paper discusses some design considerations associated with Photovoltaic cells in the textile domain by taking also into account the consumer need.
Certainly, we are more and more sensitive to the ecology, but the tendency is not less important to the comfort and to our well being.
A good management of the energy consumption and the use of the renewable energy such us the solar energy for textile applications are some solutions to conserve our ecology and to give some idea for the textile design for more functional textile applications to bring more comfort and well being in our live.
We are going in this survey to bring some new functionality to a classic shirt by integrating electronic components to facilitate our daily by emitting light and improving thus the user's visibility for more comfort and functionality and by carrying ecological message.

KEYWORDS

Illuminating shirt; photovoltaic cells; eco-design; functionality.

1. INTRODUCTION

Integrating electronics into clothing and textile products is a major new concept, which opens up a whole array of multi-functional, wearable electro-textiles for sensing/monitoring body functions, delivering communication facilities, data transfer, individual environment control, and many other applications. With revolutionary advancements occurring at an unprecedented rate in many fields of science and electronics the possibilities offered by electronic textiles are tremendous and widespread. These advancements will transform the world and will soon begin to permeate into commercial products. (Post et al., 1997).

Ideally, electronic devices provide new capability and also function for textile products. Electronic textiles (e-textiles), fabrics that contain electronic or computational devices, are perfectly suited to creating these dual-role devices. The primary challenge in electronic textiles is to find materials and devices that provide the desired functionality and that can be easily meshed into hybrid materials. Photovoltaic cells offer such promise for e-textiles applications. Photovoltaic cells have a number of useful features and are available in a variety of form factors with reasonable development complexity.
Textiles products, used in all domains, constitute a very big surface; in fact, we are surrounded by textile products, that we can exploit like support of solar panels for various applications.
These cells can give energy to the electronic components that can supply more comfort and well being by the multitude of functions that offer.

* : Corresponding author. Email : amineht@yahoo.fr

For years the textile industry has been weaving metallic yarns into fabrics for decorative purposes. But now it can be for more functional purpose to conduct electricity for example for electronic device integrated in textile materials.
We tried in this work to put the accent on the multidisciplinary character of the smart textile of tomorrow to meet the expectations of the consumers. This work regroups several sectors at a time in this case the textile sector with all its disciplines, the electronic, energy, ecological field, etc…
Besides, the emerging smart textiles in the fashion domain, there is also another tendency which is the ecological preoccupation when conceiving new products.
Indeed, each of us in his domain has the duty to participate in the preservation of our environment, for this reason we are going, in this survey, to use the solar energy to conceive solar illuminating shirts that can be also carriers of sensitization ecological messages for our planet and while adding an aesthetic touch to these products for a better acceptance of these products by the consumer and thus to facilitate the integration of these e-textiles in the market.

In this research, we tried to participate in to create textiles permitting to meet the expectations of the consumers in term of well-being and of comfort an ecological preoccupation. We will use some electronic components like, Light Emitting Diode (LED) powered by photovoltaic cells to give new functionality of illumination to a classic shirt by adding those electronic components. The function of the principal electronic components is represented in the figure 1.

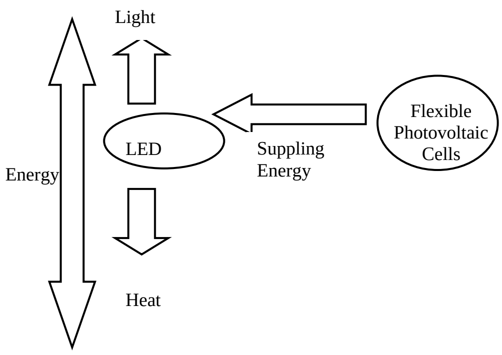

Figure 1. Function of the electronic devices integrated in the illuminating shirt (Hadj Taieb et al., 2009)

