SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V12I8P105

Volume 12 Issue 8, 38-45, August 2025

Original Article

Design of a Backpack with a Solar Energy System and a Retractable Arm for Autonomous Multimedia Capture in Remote Environments

Victor Roy Caceres Huaman[1], José Francisco Gómez Samaniego[2]*, Albert Jorddy Valenzuela Inga[2], Boris Senin Carhuallanqui Parian[3]

[1]*Faculty of Mechanical Engineering, Universidad Nacional de Ingeniería, Lima,Peru.*
[2]*Faculty of Engineering, Universidad Continental, Huancayo, Peru.*
[3]*Institute for Statistical Studies and Economics of Knowledge (ISEEK), HSE University, Moscow, Russia.*

**Corresponding Author : 71849684@continental.edu.pe*

Received: 04 June 2025 Revised: 06 July 2025 Accepted: 05 August 2025 Published: 30 August 2025

Abstract - *The increasing demand for mobility and the proliferation of portable electronic devices have driven the development of autonomous energy solutions, especially for professionals who perform their work in remote environments or with limited access to the power grid. Journalists, content creators, field researchers, and other itinerant users rely on a variety of electronic equipment, such as cameras, microphones, smartphones, and laptops, to carry out their work efficiently. In response to this scenario, the design of a technological backpack equipped with a solar energy harvesting system and a retractable arm for multimedia device support, guided by the VDI methodology, is presented. The incorporation of a flexible solar panel into the backpack's structure enables the conversion of solar energy into electricity, which is stored in internal batteries for the continuous powering of various devices. The proposed system achieved an estimated energy efficiency of 80%, with autonomous operation for 6 to 8 hours under standard solar irradiance. It includes a 5555 mAh lithium-ion battery, two USB Type-A ports, and one Type-C output for device charging. The proposed design is compared with existing solutions, highlighting its unique combination of energy autonomy, ergonomic design, and integrated workflow support. The integration of renewable energy aligns with sustainability goals and offers a practical solution for on-the-go power needs.*

Keywords - *Backpack, Design, Mobile charger, Solar cell, Solar energy.*

1. Introduction

The increasing demand for mobility and the proliferation of portable electronic devices have driven the development of autonomous energy solutions [1, 2], particularly for professionals who conduct their work in remote or off-grid environments. Journalists, content creators, field researchers, and other itinerant users rely on a variety of electronic equipment, including cameras, microphones, smartphones, and laptops, to perform their tasks efficiently [3, 4].

In these scenarios, energy autonomy becomes critical to ensure operational continuity, especially due to the absence of compact, fully integrated systems that combine energy generation, storage, and multimedia operation in a single portable platform. Current solutions for powering electronic devices in mobile scenarios present several limitations [5, 6]. External batteries, for instance, while useful, tend to be bulky, require frequent recharging, and do not always offer a sustainable energy source [7]. In contrast, despite their portability, traditional backpacks lack the ability to autonomously generate and manage energy and integrate ergonomic systems that enable the efficient use of multimedia capture devices. This identifies a specific technological gap, which this study aims to address with a holistic design approach combining mobility, energy independence, and functionality. Technological advancements in portable photovoltaic devices and embedded electronics have enabled the development of more compact and efficient energy generation and management [8, 9].

The integration of flexible solar panels has broadened the possibilities for integration across various surfaces, paving the way for hybrid portable systems that combine mobility with energy capacity [10]. Concurrently, the development of energy management modules such as MPPTs, charge controllers, and low-power microcontrollers has facilitated more efficient energy harvesting, storage, and distribution in mobile systems [11]. This technological evolution has fostered the creation of intelligent, autonomous, and more environmentally friendly devices [12]. In recent years, various technologies and approaches have been explored to address the challenge of energy autonomy in mobile devices, and it is crucial to position our proposal within this landscape. A common thread is the recognition of the potential of solar energy; however, the studies differ in their scope and focus. For instance, several studies specifically focus on the integration of solar energy in portable solutions for mobile device charging. Deepikavalli [13], Taverne et al. [14], and Usikalu et al. [15] explore the design of solar backpacks, highlighting their capacity to provide a convenient and mobile energy source.

However, while Deepikavalli [13] focuses on the system simulation with a DC-DC converter, Taverne et al. [14] delve into the design of the charging system, and Usikalu et al. [15] report the construction and testing of a prototype, this research distinguishes itself by adding the ergonomic functionality of a retractable arm for multimedia equipment. Selim et al. [16] also present a solar charger integrated into a backpack. However, their primary focus is on evaluating the solar energy harvesting performance. In contrast, Hasan et al. [17] propose a similar design for a cap, which highlights the versatility of solar energy in different portable devices.

