



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
Trinity Saint David

A study into developing a portable automated solar panel

ACDA5017: Group Project

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(Hons) Embedded electronics**

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Abstract

This project focuses on the design and development of a portable, automated solar panel system that tracks the sun to improve energy efficiency in off-grid and remote applications. The primary aim was to create a lightweight, cost-effective, and user-friendly solar solution capable of adjusting its orientation throughout the day to maximise solar energy capture.

The system uses a dual-axis sun tracking mechanism operated by servo motors and guided by a light sensor array. A PIC microcontroller processes sensor input to control the panel's position in real-time. The solar panel is mounted on a foldable, lightweight frame for ease of transportation. A battery system, connected through a charge controller, stores the generated power and provides stable output to external devices.

The methodology involved breaking down the project into key stages: initial research and concept development, component procurement, mechanical and electrical assembly, programming, testing, and evaluation. Various concepts were considered, and the servo-based solution was selected for its balance of portability, low cost, and simplicity.

The final product was tested under real sunlight conditions and demonstrated successful automatic tracking of the sun with noticeable improvement in power output compared to a stationary panel. It was lightweight, foldable, and capable of charging standard devices via USB or 12V output.

In conclusion, the project successfully met its objectives, delivering a working prototype of a portable solar tracker suitable for field use. It is recommended for applications like camping, mobile workstations, and emergency power. Future improvements could include enhanced weatherproofing, increased battery capacity, and integration with IoT for performance monitoring. This project demonstrates the potential of accessible solar tracking systems in improving renewable energy use in mobile and remote scenarios.

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Introduction

Aims and objectives

Aims

To design and build a fully functional dual-axis automated solar tracking system that maximises solar energy capture by continuously aligning with the sun throughout the day.

To create a self-powered and low-maintenance solar panel system that operates autonomously and efficiently under various environmental conditions.

Objectives

Design and construct a dual-axis solar panel mount with roller bearing support and motorised actuation on both axes.

Completed mechanical and electronic prototype that can track the sun's movement.

Based on available tools, materials, and components like microcontrollers, stepper motors, and sensors.

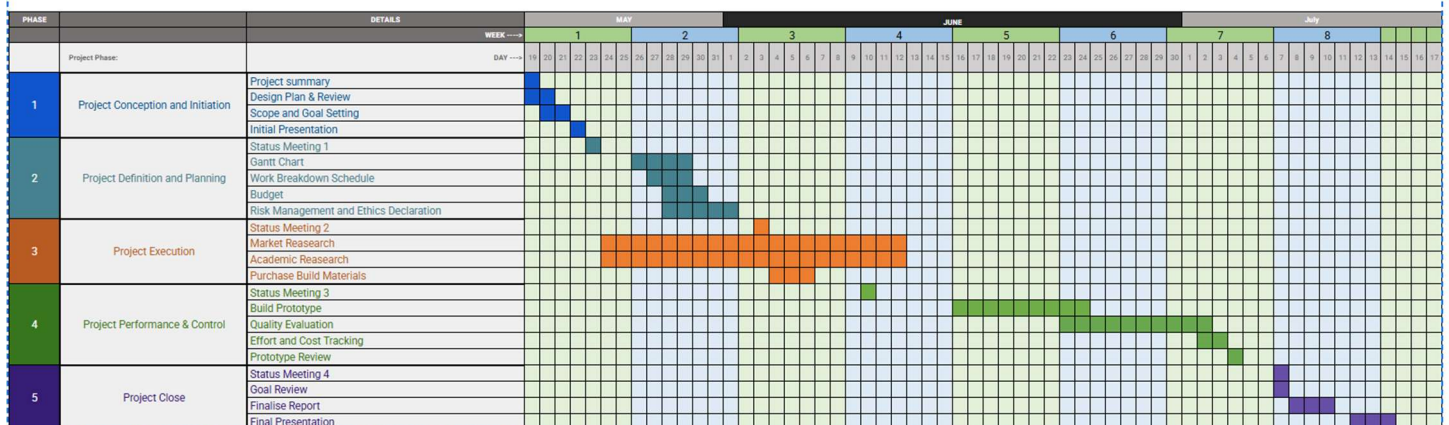
Supports the aim of building a functional and autonomous tracking system.

Complete before the 17th of July

Timeline of events

HELIANTHUS PROJECT TIMELINE

PROJECT TITLE	Helianthus	MODULE NAME	Group Project
PROJECT MANAGERS	Jamie, Gabe, Emily, Owen & Oscar	DATE	27/5/2025



Problems that may arise during the project

Several factors can cause issues in a group project, especially when timelines and collaboration are critical. Sick or annual leave can reduce the workforce unexpectedly, slowing progress and creating communication gaps. Delays in parts delivery can halt development stages that depend on those components, leading to bottlenecks.

Discrepancies between design results (such as in Proteus simulations) and actual physical outcomes can lead to rework and troubleshooting, consuming valuable time. Coding bugs or hardware malfunctions can also introduce delays and require attention to resolve. Additional issues might include miscommunication between team members or unclear task delegation, all of which can undermine coordination and project efficiency.

Responsibilities

Task	Emily De Lange	Gabriel Pan	Oscar Smith	Owen Miller	Jamie Hamilton-Swingewood
Gantt Chart		1			2
Initial presentation	1	1	1	1	1
Responsibility chart	1	2			
Ethics form	1				2
Market research	1		1	2	
Academic research				1	1
Mechanical design ideas	1		2		
PCB design ideas		1		2	1
Parts ordering	1				
PIC programming		2			1
Building prototype		1	1		2
Testing	2	1	2	2	1
Building final	1	1	1	1	1
Report writing	1	1	1	1	1

Proofreading & submitting	2		1		1
Final Presentation	1	1	1	1	1

Table 1, Table of responsibilities

Market Research

The market for portable solar panels and sun-tracking systems is experiencing significant growth, driven by increasing demand for off-grid power solutions, outdoor recreation, and sustainable energy technologies.

Portable Solar Panels

The global portable solar panel market was valued at approximately £1.47 billion in 2024 and is projected to reach £7.37 billion by 2034. This growth is fuelled by rising environmental awareness, government initiatives promoting solar energy, and the increasing need for mobile power solutions in remote areas. [1]

Solar Trackers

The global solar tracker market was valued at £7.88 billion in 2023 and is expected to grow to £25.24 billion by 2032, exhibiting a CAGR of 14.3%. Solar trackers enhance the efficiency of solar panels by adjusting their orientation to follow the sun's path, thereby maximizing energy capture. [2]

Relevant Technologies and Innovations

- **Portable Sun-Tracking Systems:** Researchers have developed low-cost, portable sun-tracking devices that can increase solar panel current output by approximately 37%. These systems use simplified mechanical tracking mechanisms, making them suitable for off-grid applications. [3]
- **Integration with Consumer Electronics:** Manufacturers are focusing on integrating features like USB ports and wireless chargers into portable solar panels, catering to the growing usage of consumer electronics. [1]

Semiconductors

- **How they work:** A diode is the simplest semiconductor device. This will block current in one direction while letting current flow in another direction [2]. They can be used as a conductor or insulator. They are used from simple clocks to aircrafts.
- **Make up:** Most are made up of crystals made of several materials.
- **N-Type:** The Electrons have a negative charge
- **P-type:** The absence of an electron creates the effect of a positive charge

Oscar. S {

Initial Computer Aided Design & Final Promotional Material Model

In almost every project there is a requirement for an initial design, this is usually made in a CAD (Computer Aided Design) software such as Fusion360, SolidWorks or Blender.

The Blender 3D CAD software was appropriate for this project because it has a good suite of supplemental features such as texturing algorithms, animation capability and a video sequencing tool that facilitated the production of a promotional video. The feature that finally inspired the use of Blender for this project was the fact it has a scripting feature, this utilises a python library called BPy to allow the user to operate the vast majority of Blender's functions with python code. The scripting feature made Blender the obvious choice, because it increases the relevance of the 3D design aspect of the project to the apprenticeship and degree.

The code below creates the stack of primitive shapes to the right, it is a good example of how the BPy library is used to manipulate the 3D model and scene within the Blender software.

The initial structure of the project is incredibly simple, 4 shapes created in 29 lines of code. The "bpy.ops" function allows python to call operators within Blender, the ".mesh" operator is for constructing meshes within the scene and it can be used to create many pre-set shapes, or to construct a custom mesh. In this case it is used with the ".primitive_cylinder_add" and ".primitive_cube_add" to create 3 cylinders of varying sizes. At the time, the measurements for components such as the motors, battery and solar panels were not available. For that reason the measurements are arbitrary, proportioned for aesthetic purposes only, but they can be changed easily simply by editing the values (m) in the "parts" lookup table.

```
parts = [
    ("Pot", "cube", {"size": 2.0}, 2.0, pot_mat),
    ("BaseMotor", "cylinder", {"radius": 0.2, "depth": 0.2}, 0.2, motor_mat),
    ("Stalk", "cylinder", {"radius": 0.12, "depth": 4.0}, 4.0, stalk_mat),
    ("TiltMotor", "cylinder", {"radius": 0.12, "depth": 0.2}, 0.2, motor_mat),
    ("Hub", "cylinder", {"radius": 0.4, "depth": 0.05}, 0.05, hub_mat),
]
created = {}
bottom_z = 0.0
```

```
for name, shape, kw, h, mat in parts:
    center_z = bottom_z + h / 2
    if shape == "cube":
        bpy.ops.mesh.primitive_cube_add(size=kw["size"], location=(0, 0, center_z))
    else:
        bpy.ops.mesh.primitive_cylinder_add(
            vertices=32,
            radius=kw["radius"],
            depth=kw["depth"],
            location=(0, 0, center_z)
        )
    obj = bpy.context.active_object
    obj.name = name
    obj.data.materials.append(mat)
    if name == "Stalk":
        bmod = obj.modifiers.new("Bevel", "BEVEL")
        bmod.width = 0.02
        bpy.ops.object.modifier_apply(modifier=bmod.name)
    created[name] = obj
    bottom_z += h
```



The next addition is a step up in complexity, adding the petals to the model. Thankfully BPy includes geometry and maths tools that can be used to make the petals symmetrical. In this case the “math” library is also imported to aid in calculations, with useful functions such as “math.pi”, “math.sin” etc.

The properties of the petals are defined at the top of the code snippet, this makes adjustments easy for testing different combinations, and once the measurements of the solar panels are available, allows visualisation of the final model before committing to building a prototype.

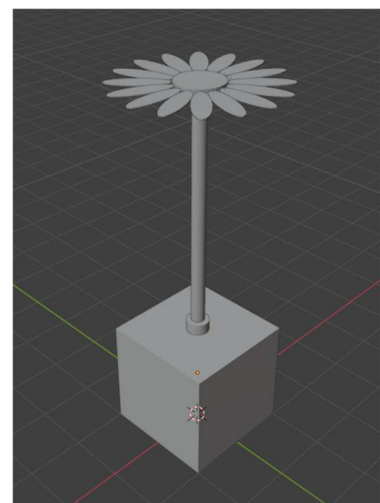
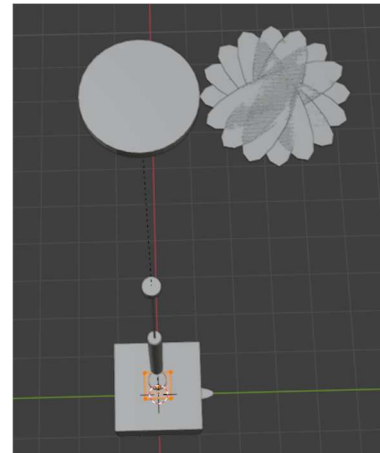
Each petal is simply a cylinder generated by the “primitive_cylinder_add” function, that has been sculpted into a flat oval. The “bpy.context.active_object” function directs the parameters to the currently selected object in Blender, objects can be selected using “bpy.data.objects[‘Cube1’]”, but in this case since the petal was the last object created, it is already selected.

The “math” library makes it possible to create a for loop that places the petals evenly around the circumference of the hub.

The loop in the code snippet below utilises polar - Cartesian coordinate conversion to place each petal at a specific point on the circle, “angle = 2*math.pi*i/petal_count” gives the spacing between each petal, multiplying by the loop index “i” steps around the circle one petal at a time.

“x = math.cos(angle)*R” and “y = math.sin(angle)*R” provide the x and y coordinate for the petal to be placed on the hub. cos(θ) and sin(θ) provide the unit circle coordinates at angle θ , multiplying by R pushes each coordinate out to the right distance from the center. The petal can then be created and placed using the 3D coordinates “location=(x, y, petal_center_z)” and rotated to the correct angle using “rotation=(0, 0, angle)”. Once in position the final parameters are applied such as naming the petal and assigning it a material and parent.

This was a matter of trial and error as evidenced by the top photo on this page where the petals have generated off center and the initial “Petal_0” has generated underneath the “pot”.



```
petal_length = 1.0
petal_width = 0.3
petal_thick = 0.02
petal_count = 16
petal_center_z = bracket_top_z + (petal_thick/2)
R = hub_radius + petal_length/2

bpy.ops.mesh.primitive_cylinder_add(
    vertices=16,
    radius=petal_width/2,
    depth=petal_thick,
    location=(R, 0, petal_center_z)
)

petal_proto = bpy.context.active_object
petal_proto.name = "Petal_0"
petal_proto.scale = (petal_length/petal_width, 1.0, 1.0)
petal_proto.data.materials.append(petal_mat)
petal_proto.parent = hub
petal_proto.matrix_parent_inverse = hub.matrix_world.inverted()

for i in range(1, petal_count):
    angle = 2*math.pi*i/petal_count
    x = math.cos(angle)*R
    y = math.sin(angle)*R
    bpy.ops.mesh.primitive_cylinder_add(
        vertices=16,
        radius=petal_width/2,
        depth=petal_thick,
        location=(x, y, petal_center_z),
        rotation=(0, 0, angle)
    )
    p = bpy.context.active_object
    p.name = f"Petal_{i}"
    p.scale = petal_proto.scale
    p.data.materials.append(petal_mat)
    p.parent = hub
    p.matrix_parent_inverse = hub.matrix_world.inverted()
```

Moving Parts

```
scene = bpy.context.scene
bpy.types.Scene.sun_rot = FloatProperty(name="Rotate Head", default=0.0, subtype='ANGLE', unit='ROTATION', min=-math.pi, max=math.pi)
bpy.types.Scene.sun_tilt = FloatProperty(name="Tilt Head", default=0.0, subtype='ANGLE', unit='ROTATION', min=-math.pi/4, max=math.pi/4)

drv = created['BaseMotor'].driver_add('rotation_euler',2).driver
v = drv.variables.new(); v.name='r'; v.type='SINGLE_PROP'
t = v.targets[0]; t.id_type='SCENE'; t.id=scene; t.data_path='sun_rot'
drv.expression='r'
drv2 = tilt_pivot.driver_add('rotation_euler',0).driver
v2 = drv2.variables.new(); v2.name='t'; v2.type='SINGLE_PROP'
t2 = v2.targets[0]; t2.id_type='SCENE'; t2.id=scene; t2.data_path='sun_tilt'
drv2.expression='t'

class SUNFLOWER_PT_controls(bpy.types.Panel):
    bl_label='Sunflower Controls'
    bl_idname='SUNFLOWER_PT_controls'
    bl_space_type='VIEW_3D'; bl_region_type='UI'; bl_category='Sunflower'
    def draw(self,ctx):
        l = self.layout; sc=ctx.scene
        l.prop(sc,'sun_rot',slider=True); l.prop(sc,'sun_tilt',slider=True); l.prop(sc,'env_rot',slider=True)

bpy.utils.register_class(SUNFLOWER_PT_controls)
```

The “bpy.types.Scene.sun_rot/sun_tilt” lines of code simply define sun_rot and sun_tilt as FloatProperties, this allows Blender’s python API to store them as a floating point value that is integrated into Blender’s UI. The values of both “sun_rot” and “sun_tilt” default to 0°, and the min/max values limit “sun_rot” to ±180° and “sun_tilt” to ±45°.

The next step is to create the drivers for the relevant parts, in this case “BaseMotor” and “TiltPivot”, or the motors at the bottom and top of the “stalk”. To do this, the line “drv =” assigns the euler rotation driver to the “BaseMotor”/“TiltPivot” object, “v =” and “t =” assigns a variable named “r” (rotation) or “t” (tilt), of the type “SINGLE_PROP” meaning it rotates around a singular axis, and links it to the “sun_rot”/“sun_tilt” float.

Finally the GUI can be created, the “bl_label = ...” line gives it the name “Sunflower Controls”, the “bl_space_type = ...” line tells Blender to create a tab under the UI options in the 3D View space. Lastly the line “l.prop(...)” adds 2 sliders to the tab, one connected to “sun_rot”, the other to “sun_tilt”.