2. METHOD AND MATERIAL

2.1. Eco-design method

Design is a process of constructing a description of a product that satisfies functional specification or aesthetic effect, meets certain performance criteria and resource limitations, realisable in an available technology, and satisfies criteria such as simplicity, testability, manufacturability, reusability…
Designing textile-related products has been carried out for thousands of years in a traditional and intuitive way. However, in the last few decades, industries have recognized the importance of design because of the growing needs of the industry and the consumer. The design process itself may also be subject to certain restrictions, such us time, human power, cost…The design is usually carried out manually, based on experience and trial and error. In the last two decades inexpensive computers have made the design of textile products more popular. Furthermore, simulation and other technologies are brought into use to design and develop quality products.
Nowadays, textile products have found a wide range of application in apparel, domestic and industrial area. The applications include not only clothing and accessories, bedding and interior decoration, but also textile structures that are used to make cables, cords, parachutes, hot-air balloons, tents… The ever-increasing application of textile products in various fields is making the design task more important and challenging.
Although a considerable amount of research has been done on colour or pattern designing related to fabric appearance and fashion, the material-designing technology for textile products is still at the development

stage. Those types of design are usually to satisfy certain performance requirement, which include, for apparel, structure and aesthetic properties which are the primarily factors.
This ecological deign tendency is related to the big dangers provoked by the pollution that generate a consumer's consciences and an aesthetic conscience of the richness of the nature. Those consciences provoked a new shape of design which is the eco-design.

The Eco design consists in integrating the environment in the conception of an article since the production of the raw material until its end of life.
The textile sector is concerned progressively by this approach. This last appears in a more global concept of lasting development. Notably two fundamental stages have been studied, on one hand the choice of the raw material which is the linen fiber, on the other hand the procedure of manufacture.
More and more, the environment is one of the major preoccupations of the 21st century. The universe of the fashion understood it well and tent to make put into verse elegance and ecology.

2.2. Market tendency: Functional and ecological textile product

Textile article specially conceived as artificial mediator between man and his natural and social environment depending on necessities has the capacity to materialize a certain social command.
Social command in the textile manufacture field can be defined as all the requests expressed by users regarding the commodity, also containing requests of psychical order that consider fashion, culture, taste, aesthetic education, financial possibilities.

Many writers have argued that clothing was born out of necessity like Malinowski (Malinowski, 1976) suggesting that clothing was created by people in response to a physical need for shelter and protection. In the modern world, one can find many studies stressing the importance of client requirements as a source for new product ideas (Logan, 1997; Wood, 1996). Also many other studies have found that the factors which distinguish new product success from failure are the consideration and understanding of user requirements (Maidique et al., 1985; Cooper, 1987; Walsh et al., 1992). The most frequent cause of project failure during the design stage is a failure to properly define at the outset the objectives and design requirements.

With regard to the future life styles, the e- textiles must bring a specific service in the good place and to the good moment according to the environmental context. Besides, the consumer is concerned more and more by how e- textile can improve him his quality of life in term of health and well-being (Ariyatum et al., 2005), whereas few people believe that the future style of life is directed toward the artificial intelligence. On the other hand, interrogated several people are interested in the ecological solutions and like to have some products with a certain tactile aspect.
Based on the profile of the consumer and his needs, of his vision for his future style of life, according to the survey of Ariyatum and al., the main criteria that affect the purchase of e-textiles by the customers are summarized in the table 1.

Table 1. The factors that affect the consumer's purchase for the smart textiles (Ariyatum et al., 2005)

Criteria	Importance of choice criteria
Matching the live style	51.4%
Good design	21.4%
Differents features/multi use	8.6%
Confidence/ High quality	5.7%
Praticability	2.9%
Newness/ tendency	2.9%
Others	7.1%

The importance of the criteria of choice for the e-textiles can be modified according to the application of the consumer, of his life style, his age…

So in this survey we will present for fashion designer a photovoltaic cells application in clothing for more added textile value. Indeed, electronic effects are essential for producing higher value added textiles, important not only for new technical applications but also for more "traditional" uses such as clothing and home textiles with high product differentiation The consumers are demanding textile products with higher performances, even in the "traditional" clothing and home textiles areas. In fact, significant product differentiation in the area of textiles can be achieved by high performance properties, in parallel with visual appearance. Some of these properties were developed mainly for "protective" clothing but nowadays they are often present in e-textiles used for "normal" clothing. Many fabric producers are devoting more and more attention to try to put into the market products with new smart effects that can represent an important added value (Almeida, 2005).

