Advantage

The Professional AI Tennis System

10 Page Summary

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GU 68

The Problem

The need for a personal, portable coach

Tennis is an incredibly complex sport, that involves the synchronisation of the body to move, track and strike a ball at speeds over 100mph, placing it with a specific spin and precision on the other side of the court. To improve in tennis, a player's technique needs to be analysed from multiple directions, to identify weaknesses and subsequently develop strategies to improve. This analysis is conventionally undertaken by a coach, however there exists the following problems:

A tennis player cannot improve without access to a coach

Players have no way of understanding how to improve by themselves: they need someone to show them.

There are 87 million tennis players, and only 149,000 coaches.

On average a coach is responsible for 680 players in the UK; players are unable to access a coach when they need to.

Players need coaching at every session, not once a week.

88.9% of players agree that if they were coached at every session, their tennis would improve. At £28 per hour however, hiring a coach for each session is not feasible.

4x 4K 60fps Video Capture

Each camera stitches together the footage to create a 3D video that can be viewed from multiple angles.

Hassle Free Charging

Both cameras charge simultaneously when stored in the case.

Control via your phone or tablet

View all of your shots and receive coaching inside the AI Advantage App.

The Product

WHAT

Stereoscopic 3D motion capture AI coaching system.

WHO

Intermediate to advanced tennis players that wish to improve their tennis.

WHERE

Designed to fit inside your tennis bag. Take it wherever you wish.

WHY

Improve your game without depending on a coach. Quickly identify weaknesses during training.

WHEN

View playback during your training session, compare your technique to the professionals and check up on your statistics post match.

360 DEGREE PLAYBACK

Equipped with point cloud technology, you will be able to view your shots back from any direction.

AI EQUIPPED COACHING

Using human pose estimation, Advantage can analyse and coach you on specific shots in real time, reducing your dependence on a coach to improve.

RECORD YOUR TRAINING

Advantage can record your session, tracking you and the tennis ball to deliver key statistics post session.

LONG BATTERY LIFE

The system will last for 6 hours, featuring a 45Wh battery in each device, lasting for at least 3 training sessions before needing to be recharged.

1 | Research

Online Research

A player must be able to visualise their play, without the need for a coach. Research into current visualisation technology revealed that most tennis tailored products are gimmicky, give unreliable information and can be obtrusive for the player. Alternative sports technologies highlighted successes in visualisation, particularly in technical sports such as golf. The products and their features were researched thoroughly to help derive a suitable tennis alternative.

Contacting Experts

Contacting experts helped shape the overall focus of the product, giving insights into complex high end biomechanical tracking and ball tracking technologies, and how this could potentially be achieved at a much more consumer-based price.

Hawk Eye Employee

Sports Science Professor

Sports Biomechanist

Task Analysis Research

Analysing competitive systems

Video Analysis

Setting up Filming

Task analysis was undertaken with a number of clients, to understand more about competitive products and how a player responds to footage of themselves. Players found it difficult to self analyse their play from one video direction, and tasking users to film themselves for analysis proved time consuming and difficult to set up.

User Research






A 148 person survey revealed multiple crucial insights for the project. Users were categorised based on their ability, and asked a multitude of questions regarding how they felt about the demand for a self coaching tool. Every standard wanted to analyse weaknesses and compare their play in 3D, hence the product decision to use dual stereoscopic camera technology. There was a direct correlation between contact with a coach and tennis standard, demonstrating that those who received more coaching tended to improve better. At a beginner level, it was noted that players do not play enough to benefit from any coaching, playing only once per week. Likewise, professional tennis players had constant access to a coach at training sessions, and thus having access to a coaching product would not make sense. The intended user was therefore refined to intermediate to advanced level tennis players.

What If?