In contrast to these charging-centric approaches, Gunarathne et al. [18] broaden the scope by designing a "smart backpack" that, in addition to solar charging, incorporates sensors to monitor the user's health and environment, which underscores the potential for integrating solar energy into more complex systems. In summary, while the feasibility of solar energy in portable systems is widely acknowledged, this work addresses a unique combination of autonomous multimedia support, ergonomic design, and modular energy management elements rarely integrated together in prior studies.

In this context, the present study proposes the design of a technological backpack equipped with a solar energy harvesting system and a retractable arm for multimedia device support, intended to be autonomous, efficient, and easily portable, while also integrating principles of ergonomic design and modularity. Beyond addressing technical needs, this proposal is framed within a technological sustainability approach.

According to the United Nations (UN) Department of Economic and Social Affairs, generating energy from renewable sources contributes to the fulfilment of Sustainable Development Goal (SDG) 7, which promotes access to affordable, reliable, sustainable, and modern energy for all [19]. Consequently, the design of this backpack aims to enhance energy autonomy in the devices used by journalists, content creators, field researchers, and other users by combining various renewable energy technologies to maximize the efficiency and reliability of sustainable energy generation [20, 21]. Therefore, this study delivers a functional prototype and contributes to the ongoing development of sustainable and user-centred technologies for field applications.

The following sections detail the conceptual and technical aspects of the proposed system, including the structural design of the backpack, the configuration of the photovoltaic system, the retractable mechanism, and the internal arrangement of the electronic components. Furthermore, its feasibility in real-world operating scenarios is discussed, with particular attention to energy performance and ease of use in field conditions.

2. Materials and methods

The methodological process followed for the conception and design of the backpack with a solar energy system and retractable arm for autonomous multimedia capture in remote environments is based on the VDI 2221 guideline [22], with an adaptation to emphasize the conceptual design phase.

2.1. Specification

Table 1 shows the list of design specifications for the backpack with a solar energy system and retractable arm for autonomous multimedia capture in remote environments, which is classified into four categories: design, functionality, energy, and control.

Table 1. List of specifications

Category	Specification
Design	Incorporating a stable and adjustable mount for the stabilizer, camera, and microphone with smooth extension and retraction mechanisms and integrating and efficiently using a solar panel and battery to maximize autonomy.
Functionality	Supplying power to electronic devices for an extended period, facilitating video and audio recording in remote environments.
Energy	Provide continuous power for at least 5 hours under typical usage conditions. Maximize the efficiency of solar energy conversion and storage.
Control	An intelligent energy management system to optimize battery charging, discharging, and protection and indicate battery status.

2.2. Function Structures

Figure 1 shows and describes the main functions of the system and their interconnections. The solar energy system begins with solar energy harvesting, followed by voltage conversion to charge a device, and subsequently, unused energy is stored in a battery for use when needed. The retractable support for multimedia equipment does not influence the energy distribution.