2.3. Solar energy in textile products between eco-design and functionality

We are may be more familiar with PV cells as solar cells that power watches and calculators. But PV can do much more. It can provide electricity for residential and commercial buildings, including power for lights and air conditioning. PV can also be a convenient source of power for pumping water, electrifying fences, or aerating ponds in remote applications to use energy efficiently and add cleaner, renewable energy to our life.

We can classify the advantages of this energy in advantages for the ecology and others for the consumers:

Advantages for the ecology:

- Decrease of CO2 broadcasts
- Decrease of consumptions of batteries and consequently decrease of damages caused by these batteries
- Decrease of the consumption of the mineral fuels, fuels liquids, gas,
- Silent transformation

Advantages for the consumers:

- Autonomy of satisfaction of the needs in energy
- Improvement of the life quality
- Satisfaction of energy needs in the distant regions (for example distant islands, villages on high mountains with some inhabitants)
- Satisfaction in energy of the needs of the climbers, of the tourists (for example cell phones, portable radio, etc…)
- Protection more efficient of the heat (Kourtidis, 2000).

The photovoltaic cells offer real advantages for electronic textile: In fact, the marriage of textile field and solar energy application is being interesting from technological and environmental point of view, seen the numerous advantages of the textile products like supports for the solar cells that are (Smestod, 1998):

- Great surface in contact with sun
- Flexibility
- Lightweight
- Easy transfer
- Easy inshirtment
- Accessible

Consumer electronics are typically designed with a battery power source and are carried in light limited pockets or bags. The marriage of electronic devices and textile products provides the opportunity to utilize surfaces exposed to the sun to generate energy to power the electronic devices. Photovoltaic flexible thin film converts solar energy into electrical energy. This photovoltaic thin film has a similar thickness to paper and has material properties much like those of camera film. The photovoltaic flexible modules come in various sizes ranging from 2x4in to 8.5x11in sheets. They can be rolled into a three inch diameter without physical damage and continue to function if scratched or punctured. The durability and efficiency of these photovoltaic flexible thin film modules have improved to a point where they are a viable option for incorporation into textile products. Ultimately, these thin film photovoltaic cells can reduce the amount of battery storage engineered into electronic devices and eliminate maintenance related to replacing batteries. Electronic devices such us iPOD, sensor integrated into garments, are examples of smart textile where battery maintenance or battery weight could be reduced by using photovoltaic flexible thin film for charging. Nowadays, there is the possibility of the incorporation of solar panels in the clothing, to keep the patients and the aged people hot for example (Zampetakis, 2005).

3. RESULTS

3.1. Design of the illuminating solar cloth

The solar energy a source of inspiration in several domains and why not in the domain of the e- textiles in order to make operate electronic components integrated in our textile products. Indeed, these textile material represent a very big surface that can be in contact with the sun, and thus to provide a very big quantity of energy.

We try to make classic cloth more functional, more intelligent and that react with the obscurity to illuminate our setting. A simple application but that is able to bring a lot of gain of energy, a lot of good to our planet that blows more and more because of an industry less and less conscious of the dangers of our non-responsible practices.

The solar cloth is compounded of photovoltaic cells, LED and electronic cards. The electronic card contains electronic compounds which act as day/night detection and which make this cloth smarter by acting according to its environment.

