SIMULATION OF PHOTOVOLTAICS FOR DEFENCE AND COMMERCIAL APPLICATIONS BY EXTENDING EXISTING 3D AUTHORING SOFTWARE

A Validation Study

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Abstract: The use of photovoltaic (PV) technology for the harvesting of renewable energy is a reality and is widely employed today. However this is mainly focused towards house and industry energy harvesting. Recent development in thin and flexible materials mean that photovoltaic technology can be integrated into wearable computing and expanded to other commercial as well as defence applications. This paper presents work under the Solar Soldier project that is developing a new photovoltaic simulation platform, based on flexible/wearable PVs and by extending commercial 3D design, animation and light analysis software, namely 3DS Max Design. The platform currently under development will allow the semi-automatic simulation of different scenarios and will also enable the unique feature of lighting analysis and data export of animated objects, which currently do not exist in other systems. This paper also presents a validation study of the light analysis simulation platform against actual light measurements in an outdoor scenario. This is one of the first systematic and thorough validation studies of 3DS Max Design focusing exclusively in outdoor conditions as all previous studies have focused mainly in indoor settings scenarios. The study results are extremely encouraging showing that the actual measurements and those simulated in 3DS Max Design are very similar.

1 INTRODUCTION

Renewable energy technology such as photovoltaics (PV) has become an important energy generation solution that is friendly to the environment. Nowadays there is a dramatic increase in the use of PV for commercial applications outdoors, ranging from powering street lights to house-energy generation. Although most PV efforts are currently focused on the commercial market there are opportunities for extending this even further with the use of PVs for a wider range of commercial applications (i.e. mobile phone, as well as indoors use) as well as defence applications. This is further facilitated by the recent development of thin, flexible and wearable PVs that allow them to be integrated onto of textile material such as clothing.

One of the key issues though for the adoption of such technology is the correct placement (this depends on factors such as location, weather, etc) of PVs on buildings, other infrastructure as well as humans in order to maximize energy generation. This paper presents work funded under the Engineering and Physical Sciences Research Council and Defence Science and Technology Laboratory (EPSRC/DSTL) funded Solar Soldier project that aims at developing an integrated wearable Photovoltaic – Thermoelectric (PV-TE) for defence applications.

The paper presents a brief overview of the design and development of a PV planning and simulation platform that employs and extends commercial 3D tools such as 3D Studio Max Design (3DSMD). It also presents a validation study that compares actual outdoor light intensity data against those of the 3DSMD light analysis system to investigate its effectiveness and efficiency. Lastly it offers a discussion on the proposed future work.

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2 SOLAR SOLDIER

2.1 Project Background

The Solar Soldier is an EPSRC/DSTL jointly funded project and is comprised of a consortium of UK universities[1]. The type of warfare as well as the humanitarian campaigns we are engaged in nowadays uses foot soldiers a lot more, resulting in soldiers having to carry equipment that often reach and sometimes exceed fifty kilos with several of these including bulky and heavy batteries to power several of the electronic equipment soldiers use. The challenge here is to reduce this physical burden on the modern infantry soldier moving towards a battery-free solution. The project received a lot of media attention recently with an article notably by the Daily Mail[2] and Discovery News[3] as well as being translated in several languages.

The aim of the Solar Soldier project is to design and develop a system that integrate photovoltaic (PV) and thermoelectric (TE) energy to power several of these electronic equipment reducing therefore the need to carry batteries. Both PV and TE will be integrated onto the infantry soldier using advanced and novel flexible and nanostructures of the required materials. The idea is that during the day the system will collect light energy using the PV, then during the night we can use the heat from the soldier, and the outside temperature which is much lower, to generate power. Due to the novelty of the project and the brief time duration of two years, the system to be developed at the end of the project will be a small-scale prototype.

2.2 Our Motivation and Aims

This project raises a number of challenges which lead to the design and development of a 3D simulation platform that is presented in this paper:

a) how to integrate best this technology into the infantry soldier since the final outcome of the project will develop a small scale prototype.

b) how to access the incorporation of the PV/TE technology on the infantry soldier.

c) how to simulate the use of the PV/TE technology based on soldier's different fields and types of operations (e.g. movement, environment, and under different light conditions).

