

# Considerations When Applying UAS-based Large-Scale PIV and PTV for Determining River Flow Velocity

- How can we work towards an optimisation of techniques?
- What is regarded as “best practice”?
- What are the focuses for mobile platforms?

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## Considerations When Applying Large-Scale PIV and PTV for Determining River Flow Velocity

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Large-scale image velocimetry is a novel approach for non-contact remote sensing of flow in rivers. Research within this topic has largely focussed on developing specific aspects of the image velocimetry work-flow, or alternatively, testing specific tools or software using case studies. This has resulted in the development of a multitude of techniques, with varying practice being employed between groups, and authorities. As such, for those new to image velocimetry, it may be hard to decipher which methods are suited for particular challenges. This research collates, synthesises, and presents current understanding related to the application of particle image velocimetry (PIV) and particle tracking velocimetry (PTV) approaches in a fluvial setting. The image velocimetry work-flow is compartmentalised into sub-systems of: capture optimisation, pre-processing, processing, and post-processing. The focus of each section is to provide examples from the wider literature for best practice, or where this is not possible, to provide an overview of the theoretical basis and provide examples to use as precedence and inform decision making. We present literature from a range of sources from across the hydrology and remote sensing literature to suggest circumstances in which specific approaches are best applied. For most sub-systems, there is clear research or precedence indicating how to best perform analysis. However, there are some stages in the process that

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# Introduction

- The aim of this review was to:
  - Present and discuss the key challenges and considerations when seeking to acquire image velocimetry data within a fluvial setting
    - i.e. large-scale image velocimetry
    - Using fixed and UAS systems
- The key stages in large-scale image velocimetry work-flows can be characterised as:
  - I. capture optimisation
  - II. pre-processing
  - III. image processing
  - IV. post-processing steps

# Overview of sections

## I. Capture Optimisation

- Ground Sampling Distance (GSD)
- Tracers
- **Capture Rate**
- External Environment
- Choice of Platform\*