3.2. Technical Specification

The power requirements of e-textile have a direct impact on the photovoltaic thin film module surface area needed. The voltage requirement of the circuit in the textile product also dictates how the photovoltaic thin film module pattern will repeat. The cloth was designed with the intent of alimenting a LED. Thin Film of solar panel can be applied to the front area of the cloth. The flexible solar panels were coated with a laminate that protects the solar material. When energized, the solar panels act similar to batteries. For connecting the panel to a circuit, a connection bus made of electrically conductive tape is adhered to the plastic panel.

3.2.1. Fabric structure of the solar cloth

The fabric structure of the cloth is constituted of 3 layers:

- A outside layer resistant to water. On this layer we are going to place the photovoltaic cells to the level of the epaulette, a discreet enough site with a good orientation toward the sun.
- An intermediate layer containing the electronic components permitting to make operate the LED when him there more of solar rays
- An lining layer permitting to improve the thermal insulation and to hide the electronic components for more of discretion. We can also add some structures to increase the comfort and to participate also in our good being.

The fabric structure of this cloth is represented in the figure 2.

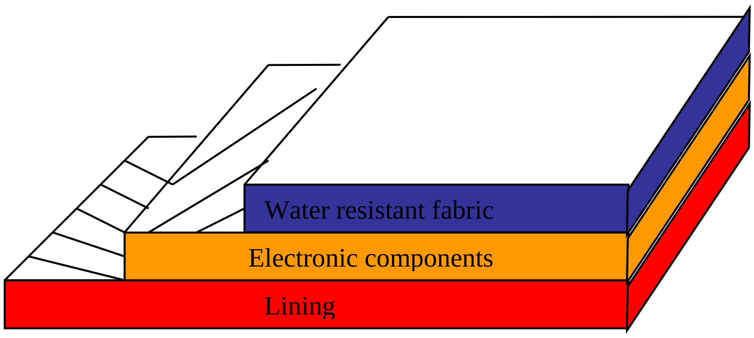

Figure 2. Multilayered structure of the illuminating cloth

The photovoltaic cells can be detachable; the electronic components of the lighting are exploded to the level of the shirt to assure a bigger discretion especially as the aesthetic constraint is primordial in the clothing.
This system of lighting can be useful for people walking the night, to improve their visibilities and to assure a better security thus and facilitating our daily thus with more of functionality.

3.2.2. Connections of the electronic components on the cloth

The electronic components can be detached of the cloth (a shirt for example) or there to be integrated by the use of Velcro ribbon.
The electronic components introduced between the lining layer and the outside layer are represented in the figure 3.

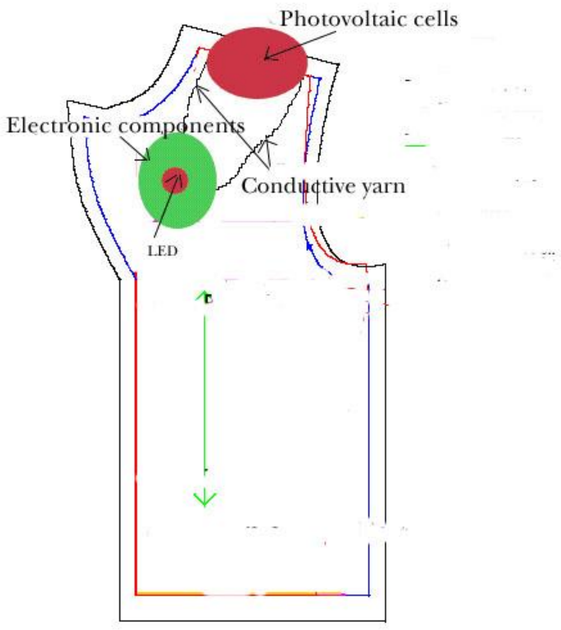

Figure 3. Placement and connexion of the electronic components in the shirt

3.2.3. Electronic shirt components

This shirt is constituted of:
- A thin film of photovoltaic cell to capture the solar energy and to transform it in electric energy,
- a battery to stock the electric energy and to reuse it in case of requires,
- an electronic circuit to assure the working of the LED when there is not any more light
- a LED