Therefore our key aim is to investigate the most efficient and effective placement of the PV/TE on the soldier's uniform and kit to generate the highest amount of energy, without detracting the soldier from his main job and taking into account the very specialized and demanding requirements of the infantry soldier. Furthermore, the required simulation platform has to be capable of performing analysis of a scene with objects (human avatar) in motion. This is a feature that is not available in any of the current commercial lighting or thermal analysis simulation software packages.

2.3 The 3D Simulation Platform

Following the aforementioned aims and requirements we are in the process of designing and developing a 3D simulation platform. We have also liaised with DSTL and have received valuable information and user requirements as possible scenarios for the placements of the PV-TE on the soldiers. We intend to simulate these scenarios within the platform and compare the output data for each one of these.

More precisely the platform consists of easy-to-use and step-by-step panels on each of which the user can adjust the landscape, human avatar (i.e. soldier, civilian), type of movement and light condition combination. Thus, semi-automatically the user can create a virtual environment/scenario comprising of an animated virtual human where light sensors can be placed upon him/her to be analyzed in terms of lighting conditions. The first step of the wizard (illustrated in figure 1) allows the user to select the landscape among a range of available models, as well as import his/her own. It also provides the ability of slight adjustments of those landscapes (e.g. the density of vegetation on the forest scene). Next, the human avatar (virtual soldier in the case of our project) is adjusted in terms of equipment it carries and the range of movements again selected from the available library of animated movements. The range of animated movements matches the range of movements that the soldier performs during several military operations (e.g. march, guard, patrol, etc). Lastly, the lighting conditions have to be modified as explained in the Methodology section of the Platform Validation

[1]Jointly funded by EPSRC/DSTL. The consortium includes Glasgow University (PI), Loughborough University, Strathclyde University, Leeds University, University of Reading and Brunel University.

[2]http://www.dailymail.co.uk/sciencetech/article-1366173/Solar-soldier-scientists-developing-power-pack-British-troops-50-lighter.html

[3]http://news.discovery.com/tech/battlefield-battery-packs-work-day-and-night-110316.html

section of the paper. The user defines the date, the time of day, the light intensity of the source (mr Sun) and the geographical location in order to reconstruct the actual conditions under investigation.

Figure 1: The first step of the 3D Simulation platform.

The end product of this procedure would be a virtual scene with equal daylight and same architectural characteristics as a corresponding real place and an animated human avatar with virtual light sensors attached ready to be analyzed in terms of light levels. Figures 2 and 3 illustrate two examples of the aforementioned rendered outcome. The analysis of a scene containing virtual sensor in movement is a unique feature, which none of commercially available software intended to perform such kind of simulations include it in their list of features. That is the main reason we chose 3DSMD, since with its state-of-the-art animation and lighting analysis capabilities and its powerful integrated Application Programming Interface (API), it provides an unswerving foundation for developing such a unique tool as the one proposed by this project. The attached virtual light sensors yield light intensity values on the uniform of the avatar. These values are exported in a specific data format and are stored externally from the platform for later evaluation such as statistical analysis. The use of 3DSMD's incorporated API named MaxScript enables the programming of that procedure. We use a special file inport/export element of the API in order to collect and export the results of the animated scene in a spreadsheet in Comma Separated Values (CSV) format which is compatible with Microsoft Excel and other spreadsheet software in order to enable the user to further analyse the statistical data. In addition to this a number of formulas can be added so that based on the gathered, from the light sources data, one can calculate the solar energy to be produced for the given simulated time duration. This platform is currently under development. For this reason we present here a validation of a still scene since the animated scene functionality is still under development and only preliminary results have been recorded.

Figure 2: Rendered image of a light analysed scene.

Figure 3: Rendered image of a light animated scene.

In recent years there has been a lot of research and publications in the area of PV effectiveness and materials such as the work of Bhubaneswari, Iniyan, Ranko (2011) and the work of Chow (2010) (as well that that of many others, which is beyond the scope of this paper) that summarise the solar photovoltaic technologies as a review including the perspective of effectiveness and materials.