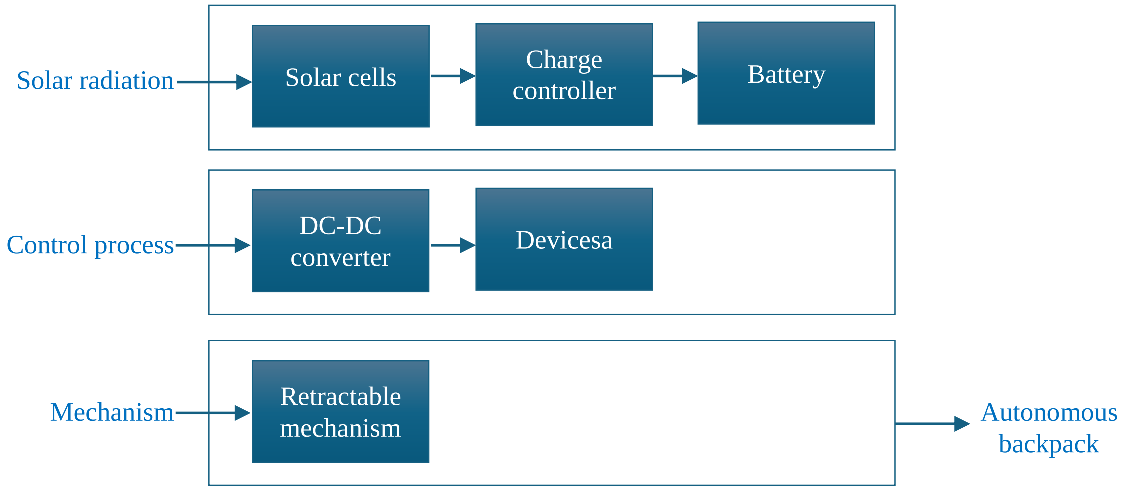

Fig. 1 Function structures

2.3. Principal Solutions

The choice of a solar cell array as the primary energy source aligns with the trend observed in studies such as Selim et al. [16], who developed a solar energy harvesting-based integrated backpack charger to overcome the energy limitations of mobile devices. The decision to configure the cells in parallel to obtain a voltage compatible with USB charging is also based on the common functionality of portable chargers. The dimensions of the harvesting area (approximately 30 cm x 20 cm) seek a compromise between maximizing incident solar energy and the practicality of integration into a backpack, an important consideration in the design of portable solar chargers in the research by Taverne et al. [14]. For the multimedia equipment support, a 6061-aluminium telescopic retractable arm, integrated into the back, was implemented, offering stability and an extension range of up to 50 cm, while maintaining portability due to its retraction capability. Usikalo et al. [15] emphasizes that energy storage relies on a 5V lithium-ion battery, selected for its high energy density and suitable weight for portable applications, with a capacity calculated to charge multiple devices. Efficient energy management is achieved through a PWM charge controller with an internal DC-DC converter, with an estimated efficiency of 80% for battery charge regulation and powering the USB ports.

3. Mechanical and Electrical Systems

3.1. Mechanical System

The structural configuration of the backpack is illustrated in Figure 2. This design compactly integrates the arm into the interior of the backpack when retracted, allowing for comfortable and unobstructed transport. Furthermore, the components of the solar energy system integrated into the backpack are also shown. To understand the individual arrangement of the elements and their assembly, Figure 3 shows an exploded view of the backpack. All the main components that make up the structure of the backpack are listed in Table 2 to complement this visual representation.

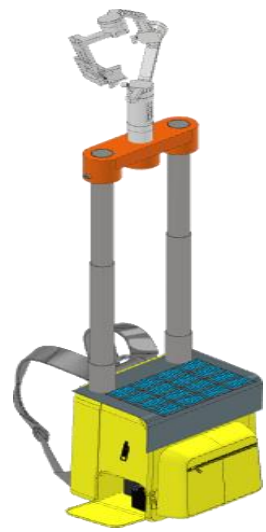

Fig. 2 Isometric view of the backpack

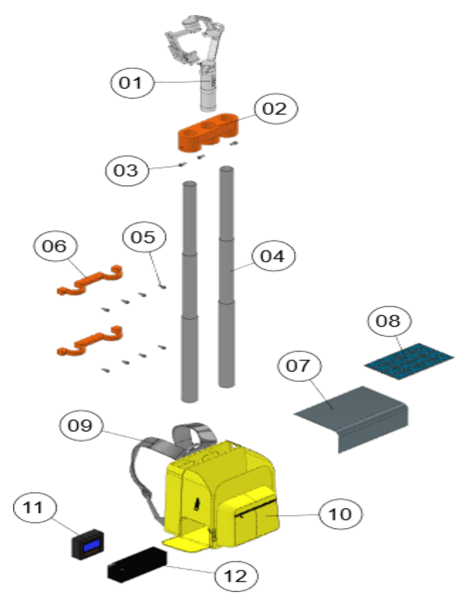

Fig. 3 Exploded view of the backpack

Table 2. List of components

Number	Part	Number	Part
01	Camera Stabilizer	**7**	Carrying case
02	Mounting Base	**8**	Solar cells
03	Long Screws	**9**	Padded backpack strap
04	Retractable Arm	**10**	Backpack
05	Short Screws	**11**	PWM charge controller
06	Clamps	**12**	Lithium-ion battery

The retractable arm mechanism, shown in Figure 4 and listed in Table 2, is mainly composed of the retractable mechanism itself, the mounting base, the clamps, and the long and short screws. The telescopic sections are made up of 6061 aluminum circular tubes, a material selected for its excellent strength-to-weight ratio and good machinability, which facilitates the fabrication of the sliding sections of the mechanism [4]. The mounting base allows for a robust attachment to the rear side of the backpack using screws and clamps.