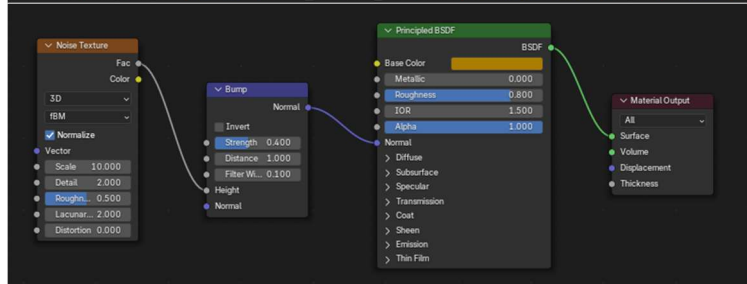


Finishing Touches

Textures

The code snippet shown here is what creates the 4 nodes below, which in turn creates the texture on the surface of the “dirt” in the 3rd image. Since all of the textures are coded in a similar manner, explaining one of them explains all of them, in this case the nodes “Noise Texture” (Brown), “Bump” (Blue), “Principled BSDF” (Green), and “Material Output” (Maroon) are created through the “dirt_mat.node_tree.nodes.new” function, with the “ShaderNodeTexNoise”, “ShaderNodeBump” and “Principled BSDF” parameters respectively. The “Material Output” node is created automatically, and the links are handled through the “dirt_mat.node_tree.links” function, apart from the link between the “BSDF” output and the “Surface” input which is handled when the “dirt_mat” material is initially defined. Adjusting the variables contained within the nodes is also simple thanks to the BPy API handling the sliders as

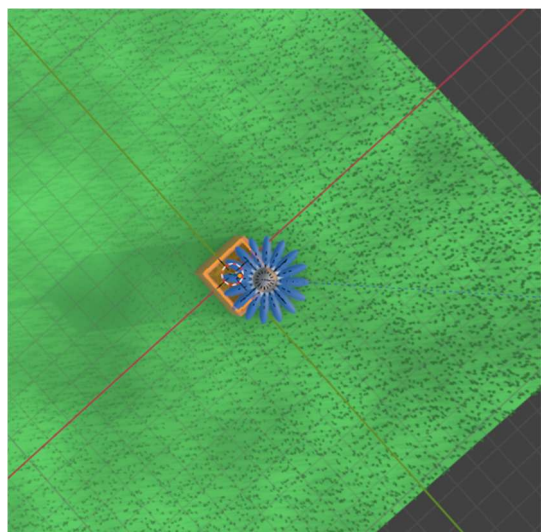
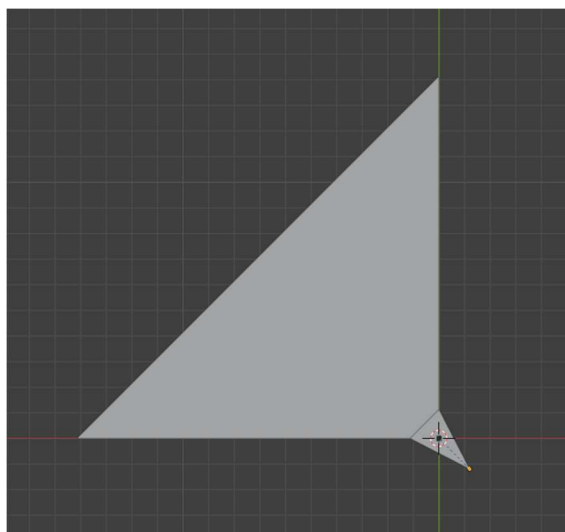
```
nodes = dirt_mat.node_tree.nodes
links = dirt_mat.node_tree.links
noise = nodes.new('ShaderNodeTexNoise')
noise.inputs['Scale'].default_value = 10
noise.inputs['Detail'].default_value = 2
bump = nodes.new('ShaderNodeBump')
bump.inputs['Strength'].default_value = 0.4
links.new(noise.outputs['Fac'], bump.inputs['Height'])
links.new(bump.outputs['Normal'], dirt_mat.node_tree.nodes['Principled BSDF'].inputs['Normal'])
```



“dirt_mat.node_tree.nodes.new(‘ShaderNodeTexNoise’).inputs[‘...’].default_value = ...”, which, thanks to variables, comes out to “noise.inputs[‘...’].default_value = ...”.

Grass

The grass was particularly difficult to get right. Because Blender’s Python API comes preloaded with modules such as BPy, mathutils, and bmesh, and it does not have access to the internet, an optimised hair simulation could not be imported. This meant that one had to be created from scratch.



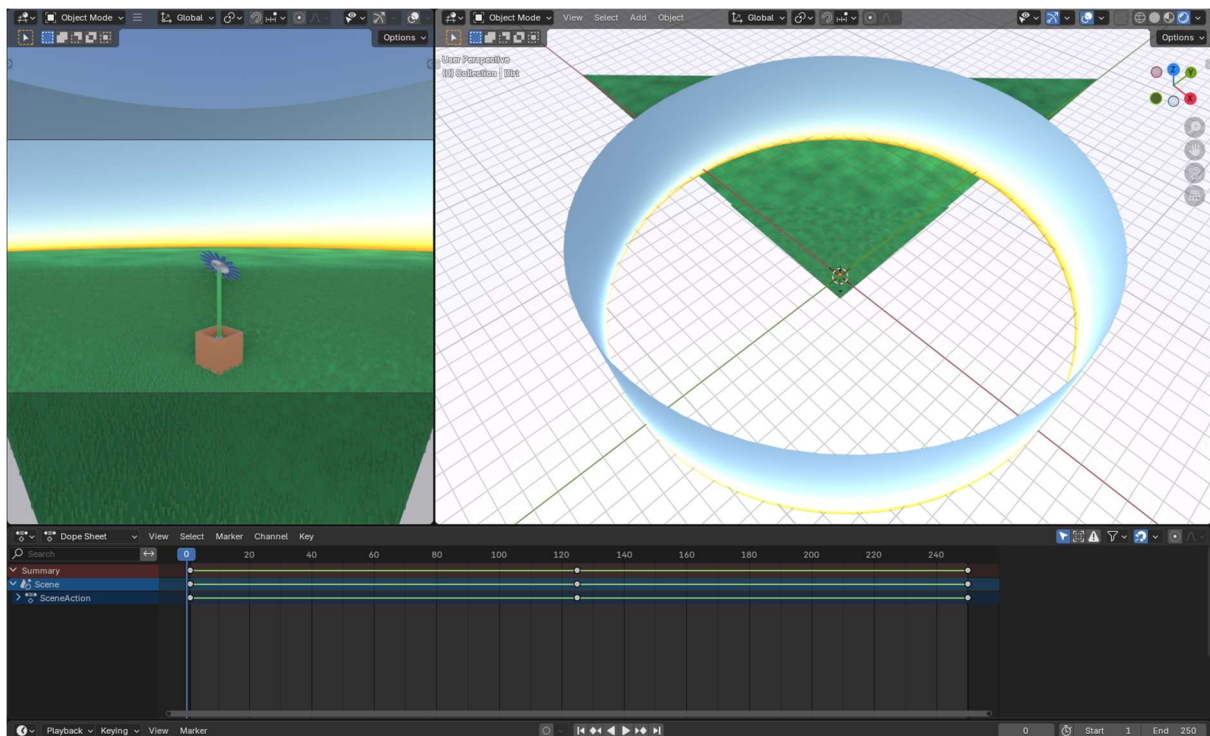
Initially the code was simple, it created a hair particle emitter plane and used the inputs to make each particle look like a blade of grass, unfortunately it quickly became apparent that the device that this project was being rendered on couldn't handle the memory requirements of 60,000 hair particles with a 5% child particle ratio, this created a requirement for an algorithm that would allow the density and size of the particles to decrease as the distance from the scene camera increased.

The code to the right is the algorithm that solves the memory issue, the “cam2d=Vector(...)” line takes the scene camera x/y coordinate and stores it as a 2D vector, the “hub2d” line does the same for the hub object. Storing these values as vectors allows the horizontal distance between the two

```
cam2d=Vector((cam.location.x,cam.location.y))
hub2d=Vector((created['Hub'].location.x,created['Hub'].location.y))
dist_val=(hub2d-cam2d).length
hair_rad=dist_val+pot_size*10.0
vg=hair_emitter.vertex_groups.new(name='Fade')
for vidx, v in enumerate(hair_emitter.data.vertices):
    d=(Vector((v.co.x,v.co.y))-cam2d).length
    w=max(0.0,1.0-(d/hair_rad))
    vg.add([vidx],w,'REPLACE')
psys=hair_emitter.particle_systems['GrassPS']
psys.vertex_group_density='Fade'
psys.vertex_group_length='Fade'
```

points to be measured, this measurement is stored in the “dist_val” variable. The “hair_rad” variable defines how far the grass fade effect extends. The for loop goes through each vertex (“for vidx, v in enumerate(hair_emitter.data.vertices)”), retrieves its coordinates (v.co.x/y), measures its distance from the camera (“d=(Vector(...))”), and based on the distance assigns a normalised weight that falls from 1 at d=0, to 0 at “hair_rad”. This weight is what tells the hair particles to reduce their density and length through the “psys.vertex_group_density/length” functions.

A few other finishing touches were added, such as the rotating “sky” background shown in the image below. Since they were mainly for aesthetic purposes and didn't require a high level of mathematical, engineering or programming knowledge they will not be covered in this document, however they were essential for creating a rendered video to be used as promotional material for our project, in order to help draw funding.



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Components & Roles

Component	Purpose	Notes
PIC16F877A (Microcontroller)	Brain of the system, controls the tracking mechanism and logic (based on LDR input)	Widely used in embedded systems.
LDRs (Light Dependent Resistors)	Detect light intensity to help orient the solar panel to face the strongest sunlight (i.e., solar tracking)	A set of 4 is typical for 2 axis tracking.
LM393 (Comparator)	Compares light levels from LDRs to provide analogue signals that can be interpreted for direction	Good for simple LDR input processing.
Transistors (2N1711)	Likely used to drive motors or switching logic	Acceptable NPN general purpose transistors.
Stepper Motors (28BYJ-48 + ULN2003)	Adjust the solar panel position (pan/tilt for solar tracking)	Budget-friendly motor + driver for small, lightweight panels.
Solar Panels (Round & Rectangle)	Generate electricity	Fine for demonstration or light loads. Size and power are limited (5V, 30mA per panel).
Battery Pack + Charge Controller	Store energy and regulate charging to prevent overcharging	USB based charger is ok but not ideal for direct solar charging without DC-DC conversion.
Wood	Base/chassis to mount the system	Cost effective and customisable.
Power Bank (10,000 mAh)	Stores electricity for later use	Suitable, but cautious with voltage compatibility with motors and microcontroller.

Testing Kit (DOKIO Panel)	For lab-based larger power generation tests	Overkill for shoebox size, used for development/testing.
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Table 2, Components

Potential Issues

Power Output: Panels that are low wattage may struggle to charge the 10,000mAh power bank effectively.

Charge Controller: The USB-type charger may not be efficient or appropriate for solar input no buck/boost regulation.

Motor Draw: Stepper motors may consume more current than panels can support during operation.

Voltage Mismatch: Be cautious of voltage differences between PIC, motors, and power source.

Safety considerations

Fire:

Most solar panels don't have an automatic fire detection system, so a fire can take hold quickly and spread before it is discovered.

Battery:

It is essential to calculate the appropriate overall capacity and voltage requirements to meet the device needs during non-sunlight hours. Under sizing the battery bank capacity risks running out of stored power too quickly, while oversizing adds unnecessary weight and expense if abilities go unused.

Solar Charge Controller:

A vital component in a portable solar system is a solar charge controller. Its key role is to regulate the flow of electricity from the solar panels to the battery bank to prevent issues like overcharging. Charge controllers protect batteries from damage by capping the voltage and current flow during charging.

Connections:

Loose wiring and connections, weathering, or damage, which could degrade function or pose safety risks if left unchecked.

Parts list

Round solar panel

[Gdfnmogo 120Mm Circular Solar Cell Module 1.1W 5V Polycrystalline Silicon Panel Portable Lightweight Green Energy Source for DIY Projects, Solar Panel : Amazon.co.uk: Business, Industry & Science](#)

Square solar panels

[SUNYIMA 10Pcs 5V 30mA Mini Solar Panels for Solar Power Mini Solar Cells DIY Electric Toy Materials Photovoltaic Cells Solar DIY System Kits 2.08"x1.18"\(5V 30mA 53mmx30mm\) : Amazon.co.uk: Business, Industry & Science](#)

Diodes

[20 Pcs Photoresistor Diodes Photo Light Sensitive Resistors LDR Resistors Photo Light Sensitive Sensors for DIY and Experiments 5537 GL5537 : Amazon.co.uk: Business, Industry & Science](#)

Battery charger control

[Hailege 10pcs Type-C USB 5V 1A 18650 Lithium Battery Charger Module Charging Board with Dual Protection Functions: Amazon.co.uk: Business, Industry & Science](#)

Motors (5V)

[Alcric 2Sets 28BYJ-48 DC 5V Stepper Motor + ULN2003 Driver Test Module Board : Amazon.co.uk: Business, Industry & Science](#)

Testing kit

[DOKIO 100W 12V Foldable Solar Panel Kit Monocrystalline with Solar Controller \(2 USB Output\) for 12V Battery Charging, Caravan, RV, Boat, Camper : Amazon.co.uk: Business, Industry & Science](#)

Alternative Parts list

TP4056 battery charge module

[10pcs TP4056 Type-c USB 5V 1A 18650 Lithium Battery Charger Module Charging Board with Dual Protection Functions: Amazon.co.uk: Electronics & Photo](#)

3.7V Lipo battery

[EEMB Lithium Polymer battery 3.7V 2000mAh 103454 Lipo Rechargeable Battery Pack with wire JST Connector for Bluetooth Speaker and Dashcam-confirm device & connector polarity before purchase: Amazon.co.uk: Electronics & Photo](#)

Arduino Nano

[Nano V3 Module with Mega328 XTVTX 5 Pieces Nano Module Chip CH340 Type-C Connector 5V 16M Microcontroller Compatible Arduino: Amazon.co.uk: Business, Industry & Science](#)

ESP32 board

[3 pack ESP32 ESP-32S Development Board 2.4 GHz Dual Core WLAN WiFi + Bluetooth 2-In-1 Microcontroller ESP-WROOM-32 Chip CP2102 for Arduino \(3PCS\): Amazon.co.uk: Business, Industry & Science](#)

}EDeLange

Jamie Hamilton-Swingewood & O Miller {

Background Research

Solar photovoltaic (PV) technology has rapidly become a cornerstone of clean power generation worldwide. Global installed PV capacity surpassed 2 terawatts (TW) by the end of 2024 after a record ~600 GW of new solar was added in that year alone [5]. Europe and the UK are major contributors, accounting for about 23% of cumulative PV installations as of 2024. In the United Kingdom, solar adoption has grown significantly, with the total PV capacity reaching approximately 17.6 GW by the end of 2024 [6,7]. Solar panels now provide a substantial share of electricity in many countries and are integral to strategies for carbon reduction and energy security in the UK, Europe, and globally.

Varieties in Solar Panels for Electricity Generation

Modern solar panels can be categorised by the semiconductor technology they use. The vast majority of today's solar PV production is based on crystalline silicon, like most semiconductors today, but other more novel technologies exist.[6]

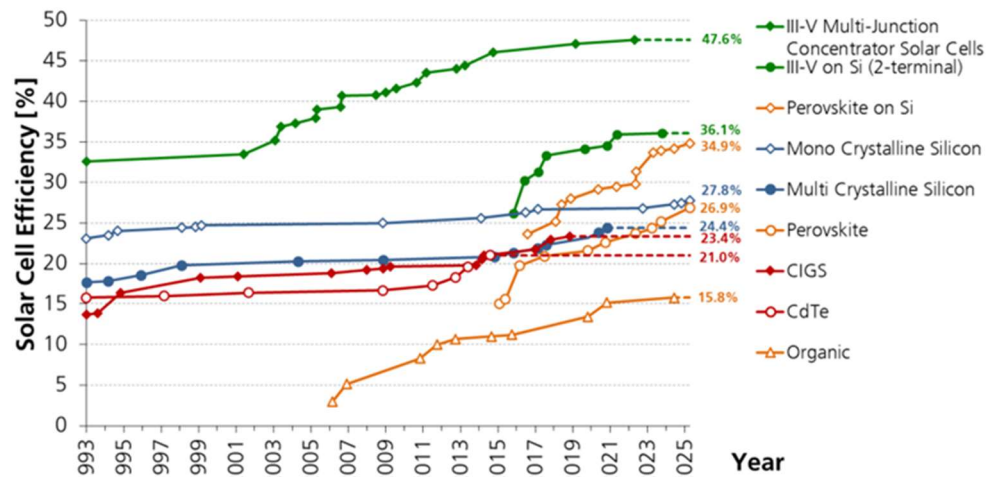
Crystalline Silicon

This includes monocrystalline and polycrystalline silicon cells. Monocrystalline silicon cells are cut from single-crystal ingots, appearing uniform dark black, and are currently the dominant technology, having largely overtaken polycrystalline in market share. These cells offer high efficiency as typical commercial module efficiencies are in the 20% range and long-term stability. Lab-scale monocrystalline silicon cells have achieved record efficiencies around 27%. Polycrystalline cells, made from cast blocks of multi-grain silicon, were historically cheaper and easier to manufacture, but less efficient. Advances in cell designs (like PERC and heterojunction cells) have continually improved crystalline silicon performance – for example, the average silicon module efficiency has climbed from ~16% to over 22% in the last decade. Crystalline silicon panels currently dominate residential and commercial installations due to their reliability and steadily decreasing cost [6].