However there is limited work conducted and published in the area of PV simulation tools. The list of those publications include the work of Reinders (2007), Reich, van Sark, Turkenburg, Sinke, (2010) and the earlier mathematical simulation approach by Reinders, van Dijk, Wiemken and Turkenburg (1999). There have been autonomous software developed in the boundaries of other academic projects like the work of Chryssoluris, Mavrikios Fragos and Karabatsou (2000) and the work conducted by Abdel-Malek, Yang, Kim, Marler, Beck, Swan, Frey-Law, Mathai, Murphy Rahmatallah and Arora (2007) and Yang, Rahmatalla, Marler, Adbel-Malek and Harrison (2007) for the project of SantosTM as well as the work of Shaikh, Jarayam, Jarayam and Palmer (2004), Honglun, Shouqian and Yumhe (2007) and Lind, Krassi, Viitaniemi, Kiviranta, Heilala and Berlin (2008) that demonstrate the use of virtual avatars and environments but these studies focus mainly on the perspective of ergonomics and human factors and not the integration, planning and simulation of PVs on human virtual avatars. Also none of the above is an extension to a commercially available software package. Our study is the first that utilizes virtual reality in a technical manner in order to acquire measurements of a physical quantity such as the light intensity into a virtual environment incorporating mobile objects (PIPVs in movement).

3 PLATFORM VALIDATION

The validation study of 3DSMD lighting analysis tool, especially in outdoors condition, forms an essential and a significant task in our project, since we wish to ascertain how close to the actual condition our simulation platform would be. As already mentioned we have selected to extend the Autodesk 3DS Max and Max Design tools, especially as the later offers a built-in light analysis tool. The light analysis tool is based on the ExposureTM plug-in and it has been so far mainly employed for interior light analysis by architects and interior designers. There is also a validation study conducted by Reinhart and Breton (2009) at the National Research Council of Canada (NRCC) but this also mainly focuses on an interior scenario with a very brief and unsystematic validation in an external condition/scenario. Thus the utilization of the tool for exterior use has not been widely used and there is a lack of thorough and systematic validation studies focusing on outdoor conditions.

3.1 Methodology

The validation study of the 3DSMD lighting analysis tool could be satisfied only by providing two essential requirements. These are access to light intensity data measurements (measured in lux) of a particular place, with long time intervals defined (e.g. days or months) and the precise 3D CAD model of this place. Thankfully for the purposes of this study, Brunel University runs two, unrelated to this, projects that fulfil the aforementioned requirements. Light intensity data are collected on a daily basis since October 2006 by the weather station of the SunnyBoy project conducted by Chowdhury, Day, Taylor, Chowdhury, Markvart and Song (2008). The aim of this project is the data acquisition and performance analysis of a PV array installed within the Brunel campus as illustrated in Figure 4.

Figure 4: Rendered image of the Brunel University 3D Campus project.

The next element towards this study is the 3D model of the campus. Accurate models of this are also available by a past project of Brunel University. Therefore, the basic toolset of the study is acquired and the next step is the modification of the simulation setup.

3.2 Simulation Setup

A number of scenarios have been set up for this study. These scenarios cover all the possible daylight conditions, which are three. Namely a sunny, a partially cloudy and a cloudy day. For this purpose, we chose three corresponding days to those conditions. These days were selected based on weather forecasts and observation and light intensity values collected with the proper equipment (lux meter) on site during those particular dates. The investigated scenarios are defined in Table 1.

Table 1: Lighting Simulation Setup Scenarios.

Scenario	Daylight Condition	Date
SC1	Sunny day	03-June-2010
SC2	Partially cloudy day	25-October-2010
SC3	Cloudy day	17-November-2010

3.3 Lighting Analysis Rendering Setup

The light analysis system requires a virtual sensor to be designed in the scene in order to yield results for this sensor. The weather station is located on the spot indicated by the red star in Figure 4. Therefore, a lighting analysis sensor (Light Meter) is designed on the exact same spot with the corresponding area that the measurements were conducted. The lighting analysis in 3DSMD uses mental-ray to simulate physical lighting, thus the accuracy of the results lie beneath the precision of the rendering settings. The lighting analysis assistant by ExposureTM plug-in provides a Lighting Analysis Render Preset of adjustments for the parameters of the simulation. It utilizes the mental-ray raytracer with the method of backward raytracing and with Raytrace and Final Gather setting enabled as referred in the Functional overview of mental ray v1.5 by mental-images (2007). The only modification to that preset, required for reasons of presentation, is the scaling of the Analysis of Value Colour Coding. The minimum illuminance value in lux is 0 which corresponds to darkness and the maximum is set to 120,000 lux which is the typical maximum illuminance value for a clear sky day.