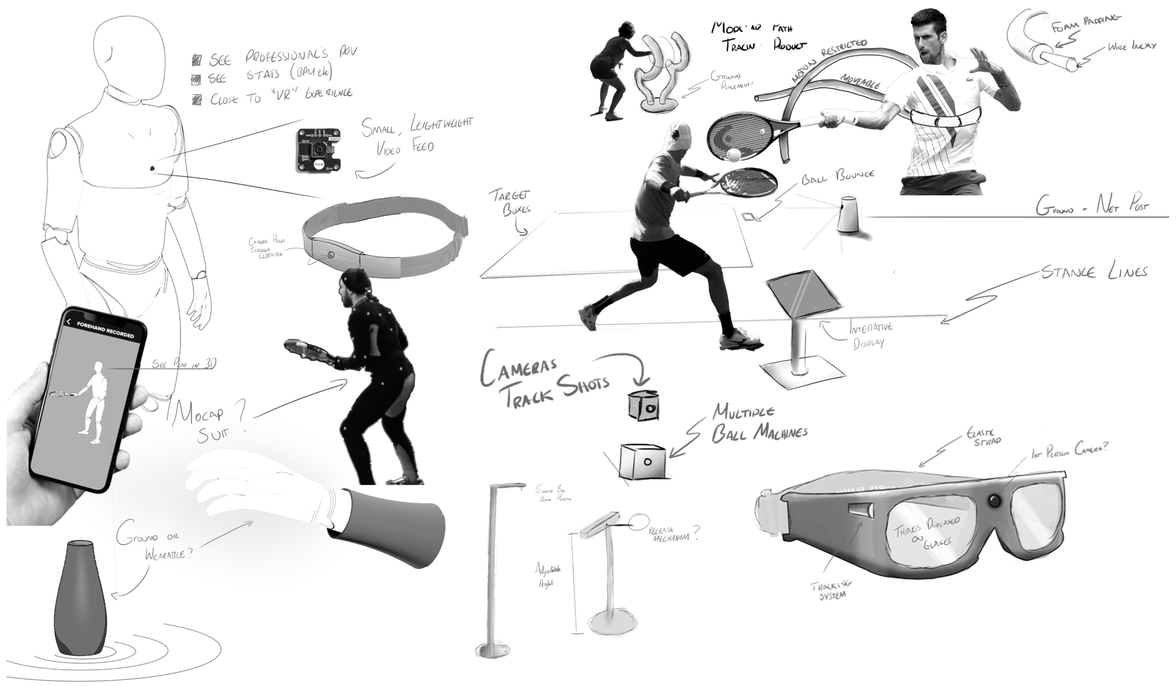



User personas were generated for intermediate to advanced tennis players as well as coaches, documenting their current approach to tennis and how it interacts with their daily life. These personas were generated based off real individuals, as well as insights gathered from the user survey, enabling a series of "What if..." statements to be generated, that would guide the subsequent concept generation.

2 | Product Development

Concept Generation

Concepts were generated based on the research insights and determined "what if..." statements. Promising concepts were emphatically modelled such as recording with a video camera on the body, helping with the evaluation and development.



Concept Evaluation

Hawk Eye Employee

Ex-Professional Player

Professional Tennis Coach

Advanced Player

After discussing the concepts with multiple users and an expert in top professional tennis visualisation software Hawk-Eye, a concept evaluation matrix was drafted narrowing the concept down to an AI motion tracking system, that would be able to track a player on a tennis court and offer technical coaching advice.

The User Journey

A considerable amount of time was spent really understanding the user journey. Observational analysis was undertaken to record the patterns of different training sessions to identify the needs of a motion capture system, and from this research two key user journeys were identified:

1. Portable System

The user wishes to figure out what is going wrong with his serve. They walk to their bag and take out the system, which they then pairs with their phone. The system is placed on the court and the motion capture tracks their shots, advising them on how to improve.

2. Built in System

The user wishes to practise his serve. They walk to the interface and select start, informing the user to place the system in the specific locations. A serve is hit and the user is informed on how to improve.