Thin-Film Solar Cells

These panels use thin layers of semiconductor deposited on glass or flexible substrates, allowing for lighter and sometimes semi-transparent modules. The main commercial thin-film technologies are cadmium telluride (CdTe) and CIGS (copper indium gallium selenide), with a small share for amorphous silicon. Thin-films generally have lower efficiency than crystalline silicon, but can be cheaper to manufacture at scale and perform better in high temperatures or diffuse light. CdTe, in particular, has seen success in utility-scale projects – it makes up around 30% of the U.S. utility-scale PV market. Module efficiencies for CdTe have reached about 18–19% in production, up from ~9% a decade ago. Lab cell efficiencies for CdTe and CIGS are improving; current records stand at roughly 21.0% for CdTe and 23.4% for CIGS. These remain slightly below silicon cell records. Thin-film panels are typically used in large solar farms and niche applications like building-integrated PV[6,8].

Development of Laboratory Solar Cell Efficiencies



Laboratory results for the solar cell efficiency of various types of solar cell. Credit Fraunhofer ISE [6].

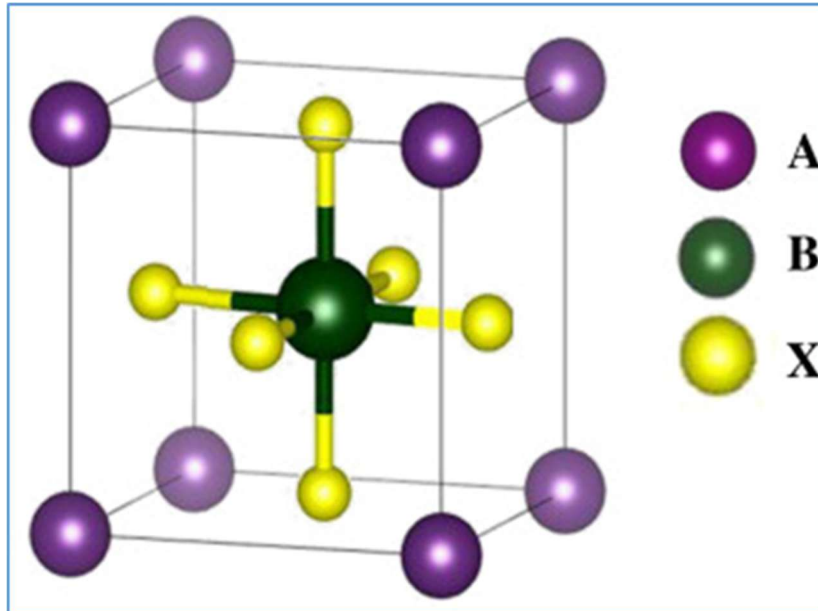
Emerging PV Technologies - Perovskites and Beyond



A perovskite is a type of crystal structure made of 3 different elements with a formula of ABX_3 , but was originally discovered by Gustav Rose in 1839 from the mineral calcium titanite, chemical formulae $CaTiO_3$, known as perovskite where the crystal structure gets its name .

Perovskite, from Magnet Cove, Arkansas.
Andrew Silver/U.S. Geological Survey

With the atomic structure forming around atoms A and B (cations) of different sizes forming the shapes, cuboctahedron and octahedral respectively and the X being bound in a face centred cubic position.[6,9,10].



Representation of a perovskite crystalline unit cell structure, with A and B the cations and X being an anion such as oxygen. Credit [5]

Perovskites have attracted enormous research interest. Perovskite cells can be fabricated by solution-based processes, such as printing, offering the prospect of very low-cost, lightweight panels. They have achieved remarkable efficiency gains in a short time; single-junction perovskite lab cells now exceed 25% efficiency [6]. A major breakthrough has been perovskite/silicon tandem cells, which stack a perovskite cell atop a silicon cell to capture a broader solar spectrum. Tandem lab cells have already reached about 28–29% efficiency, outperforming the theoretical 30% efficiency limit of silicon-only cells. In 2023, Oxford PV announced a commercial-size tandem solar panel achieving 25% module efficiency about 20% higher output than typical silicon modules. Other emerging technologies include organic photovoltaic cells (conductive polymers, offering flexibility) and quantum-dot or III-V multi-junction cells (used in specialized applications like space). Many of these are still in R&D or early commercialization stages. Overall, crystalline silicon remains the workhorse for mainstream use due to its proven performance and cost, while thin-films and novel cells target specific niches or promise future improvements.[7,9-12]

Recent Breakthroughs and Developments

Solar technology is progressing on multiple fronts, be it the compounding effect of incremental improvements in mainstream silicon panels to novel materials at the cutting edge. Some of the notable recent breakthroughs include:

Higher Efficiency Cells and Modules

Efficiency records continue to be broken each year. In the silicon realm, manufacturers have transitioned from standard aluminum-back-surface-field cells to high-efficiency architectures like PERC, TOPCon, and heterojunction. This has raised average module efficiencies above 22% [6], and the best commercial silicon modules now exceed 24% efficiency [13]. In late 2024, the industry roadmap saw a rapid shift toward n-type silicon wafers and TOPCon cell technology, which was expected to make up over 70% of new production by 2024, bringing further efficiency gains.[11] On the cutting edge, tandem and multijunction devices have made headlines: Oxford PV's perovskite-silicon tandem panels mentioned earlier achieved 25% module efficiency (producing 421 W from a 1.68 m² panel) in 2023, in collaboration with Fraunhofer ISE. This world-record panel is poised for commercial deployment and delivers 20% more power than conventional silicon modules of the same size. Meanwhile, specialized multijunction cells (using III-V semiconductor layers) set a new efficiency record of 36.1% (without concentrators) for a silicon-based triple-junction cell in 2023. [14]

Cost Reductions and Scale:

A less glamorous but equally important breakthrough has been the dramatic reduction in solar costs, which continued through 2023. An oversupply of PV modules, coupled with improvements in manufacturing, drove module spot prices down by about 50% in 2023 alone. [11] This steep price drop, on top of decades of cost decline, has made solar the cheapest form of new electricity in many regions. Even in the UK and northern Europe (with moderate solar resources), the levelled cost of solar electricity has become very competitive. The plunging cost has accelerated deployment: global PV installations nearly doubled from 2022 to 2023, reaching ~430 GW of new installs in 2023i. The scalability of manufacturing (especially in China, which now dominates module production) is itself a breakthrough, enabling multi-terawatt deployment of PV in the coming decade. Industry forecasts project that by 2030 the world could be installing 1 TW of solar per year, driving cumulative capacity well beyond 7 TW. In Europe, new policies under the Green Deal and REPowerEU are aiming to boost domestic manufacturing and deployment, recognizing solar as a strategically vital technology.[5,11]

}Jamie Hamilton-Swingwood & Owen Miller

Design and implementation

Build considerations

How the device will be powered:

Since the panel is solar-powered:

Primary Source: The solar panel itself.

Backup or Storage: A battery pack to store excess energy and power the system during cloudy periods or at night.

How to harvest the power collected:

Harvesting the energy absorbed by a solar panel involves converting the sunlight into usable electrical energy and storing or using it efficiently. Solar panel converts sunlight into DC electricity. A charge controller with inbuilt protection was used for preventing overcharging

Regulates voltage to battery-safe levels

Controls charging current.

Output: 5V, regulated to match motor and controller requirements.

Size constraints:

For this device to be portable it needs to be small, paying careful consideration to:

- Internal component space
- Solar panel area
- Battery size
- Cooling/ventilation
- Movement of motors
- Weight

Part & Motor Restraints:

As the project is working within restraints, due to size, weight, time and cost, then it's essential to prioritise compact, efficient, and multi-functional components.

All design ideas were created with this in mind

Using two 5V motors for rotation

Estimate per motor: ~150–250mA under normal load

Daily run time, (if moving every 5-10 minutes for a few seconds

Total energy usage per motor/day:

$(0.25 \text{ A} \times 5\text{V} \times 10 \text{ min}/60) \approx 0.21 \text{ Wh}$ per motor

Total for 2 motors $\approx 0.4\text{--}0.5 \text{ Wh/day}$

Power being 5V and resistance due to weight on the rods

Motor Load and Wear:

If the panel is unbalanced, the motors must work harder to overcome gravity or uneven distribution of force.

Over time, this leads to increased wear on the motors, reducing lifespan and increasing maintenance costs

Accuracy and Efficiency:

Balanced systems respond better to control signals, leading to smoother and more accurate tracking of the sun.

Minimizes backlash and drift, important for maximizing solar energy harvest.

Low Power Consumption:

In a self-powered system, any power wasted turning an unbalanced load is energy not going into charging the battery or powering devices.

Proper balance allows for smaller, more efficient motors and controllers.

Structural Components:

Imbalanced forces create stress on mechanical components such as bearings, mounts, and brackets. This can lead to bending, cracking, or failure under wind loads or during rotation.

Mount the solar panel directly on top of the box, put the servos and tilt mechanism just under the panel. Place the battery and electronics in a dedicated tray or under-deck inside the box.

Design ideas

Side view of box, bearing and motor, solar array will be fitted on top of the platform.

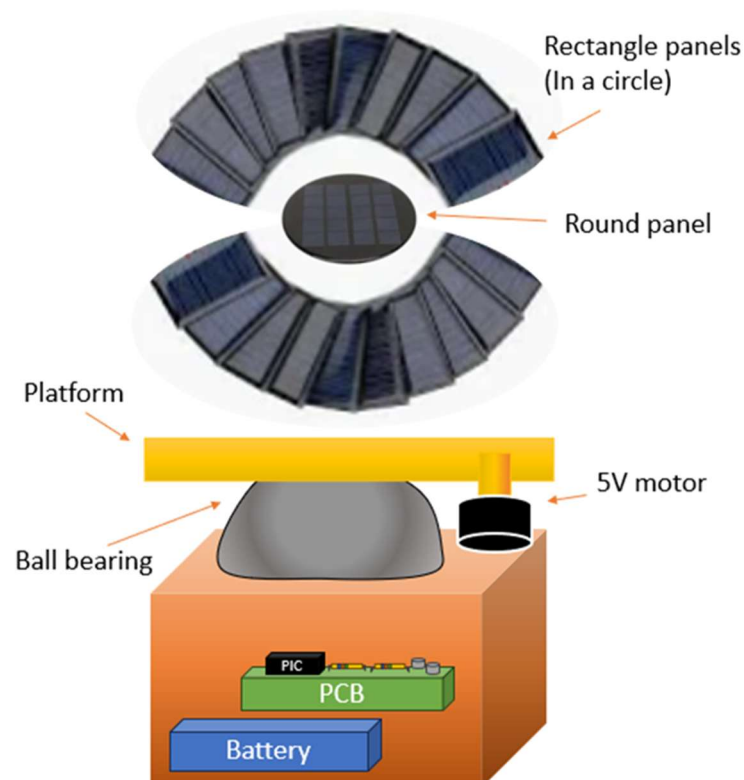


Figure 2, Side view design concept

Top view of platform

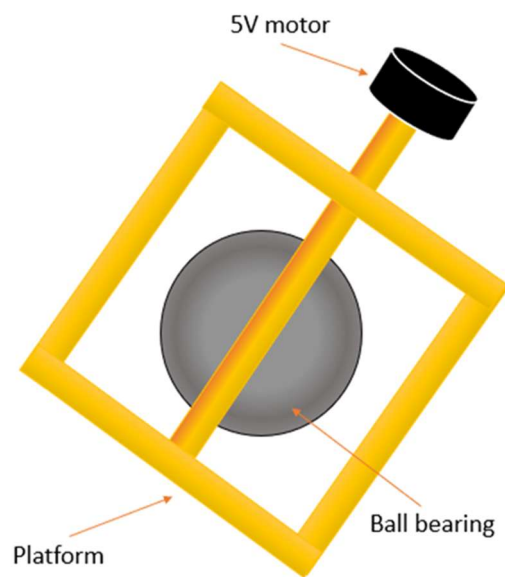


Figure 3, Top view of platform design concept

Weighted platform idea

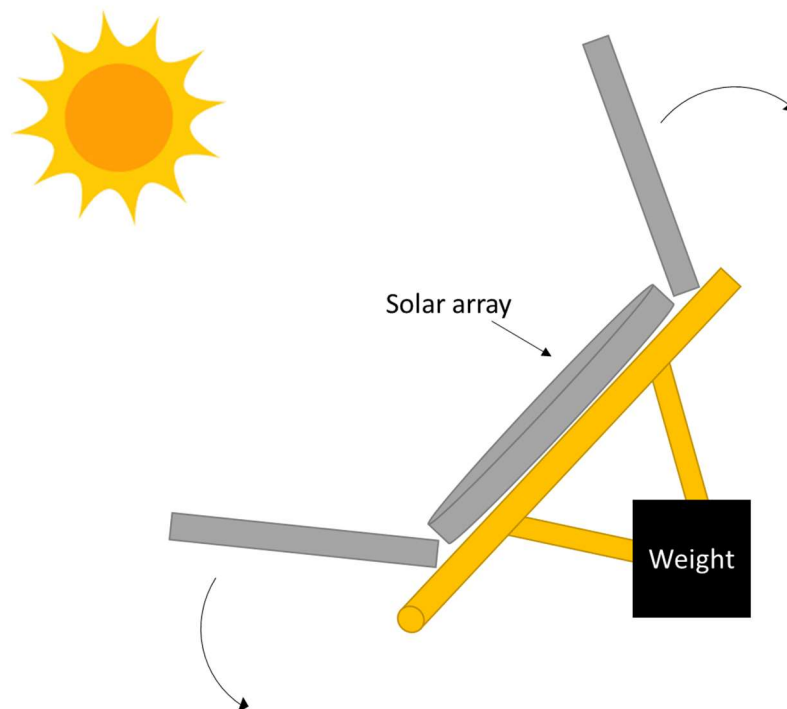


Figure 4, Weighted platform idea

Flow chart

Start point is the sunlight

Solar panels convert sunlight into electricity

Charge controller regulates charging to battery

Battery, stores energy

Step up converter converts voltage

Microcontroller, controls the system, reads sensors and sends commands

LDR sensor, decides how to adjust motor

Motors, move the solar panels for optimum charging

End

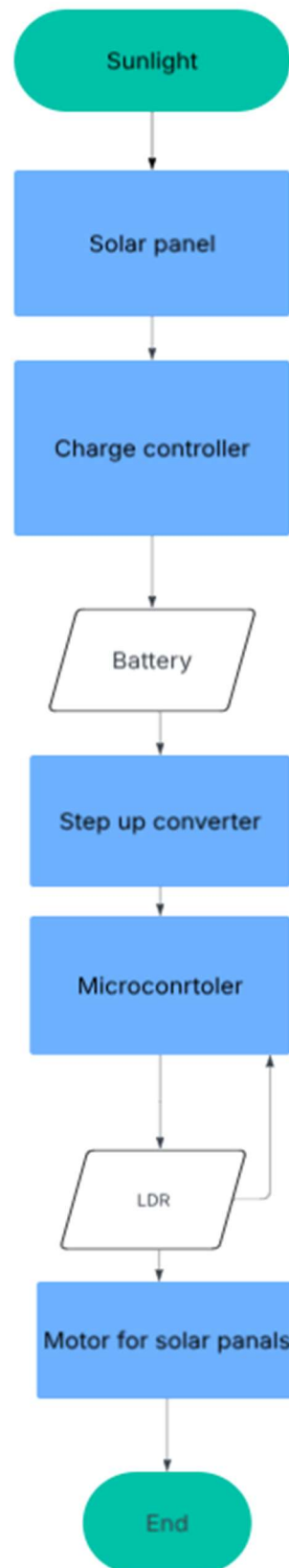


Figure 5, Flow chart

Cost

Direct costs:

Labour, materials, tools.

Indirect costs:

Utilities, rent, overheads

Contingency costs:

Uncertainties

$$C = (\text{Labor} \times \text{Time}) + (\text{Parts Cost} \times \text{Scope}) + (\text{Performance})$$

40 hours x 5 = 200 hours

Parts cost = £236.53

Scope = Five team members, medium difficulty

Performance = Time for testing and quality control, Industry standard soldering class 3.

}EDeLange

Simulation and design

First, a simulation had to be made to test and confirm any potential design ideas. The priorities of the functionality of this circuit is that it somehow senses sunlight then correctly outputs to a motor system redirecting the direction in which the solar panel is facing. To achieve this in the most cost effective and electronically efficient way possible it was decided to use LDRs (Light Dependent Resistors) as the components to detect the sunlight's intensity. To then be able to track the sun's position, these will be placed on each of the four sides of the solar panel and one in the centre as this could be interpreted by a control IC (Integrated Circuit), for example when it detects a higher light source than in the centre on one of the sides of the solar panel it will move in the corresponding direction until the centre is absorbing the most light possible. The simulation that was first designed can be seen below.