3.4 Lighting System Setup

The lighting system has to be setup too. Although 3DSMD as mentioned above utilizes ExposureTM plug-in for lighting analysis, there have been some studies such as the study of Reich, (2010) that adopt a different approach, scaling visible light to yield energy levels. In the case of this study, the lighting system of Exposure is used by employing the Perez-all Weather sky model as mentioned in both the daylight simulation guidelines by Autodesk (1), (2) (2009). The daylight system in our setup is the mr Sun and mr Sky and we set the longitude and latitude of the landscape to 51.53285º and -0.47283º respectively, which is the exact position of Brunel University.

3.5 Material Adjustments

Another simulation parameter that has to be adjusted, according to the Daylight Simulation guide provided by Autodesk (1), (2) (2009), are the materials of the 3D objects as those define the optical properties of the objects. The only applicable materials for lighting analysis by default are the mr Architectural Design materials and the "ProMaterials". As indicated in the study by Reinhart (2009) these materials are complex in terms of parameters whilst accuracy lies in the detail. In an outdoor scenario like the one examined in this paper, the light values are far higher than an indoor scenario and shading is less, consequently the accuracy of results is not highly material dependent. Thus, materials that match the optical properties and colour of the actual architectural structures are utilized. These include the effects of reflectance of solar rays on the surfaces as accurately as possible. Furthermore, in every scene object a map is assigned, which increases the precision of the optical properties in complex materials like the camouflage and vegetation. The map assigned along with the appropriate shader will provide the object with the optical properties required.

4 RESULTS AND DISCUSSION

The results of the validation study as well as our proposed future work are offered in this section.

4.1 Platform Validation Results

Every single value of light intensity (lux) that corresponds to a specific time during the day has to be simulated within 3DSMD. After that all the resulting virtual values are plotted in graphs and contrasted with the graph constructed by the actual measurements.
For the three different scenarios of the study there are 6 plots compared in pairs resulting to three graphs as illustrated in Figures 5, 6 and 7. The Y axis represents the illuminance values measured in lux. The higher the lux values are the higher are the light intensity values that reach the PV panel. The X

axis represents the time of the specified day. One may notice that across the three figures the overall time duration varies by a few hours. This is due to the specific date and season that these measurements took place.

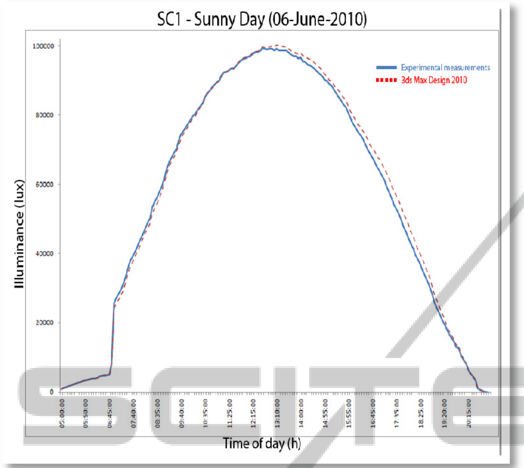

Figure 5: Scenario 1 – Sunny Day.

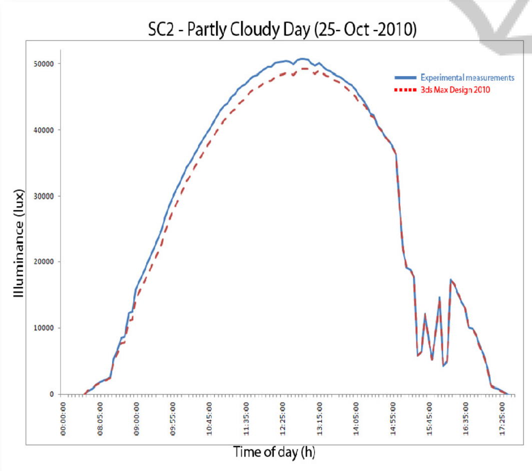

Figure 6: Scenario 2 – Partially Cloudy Day.

For instance the measurement of Figure 5 was taken place during summer, whereas the one in Figure 6 is in winter, where there is light for less parts of the day. The values demonstrated in the figures are taken on a five minute interval. The changes seen in the lines (peaks and drops) simply illustrate the amount of light in lux that the measurement devices record and simulated in 3DSMD. Thus if the sun is on the middle of the sky with no clouds obstructing it there is a peak (high lux value). If on the other hand there is a cloud passing between the sun and the measurement unit the lux level drops.