User Journey System Requirements

In order to evaluate the appropriate technology for a motion capture system, a list of requirements based on the user journey and ideal experience was created:

The product must be easily accessible for tennis players
The product must be quick to set up
The product should aim to be as unobtrusive as possible
The product must work reliably in all weather conditions
The product must be affordable (whether that be for a tennis club or an individual)

3 | Technological Development

Determination of Motion Capture Technology

Ouster LIDAR Sales Representative

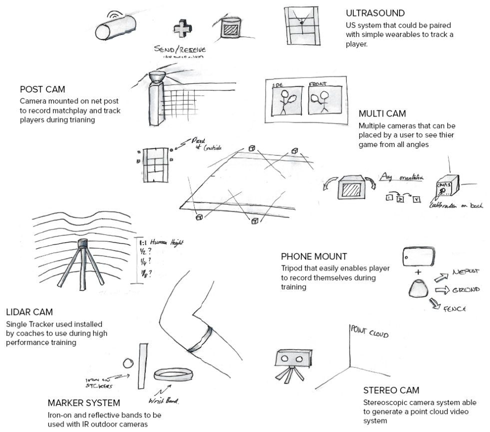
Motion Tracking Sales Representative

Computer Vision and Machine Learning

Ultrasound Expert

Robotics and Control Expert

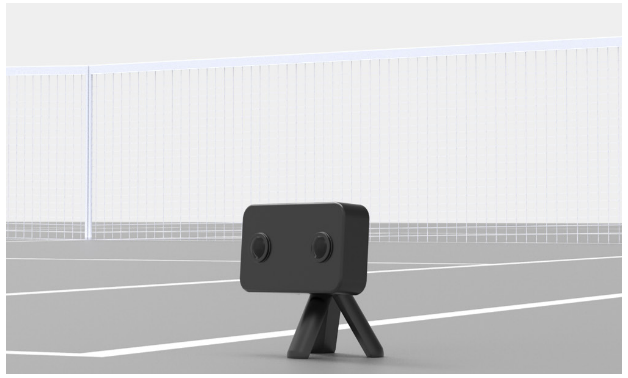
To choose the appropriate motion capture technology, it was important that each technology was researched and explored. Contacting experts in the relevant fields helped guide inspiration for different motion capture systems, and concepts were generated. These technologies were also evaluated against the ideal user journey requirements, ultimately choosing AI optical with the potential for stereoscopic imagery.



Technology concepts generated

	Brief Description	Computational Power Required	Number of Recording Points	Works (Reliably) Outdoors?	Unobtrusive?	Universal Between Users (no set up time between players)	Recorded Data Can be useful on its own - removing AI yields a useful output.	Track at High Frame Rates	Affordable for Tennis Club (<£20,000)	Affordable for Tennis Player (<£200)
Optical Depth Infrared	Camera and depth sensor combined to determine person and movement	Low	1 +	✗	✓	✓	✓	✓	✓	✗
Point Tracking	Multiple IR camera system that detects IR reflective balls on body.	Low	32-300 Markers 8-12 Cameras	✗	✗	✗	✓	✓	✗	✗
Acoustic Tracking	Ultrasound to determine depth map to create person.	High	Unknown	✗	✗	✓	✗	✗	✓	✓
Multiple Camera Optical Tracking	Multiple Camera motion tracking system	High	8-12 Cameras for full body capture	✓	✓	✓	✓	✓	✓	✗
IMU Sensors	Multiple Sensor body tracking system	Low	15 +	✓	✗	✗	✓	✓	✓	✗
IMU and RGB Camrea	Blend between IMUs and RGB Cameras	Low	2+ Cameras 5+ IMU sensors (could be less through testing)	✓	✗	✗	✓	✓	✓	?
AI Assisted Optical Tracking	Camera system that utilises machine learning to create mesh	High	1+	✓	✓	✓	✓	✓	✓	✓
Optical Depth Stereoscopic	Dual Camera system that creates RGBD map	Medium	1+ Cameras	✓	✓	✓	✓	✓	✓	✓
Superior Infrared Point Tracking	Infra-Red trackers that work outdoors	Low	8+ Cameras	✓	✓	✓	✓	✓	✗	✗
LIDAR	Near Infra-red point cloud capture tool	Low	1+ Measures everything in its path	✓	✓	✓	✗	✓	✗	✗

Technology evaluation matrix: AI optical tracking and optical depth stereoscopic tracking were identified to be the most ideal.