## II. Pre-Processing

- Stabilisation
- Orthorectification
- **Image Manipulation**

## III. Image Processing

- **Founding Principles**
- **Flow State**
- Feature Tracking Schemes

## IV. Post-Processing

- **Vector Correction**
- Applications

\*Today's focus is mobile platforms

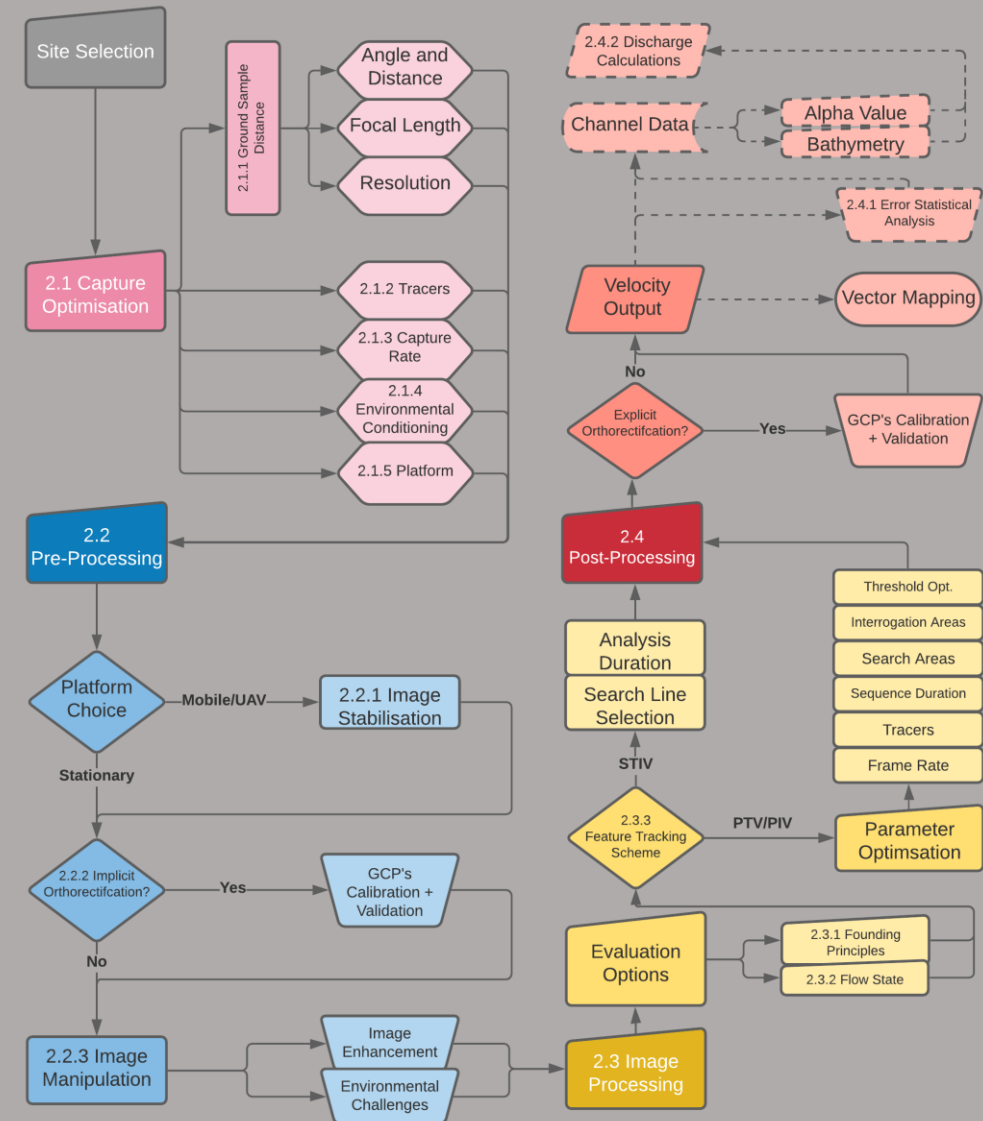


Figure 1: Generalised processes of Image velocimetry

# Part one: Capture optimisation

- Platform type
  - Using mobile platforms (or fixed)
- Ground Sampling Distance (GSD)
  - How to obtain reliable data
- Tracers
  - What are tracers and why are they important?
- ~~Capture rate~~
- Environmental conditions
  - What challenges are we facing?

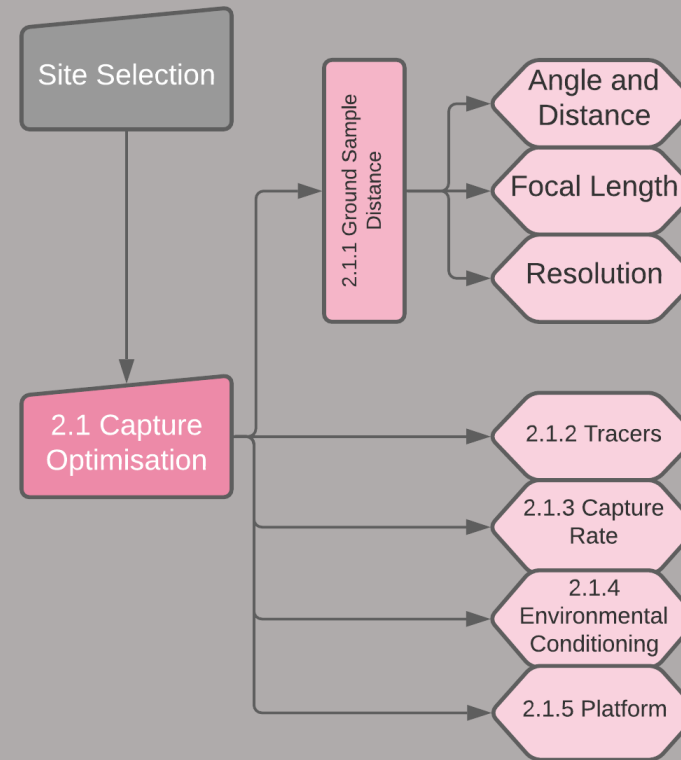


Figure 2: Generalised processes of Capture Optimisation

# Part one: Capture optimisation

## • Platform Type



Figure 3: AcuSense Varifocal  
Bullet Network Camera  
(Fixed sites)

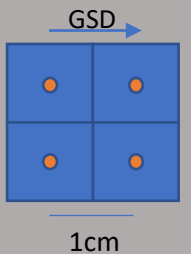


Figure 4: DJI P4 Multispectral  
Drone  
(Mobile platforms)