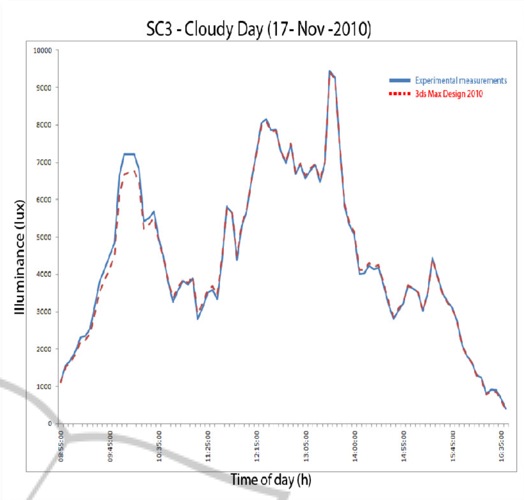

Figure 7: Scenario 3 – Cloudy Day.

The results clearly demonstrate that for any outdoor daylight condition scenario the lighting analysis tool of the 3D software yields values of light levels extremely close to the actual measurements. More precisely for sunny days, as illustrated in figure 5, the values generated by 3DSMD and those of the actual measurements are very much the same. In the case of a partially cloudy day, as illustrated in figure 6, 3DSMD's values are very close to the actual measurements for the majority of the day's duration. There is a very small discrepancy during ten to one o'clock between 3DSMD and the actual measurements, but this is in the range of 50lux at its peak and it is thus a negligible amount to take into consideration.

For applications that require long term analysis of light levels as for example a study of light levels for Product Integrated PhotoVoltaics (PIPV) at a particular place and for a given long time interval such as a whole day, the approach adopted by this study derives to qualitative results. In other words, the requirements of light level analysis for PIPV applications can be substituted by the virtual tool offered by 3DSMD and ExposureTM. However, the complexity of this tool added by the compound procedures of rendering and analysis are an obstacle to users or scientists who wish to employ a virtual tool in their projects. That is one of the essential aims of the project to which this study is part of. Utilizing the design and development of a Graphical User Interface (GUI) we are trying to solve this aforementioned issue and semi-automating and simplifying the procedures of virtual lighting analysis for outdoor applications of PIPV. The GUI will offer the end user the capability to synthesize and modify in few simple steps their landscape and weather conditions and furthermore to analyze and infer safe, as proved above, results for further statistical analysis and planning of the applications.

4.2 Future Work

The project is nearly half way through with an additional 10 months left. Within that period we aim to finish the design and development of the proposed Solar Soldier light simulation platform. Once this is completed we would be able to run several more experiments and much more efficiently since the simulation process will be semi-automated. We would particularly look to simulate a virtual infantry soldier with the light sensors placed on the most effective (and based on scenarios given to us by DSTL), from a light gathering perspective, parts of his uniform and kit and generate data across different terrains (desert, urban), environments (winter, summer) and mission types (patrol, guard, etc).

In addition to this we would be running more outdoor validation studies from non-stationary positions to see and compare the data generated when in motion.

Finally it is within our scope to design and employ the platform simulation tool for commercial applications as well and we are in the process of developing commercially-based scenarios in our system too.

5 CONCLUSIONS

The paper has presented a brief overview of platform that extends commercial 3D authoring and light analysis tools to produce a 3D planning and simulation tool mainly for defence but also for prospective commercial applications. The unique and novel feature of this tool is the introduction of the analysis of technical aspects such as lighting intensity not only for still scenes but for animated objects as well.

The paper has focused on a validation study of the 3DSMD with its light analysis tool for the time being and as a proof of concept only in an outdoor still scene scenario. A number of daylight scenarios have been produced modelled and tested using both 3DSMD as well as actual measurements from a weather station. This is one of the first amongst a scarce number of studies with thorough validation studies focusing on outdoor conditions performed on 3DSMD, producing very encouraging outcomes, as the data from 3DSMD and the actual PV match extremely closely under sunny, partially cloudy and cloudy conditions. Thus, we demonstrated that tools such as 3DSMD can be employed for simulating outdoor daylight condition scenario which is among the basic aims of the project. The tool however is fairly complex requiring a number of settings to be configured and requiring that the end-user is highly experienced with the tool. As part of our proposed platform we aim to semi-automated and simplify this process rendering it more accessible as well as suitable for a number of defence and commercial scenario applications.

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