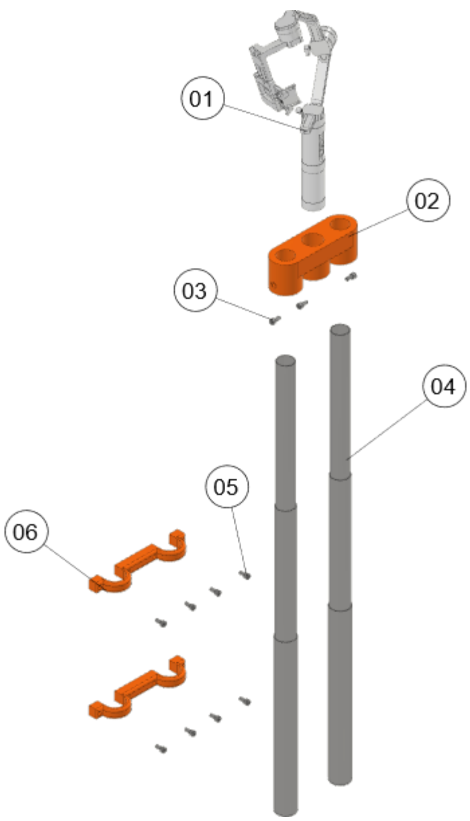

Fig. 4 Isometric view of the backpack

3.2. Electrical Systems

Figure 5 shows the electrical system of the backpack with a solar energy system, which focuses on solar energy harvesting, its conversion to a suitable format, storage in a battery, and controlled distribution to external electronic devices via the Pulse-Width Modulation (PWM) charge controller. The energy flow is managed through the interconnection of the following main components, illustrated in the electrical system, which includes a solar panel, a PWM charge controller, a lithium-ion battery, and culminating in USB output ports for device charging.

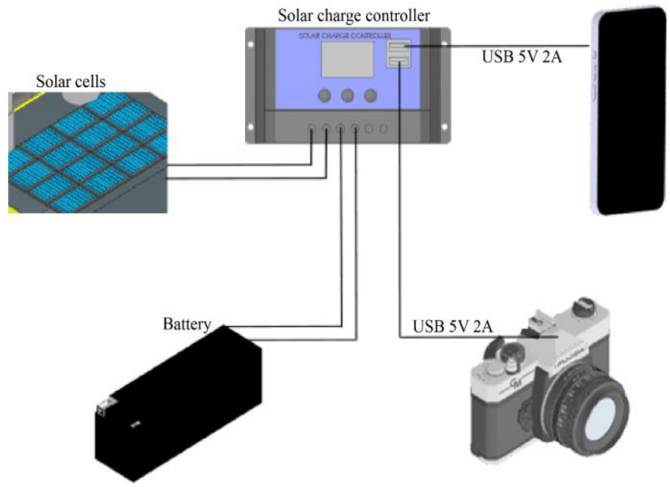

Fig. 5 Electrical system

The electrical system of the backpack relies on the harvesting of solar radiation using an array of 16 solar cells, which will be followed by regulation of the generated energy through a PWM charge controller, storage in a lithium-ion battery, and the distribution of energy to external devices via the USB ports integrated into the charge controller with a 5V and 2A output.

For the required charge calculation in the lithium-ion battery selection, the solar cells' connection and the type of charge controller must be considered. For the proposed design, 16 individual solar cells from the manufacturer DFRobot are used, each with an open-circuit voltage (Voc) of 5V and a short-circuit current (Isc) of 1A [5]. A parallel connection is chosen to maximize the output current without increasing the voltage beyond the limits allowed by the PWM controller [6]. In this configuration, the system voltage remains constant, and the current from each cell is added.

Equation 1 calculates the total current where n =16 is the number of solar cells connected in parallel, $\mathrm{I_{cell}}$ is the current generated by each solar cell and $\mathrm{I_{array}}$ is the total current, which is used to increase the total current. In this configuration, the total voltage of the solar array will remain at 5V, while the total current increases.

$$I_{array} = n \times I_{cell} \quad (1)$$

Solving the equation gives a total current of 16A generated by the 16 solar cells connected in parallel. The selected PWM charge controller has an input current limit of up to 10A [6]. Since the array could supply up to 16A under optimal conditions, it is recommended to physically limit the array current to 10A using current regulators.