The used electric circuit permits to reload the battery by the photovoltaic cell when there is light. In the case where there is no more light, the battery permits to make operate the LED. The connexion and the placement of the electronic components of the shirt are represented in the figure 3.
These electronic devices can have many applications among them; we can integrate these devices in a bag, to illuminate the inside of it or in the bag of the medicines of the aged people, to improve the visibility or for more security, when this person especially looks for his medicine when light is insufficient.
We can also integrate these electronic devices in a tent to be used when we are looking for light especially when we are in an isolating place.

3.3 Dimensionality of the alimentation system

The dimensionality of a photovoltaic system is actually a relatively complex process because there are many parameters to take in consideration, a certain dose of imponderable (the weather report), and especially of multiple interactions between the choices (Kamitsis, 2002).

3.3.1. Assessment of the needs (Nd)

The first stage in the dimensionality is the assessment of the needs. In our case the chosen application that one LED requires 1 watt whereas the daily use time is "n" hours. And we suppose that the number of LED is 5 dispatched in the tee-shirt.
The Need per day Nd is calculated according to the following formula (1):

$$Nd = P1xt1+P2xt2+\ldots Pnxtn \quad (1)$$

with:

- Nd : Daily electric need
- Pi :The power consomption of the ith application
- ti : Use time of the ith application per day

In our case, we have a daily need of Nd = 1 * n * 5 Wh. For it the cells (PV) must assure this daily need that depends on the number of hour of use. If the use of this tee-shirt is 1 hour per day, then the daily need will be Nd = 5 Wh/day.

Table 2. Daily electric Need (Nd)

	Consumption (Watt)	Number	Utilisation(Hours/day)	Total consumption Nd (Wh/day)
LED	1	5	1	5

Under a tension of 12 VDC, the daily consumption in mAh for a use of a 1 hour in this system of relaxation per day is equal to 5/12 = 416 mAh.

3. 3. 2. Recoverable solar energy

Tunisia is between 33°N and 37°N (35°N on average) of the equator, the best position of the photovoltaic modules is (35 +10) ° therefore the best inclination of the photovoltaic panel is 45° in direction of the equator.
In Tunisia 1 m² receive between 3000 and 6000 W per day between the winter and the summer. In our case, this system of relaxation is used all seasons, for this reason we are going to choose the sunshine of the winter (weakest) to make the dimensionality, we go, so to suppose that 1 m² receives 3000 W.

3. 3. 3. Definition of the photovoltaic modules

The number of equivalent hour depends on every season and regions. Since our application is used in winter and in summer, the number of middle equivalent hour is chosen that is not =3 hours. This number of middle equivalent hour concerns Africa and the Mediterranean basin in general and Tunisia in particular in winter.

So for the relaxing electrodes, we need cells (PV) permitting to provide" 5 x n Wh" with n numbers it of hour of use. So we need cells (PV) having a Power crest (Pc) according to the following formula:

$$Pc=5\ n/Ne. \tag{2}$$

While taking a number of hour of equivalent sunshine Ne = 3heures, the power crest (Pc) of the photovoltaic cells (PV) for luminescent system is

$$Pc = 5n/3 = 1.66*n\ (W) \tag{3}$$

If the number of hours of use of luminescent system is then "n" = 1h per day, so Pc is equal to: 1.66 (W).

This formula is only true for a panel isolated in ideal conditions: it doesn't take into account the losses unavoidable of a complete system in the real conditions.

In our case, in December, in Tunisia, the sun provides 3 kWh/m² * day. We will assimilate this day to 3h a radiance of 1000 W/m².