Chosen technology: AI optical with the potential for stereoscopic imagery

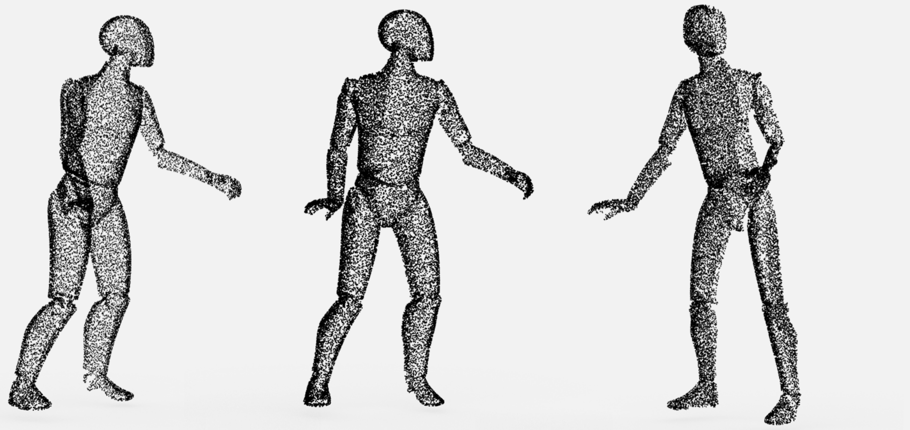
Capture Requirements

The system will identify weaknesses and deliver the tangible information to the user. To determine the exact requirements of a system for AI, the most complex shot in tennis was considered: the serve. Being the fastest shot in tennis, if the serve is able to be tracked then all other shots will be able to be analysed. To capture the key data, there must be a capture location from the side and back of a shot, meaning at minimum the AI system will have two cameras.

Critical capture locations for any shot is the side and back, will this be enough data for generating a stereoscopic point cloud?

Camera Number Determination

Stereoscopic imagery can be utilised to create an rgbd depth map, that tracks pixels in 3D space and applies an appropriate colour to them. Two cameras were determined to cover enough data to accurately capture a tennis pose, by utilising mesh manipulation to keep only the faces perpendicular to the side and back. Point cloud generation is possible.



Simulated point cloud. The player's outline is visible despite data only being captured from the side and back.

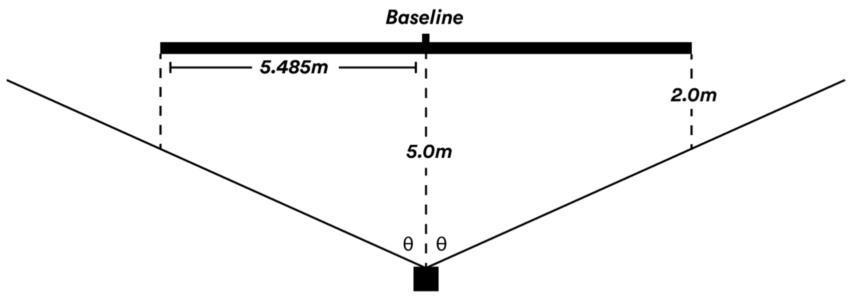
4 | Technological Specifications

Camera Capture Height

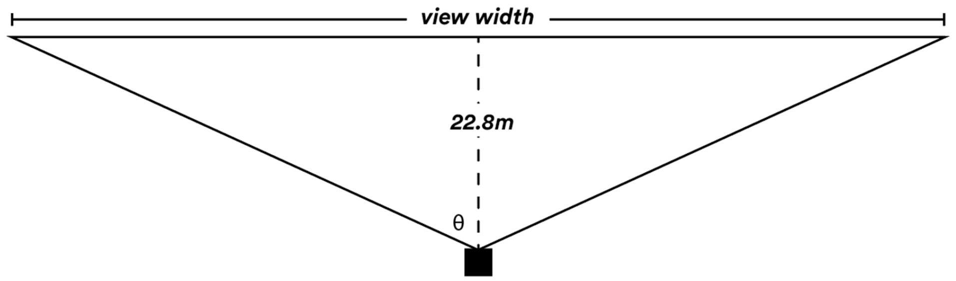
To confidently track a player in 3D space, the system had to be aware of its surroundings. An experimental set up was used to determine its location based on the detection of the lines on the tennis court. This concluded that the height of the camera system must be placed 0.85 m off the ground.