Equation 2 calculates the power required for a full charge, where E_d is the energy required to charge a mobile device, considering that each typical mobile device has an average battery capacity of 3000 mAh with a nominal voltage of 3.7V.

$$E_d = \left(\frac{3000mAh}{1000}\right) 3.7V = 11.1\ Wh \quad (2)$$

Solving the equation, we have that the power required to fully charge a mobile device is 11.1 Wh, and to supply 2 devices simultaneously, because the PWM charge controller has 2 USB ports, it would be 22.2 Wh. Equation 3 calculates the minimum power supply to the battery, where E_b is the minimum power for the battery supply, and an overall system efficiency of 80% is considered, including losses in the controller, battery and cables.

$$E_b = \left(\frac{22.2\ Wh}{0.8}\right) = 27.75\ Wh \quad (3)$$

Equation 4 calculates the minimum battery capacity, where C_b is the minimum capacity the battery must have. The PWM controller has a 5V output USB port. Therefore, it is assumed that the battery will operate at a nominal voltage of 5V.

$$C_b = \left(\frac{27.75Wh}{5V}\right) = 5.55Ah = 5555\ mAh \quad (4)$$

As a result, to cover unforeseen losses and allow for at least two full charges of mobile devices, it is recommended to use a battery of at least 6000 mAh. In a similar context, Selim et al. [1] investigated the design of a solar energy-based backpack charger, employing a solar module of comparable dimensions (16 cm × 6 cm). In their study, under a resistive load of 100 Ω, a maximum output voltage of 3.6 V was observed. While the specific characteristics of the solar cells used in their work may differ, this result provides a practical reference for the order of magnitude of the voltage that can be obtained from a compact solar panel integrated into a backpack. Therefore, the proposed design will seek to optimize the arrangement and characteristics of the 16 solar cells to maximize energy harvesting within the size and weight constraints inherent to a portable backpack.

3.3. Block Diagram

Figure 6 presents the flowchart of the solar energy system integrated into the backpack, illustrating the process from energy harvesting to mobile device charging. The process begins with the deployment of the solar cells, exposing the photovoltaic surface to incident solar radiation. If a mobile device is connected, the energy harvested by the solar cells directly charges the mobile device through the charge controller, which incorporates an internal DC-DC converter that regulates the 5V 2A output.