We consider that the smudges don't provoke a loss of more than 10% and that the battery has an output superior or equal to 80%. Therefore we are going to consider that the loss of the current (Cp) is then of 0.72 calculated according to this formula

$$Cp = 0.9 \times 0{,}8. \tag{4}$$

Under a nominal tension wished 12 VDC, The intensity (Im) is calculated according to the following formula:

$$Im = Nd/(Esol \times Cp) \tag{5}$$

Avec :

- Im : Intensity at maximum power STC
- Cp : Coefficient of courant loss
- Esol : Solar energy per day (kWh/m².day), in our case, for Tunisia Esol is equal to 3 (kWh/m².jour) in December
- Nd : Daily need per application (Ah/jour)

So, Im = (5/12) / (3x0.72) = 0.42 / 2.16 = 0.19 Ah.

The minimal value of the photovoltaic power of the system, Pc, if the modules have a maximal tension of 12V would be of :

$$(Pc) = Im \times 12 \tag{6}$$

So Pc = 0.19 * 12 = 2.28 (W), while taking into account the electricity loss.

Finally, we add also the case if we use this tee-shirt in the summer, so the Ne will increase from 3 to 6 in Tunisia. Those results are summarised in the following table.

Table 3. Figures of the requested photovoltaic cells

Tension used	Esol in Tunisia (kWh/m².day)		Used time (hours/day)	Nd (Wh/day)	Cp	Pc (W)		Im (Ah)	
	Winter	Summer				Winter	Summer	Winter	Summer
12 VDC	3	6	1	5	0.72	2.28	1.15	0.190	0.096

So if the system can work in winter, it can also work in summer, because the solar energy captured in summer is bigger. Thus, we will take the characteristic needed in winter to be used by the luminescent cloth.
While the photovoltaic cells are integrated in the shoulder level of the cloth we can use amorphous silicon to be flexible as technology of the modules
For flexibility constrains, the used photovoltaic module is the module supple PowerFilm 6V 50 mA.
According to the tension of the modules and the field to construct, we are going to compose the photovoltaic field (in series and parallel, or only parallel).
If we use 7 modules 0.3W-6 VDC, we will provide: 7*0.3 = 2.1 W, what is not sufficient here, because we need 2.28 W. On the other hand, if we use 8 modules, we will provide 8*0.3 = 2.4 W, what is sufficient here.
While arranging the modules 2 in series to 2, we will have 4 sets of 12 V, what corresponds to the nominal tension that we chose, then. It remains to arrange them in parallel, in order to add the currents between them, and to reach the necessary power of 2.4 W. This disposition permits to provide a current of = 50 x 4 = 200 mh, what is sufficient here, because we need only 190 mA.
The construction of the photovoltaic field for the second case is shown in the following figure.