Experimental output of the line detection software. Detection accuracy increased as the height off the ground increased.

Camera FOV and Resolution



Capture requirements required a player to always be in frame of the camera. Using simple trigonometry, it was concluded that a lens FOV must be 125 degrees. This wide FOV would also enable the system to maintain accuracy even if placed slightly off centre. Likewise, for the system to detect a tennis ball, a minimum of 3px must be used. Dividing 3px by the length of a tennis ball gives a minimum of 45.96 pixels per m. At a maximum ball tracking distance of 22.8 m (back of the court to the service box for serve ball detection), a 4K camera resolution was required to satisfy the required pixel density.



Fps and Chosen Sensor

Analysing professional serve data and given that the time of a contact window is 5ms helped determine a minimum frame rate of 86fps is required to accurately record the contact point location. Through inter frame averaging, this was reduced to 60fps. Considering costs and minimum camera specifications, the SONY IMX 477 image sensor was chosen as the capture device.

Analysis of tennis footage to determine 60 fps frame rate

Stereoscopic Camera Spacing

Stereoscopic imagery relies on the comparison between the disparity of pixels between coincident cameras, whose range depends mostly on the spacing between them. Using the camera specifications and the requirement that the system must be able to track the player to a distance of the width of a tennis court, the spacing between lenses was determined to be 104mm.

Testing of Human Pose Estimation and Ball Tracking

Human pose estimation was tested throughout this project, a method of determining joint angles and tracking objects through computer vision. The specified image sensor was tested at its required height and human pose estimation undertaken on the device. When comparing the results with a professional tennis coach, it was concluded that this method is a valid approach in training an AI system to coach a player without the need for a coach.

Human pose estimation using SONY IMX 477

User **Journey**

Testing multiple user journeys from a variety of concepts, the decision was made to not utilise a display, and have all interaction between the user and the system via their mobile phone. The user journey of the product is as follows.

User arrives at the tennis court ready for a training session

User removes Advantage from its carry case and attaches to tripod

User turns on both systems and they pair with each other

User selects to practise serve and places the cameras in the rough positions, and hits some serves

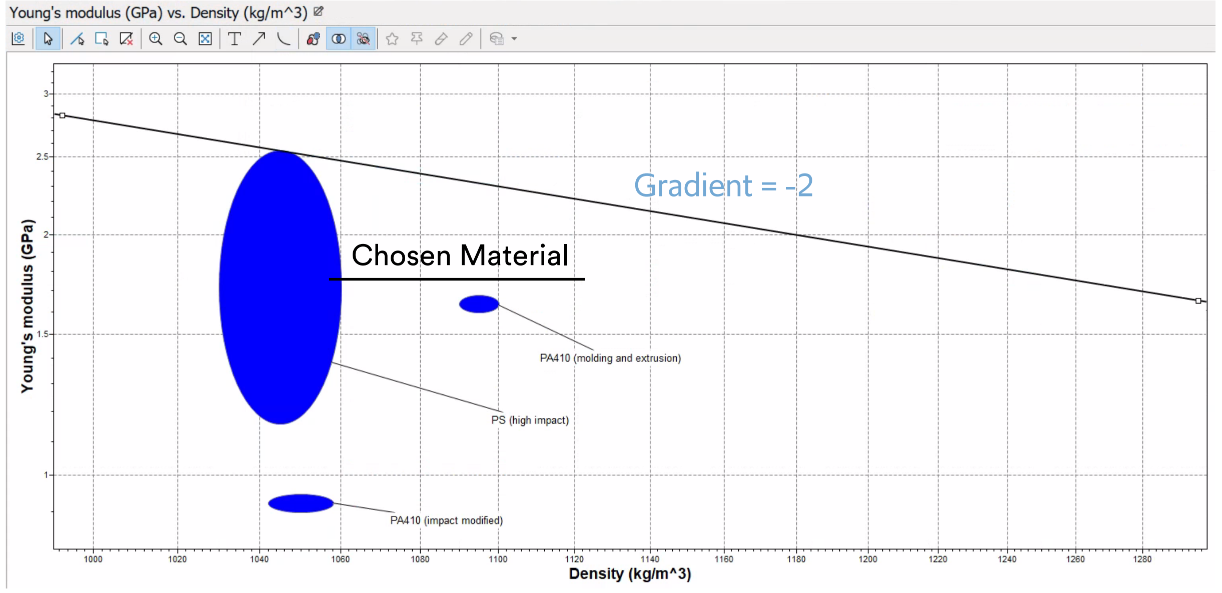
The AI system analyses the footage and suggests improvements, whilst showing the player a 3D view of their serve in slow motion

Once the user is finished, the device is placed back in its case where it charges for the next session.