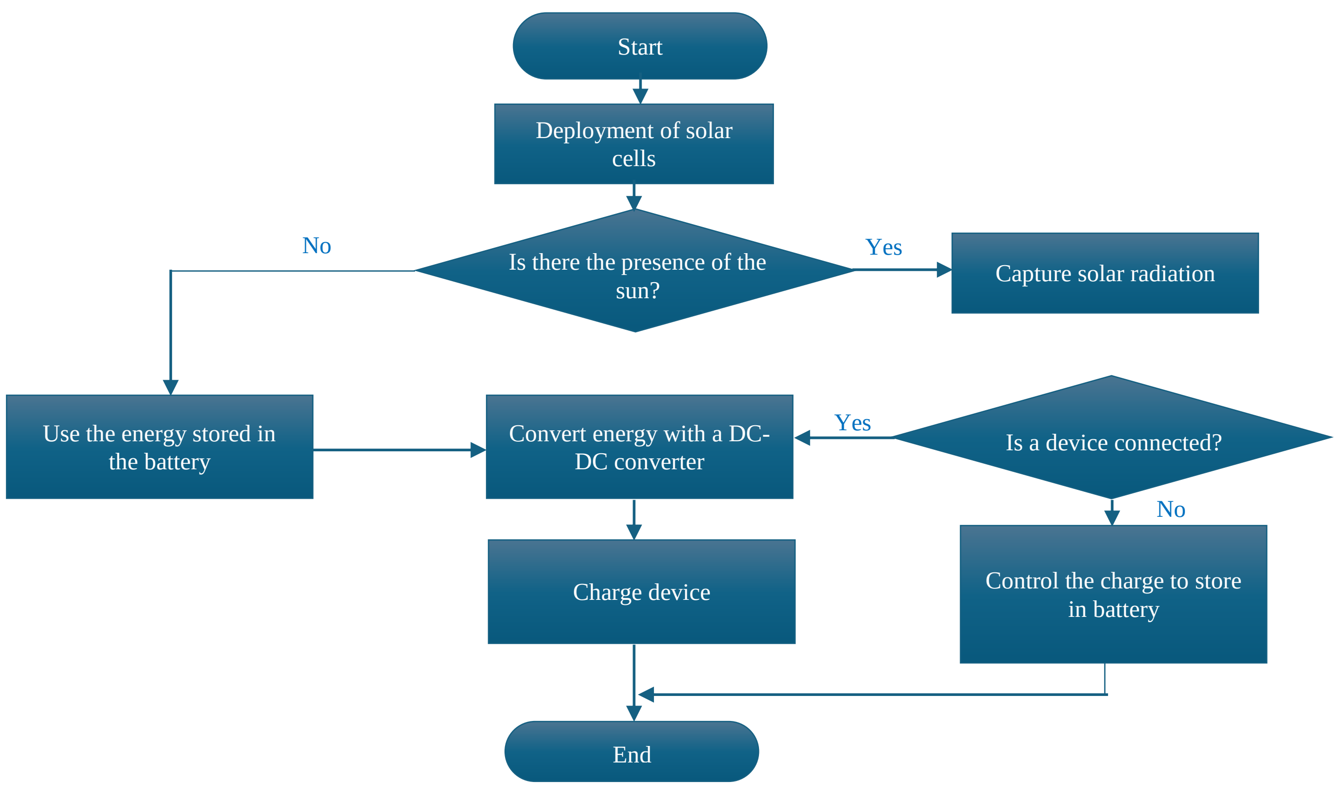

Fig. 6 Flowchart of the backpack with solar energy system

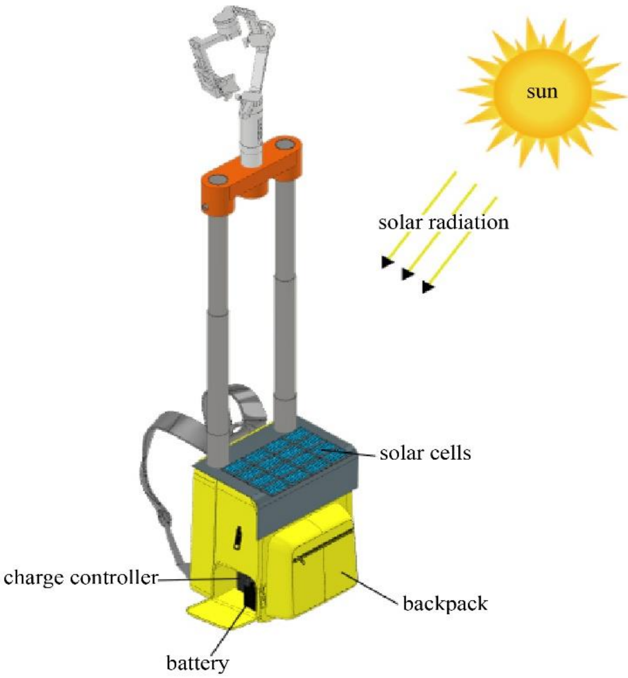

Fig. 7 Representative view of solar radiation capture

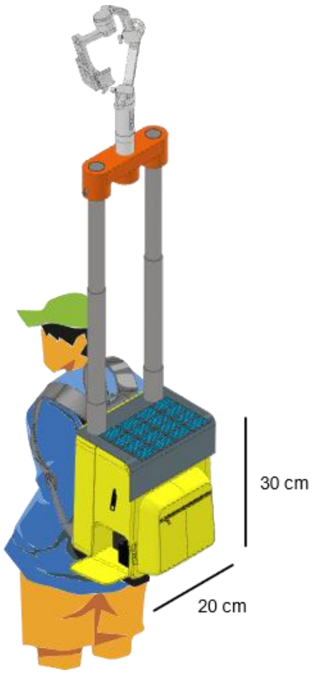

Fig. 8 Solar backpack charger

Figure 7 shows the representative view of radiation capture by the backpack with the solar system; the distribution of solar cells is visible on the top of the backpack, above the case, to capture solar radiation more accurately.

4. Results

The backpack's conceptual design, which has a solar energy system and a retractable arm for autonomous multimedia capture, has been developed. It integrates a solar panel of monocrystalline cells, strategically arranged on the upper front panel of the backpack with approximate dimensions of 30 cm x 20 cm, as detailed in Figure 8. This location was selected to optimize the capture of solar radiation during outdoor use. The retractable arm, made of a lightweight 6061 aluminum alloy, is integrated into the rear of the backpack and employs a two-section telescopic mechanism, allowing an extension of up to 50 cm for mounting cameras and microphones. In its retracted state, the arm is easily accommodated, maintaining the compactness of the backpack during transport.