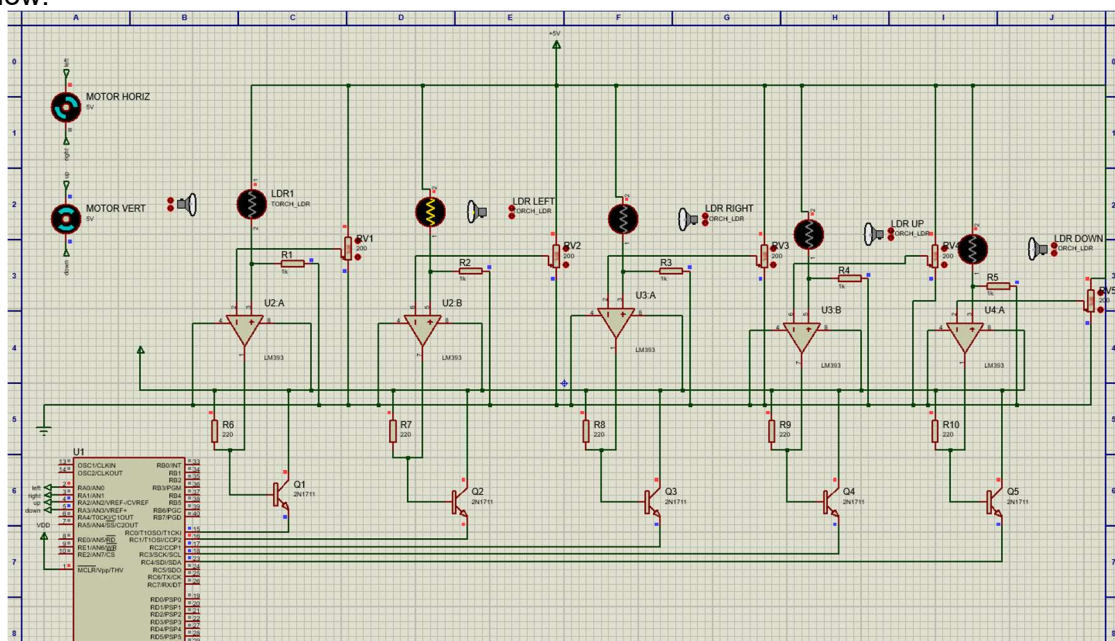
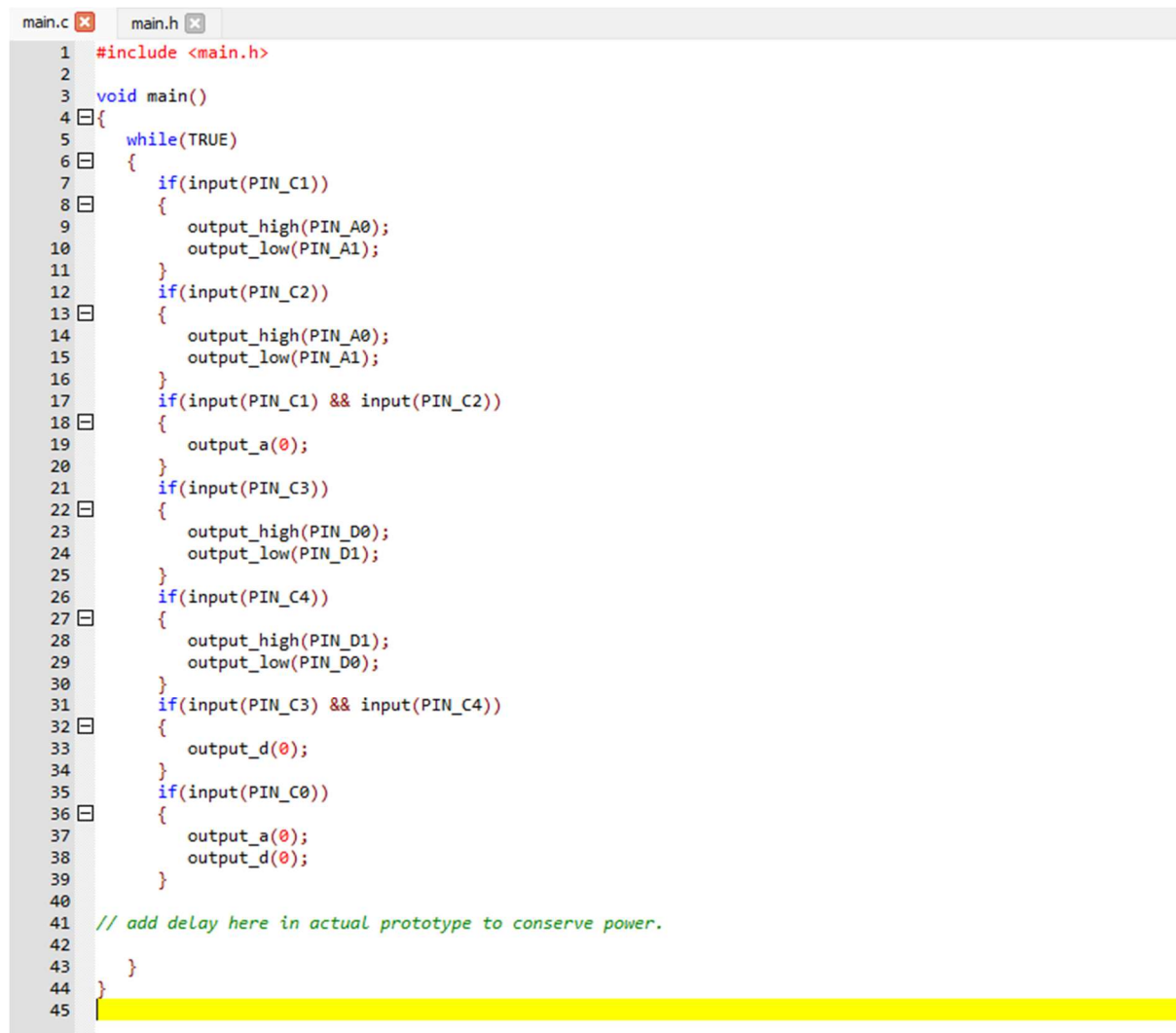


Figure 6, Wiring circuit

This design uses several comparators to correctly measure the lights intensity and output to the IC if the lights intensity reaches a specified threshold. This is achieved due to the characteristics of the comparators; a comparator operates by quantifying 2 voltage sources, one to flow into the “+” (non-inverting) input and another to the “-” (inverting) input. And if the non-inverting input is higher than the inverting, the output will sink the current it's holding to ground through the ground pin. The operation of the comparator is powered by a separate voltage source. To translate the light which is being sensed to the comparators outputting, the LDRs were inputted into the non-inverting input from the main power line and a line with a set resistance was plugged into the inverting input, acting as a reference voltage. So, if the LDR reaches a low enough resistance by light shining on the component, the voltage will increase which is flowing into the non-inverting until the voltage is greater than the inverting input the the comparator will sink the output to ground. This system effectively measures the light intensity of whatever location the LDRs are placed and converts it to a digital data form of +5V or 0V. This could easily be interpreted by a control IC.

The control IC picked was a PIC16F877A as this is one of the most used and readily available PICs and we are used to working with PIC microcontrollers. However, this could be improved by using a smaller IC as this design only uses nine digital I/O pins, and this would use less power, but I can anticipate a potential issue with the motors in future tests where the motors can only run at full speed and the PIC16 will allow us to use its PWM (Pulse Width Modulation) capabilities, this will solve the potential issue with the motors as this will set a slow enough speed for the motor to spin with the set duty cycle. The code in the PIC was decided on as C, this is due to the adaptability of the language compared to assembly. The first code written is in the simulation and can be seen below.



```

1  #include <main.h>
2
3  void main()
4  {
5      while(TRUE)
6      {
7          if(input(PIN_C1))
8          {
9              output_high(PIN_A0);
10             output_low(PIN_A1);
11         }
12         if(input(PIN_C2))
13         {
14             output_high(PIN_A0);
15             output_low(PIN_A1);
16         }
17         if(input(PIN_C1) && input(PIN_C2))
18         {
19             output_a(0);
20         }
21         if(input(PIN_C3))
22         {
23             output_high(PIN_D0);
24             output_low(PIN_D1);
25         }
26         if(input(PIN_C4))
27         {
28             output_high(PIN_D1);
29             output_low(PIN_D0);
30         }
31         if(input(PIN_C3) && input(PIN_C4))
32         {
33             output_d(0);
34         }
35         if(input(PIN_C0))
36         {
37             output_a(0);
38             output_d(0);
39         }
40
41         // add delay here in actual prototype to conserve power.
42     }
43 }
44
45

```

Figure 7, Code for device

The code above is a very basic example which has not been refined yet. But this demonstrates how simple, thanks to the circuitry, the code can be as it only has to interpret five inputs and four outputs which are all basic digital I/O (Input/Output) pins. It may be seen at the bottom of the code, there is some green text saying to add a “delay”, this is an integral part of the code as the sun will move very slowly in angle and there may be more intense light being sensed from reflected sources etc, however if a long time delay was implemented it would only move consistently with where the sun is in small steps via the PWM outputs to the motors.

Breadboard design

Next it was required to begin breadboarding and testing of the circuitry that was designed in the simulation. This was tested by replacing the outputs with LEDs to signify what the PIC would read (either +5V or 0V). The first breadboarded circuit was made using one LED (one output) this seemed to work fine but when a second LED was added to the breadboard the circuit wasn't working properly, after some troubleshooting the circuit was redesigned to a more effective and slimlined circuit. Which resulted in a breadboard appearing as below.

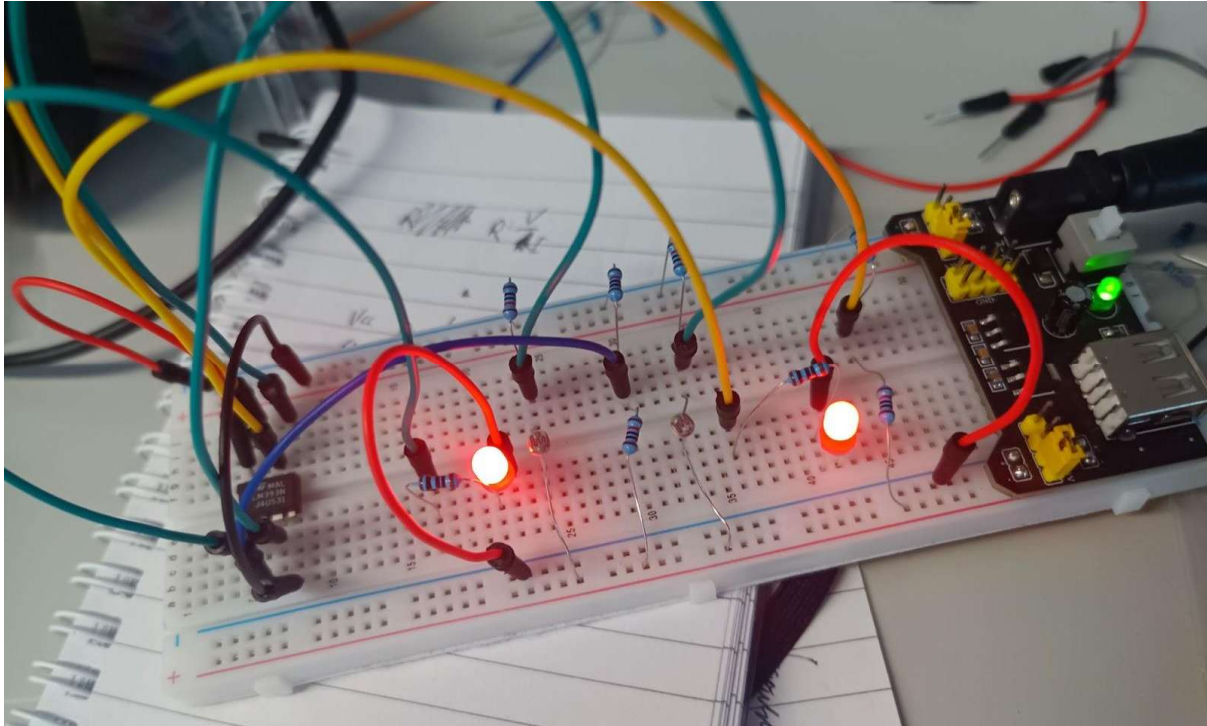


Figure 8, Breadboard design

The modifications to the circuitry can be seen in the redesigned proteus simulation below.

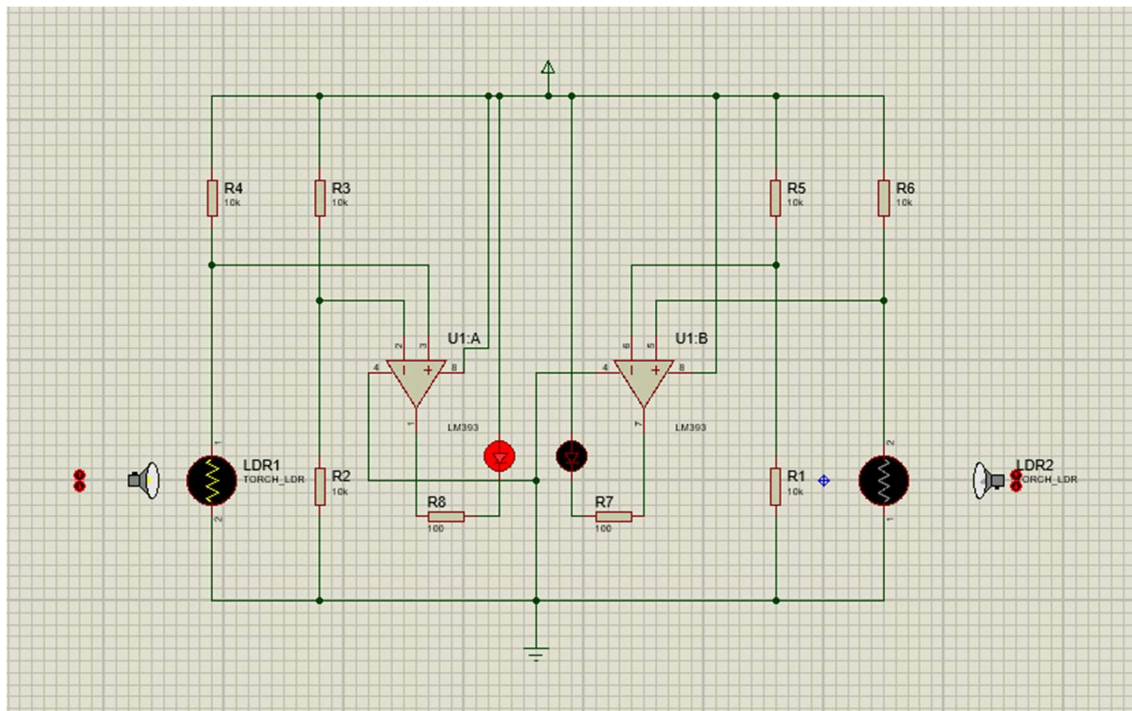


Figure 9, Modified circuit

The modifications included:

- Removing the transistor sub-system as they were not needed to output the desired voltage as previously thought.
- Simplifying the inverting and non-inverting input sources by having a set resistance in the voltage reference.
- Switching the inverting and non-inverting inputs so that the inverting input is the voltage reference and the non-inverting as the measuring source connected to the LDR.
- Only having one power rail and one ground rail, this will massively simplify the eventual PCB/circuit.

Circuit Design

From this a soldered version was made which included all the required comparators, using the LM393 dual-comparator component which is a very common 8-pin chip which contains the functionality of two comparators. All other components used are standard and the same as the simulation. This can be seen below.

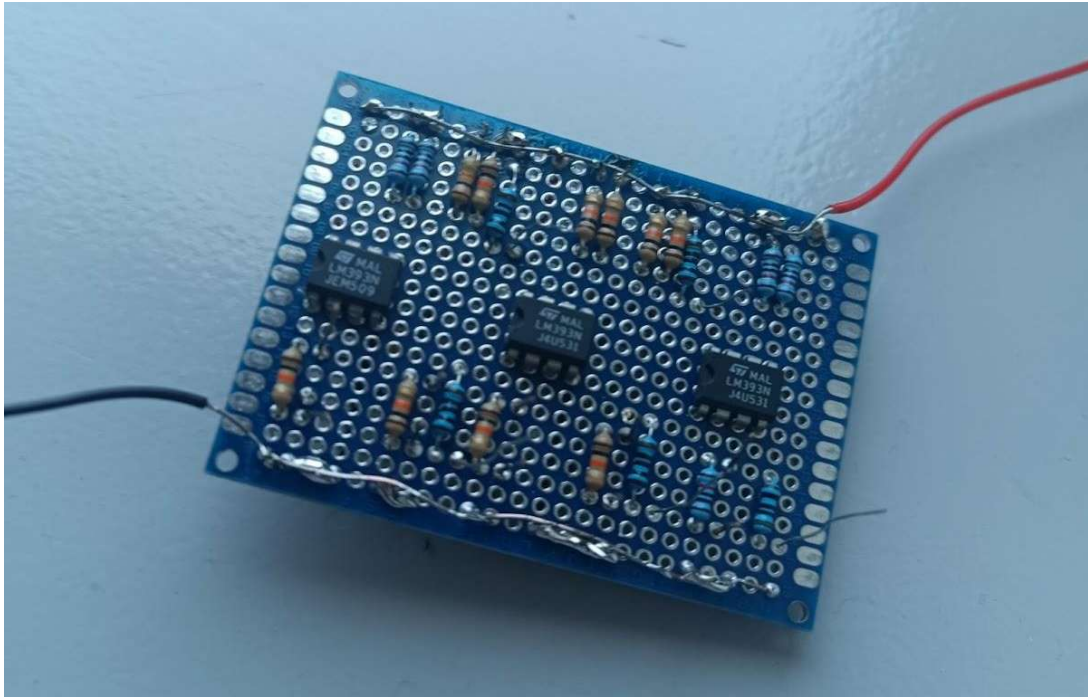


Figure 10, Top view of circuit

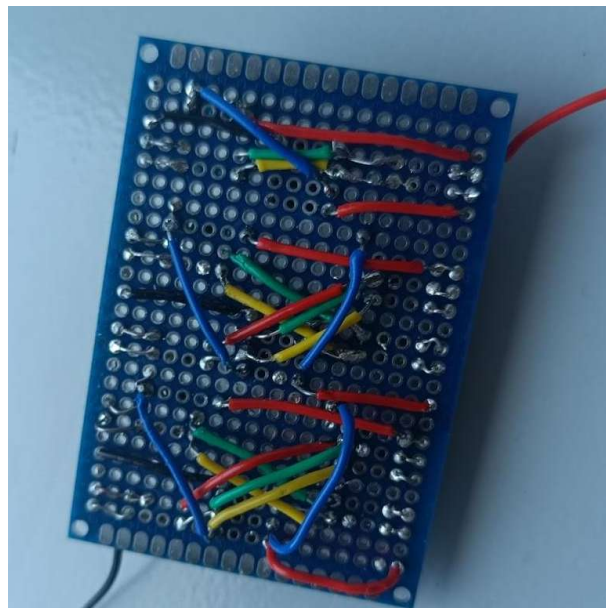


Figure 11, Bottom view of circuit

This design is run off of a single ground line and a single power line with naked wires for the positive and negative wires for the LDRs and each of the comparators outputs for all of the I/O pins of the PIC. Due to this not being a solid PCB with simple power lines modification, repairs and resoldering may be completed with relative ease if needed, for example swapping out resistors for a more or less sensitive light sensor system or resoldering a joint due to a lack of connection.