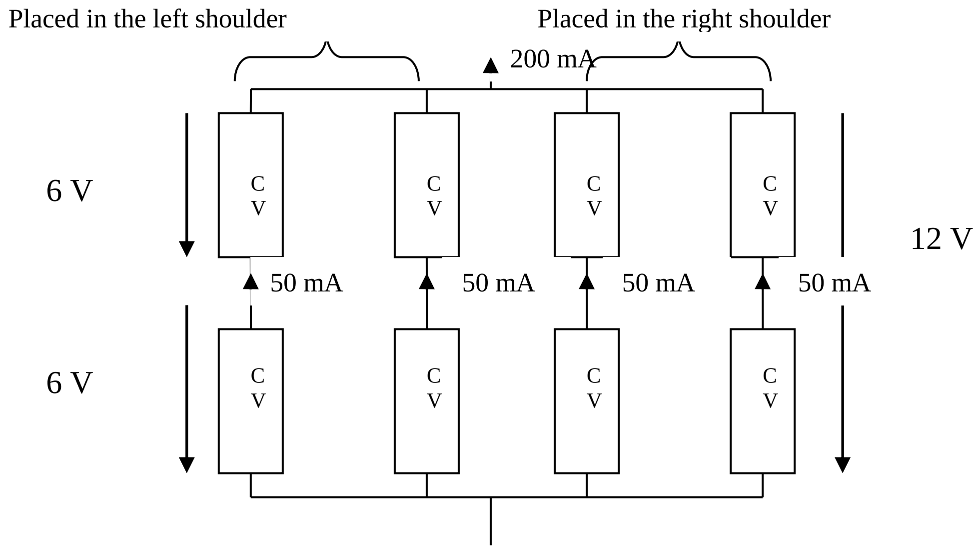

Figure 4. The construction of the photovoltaic field

In this luminescent cloth, we can place 2 parallel assemblies on the left shoulder and the two others in the right shoulder of the cloth as represented in the figure 4.

3.3. 4. Dimensionality of storage energy

For the two cases, the useful capacity of the battery (Cu) is:

$$Cu = Nda \times Nd = 2 * 416 = 832 \text{ mAh} \quad (7)$$

With: Nda = the number of autonomy day
Nd : Daily need per application (Ah/jour)

In this case, Nda is 2days and Nd is 416 mAh.
So Cu is equal to 2 * 416 = 832 mAh,

The figures of the proposed battery are described in the table 4.

The placement of the battery doesn't require to be exposed in the sun and must be protected against the humidity, so a placement in a cloth’s pocket is preferred. We can design battery pocket as described in the figure 3.

Table 4. Figures of the proposed battery

Input	Min 10 V. Max 15 V
Time of charge	AC / DC 3 hours 30 minutes or 8-10 hours of solar exposition
Type of battery	Li-Ion
Time of discharge	roughly 55 hours
Weight	133g
Dimensions	76 x 58 x 26 mm

4. CONCLUSION

The design space for photovoltaic cells and electronic textile is too large to be efficiently explored. E-textile present new challenges to the textiles and apparel industry. There is a balance between integrating technology so it adds value to the textile products and maintaining visual appeal. Textile products solutions appeal to niche consumers meaning small quantity manufacturing will be necessary. We need to meet these challenging demands by integration of flexible photovoltaic thin film cells or other electronic components. The rigidity of the solar panels must be taken into account when designing accessories.

We have shown how to combine conventional textile materials and photovoltaic cells to create interactive textile products like the illuminating skirt by adding new functionality to this classic product to improve our well being and facilitate our daily by improving visibility.

The use of the solar energy in the textile products can also be an ecological message for sensitising consumer about our need for preserving ecology and our need for more and more comfort and functionalities. But, the successful integration of photovoltaic thin film cells into textile products is tightly linked to the consumer concept of fashion. In the consumer market, smart clothing must remain visually attractive; otherwise it will not be commercially successful.

The photovoltaic cells are well suited to many different e-textile applications. They consist of devices that are standard to the industry, providing easy integration into fabrics. We hope that this system will be used as a base platform for future development of photovoltaic cells integrated into the e-textiles.

The successful integration of photovoltaic thin film cells into textile products is tightly tied to the consumer concept of fashion. In the consumer market, textile product must remain visually attractive and complement or enhance the user's appearance; otherwise it will not be commercially successful. In order maximize energy collection, it is necessary to place the photovoltaic film in visibly prominent areas on the textile product. These solar cells are graphically strong and as a result need to be more visually integrated into the fabric structure.

Digital textile printing enables the designer to incorporate unusual components into a design by printing fabric that matches the pattern of the component (Parsons and Campbell 2004). Direct digital textile printing technologies typically employ the use of ink jet printing to allow the user to print designs directly from the computer to fabric (Hynek et al., 2003).

Finally, the wide variety of textile products to which photovoltaic thin film cells can be applied requires wide variety of fabrics to make these products. So, the digital print allowed the solar panels to be placed on the visually prominent face of the textile shirt and create an unbroken pattern. This application of digital textile printing technology shows that it can play a significant role in the creation of visually appealing solar enabled textile products.

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