Internally, the backpack houses a dedicated compartment for the lithium-ion battery with a capacity of 5555 mAh and a nominal voltage of 5 V. This type of battery was chosen for its favorable energy density-to-weight ratio, crucial for a portable application. The energy management charge control, which includes a DC-DC converter with an estimated efficiency of 80% due to energy loss in the cables, the PWM charge controller, and the battery itself, with integrated overcharge protection, is also housed in this compartment. The output ports for powering external devices consist of two USB Type-A ports and one USB Type-C port on an easily accessible side.

5. Discussions

The conceptual design of the autonomous backpack for multimedia capture presents an integrated solution for powering devices and providing ergonomic support in remote environments, addressing a growing need identified by Selim et al. regarding the energy limitations of mobile devices beyond the reach of conventional power outlets.

The integration of a solar panel of approximately 600 cm^2 (30 cm x 20 cm) for solar energy harvesting represents a considerably larger surface area than the 96 cm^2 (16 cm x 6 cm) module used by Selim et al. [16]; theoretically, this could translate to a greater capacity for energy harvesting under optimal solar irradiance conditions. However, their experimental results, which reported a maximum harvested power of 140 mW, underscore the importance of considering the actual efficiency of the system and the operating conditions.

The significant difference between the potential power of our cell array, being 80W under ideal conditions, and the experimental results of a similar system suggests that losses in photovoltaic conversion, the efficiency of the charge controller, and the actual environmental conditions will play a crucial role in the energy performance of the proposed design.

The adoption of a PWM charge controller with an internal DC-DC converter aligns with the energy management strategy explored in the simulation of solar backpacks by Deepikavalli [13]. DC-DC conversion is essential to adapt the variable voltage of the solar panel to the charging needs of the battery and the stable power supply of USB devices. The estimated efficiency of 80% for this process acknowledges the inherent losses in the conversion and transmission of energy through the cables and the controller itself.

The design of the 6061-aluminium retractable arm seeks to provide a robust and lightweight solution for supporting multimedia equipment, addressing an ergonomic need for content creators on the move. While the primary focus of this conceptual design is the electrical system, the stability and functionality of the mechanical support are important considerations for the overall usability of the backpack. In comparing the trend towards smart backpacks by Gunarathne et al. [18] and the specific designs of solar charging backpacks by Usikalu et al. [15] and Taverne et al. [14], this research focuses on the synergy between energy autonomy and support functionality for multimedia capture.

Future developments could explore the integration of additional smart system features, among other improvements, to enhance the user experience. A comparative analysis regarding battery capacity, solar system efficiency, and support mechanisms-as previously examined in related works-could provide valuable insights into the potential advantages and limitations of the proposed design.

6. Conclusion

The design of an autonomous backpack with a solar energy system and retractable arm integrates renewable energy generation and ergonomic support into a portable solution for multimedia capture. The selection of components like monocrystalline solar cells, the PWM charge controller with DC-DC conversion, and the lithium-ion battery, along with the design of a lightweight aluminum retractable arm, aims to balance functionality, efficiency, and portability.

A conceptual design study has inherent limitations. Validating estimated energy performance through experimental testing under real-world usage conditions is crucial for determining the practical viability of the solar charging system. A more detailed mechanical analysis of the retractable arm, including stress and stability simulations under various loads and environmental conditions, is necessary to optimize its design.

Future research should focus on building a functional prototype to evaluate system performance in real-world scenarios and exploring the integration of additional features that could improve this autonomous backpack's utility and user experience for multimedia capture.

References

[1] Pitchai Pandiyan et al., "Technological Advancements toward Smart Energy Management in Smart Cities," *Energy Reports*, vol. 10, pp. 648-677, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[2] Minki Kang, and Woon-Hong Yeo, "Advances in Energy Harvesting Technologies for Wearable Devices," *Micromachines*, vol. 15, no. 7, pp. 1-19, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[3] Chamin Morikawa et al., "Image and Video Processing on Mobile Devices: A Survey," *The Visual Computer*, vol. 37, no. 12, pp. 2931-2949, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[4] Salah Mohammedsalih, "*Mobile Journalism: Using Smartphone in Journalistic Work*," Master Thesis, Uppsala University: Department of Information and Media, 2017. [Google Scholar] [Publisher Link]

[5] Krishna Sekar, "Power and Thermal Challenges in Mobile Devices," *MobiCom'13: Proceedings of the 19th Annual International Conference on Mobile Computing & Networking*, Miami Florida, USA, pp. 363-368, 2013. [CrossRef] [Google Scholar] [Publisher Link]