Assuming that this is the final circuit design, the final design for the whole sensor system would appear as the adapted simulation below with the PIC on a separate control board connected to the motors, power and the sensor circuit.

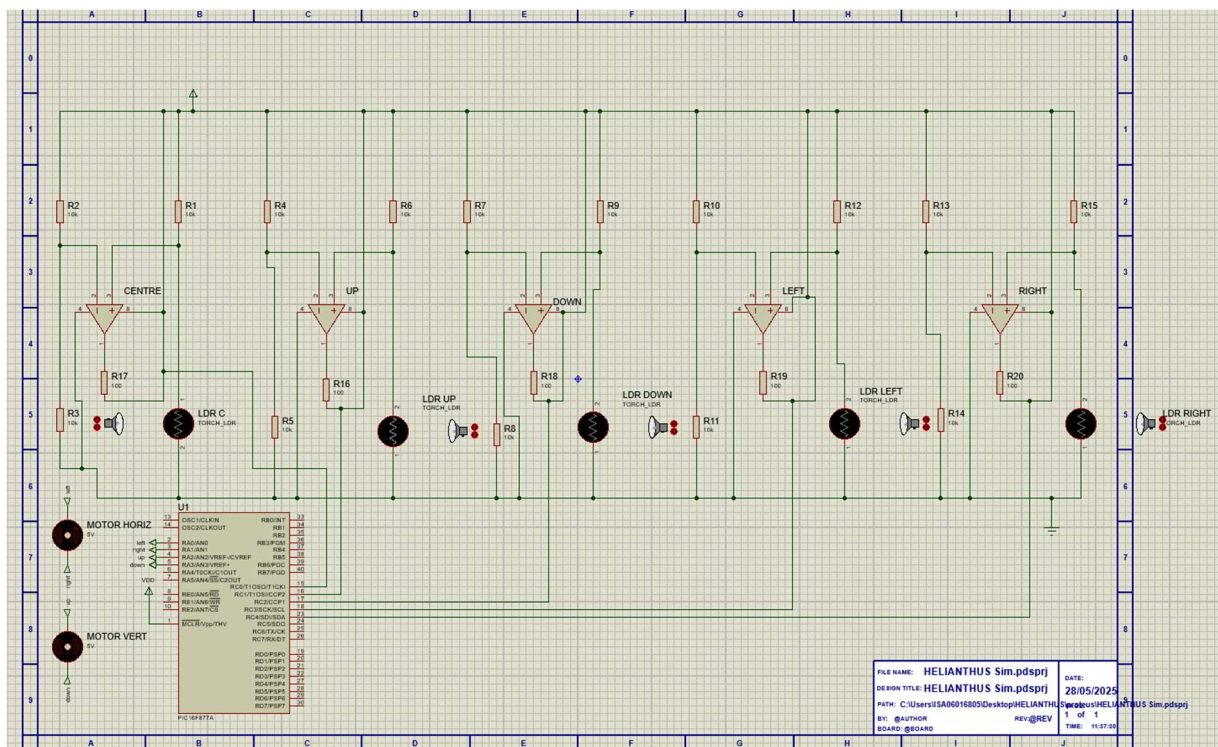


Figure 12, Final circuit design

Control IC Integration

For the integration of the PIC microcontroller it was first researched about how to set up and power a PIC and what equipment would be needed. It was found that first software would be needed, specifically "MPLab X IDE" which is an expandable and highly configurable piece of software designed to help program microcontrollers, specifically PICs. An IPE (Integrated Programming Environment) would also be needed to be able to actually write the code in C that will then compile the data into hex form (hexadecimal) so that the chip can interpret the commands that are needing to be completed. Then some hardware would be needed to be able to connect to the PIC on a testing board, this includes a "programmer" or "debugger" such as a PIC Kit, this will allow the chip to be able to connect to a laptop or desktop to be able to upload the code and "debug" the chip. A programming circuit is also needed to be able to connect the data flow to the correct pins on the PIC such as the ICSP (In-Circuit Serial Programming) pin. Lastly, a target board would be needed to connect the microcontroller to the programmer and other components in the form of a breadboard or PCB.

The code that is implanted into the PIC will have to be adapted due to the resign, this is due to the power line being directly connected to the input pins of the PIC, this means that the PIC will have to register a low input as the input instead of a high input. This is an easy fix and the code will appear as below.

```

void main()
{
    while(TRUE)
    {
        if(!input(PIN_C1))
        {
            output_high(PIN_A0);
            output_low(PIN_A1);
        }
        if(!input(PIN_C2))
        {
            output_high(PIN_A0);
            output_low(PIN_A1);
        }
        if(!input(PIN_C3))
        {
            output_high(PIN_D0);
            output_low(PIN_D1);
        }
        if(!input(PIN_C4))
        {
            output_high(PIN_D1);
            output_low(PIN_D0);
        }
        if(!input(PIN_C0))
        {
            output_a(0);
            output_d(0);
        }

        // add delay here in actual prototype to conserve power.
    }
}

```

Figure 13, Final code

Comparing this to the original code, they are widely the same besides the “!” before the input statements, this effectively changes the statement from “If input, do this” to “If no input, do this”. This modification fixes the problem of the circuit switching the high and low inputs into the microcontroller. The code seen above should be efficient in tracking the sun’s light, as it works by only moving if there is little sunlight detected in the centre and then moves in the direction where light is detected then stopping when the sunlight is at an adequate intensity in the centre again. This means that if random sources of light shine on it, it will not move as sunlight is still detected in the centre, this increases the overall accuracy of the solar panel throughout the day.

The next step was to start to integrate the PIC microcontroller into the wider circuit, this was achieved by first breadboarding the, now programmed, PIC into a circuit which powers and regulates the operations of the microcontroller, this was completed and no technical difficulties were present. The circuit needed to power and regulate the PIC can be seen below.

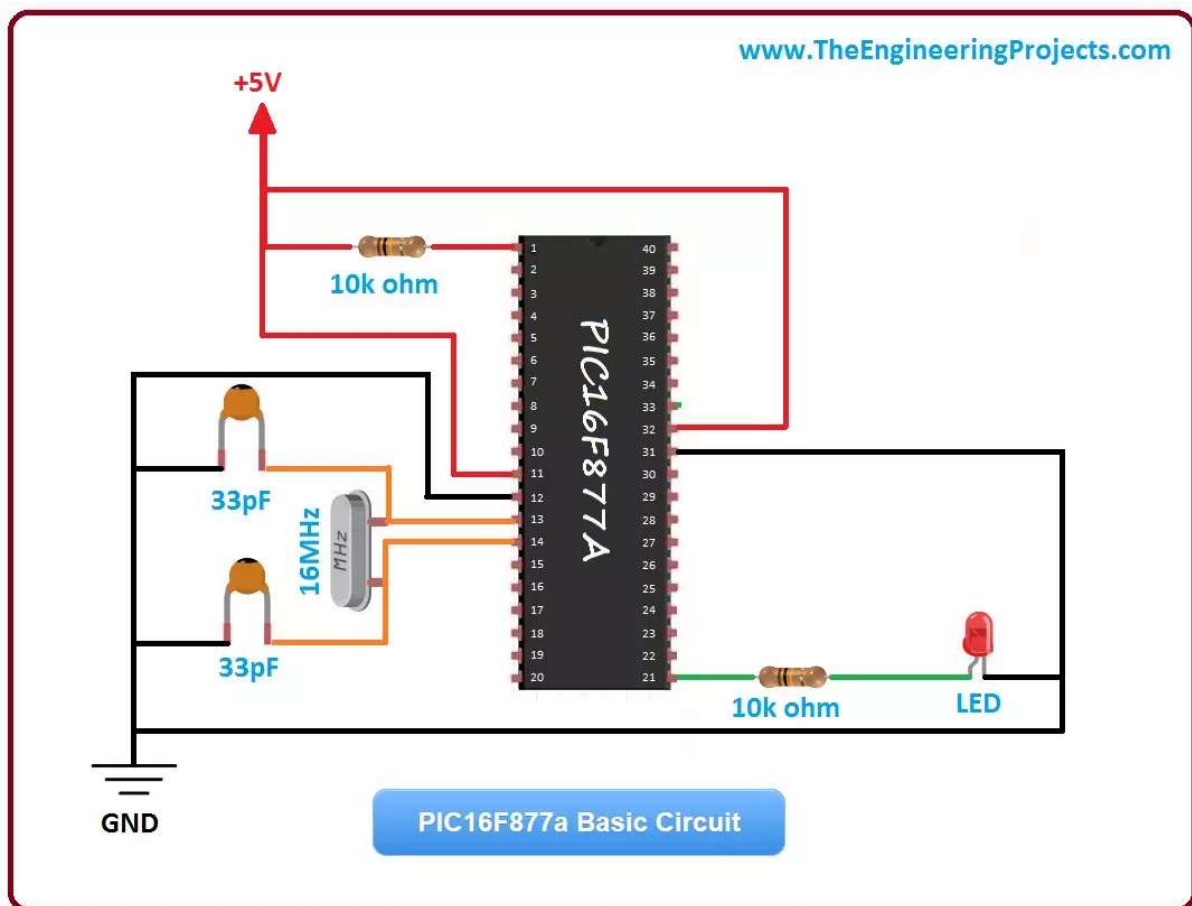


Figure 14, Pin allocation

Next, the input pins were connected to a dual power supply to signify a high or low input, and the output pins were connected to a multimeter. This was done to test the functionality of the programmed PIC and the PIC was performing as expected according to the code that was uploaded to it.

The circuit was then converted into a soldered version with the same components with multi-core wires connected to the I/O pins and the power and ground lines. This was tested by then connecting the input pins to the outputs of the sensor circuit and observing if the pic would still output with the inputs from the sensor circuit, this was tested via the same methods as the previous test, using a dual power supply to power both circuits and a multimeter to measure the outputs. This test concluded that the circuit functioned as intended.

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Jamie Hamilton-Swingewood {

Programming The PIC16F877A - Hex to Hardware

For the microprocessor and system to function as intended the code as shown above needed to be put on the PIC16F877A. There are a variety of ways this can be achieved, from wiring up a breadboard and connecting the relevant pins into a pickit and loading code directly from MPLABX or using third party software and hardware such as the DataMan line of ZIF socketed general purpose programmers. The ultimate aim is the same in all cases, get the compiled instructions in the form of a .hex file onto the microchip. Individual use cases will vary from project, personal preference and available resources. In this project the GALEP-5 (G5) universal programmer was used.

The G5 is a USB enabled, embedded-Linux device, boasting a 48 pin ZIF socket with the pin driver being a field programmable gate array (FPGA) that generates the required pin sequences, potential difference and timing for functionality with a range of processors but specifically Microchip's serial programming algorithm to work with the PIC16 family.



A GALEP-5 programmer. Credit: <http://www.conitec.net/english/galep5.php>

With the code written and compiled it was next necessary to to install the GALEP-5 desktop software for windows. The G5 was then connected to the computer via a USB port where it was detected and recognised by the software. The operator then selected the relevant device, in this case it was the PIC16F877A, in the device menu before inserting the PIC into the ZIF socket when prompted by the graphical user interface. The PIC was then verified and erased in preparation for receiving new instructions. The previously compiled HELIANTHUS.hex file was then loaded into the software buffer, this is the storage interface of the code/instructions, like handing off a wrapped package for someone to open, before being loaded into the PIC. Below is a screen shot of the GUI post install where the instructions and their location on the microchip can be seen. Vitally important was the verifying step seen below in green text bottom right, this verifies the integrity of the instructions and chip to ensure the .hex file was transferred as intended and has not corrupted. Particularly handy in the GALEP-5 software package is the ability to modify and insert instructions that may have been forgotten, such as fuses, watchdog timer and oscillator type/frequency without having to re-write and re-compile any code.

GALEP5 (V.2.7.13) - [PIC16F877A - Data Buffer - C:\Users\JHS\Documents\Helianth.hex]

File Edit Device Action Options View Window Help

Start Cancel

Device pin 1

Verify Action in progress ...
Doing Continuity Test
Total = 4, Connected = 4
Load FPGA(s) with HDW OK.
Check Device ID
Verify Action in progress ...
Program Memory
User-IDs
Configuration
Data Memory
Verify OK
Galep disconnect detected.
Galep disconnect detected.

PIC16F877A

Start addr. 0 IC 1
Cur. addr. 21FF IC 2
End addr. 21FF IC 3
IC 4

☒ Continuity Test
☐ Extra notification on error
☐ Play Error Sound

ADR:	00	01	02	03	04	05	06	07	
00000000	3000	008A	2804	0000	0803	391F	0083	30FF	0 0 (00 9 y0
00000008	00A0	1683	141F	149F	151F	119F	3007	009C	00 0 0 0 0000
00000010	1383	1283	14A0	0820	1683	0087	1283	1887	00 00 0 0 00 00 00
00000018	2821	1683	1005	1283	1405	1683	1085	1283	! (0000 0000 00 00 00
00000020	1085	1520	0820	1683	0087	1283	1907	2830	00 0 0 00 00000(
00000028	1683	1085	1283	1485	1683	1005	1283	1005	00 00 00 00 0000 0000
00000030	15A0	0820	1683	0087	1283	1987	283F	1683	0 0 0 00 00 ? (00
00000038	1008	1283	1408	1683	1088	1283	1088	1620	00 0000 00 00 00 0
00000040	0820	1683	0087	1283	1A07	284E	1683	1088	00 0 0000N(00 00
00000048	1283	1488	1683	1008	1283	1008	1420	0820	00 00 0000 0000 0 0
00000050	1683	0087	1283	1807	285D	1683	0185	1283	00 0000] (00 00 0
00000058	0185	1683	0186	1283	0186	2812	0063	FFFF	00 00 00 00 000 (c yy
00000060	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000068	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000070	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000078	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000080	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000088	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000090	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000098	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000A0	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000A8	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000B0	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000B8	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000C0	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000C8	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000D0	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000D8	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000E0	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000E8	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000F0	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
000000F8	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000100	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000108	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000110	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000118	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000120	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000128	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000130	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000138	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000140	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000148	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000150	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000158	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
00000160	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	FFFF	yyyyyyyyyyyyyyyyyyyy
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Workspace Devices F8 Action Data Buffer File/Buffer Options PIC16F877A Options Device Help Device Counter

Program F3 Verify F4 Blank F5 Read F6 Erase F7

}Jamie Hamilton-Swingewood

Conclusions and recommendations

Test plan

To verify the correct functioning of an automated solar tracking system using 5 LDRs for sun position detection, motor-driven panel adjustment, and efficient battery charging using a charge controller.