Materials & Manufacturing

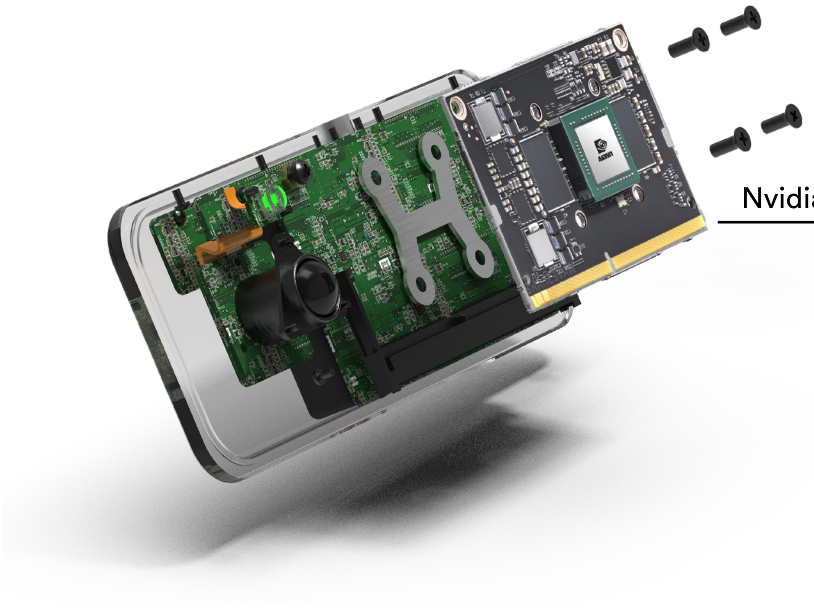
Material Selection

Material Selection was utilised to determine the optimum impact resistant material for the outer shell of the camera system. This was determined to be Polystyrene, High Impact. A D2 surface finish was chosen, giving draft angles of 1.5 degrees and an overall wall thickness of 3mm for the chosen injection moulding procedure.



Processor and Battery Considerations

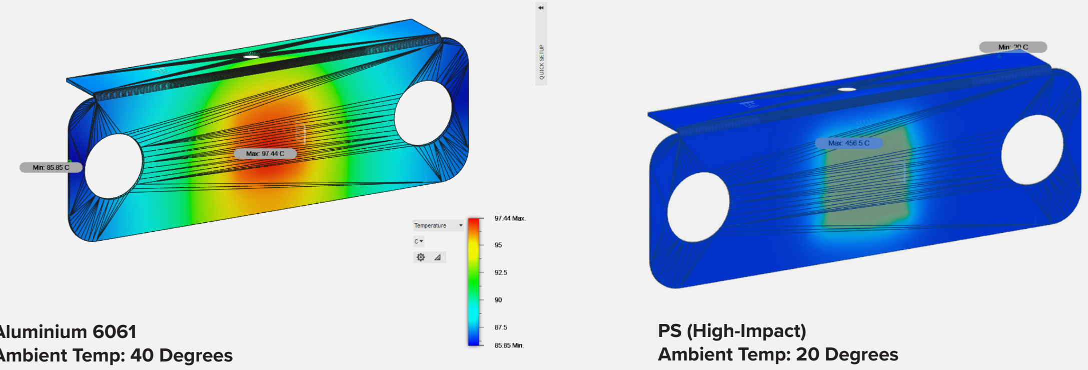
The Nvidia Jetson TX2 NX AI processor was chosen, featuring 1.33 TFLOPs of computational power, capable of advanced AI operations whilst capturing 2x 4K Video at 60fps at an affordable unit cost of $115. With a power draw of 7.5W, Lithium-ion was chosen as the battery of choice, with a calculated capacity of 45Wh to last 6 hours (2 training sessions on average).