[6] Ban H. Alajrash et al., "A Comprehensive Review of FACTS Devices in Modern Power Systems: Addressing Power Quality, Optimal Placement, and Stability with Renewable Energy Penetration," *Energy Reports*, vol. 11, pp. 5350-5371, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[7] Zach Cabading, How to Use a Portable Charger: The Ultimate Guide to Power Banks, HP Development Company, 2024. [Online]. Available: https://www.hp.com/us-en/shop/tech-takes/how-to-use-portable-charger-power-bank-guide,

[8] Md. Tonmoy Hossain et al., "Next Generation Power Inverter for Grid Resilience: Technology Review," *Heliyon*, vol. 10, no. 21, pp. 1-40, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[9] Abdelrahman O. Ali et al., "Advancements in Photovoltaic Technology: A Comprehensive Review of Recent Advances and Future Prospects," *Energy Conversion and Management: X*, vol. 26, pp. 1-28, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[10] Xiaoyue Li et al., "Review and Perspective of Materials for Flexible Solar Cells," *Materials Reports: Energy*, vol. 1, no. 1, pp. 1-24, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] Ahmed Aghmadi, and Osama A. Mohammed, "Energy Storage Systems: Technologies and High-Power Applications," *Batteries*, vol. 10, no. 4, pp. 1-21, 2024. [CrossRef] [Google Scholar] [Publisher Link]

[12] Chia-Nan Wang, Hoang-Kha Nguyen, and Nhat-Luong Nhieu, "Integrating Prospect Theory with DEA for Renewable Energy Investment Evaluation in South America," *Renewable Energy*, vol. 247, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[13] K. Deepikavalli, and R. Puviarasi, "Simulation of Solar Bag Using DC-DC Boost Converter," *2018 Fourth International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB)*, Chennai, India, pp. 1-4, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[14] Jonas Taverne et al., "Design of Solar Powered Charging Backpack," *International Journal of Power Electronics and Drive Systems*, vol. 9, no. 2, pp. 848-858, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[15] Mojisola R. Usikalu, Emmanuel Adebesin, and Leke N. Obafemi, "Design and Construction of Backpack Mobile Charger," *ARPN Journal of Engineering and Applied Sciences*, vol. 14, no. 21, pp. 3743-3746, 2019. [Google Scholar] [Publisher Link]

[16] Kyrillos K. Selim et al., "Solar Energy Harvesting-Based Built-in Backpack Charger," *Energy Harvesting and Systems*, vol. 11, no. 1, pp. 1-7, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[17] Md. Rakib Hasan, Md. Sabbir Hossain, and Kazi Pavel Rahman, "Design and Construction of a Portable Charger by Using Solar Cap," *Global Journal of Researches in Engineering: A Mechanical and Mechanics Engineering*, vol. 17, no. 5, pp. 1-5, 2017. [Google Scholar]

[18] P.D.R.P. Gunarathne et al., "Smart Backpack for Travelers," *2020 2nd International Conference on Advancements in Computing (ICAC)*, Malabe, Sri Lanka, pp. 25-30, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[19] Goal 7, Department of Economic and Social Affairs, Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All, United Nations, 2025. [Online]. Available: https://sdgs.un.org/goals/goal7

[20] Qusay Hassan et al., "A Review of Hybrid Renewable Energy Systems: Solar and Wind-Powered Solutions: Challenges, Opportunities, and Policy Implications," *Results in Engineering*, vol. 20, pp. 1-25, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[21] Tanveer Ahmad et al., "Energetics Systems and Artificial Intelligence: Applications of Industry 4.0," *Energy Reports*, vol. 8, pp. 334-361, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[22] J. Jänsch, and H. Birkhofer, "The Development of the Guideline VDI 2221 - The Change of Direction," *DS 36: Proceedings DESIGN 2006, the 9th International Design Conference*, Dubrovnik, Croatia, pp. 45-52, 2006. [Google Scholar] [Publisher Link]

[23] Manufacturing Knowledge Base, What is 6061 Aluminum? Material Overview and Design Considerations, Meviy, 2024. [Online]. Available: https://meviy-usa.com/what-is-6061aluminum/

[24] Monocrystalline Solar Panel (5V 1A) - DFRobot Drive the Future, 2025. [Online]. Available: https://www.dfrobot.com/product-1774.html?srsltid=AfmBOoqDeZ1r5cubYVLefS1PD2RbZ3EF5EQ_KqlX5eB3JbDelLfiGzPr

[25] PWM Solar PV Charge Controller, Low Energy Supermarket, 2025. [Online]. Available: https://lowenergysupermarket.com/product/pwm-solar-pv-charge-controller/