Functional test

Test	Description	Procedure	Expecting results	Pass/Fail
1	Motor activation	Power the system	Motors run smoothly	Pass
2	Motor direction control	Command motor to move in both directions	Panel moves in both directions	Pass
3	Panel positioning	Use sensors to control position	Panel reaches all angles	Pass
4	Automatic tracking response	Expose sensors to changing light	Panel tracks light smoothly	Pass

Table 3, Functional test

Performance test

Test	Description	Procedure	Expected result	Pass/fail
5	Motor load under normal conditions	Visual inspection of motor moving with panel attached	Smooth running of motors	Pass
6	Battery consumption	Run system continually and measure power draw	Power consumption stable within expected range	Pass

Table 4, Performance test

Safety and reliability test

Test	Description	Procedure	Expected result	Pass/fail
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7	Overload protection	Simulate motor stall/obstruction	System stops	Pass
8	Structural stability	Stability when motors are moving	No excessive vibration, tipping or mechanical failure	Pass

Table 5, Safety and reliability test

Results

Due to time constraints, the final implementation of the automated solar tracking system used only one motor instead of the originally planned dual-axis configuration. As a result, the system was limited to horizontal tracking, allowing the solar panel to follow the sun's movement across the sky from east to west. Despite this simplification, the system successfully demonstrated accurate light detection using the five LDRs and corresponding comparator outputs, enabling effective real time alignment with the sun. The tracking mechanism, integrated with the PIC16F877A microcontroller and battery charge controller, functioned reliably within this single axis setup, providing a solid foundation for future expansion to full dual-axis control.

Final design

The final design of the automated solar tracking system featured a sturdy cross-shaped bottom frame that housed the electronics and battery pack, providing a stable and compact base. Mounted on top was a single motor capable of 180-degree rotation, responsible for horizontal tracking. To reduce mechanical strain, a circular plate supported by ball bearings was placed above the motor, effectively distributing the load of the rotating assembly. Attached to this plate was an A-frame structure that held the solar panel and the five light sensors. This upper frame rotated smoothly in response to changes in light intensity, allowing the panel to follow the sun's movement throughout the day for optimal energy capture.

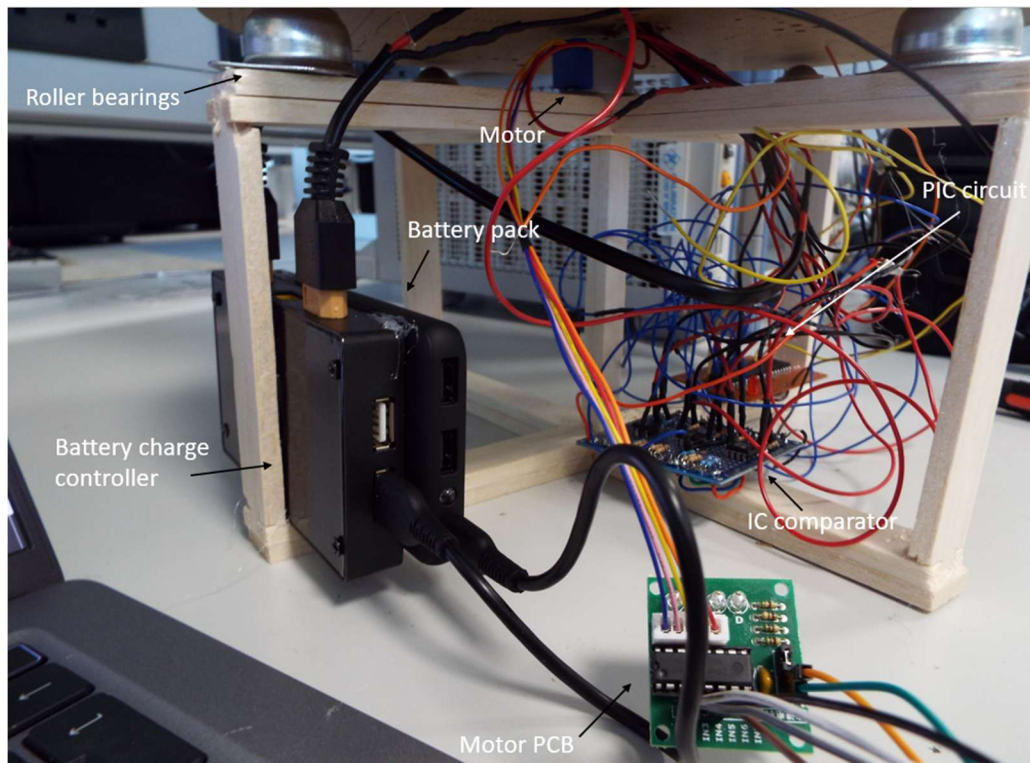


Figure 15, Frame housing

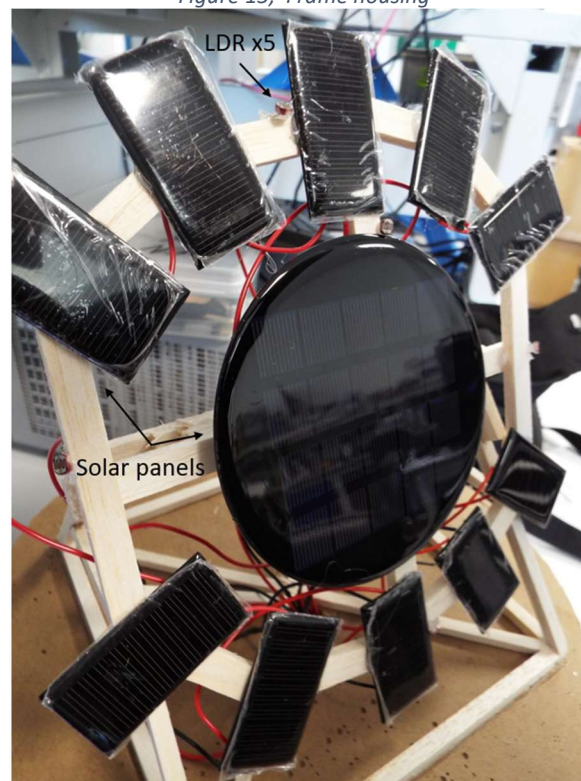


Figure 16, Solar array

Suggested improvements

Improvement	Why
Replace USB charger with dedicated solar MPPT module	More efficient charging, handles variable solar input better
Consider smaller LiPo battery and charging module	Better matched to low-power solar panels, less space, more manageable power budget
Use ESP32 or Arduino Nano instead of PIC	Easier development, more community support, can integrate sensors WiFi for added functionality
Reduce to 1 tracking axis if space or power-limited	Reduces motor count and power consumption
Consider a small supercapacitor for short-term storage	Can smooth out solar power fluctuations if powering logic directly

Table 6, Improvements

Alternative Build Ideas

1. Minimal Tracker with LiPo Battery

- 1 rectangular solar panel
- 2 LDRs + LM393
- 1 axis movement (tilt only)
- 1 3.7V LiPo battery + TP4056 charger module
- Microcontroller (e.g., ATtiny or Arduino Nano)

2. IoT Data Logger Solar Tracker

- ESP32 with built-in WiFi
- Sends sunlight data to an online dashboard
- Tracks sun with 2 axis motors

Logs power generated/stored

Project learning log

{ALL

Tasks	Emily De Lange	Oscar Smith	Gabriel Pan	Owen Miller	Jamie Hamilton-Swingewood
B1 Apply knowledge of mathematics , statistics, natural science and engineering principles to broadly-defined problems. Some of the knowledge will be informed by current developments in the subject of study	To ensure the effectiveness of my automated solar panel system, I created a structured performance tracking table. This table compares expected solar energy output with actual output measured throughout the day. I calculated the efficiency by dividing actual output by expected output and multiplying by 100. When the system produces close to or above the expected value, it indicates the automation.	When designing the initial model in the Blender software I ran into several issues regarding geometry and mathematics. For instance when implementing the simulated grass, I found that I was unable to render the image because the memory usage was too high. To solve this I had to use an equation to thin out the individual blades of grass as the grass plane got further away from the scene camera.	I had to apply my knowledge of engineering mathematics and physics to be able to draw up an initial design in a simulation software by checking the required components beforehand. For example calculating the current given the various resistances of the lines of current flow in parallel.	In the process of conducting my research, I found it essential to leverage my engineering knowledge. As I meticulously reviewed the various components of the information, I carefully assessed which aspects were pertinent to my study and which ones could be disregarded. This selection process required a critical eye, ensuring that I focused only on the most relevant data to support my findings.	Applied my background knowledge of materials physics and electronics to explain how semiconductor structures (e.g., crystalline silicon, CdTe, perovskite) govern PV efficiency and reliability, grounding the research in solid scientific principles.

B2 Analyse broadly-defined problems reaching substantiated conclusions using first principles of mathematics, statistics, natural science and engineering principles	Gather multiple data points Calculate mean (average), median, range, variance, and standard deviation of outputs. Interpret results	Throughout the design process I was consistently creating and solving problems, the majority of which related directly to engineering or mathematics. Whether practical or virtual I had to apply my knowledge of mathematics, geometry and coding to solve them.	I analysed the problem of having to get the desired sensitivity for control of the motors by changing the resistance of the voltage reference line, I achieved the desired sensitivity by testing it with actual sunlight, which is the desired amount of light intensity.	I applied my understanding of various tools to explore the mechanics of the stepper motor and its functionality. Additionally, I focused on how to seamlessly integrate it into the PIC (Peripheral Interface Controller), ensuring effective communication and control between the two components.	Analysed published data on global PV capacity, module efficiencies, and cost trajectories to identify performance drivers and challenges for UK solar deployment.
B3 Select and apply appropriate computational and analytical techniques to model broadly-defined problems, recognising the limitations of the techniques employed	By modelling the panel's imbalance and calculating motor torque demands, I found the initial design caused excessive load risking motor failure. I redesigned the structure by repositioning the panel and adding counterweights, reducing torque requirements keeping motors within safe limits. While the model simplified some dynamics, it effectively guided improvements.	While using the CAD software blender I have applied appropriate computational and analytical techniques towards many different problems, including issues with the model mesh that required adjustments to the mathematical formulas that create them, and a problem with the rotation driver that required in depth knowledge of the way that Blender interprets python code.	I used computational techniques to design and simulate the circuit with appropriate firmware and made an initial example code which would work with the design of the circuitry and the microcontroller selected.	I applied my computational skills to effectively tackle complex problems, striving to find solutions that showcase my abilities to the fullest.	Compiled firmware into a .hex file and programmed the PIC16F877A with the GALEP-5 universal programmer, using its verification step to confirm accurate instruction transfer.

B4 Select and evaluate technical literature and other sources of information to address broadly-defined problems	I looked at datasheets for different solar panels and motors, checked some basic rules for tracking systems, and read papers about sunlight and solar power. This helped me pick the right parts and figure out how to control the system. I also thought about how good each source was and if it fit my project.	In order to use the BPy library I had to continuously scour the documentation for the relevant settings and commands. On top of this I needed to read through the datasheets of the components for measurements, motor behaviours and axes and diagrams to design the mounting hardware in the initial model	I had to read and analyse the datasheets for all of the components used for the breadboard testing and the final circuit, including the operational specifics of the microcontroller and the dual comparators.	I took great care to ensure that all the research I conducted was sourced from trustworthy and credible platforms. I thoroughly vetted the information to confirm its reliability, making certain that it would be valuable and insightful for anyone who chooses to explore it further.	Selected and evaluated authoritative sources (Fraunhofer ISE, IEA, Oxford PV papers) to substantiate figures on capacity, efficiency records, and market trends.
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B5 Design solutions for broadly-defined problems that meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health & safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards	To comply with health and safety requirements, I identified electrical and mechanical risks in my solar tracking system. Protective guards were considered around moving parts to prevent injury, and insulated wiring minimised electrical hazards. The design followed relevant safety standards, ensuring structural stability and user protection. These measures make the system safer for a wide range of users and reduce the risk of accidents during operation and maintenance	The design itself was based on the idea of bringing electricity to the people who need but cannot afford it, or to places where electricity is not readily available. The project has a wider impact than the charity aspect, such as also being aimed towards people who live off-grid/campers, but the funds raised from selling the device can be directed towards the manufacture and transport of more solar sunflowers to countries where electricity is a luxury.	To build the final circuit I had to comply and exercise the health and safety regulations on using a soldering iron for a long period of time. To achieve this I used the correct fume extractor and ensured there was constant ventilation on the point of contact of the soldering iron. I also had to use the correct amount of protection for the surface i was soldering on and made sure i was doing everything possible to minimise the risk of fire.	In the course of our research, I made it a priority to ensure that we acted responsibly and ethically. I conducted a thorough examination of existing methodologies and practices to guarantee that we did not unintentionally infringe upon any patents or utilize techniques that are already in use. This careful approach underscores our commitment to innovation while respecting the contributions of others in the field.	Devised and implemented a safe and reliable GALEP-5 workflow to program the PIC16F877A, selecting the device, running erase / load / verify cycles, and configuring fuses in software to ensure the microcontroller operated exactly as intended.
B6 Apply an integrated or systems approach to the solution of broadly-defined problems	I researched how PIC microcontroller s work to understand how to program and control the solar tracking system. I soldered the components together, connecting sensors, motors, and the controller to build the hardware. Then, I created a test plan to check that all	I had to keep the initial model in a form that would facilitate easy editing, to allow adjustments once the team knew what parts we would be working with. On top of this I had to consider the placement of electronic component and ergonomic features, as well as the materials used, and ensure that	I directly applied systems thinking when i was thinking of a viable design for the initial design and for the modifications i made during the breadboard testing of the circuitry and then how to fit the final circuit on a small board using soldering techniques.	I undertook a comprehensive analysis of various methods to enhance the performance of the stepper motor in conjunction with the PIC microcontroller we are utilizing. This research encompassed an examination of technical	I evaluated three ways to program the PIC16F877A (using a PICkit on a breadboard, a DataMan ZIF programmer, and the GALEP-5) and chose the GALEP-5 because its FPGA-driven pin driver, 48-pin ZIF socket, and built-in fuse editor provided the most reliable and flexible route to transfer and verify the HELIANTHUS.hex file.

	parts worked together properly and the system tracked the sun accurately.	everything worked together.		specifications, wiring configurations, and programming strategies to optimize functionality and achieve accurate control of the motor's operation.	
B7 Evaluate the environmental and societal impact of solutions to broadly-defined problems	I researched the growing market for portable solar panels and solar trackers, highlighting their rapid expansion and increasing adoption worldwide. I evaluated how using solar energy reduces reliance on fossil fuels, lowering greenhouse gas emissions and air pollution. This analysis demonstrated the environmental benefits and positive societal impacts, such as improved energy access and job creation, supporting the sustainability of my project's solution.	As mentioned in B5, the project has been based on ethical and societal considerations from the very start. The initial idea being to bring renewable electricity to countries where it is not accessible.	I looked into the potential ethical and societal impacts of the finished device at the start of this project in the buildup to the initial presentation and found no notable impacts which would have a negative impact to society or the environment, this was reflected in the ethical forms submitted.	Throughout the research process, I maintained a strong commitment to ethical practices by thoroughly reviewing existing methodologies. This careful evaluation allowed me to avoid incorporating any techniques that are currently patented or in active use, thereby respecting the intellectual property of others and ensuring the integrity of our work.	Discussed how large-scale PV deployment contributes to carbon reduction and energy security in the UK and Europe, highlighting environmental benefits of falling levelled costs.

B12 Use practical laboratory and workshop skills to investigate broadly-defined problems	I applied health and safety rules throughout all practical work while soldering circuits to build the control system. I conducted experiments measuring motor performance and panel output, recording and analysing the data to identify issues with motor resistance caused by structural imbalance. This practical investigation allowed me to refine the design and improve system reliability.	I assisted the team with the practical aspect of the project by helping to build both the structural supports for the solar panel “petals” as well as the frame itself, on top of this I also helped to troubleshoot some issues that had arisen with the motors.	I used my practical soldering skills to make the final circuit board, involving some high level techniques to fit the circuitry on a single board, including a variety of types of joints. I also used practical lab skills to breadboard and test the functionality of the circuit prior to this.	I applied my hands-on skills to thoroughly test and calibrate the stepper motors, ensuring they operated efficiently and reliably. By doing so, I was able to identify any potential issues and eliminate any risks that could compromise health and safety.	Programed the PIC16F877A in a 48-pin ZIF socket, erased, programmed, and verified the device via the GALEP-5 GUI, following safe laboratory practice.
B13 Select and apply appropriate materials, equipment, engineering technologies and processes	I researched and selected components based on performance and project requirements. I used soldering equipment to assemble some parts of the electrical circuits and applied paint to protect structural parts from corrosion, ensuring durability. These processes, combined with proper safety practices, demonstrate effective selection and application of materials, tools, and	While designing the initial model in the CAD software Blender, I had to take into consideration the materials that would be used in the final product, that way I could think about material interactions (wear and tear through friction/heat resistance/water proofing), and ensure that our project is designed in the most efficient and cost effective manner. I also used appropriate prototyping materials when	I selected and specified all of the electrical circuitry components that would be needed for me to build the circuit I designed, I did this by theory then simulation of the circuit. I used the appropriate equipment such as simulation software, soldering iron, extractor, wire strippers, bread boards, multi-meter and many more.	I applied my understanding of various tools to explore the mechanics of the stepper motor and its functionality. Additionally, I focused on how to seamlessly integrate it into the PIC (Peripheral Interface Controller), ensuring effective communication and control between the two components.	Chose the GALEP-5 programmer and PIC16F877A microcontroller as appropriate equipment for reliable code flashing, considering pin-driver capabilities and available resources.

	engineering techniques.	building the first prototype, balsa wood is cheap but sturdy enough for our uses.			
B15 Apply knowledge of engineering management principles, commercial context, project management and relevant legal matters	I managed costs and procurement to stay within budget and scheduled orders to meet deadlines. I followed health and safety regulations during all practical work to ensure compliance. I also identified and managed risks proactively to keep the project on track, demonstrating effective engineering management.	I led both the 3D CAD design phase as well as the promotional aspect of the project. In doing so I had plenty of hands on experience with regards to budgetary requirements, effective management skills and the collaboration between members of the team who were covering different aspects of the project	I managed many aspects of work distribution and timings of project meetings, including a work trip to a fully dedicated week of project work; this was organised due to the busy nature of our jobs outside of the work.	I co-authored the research component of the project, applying my expertise in electronics to verify research, aligning it with the groups' objectives and to assess the feasibility of achieving them.	Surveyed global and UK photovoltaic deployment, compared crystalline silicon, thin-film and perovskite technologies, and summarised recent efficiency and cost milestones, providing a solid technical and economic foundation for the project.
B16 Function effectively as an individual, and as a member or leader of a team	I independently completed research, ordering, data analysis, and report writing, then shared my work by uploading it to the group OneDrive. I regularly attended progress meetings to discuss updates and collaborate with my team, ensuring effective communication and teamwork throughout the project.	I created the initial design, as well as CAD models, renders and simulations individually. I worked alongside my team doing practical and theoretical work such as building the initial prototype, troubleshooting motor issues and researching initial ideas.	As an individual I simulated, breadboarded, soldered and tested the electronic component of this project, but I have also demonstrated effective team work in this by collaborating with other members of the team so all of the parts of the project will work together, for instance the electrical with the mechanical.	I undertook independent research and presented my findings to the team, outlining potential strategies to enhance the product's effectiveness through straightforward measures.	Independently carried out and documented the full GALEP-5 erase-load-verify workflow (with screenshots and fuse settings), then shared this clear step-by-step guide so other team members could replicate the process confidently.