Nvidia Jetson TX2 NX

Heat Considerations

An important consideration for this powerful processor was the dissipation of heat. Using insights gathered from Nvidias thermal design guide, a heat sink was designed to dissipate heat to the plastic and out into the surrounding air. When simulated, this heat sink proved necessary in keeping the temperature below 100 degrees, even in an uncomfortable 40 degree heat..

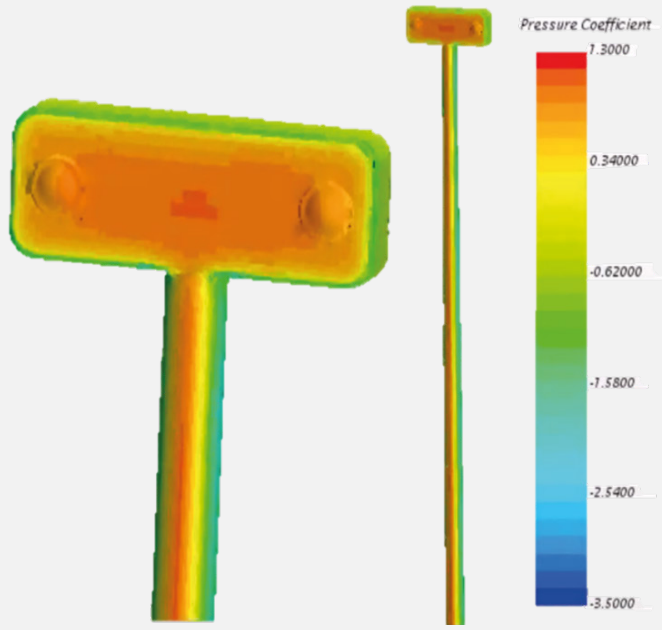


Aluminium 6061
Ambient Temp: 40 Degrees
Max CPU Temp: 97.44 Degrees

PS (High-Impact)
Ambient Temp: 20 Degrees
Max CPU Temp: 468.5 Degrees

Monopod Specifications

It was decided that for cost effective reasons a monopod should be outsourced to a company, as the design of the monopod is very similar to that of current models, yet it needs to extend to a specific 0.85 m. Computational Fluid Dynamics was utilised to determine the maximum force being applied to the camera under gale force winds, and with a camera weight of 420g, moments were calculated to determine that for a monopod to be stable, it must have legs of at least 338mm in length. To minimise overall footprint, the decision was made to keep the monopod legs outside of the case design.



CFD pressure distribution results

Product Assembly

Below details the assembly of the camera system's internal components. Given the scope of the project, the case and monopod internals were not specified, and instead an estimate was given on the product costing. 3D printing the prototype with its main internals helped validate the assembly and appropriate location for screws. Comparisons were made to similar camera systems to help design the internal layouts and material selection.

1. Front Shell

Injection moulded PS High Impact

Selected for high impact. All holes exposed to the outside will be glued with silicone adhesive to prevent water ingress. 1.5 degree draft angles with a D2 surface finish.

2. LED Diffuser

Injection moulded PS, sealed to Front Shell.

3. LED & PCB

SMC 1716D Tricolor LED + PCB

4. Aluminium Heat Sink

Aluminium 6061

Heat sink designed to dissipate heat from CPU to the plastic housing and into the surrounding environment.

5. 1/4" - 20 UNC Tripod Thread

Cast Aluminium

Standardised tripod thread length, sealed to Front Shell.

6. Nvidia Jetson TX2NX

7. Sony IMX 477 Module

Purchased from manufacturer

8. Main PCB

PCB + 2309407-1 SODIMM

Main board that connects wifi and camera components to the Jetson via a SODIMM slot.

9. Battery

45Wh Lithium-Ion Battery, custom manufactured

10. Battery and Power Button PCB

PCB + Power Button

A. M3 × 8mm

B. M2.5 × 3mm

C. M1.6 × 3mm