B17 Communicate effectively with technical and non- technical audiences	I worked with my team to create clear initial design visuals that evolved into the final solar tracking system. I helped deliver the final presentation by making technical content accessible and wrote detailed reports for technical readers, ensuring effective communication with both technical and non-technical audiences.	I have worked with my team as well as people that helped facilitate our project through sourcing materials. In the process I have communicated with technical and non-technical audiences, in the sense that I have had to explain new information to people who already have relevant knowledge, and people who do not.	I have communicated with both technical and non-technical audiences about this project, I did this by communicating /presenting to my team members and the assigning lecturers.	I have effectively communicated with both technical and non-technical audiences regarding this project. This was achieved through formal presentations to my team members and the assigned lecturers.	Authored a detailed written section that clearly communicates PV technology categories, emerging perovskite advances, and recent breakthroughs, using precise technical language and citations.
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Table 7, Learning log

Filled by ALL, initialised by EDelange}

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ePC Procurement Order Form

Please use this form for all ePC requests

Demand Name:	Emily De Lange
Date submitted:	13/06/2025
Delivery Details:	Porton Down
Demand Email:	edelange@dstl.gov.uk
Demand Phone Number:	01980 956127
Account, Project, Activity Code:	PJ800125 004
Goods/Services to be Purchased and a justification as to why they are required	Group project
Are any items available via DSTL Normal Routes (iCAS/Science Warehouse ePortal/IS Portal etc?): This is the preferred route to purchase – please use where possible or provide reason why they can't be used	No
Market Research or Single Source Justification (SSJ). Or Provide reason for no Market Research: 3 prices by obtaining quotes/process from the internet or SSJ (No Market Research - proportionality of effort is more than the value of the item or service required)	Out of stock or not available
Company Contact: If known	

Item Description, Part Number:	Quantity and Unit Cost/£:	Weblink/Quote Reference:
LDR	5x £5.99	20 Pcs Photoresistor Diodes Photo Light Sensitive Resistors LDR Resistors Photo Light Sensitive Sensors for DIY and Experiments 5537 GL5537 : Amazon.co.uk: Business, Industry & Science
Solar panel (round)	2x £5.69	Gdfnmogo 120Mm Circular Solar Cell Module 1.1W 5V Polycrystalline Silicon Panel Portable Lightweight Green Energy Source for DIY Projects, Solar Panel : Amazon.co.uk: Business, Industry & Science
Solar panels (Rectangle)	1x £15.99	SUNYIMA 10Pcs 5V 30mA Mini Solar Panels for Solar Power Mini Solar Cells DIY Electric Toy Materials Photovoltaic Cells Solar DIY System Kits 2.08"x1.18"(5V 30mA 53mmx30mm) : Amazon.co.uk: Business, Industry & Science
Battery charge controller	1x £6.59	Hailege 10pcs Type-C USB 5V 1A 18650 Lithium Battery Charger Module Charging Board with Dual Protection Functions: Amazon.co.uk: Business, Industry & Science
Battery pack	1x £14.98	INIU Power Bank, Portable Charger 10000mAh Slimmest & Lightest High-Speed USB C Input & Output, PowerBank Triple 3A Phone Battery Pack for iPhone 16 15 14 13 Plus Pro Max Mini Samsung Xiaomi iPad: Amazon.co.uk: Electronics & Photo
Motors (5V)	2x £7.19	Apicrie 2Sets 28BYJ-48 DC 5V Stepper Motor + ULN2003 Driver Test Module Board : Amazon.co.uk: Business, Industry & Science
Testing kit	1x £84.99	DOKIO 160W 18V Solar Panel Kit Monocrystalline Portable Flexible Folding Include Solar Charge Controller and PV Cable

		for 12V Battery Charging Camper Van : Amazon.co.uk: Business, Industry & Science
Ball bearing	1x £6.99	Transfer Bearing Casters Tianher 6 Pcs Roller Ball Transfer Bearing Casters Unit Mounted Flange Metal Steel Universal Conveyor Transferring Wheel for Power Systems Processing and Packaging Machinery : Amazon.co.uk: Business, Industry & Science
Comparator	1x £2.55	10 PCS LM393N LM393 DIP-8 Low Comparator : Amazon.co.uk: Business, Industry & Science
PIC	2x £8.39	DEWIN MCU Microcontroller IC Chip for PIC16F877A PIC16F877A-1/P DIP-40 8-Bit MCU Microcontroller IC Chip PIC16F877A-1/P : Amazon.co.uk: Business, Industry & Science
Total Cost (inc VAT)	£236.53	

To be completed by Officer Accountable (Approver/Project Manager):

Approver/PM Name:	Pat North
Approver Signature: (or email trail approval attached)	P North

APPLICATION FOR ETHICAL APPROVAL

In order for research to result in benefit and minimise risk of harm, it must be conducted ethically. A researcher may not be covered by the University's insurance if ethical approval has not been obtained prior to commencement.

The University follows the OECD Frascati manual definition of **research activity**: "creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications". As such this covers activities undertaken by members of staff, postgraduate research students, and both taught postgraduate and undergraduate students working on dissertations/projects.

The individual undertaking the research activity is known as the "principal researcher".

Ethical approval is not required for routine audits, performance reviews, quality assurance studies, testing within normal educational requirements, and literary or artistic criticism.

Please read the notes for guidance before completing ALL sections of the form.

This form must be completed and approved prior to undertaking any research activity. Please see Checklist for details of process for different categories of application.

Delete the Guidance Notes at the end of the form BEFORE submitting your application

SECTION A: About You (Principal Researcher)

1	Full Name:	Emily De Lange, Oscar Smith, Gabriel Pan, Jamie Hamilton, Owen Miller			
2	Tick all boxes which apply:	Member of staff:	☐	Honorary research fellow:	☐

3	Undergraduate Student	☒	Taught Postgraduate Student	☐	Postgraduate Research Student	☐
---	-----------------------	-------------------------------------	-----------------------------	--------------------------	-------------------------------	--------------------------

4	Institute/Academic Discipline/Centre:	UWTSD, Trinity of St David's
5	Campus:	IQ, Swansea
6	E-mail address:	2306894@UWTSD.student.uk
7	Contact Telephone Number:	07772650296
For students:		
8	Student Number:	2306894, 2307825, 2308342, 2204725, 2308626
9	Programme of Study:	Embedded electronics
10	Director of Studies/Supervisor:	Jenifer Prince Devaraj

SECTION B: Approval for Research Activity

1	Has the research activity received approval in principle? (please check the Guidance Notes as to the appropriate approval process for different levels of research by different categories of individual)	YES	☒	NO	☐
					Date
2	If Yes, please indicate source of approval (and date where known): Approval in principle must be obtained from the relevant source prior to seeking ethical approval	Research Degrees Committee	☐		
3		Institute Research Committee	☐		
4		Other (write in)	☒	Lecturer	

SECTION C: Internal and External Ethical Guidance Materials

Please list the core ethical guidance documents that have been referred to during the completion of this form (including any discipline-specific codes of research ethics, and also any specific ethical guidance relating to the proposed methodology). Please tick to confirm that your research proposal adheres to these codes and guidelines.		
1	<u>UWTSD Research Ethics & Integrity Code of Practice</u>	☒
2	UWTSD Research Data Management Policy	☒
3		☐

SECTION D: External Collaborative Research Activity

1	Does the research activity involve collaborators outside of the University?	YES	☐	NO	☒	
2	If Yes, please provide the name of the external organisation and name and contact details for the main contact person and confirmation this person has consented to their personal data being shared as part of this collaboration.					
3	Institution					
4	Contact person name					
5	Contact person e-mail address					
6	Has this individual consented to sharing their details on this form?	YES	☐	NO	☐	
7	Are you in receipt of a KESS scholarship?	YES	☐	NO	☐	
8	Is your research externally funded	YES	☐	NO	☐	
9	Are you specifically employed to undertake this research in either a paid or voluntary capacity?	Voluntary	YES	☐	NO	☐
10		Employed	YES	☐	NO	☐
11	Is the research being undertaken within an existing UWTSD Athrofa Professional Learning Partnership (APLP)	If YES then the permission question below does not need to be answered.	YES	☐	NO	☐
12	Permission to undertake the research has been provided by the partner organisation	(If YES attach copy) If NO the application cannot continue	YES	☐	NO	☐

Where research activity is carried out in collaboration with an external organisation

13	Does this organisation have its own ethics approval system?	YES	☐	NO	☐
14	If Yes, please attach a copy of any final approval (or interim approval) from the organisation				

SECTION E: Details of Research Activity

1	Indicative title:	Automated solar panel		
2	Proposed start date:	20/05/2025	Proposed end date:	14/07/2025
3	Introduction to the Research (maximum 300 words) Ensure that you write for a <u>Non-Specialist Audience</u> when outlining your response to the three points below: ● Purpose of Research Activity ● Proposed Research Question ● Aims of Research Activity ● Objectives of Research Activity			

	Demonstrate, briefly, how Existing Research has informed the proposed activity and explain ● <i>What the research activity will add to the body of knowledge</i> ● <i>How it addresses an area of importance.</i>
4	Purpose of Research Activity Group project (this box should expand as you type)
5	Research Question How to harbour energy more efficiently (this box should expand as you type)
6	Aims of Research Activity Harbour energy more efficiently (this box should expand as you type)
7	Objectives of Research Activity Low cost, portable, automated (this box should expand as you type)
8	Proposed methods (maximum 600 words) Provide a brief summary of all the methods that may be used in the research activity, making it clear what specific techniques may be used. If methods other than those listed in this section are deemed appropriate later, additional ethical approval for those methods will be needed.
9	Proposed Methods This research project aims to design, build, and test a portable automated solar panel system that employs sun-tracking technology to optimize energy capture. The following methods will be used across the design, development, and testing phases of the project: 1. Design and Modelling Computer-Aided Design (CAD) software such as SolidWorks or Fusion 360 will be used to create 3D models of the mechanical structure of the solar panel unit. The design will prioritize portability (foldable/compact structure), stability (base support design), and integration of motor systems for automated tracking. Simulation tools (e.g., MATLAB/Simulink, Proteus) may be used to model electrical performance, simulate sun path tracking algorithms, and test control logic before physical implementation. 2. Component Selection and System Integration Electronic components will be selected based on efficiency, size, and cost-effectiveness. These include:

- **Photovoltaic panel(s):** A small-to-medium-sized solar panel (20–100W) suitable for portability.
- **Microcontroller:** An Arduino Uno or ESP32 board will be used to control movement and data processing.
- **Motors:** Servo or stepper motors will control the azimuth (horizontal) and elevation (vertical) angles of the panel.
- **Power supply and battery:** A rechargeable battery pack will store harvested energy and power the system.
- **Sensor system:** Light-dependent resistors (LDRs) or a digital sun sensor will detect sunlight direction.

These components will be integrated on a frame that allows both movement and compact folding.

3. Sun Tracking Algorithm

The project will evaluate and implement one or both of the following sun tracking techniques:

- **Active Tracking:** A quadrant of LDRs will detect the direction of maximum light intensity. The microcontroller will compare the LDR outputs and signal the motors to adjust the panel until equilibrium is reached (i.e., maximum light falls evenly on all sensors).
- **Passive/Time-Based Tracking:** An algorithm based on astronomical equations will calculate the sun's position (based on time, date, and GPS location) and orient the panel accordingly. This method reduces reliance on sensors and may be more energy efficient.

The tracking system will operate on a dual-axis mechanism to follow the sun's daily and seasonal movement.

4. Mechanical Fabrication and Assembly

The physical system will be fabricated using lightweight and durable materials such as aluminum or PVC. The tracking unit, battery, and electronics will be housed in a weather-resistant casing. Portable and modular assembly will be emphasized to support transport and setup in outdoor environments.

5. Software Development

The microcontroller will be programmed in C/C++ using the Arduino IDE. The software will include routines for:

- Reading sensor values
- Calculating sun position (if using time-based method)
- Controlling motor positions
- Battery voltage monitoring
- Optional: Logging data (e.g., energy output) on an SD card or transmitting via Bluetooth/Wi-Fi.

6. Testing and Evaluation

The system will be tested under real sunlight conditions and compared to a static (non-tracking) panel. Parameters to be evaluated include:

	● Energy efficiency: Measured output (voltage/current) over time ● Tracking accuracy: Alignment of panel with solar azimuth and elevation ● Portability: Ease of transport and setup time ● Power consumption: Energy used by tracking system vs. energy gained Data will be collected over multiple days at different times to assess consistency and performance under variable sunlight conditions. 7. Ethical Considerations This project does not involve human or animal subjects. All testing will be conducted using electronic and mechanical systems. No personal data will be collected. Safety protocols will be followed during fabrication and testing, especially when handling batteries and solar equipment.
10	Location of research activity Identify all locations where research activity will take place.
11	Swansea UWTSD (this box should expand as you type)
12	Research activity outside of the UK If research activity will take place overseas, you are responsible for ensuring that local ethical considerations are complied with and that the relevant permissions are sought. Specify any local guidelines (e.g. from local professional associations/learned societies/universities) that exist and whether these involve any ethical stipulations beyond those usual in the UK (provide details of any licenses or permissions required). Also specify whether there are any specific ethical issues raised by the local context in which the research activity is taking place, for example, particular cultural and/or legal sensitivities or vulnerabilities of participants.
13	N/A

14	Use of documentation not in the public domain: Are any documents NOT publicly available?	NO	☒
		YES	☐
15	If Yes, please provide details here of how you will gain access to specific documentation that is not in the public domain and that this is in accordance with prevailing data protection law of the country in question and England and Wales. (this box should expand as you type)		

SECTION F: Scope of Research Activity

1	Will the research activity include:	YES	NO
2	Use of a questionnaire or similar research instrument?	☐	☒

3	Use of interviews?	☐	☒
4	Use of diaries?	☐	☒
5	Participant observation with their knowledge?	☐	☒
6	Participant observation without their knowledge?	☐	☒
7	Use of video or audio recording?	☐	☒
8	Access to personal or confidential information without the participants' specific consent?	☐	☒
9	Administration of any questions, test stimuli, presentation that may be experienced as physically, mentally or emotionally harmful / offensive?	☐	☒
10	Performance of any acts which may cause embarrassment or affect self-esteem?	☐	☒
11	Investigation of participants involved in illegal activities?	☐	☒
12	Use of procedures that involve deception?	☐	☒
13	Administration of any substance, agent or placebo?	☐	☒
14	Working with live vertebrate animals?	☐	☒
15	Other primary data collection methods, please explain in this box For example, 'focus groups'. Please indicate the type of data collection method(s) in this box and tick the accompany box.	☐	☒
16	Details of any other primary data collection method: (this box should expand as you type)		

If NO to every question, then the research activity is (ethically) low risk and **may** be exempt from **some** of the following sections (please refer to Guidance Notes).

If YES to any question, then no research activity should be undertaken until full ethical approval has been obtained.

SECTION G: Intended Participants

1	Who are the intended participants:	YES	NO
2	Students or staff at the University?	☐	☐
3	Adults (over the age of 18 and competent to give consent)?	☐	☐
4	Vulnerable adults?	☐	☐
5	Children and Young People under the age of 18? (Consent from Parent, Carer or Guardian will be required)	☐	☐
6	Prisoners?	☐	☐
7	Young offenders?	☐	☐
8	Those who could be considered to have a particularly dependent relationship with the investigator or a gatekeeper?	☐	☐
9	People engaged in illegal activities?	☐	☐

10	Others (please identify specifically any group who may be unable to give consent) please indicate here and tick the appropriate box.		
11	Other – please indicate here: (this box should expand as you type)	☐	☐

12	Participant numbers and source Provide an estimate of the expected number of participants. How will you identify participants and how will they be recruited?	
13	How many participants are expected?	(this box should expand as you type)
14	Who will the participants be?	(this box should expand as you type)
15	How will you identify the participants?	(this box should expand as you type)

16	Information for participants:	YES	NO	N/A
17	Will you describe the main research procedures to participants in advance, so that they are informed about what to expect?	☐	☐	☒
18	Will you tell participants that their participation is voluntary?	☐	☐	☒
19	Will you obtain written consent for participation?	☐	☐	☒
20	Will you explain to participants that refusal to participate in the research will not affect their treatment or education (if relevant)?	☐	☐	☒
21	If the research is observational, will you ask participants for their consent to being observed?	☐	☐	☒
22	Will you tell participants that they may withdraw from the research at any time and for any reason?	☐	☐	☒
23	With questionnaires, will you give participants the option of omitting questions they do not want to answer?	☐	☐	☒
24	Will you tell participants that their data will be treated with full confidentiality and that, if published, it will not be identifiable as theirs?	☐	☐	☒
25	Will you debrief participants at the end of their participation, in a way appropriate to the type of research undertaken?	☐	☐	☒
26	If NO to any of above questions, please give an explanation			
27	(this box should expand as you type)			

28	Information for participants:	YES	NO	N/A
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29	Will participants be paid?	☐	☐	☒
30	Is specialist electrical or other equipment to be used with participants?	☐	☐	☒
31	Are there any financial or other interests to the investigator or University arising from this study?	☐	☐	☒
32	Will the research activity involve deliberately misleading participants in any way, or the partial or full concealment of the specific study aims?	☐	☐	☒
33	If YES to any question, please provide full details			
34	<i>(this box should expand as you type)</i>			

SECTION H: Anticipated Risks

1	Outline any anticipated risks that may adversely affect any of the participants, the researchers and/or the University, and the steps that will be taken to address them. If you have completed a full risk assessment (for example as required by a laboratory, or external research collaborator) you may append that to this form.		
2	Full risk assessment completed and appended?	Yes	☐
		No	☐
3	Risks to participants For example: emotional distress, financial disclosure, physical harm, transfer of personal data, sensitive organisational information		
4	Risk to Participant: <i>(this box should expand as you type)</i>	How will you mitigate the Risk to Participant <i>(this box should expand as you type)</i>	
5	If research activity may include sensitive, embarrassing or upsetting topics (e.g. sexual activity, drug use) or issues likely to disclose information requiring further action (e.g. criminal activity), give details of the procedures to deal with these issues, including any support/advice (e.g. helpline numbers) to be offered to participants. Note that where applicable, consent procedures should make it clear that if something potentially or actually illegal is discovered in the course of a project, it may need to be disclosed to the proper authorities		
	<i>(this box should expand as you type)</i>		
6	Risks to investigator For example: personal safety, physical harm, emotional distress, risk of accusation of harm/impropriety, conflict of interest		
	Risk to Investigator: <i>(this box should expand as you type)</i>	How will you mitigate the Risk to Investigator: <i>(this box should expand as you type)</i>	

7	University/institutional risks For example: adverse publicity, financial loss, data protection		
	Risk to University: <i>(this box should expand as you type)</i>	How will you mitigate the Risk to University: <i>(this box should expand as you type)</i>	

8	Disclosure and Barring Service			
9	If the research activity involves children or vulnerable adults, a Disclosure and Barring Service (DBS) certificate must be obtained before any contact with such participants.	YES	NO	N/A
10	Does your research require you to hold a current DBS Certificate?	☐	☒	☐

SECTION I: Feedback, Consent and Confidentiality

1	Feedback What de-briefing and feedback will be provided to participants, how will this be done and when?		
	<i>(this box should expand as you type)</i>		
2	Informed consent Describe the arrangements to inform potential participants, before providing consent, of what is involved in participating. Describe the arrangements for participants to provide full consent before data collection begins. If gaining consent in this way is inappropriate, explain how consent will be obtained and recorded in accordance with prevailing data protection legislation.		
	<i>(this box should expand as you type)</i>		
3	Confidentiality / Anonymity Set out how anonymity of participants and confidentiality will be ensured in any outputs. If anonymity is not being offered, explain why this is the case.		
	<i>(this box should expand as you type)</i>		

SECTION J: Data Protection and Storage

In completing this section refer to the University's Research Data Management Policy and the extensive resources on the University's Research Data Management web pages (<http://uwtsd.ac.uk/library/research-data-management/>).

1	Does the research activity involve personal data (as defined by the General Data Protection Regulation 2016 "GDPR" and the Data Protection Act 2018 "DPA")?	YES	NO
	"Personal data" means any information relating to an identified or identifiable natural person ('data subject'). An identifiable natural person is one who can be identified, directly or indirectly, in particular by reference to an identifier such as a name, an identification number, location data, an	☐	x

	online identifier or to one or more factors specific to the physical, physiological, genetic, mental, economic, cultural or social identity of that natural person.		
2	If YES, provide a description of the data and explain why this data needs to be collected:		
	(this box should expand as you type)		
3	Does it involve special category data (as defined by the GDPR)?	YES	NO
	“Special category data” means sensitive personal data consisting of information as to the data subjects’ – (a) racial or ethnic origin, (b) political opinions, (c) religious beliefs or other beliefs of a similar nature, (d) membership of a trade union (within the meaning of the Trade Union and Labour Relations (Consolidation) Act 1992), (e) physical or mental health or condition, (f) sexual life, (g) genetics, (h) biometric data (as used for ID purposes),	☐	☒
4	If YES, provide a description of the special category data and explain why this data needs to be collected:		
	(this box should expand as you type)		

5	Will the research activity involve storing personal data and/or special category data on one of the following:	YES	NO
6	Manual files (i.e. in paper form)?	☐	☒
7	University computers?	☐	☒
8	Private company computers?	☐	☒
9	Home or other personal computers?	☐	☒
10	Laptop computers/ CDs/ Portable disk-drives/ memory sticks?	☐	☒
11	“Cloud” storage or websites?	☐	☒
12	Other – specify:	☐	☒
13	For all stored data, explain the measures in place to ensure the security of the data collected, data confidentiality, including details of password protection, encryption, anonymisation and pseudonymisation:		
	(this box should expand as you type)		
14	All Data Storage		
15	Will the research activity involve any of the following activities:	YES	NO
16	Electronic transfer of data in any form?	☐	☒
17	Sharing of data with others at the University?	☐	☒

18	Sharing of data with other organisations?	☐	☒
19	Export of data outside the European Union or importing of data from outside the UK?	☐	☒
20	Use of personal addresses, postcodes, faxes, emails or telephone numbers?	☐	☒
21	Publication of data that might allow identification of individuals?	☐	☒
22	Use of data management system?	☐	☒
23	Data archiving?	☐	☒
24	If YES to any question, please provide full details, explaining how this will be conducted in accordance with the GDPR and DPA (and/or any international equivalent):		
	<i>(this box should expand as you type)</i>		
25	List all who will have access to the data generated by the research activity:		
	<i>(this box should expand as you type)</i>		
26	List who will have control of, and act as custodian(s) for, data generated by the research activity:		
	<i>(this box should expand as you type)</i>		
27	Give details of data storage arrangements, including security measures in place to protect the data, where data will be stored, how long for, and in what form. Will data be archived – if so how and if not why not.		
	<i>(this box should expand as you type)</i>		
28	Please indicate if your data will be stored in the UWTSD Research Data Repository (see https://researchdata.uwtsd.ac.uk/). If so please explain. <i>(Most relevant to academic staff)</i>		
	<i>(this box should expand as you type)</i>		
29	Confirm that you have read the UWTSD guidance on data management (see https://www.uwtsd.ac.uk/library/research-data-management/)	YES	☒
		NO	☐
30	Confirm that you are aware that you need to keep all data until after your research has completed or the end of your funding	YES	☒
		NO	☐

SECTION K: Declaration

31	The information which I have provided is correct and complete to the best of my knowledge. I have attempted to identify any risks and issues related to the research activity and acknowledge my obligations and the rights of the participants. In submitting this application I hereby confirm that I undertake to ensure that the above named research activity will meet the University's Research Ethics and Integrity Code of Practice which is published on the website: https://www.uwtsd.ac.uk/research/research-ethics/		
	Signature of applicant:	Emily De Lange	Date: 16/05/25

For STUDENT Submissions:

32	Director of Studies/Supervisor:	Jenifer Prince Devaraj	Date:
33	Signature:		

For STAFF Submissions:

3	Academic Director/ Assistant Dean:	Date :
4		
3	Signature:	
5		

Checklist: Please complete the checklist below to ensure that you have completed the form according to the guidelines and attached any required documentation:

☒	I have read the guidance notes supplied before completing the form.
☒	I have completed ALL RELEVANT sections of the form in full.
☒	I confirm that the research activity has received approval in principle
☒	I have attached a copy of final/interim approval from external organisation (where appropriate)
☒	I have attached a full risk assessment (and have NOT completed Section H of this form) (where appropriate) ONLY TICK IF YOU HAVE ATTACHED A FULL RISK ASSESSMENT
☒	I understand that it is my responsibility to ensure that the above named research activity will meet the University's Research Ethics and Integrity Code of Practice.
☒	I understand that before commencing data collection all documents aimed at respondents (including information sheets, consent forms, questionnaires, interview schedules etc.) must be confirmed by the DoS/Supervisor, module tutor or Academic Director.
☒	I have deleted the guidance notes before submitting the PG2 for consideration

RESEARCH STUDENTS AND STAFF ONLY

All communications relating to this application during its processing must be in writing and emailed to pgresearch@uwtsd.ac.uk , with the title 'Ethical Approval' followed by your name.

You will be informed of the outcome of your claim by email; therefore it is important that you check your University and personal email accounts regularly.

STUDENTS ON UNDERGRADUATE OR TAUGHT MASTERS PROGRAMMES should submit this form (and receive the outcome) via systems explained to you by the supervisor/module leader.

This form is available electronically from the Academic Office web pages:

<https://www.uwtsd.ac.uk/academic-office/appendices-and-forms/>

Application Process

All staff research projects and all research students must submit the Ethical Approval Form to the **University Research Ethics Committee** via the Academic Office (pgresearch@uwtsd.ac.uk). Staff research directly in relation to personal study for taught undergraduate or Masters programmes should be submitted via the Institute procedures explained below.

Taught masters and taught undergraduate research Ethical Approval Forms are considered **within Institutes**. Institutes will provide details of the specific processes for this. Where the Ethical issues within any single ethical application are of particular concern the Institute will refer these to the University Research Ethics Committee. Any student activity that involves the collection of primary data needs to undergo Ethical approval, this includes assignment work as well as dissertations.

Notes for guidance in completion of this form

Section A: About You

Please complete all relevant sections

Section B: Approval for research activity

Research proposals must be approved in principle before applying for Ethical Approval. The proposal approval only becomes final when the ethical approval is received.

The process for proposal approval varies according to the individual and programme of study:

- Research students, by application on form PG1 to the Research Degrees Committee
- Taught students by review of research proposal within Institutes (Institutes provide specific details of these processes)
- Staff, by agreement by the Academic Director/Assistant Dean

Section C: External Ethical Guidance materials

Many discipline areas are required to operate with the discipline specific codes of research ethics (for example health, psychology, education etc.), any such codes must be listed and you must tick to confirm that you have consulted with these.

Section D: External Collaborative Research Activity

Provide details of the external collaborative partners, where appropriate you might want to submit a copy of the external collaboration agreement with the Ethical Approval Form. If the partner requires the research to be subject to its own internal Ethical approval process then please provide details of that process and a copy of any final (or interim) approvals received from the organisation.

Section E: Details of Research Activity

Remember that the individuals reviewing this Ethical Approval Form may not have seen your research proposal, and also may not be experts in the specific area of your research. The information provided should therefore be jargon free and clearly stated.

Indicative Title: please use the same title as used on the research proposal.

Purpose: the Ethical approval process will want to ensure that the methods you propose are adequate and appropriate to address the research aims and objectives. Excessive additional data collection can be seen as unethical.

Proposed Methods: the Ethical approval process seeks to ensure that you understand the methods that are intended, and that the implementation of those methods will be appropriate and without unnecessary impact on respondents. This section must explain how the methods described will lead to the collection of necessary and sufficient data, but not excessive data. Please be specific.

Location: this needs to mention geographical location and also local situation (for example, within Local Authority Offices in Cardiff, using a private room but close to other individuals). If you are collecting data within an organisational setting then you need to explain the permissions that you have obtained to do this.

Research Activity outside of the UK: please complete this section in detail, and note any guidance you have received. Also describe your own familiarity (or not) with the location that you will be utilising.

Section F: Scope of Research Activity

Please tick ALL of the research activities that might be undertaken. If any additional types of activity are intended then please add an extra box and describe these.

If you have answered no to all questions in F then sections G and I do not need to be completed. . Signatures are still required in section K.

Section G: Intended Participants

Please tick all categories that might apply.

Numbers & Source: if you are using a series of different methods or research activities please list numbers for each stage/phase. Be clear about how you will find respondents. Will you use intermediaries, and if so how? How will you ensure compliance with your sampling strategy?

Information for participants: all participants should be appropriately informed about the research, what is expected of them and what will happen to the information that they provide. The Ethical review process does not ask to see this documentation, but requires this to be reviewed and approved by the Director of Studies in the case of research students, the supervisor/module tutor in relation to students on taught programmes and the Academic Director/Assistant Dean in relation to staff research.

Section H: Anticipate Risks

All research carries some level of risk. The answers you provide to questions in this section will be reviewed to ensure that you have an appropriate understanding of the type of risks involved and how you can mitigate against these risks. If you have completed a full risk assessment, as required for example for laboratory work, field work, clinical tests, diving operations, or by a collaborative partner, you may append that to this form. In that case, please tick the box indicating this has been provided. You will not then be required to complete Section H.

Risk to participants Think very carefully about how your actions/questions/discussions might affect the people you are involving as participants. You might identify the risk as small but it would still be a risk. Many types of question have the potential to make respondents less content with their life / job; you need to recognise and try to ameliorate any such effects

If these are business owners, time with you may reduce profit.

In some locations physical risk is very real to both participants and yourself, please consider this.

Risk to you, the researcher Think about where you will meet people, if there are any dangers involved in the location. If you are meeting people as individuals think about using a public place. In general do not visit people in their own homes or remote locations. If you are talking to individuals about certain issues think about how their responses might affect you emotionally. What about the risk of collecting insufficient data?

Risk to the University When undertaking your research, you are acting as a member of the University (student or staff). Professionalism is important, so it is important to be well organised and well prepared. Punctuality, clarity etc. are all part of this. What will you do to ensure this? You must ensure you do not harm the good name of the University in any way and do nothing to undermine the reputation of the research it conducts and sponsors. Upholding high standards of conduct and integrity are vital in this regard. You must also conduct the research in such a way to minimise the potential for claims of negligence made against the University, its researchers and any collaborating individual or organisation. In this respect you should always comply with ethical, legal and professional frameworks, obligations and standards as required by statutory and regulatory authorities, as well as the university's Research Integrity and Ethics Code of Practice. Research misconduct in this respect can take many forms, including:

- fabrication: making up results or other outputs (eg, artefacts) and presenting them as if they were real
- falsification: manipulating research processes or changing or omitting data without good cause
- plagiarism: using other people's material without giving proper credit
- failure to meet ethical, legal and professional obligations: for example failure to declare competing interests; misrepresentation of involvement or authorship; misrepresentation of interests; breach of confidentiality; lack of informed consent; misuse of personal data; and abuse of research subjects or material
- improper dealing with allegations of misconduct: failing to address possible infringements such as attempts to cover up misconduct and reprisals against whistle-blowers

Adverse Outcomes. Think carefully about the possibilities, and cover here

Section I: Feedback, Consent and Confidentiality

Feedback to participants: outline your approach. Will interview transcripts be shared with respondents to check accuracy? Will summaries of questionnaire analysis be made available to respondents in some way? Will an overview report be provided? How and when?

Informed consent: Draft letter / e-mail / or heading (or footer) section of questionnaire must be approved by DoS/supervisor (if research student), supervisor/module tutor if taught student, or Academic Director / Assistant Dean if a member of staff.
Confidentiality/Anonymity. Explain clearly how you will ensure confidentiality and anonymity.

Section J: Data Protection and Storage

Before completing this section it is necessary to read the University's Research Data Management information. The questions that follow are designed to ensure compliance with the Data Protection Act as well as established research protocols.

Many research activities will involve electronic transfer of data and use of data management systems in the summarisation and analysis of data. You will need to explain these in relation to compliance with the Data Protection Act.

Think carefully about who will have access to your data, this will include supervisors and examiners. Also that a thesis will be made available via the University library and the British Library system. If you are seeking an access bar for a period of time after completion then mention it here. If you will provide a copy of your findings, or intend to give a presentation, to a facilitating/ supporting/accessing organisation then explain that in this section. But also think about the general principle of data sharing, as explained in the Research Data Management information.

In terms of storage of data please ensure security, and also mitigate against loss of data.

Section K: Declaration

Ensure the appropriate countersignatures have been provided

Look carefully at the checklist and ensure that you comply with and tick all that are relevant to your research.