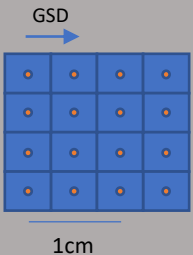
- Image velocimetry can be done using fixed cameras and capture data over a long period of time.
  - Temporal data
  - Typically issued to extend discharge rating curves
  - Typically needs orthorectification every time capture area changes
- Today's focus is using UAS and mobile platforms
  - Offers a more spatial aspect of data
  - Can improve operator safety in hard to reach, remote locations
  - New technology is advancing the field into using mobile phones for real-time processing, and satellites for larger rivers.

# Part one: Capture optimisation

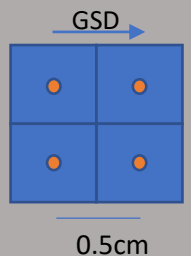
## • Ground Sampling Distance (GSD)



Original GSD = 1cm/px



Increase resolution  
GSD = 0.5cm/px



Decrease Height by 50%\*  
GSD = 0.5cm/px

\*Assuming the same camera is used throughout

- GSD = Length per pixel (e.g. cm/px)
- Two ways of improving GSD
  - Decrease distance between subject and camera
  - Increase the amount of pixels in frame (resolution)
- Resolution optimisation is undefined
  - Precedence is provided
- Optimise GSD
  - Resolution is a method but not the best way
    - Increases processing time
    - Data storage increase
    - Bandwidth increase (IP Cameras)

(Dal Sasso et al., 2018; Le Boursicaud, 2016)

(Prasad et al., 1992; Tosi et al., 2020)

Figure 5: How GSD is calculated and altered regarding height and resolution

# Part one: Capture optimisation

## • GSD using mobile platforms

### Camera at NADIR

$$1) \text{ Height (m)} = \frac{IwP \times GSD \times F}{SW \times 100}$$

- Focal length (F; mm)
- Sensor width (SW; mm)
- Image width (IwP; pixels)

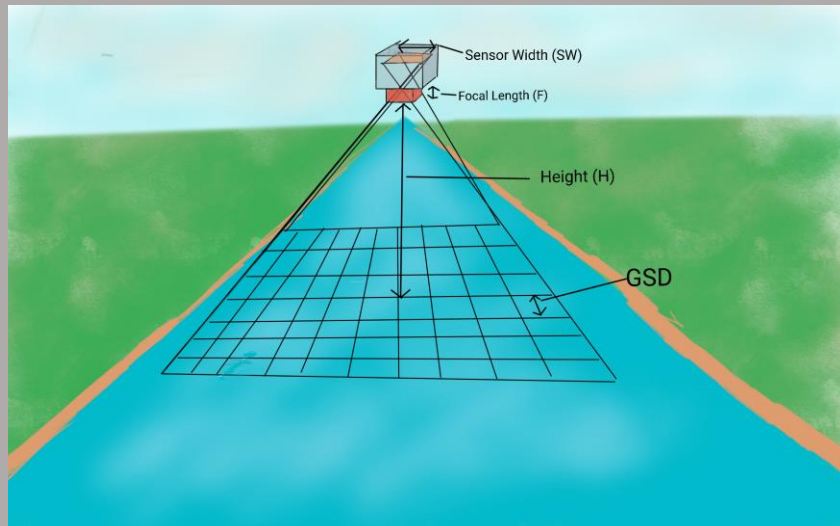


Figure 6: GSD example at Nadir

### Camera at angle

$$2) GSD\left(\frac{m}{px}\right) = \frac{L \times 200}{IwP}$$

$$4) Lv (m) = H \frac{\sin(\theta \pm \alpha v)}{\sin(90 - (\theta \pm \alpha v))}$$

- L is a multidimensional length in both the horizontal (h) and the vertical (v) width
- Focal length (F; mm)

$$3) Lh (m) = H \frac{\sin(\theta \pm \alpha h)}{\sin(90 - (\theta \pm \alpha h))}$$

$$5) \theta(^{\circ}) = \tanh \frac{SW}{F}$$

- Sensor width (SW; mm)
- Image width (IwP; pixels)
- Height (H; m)

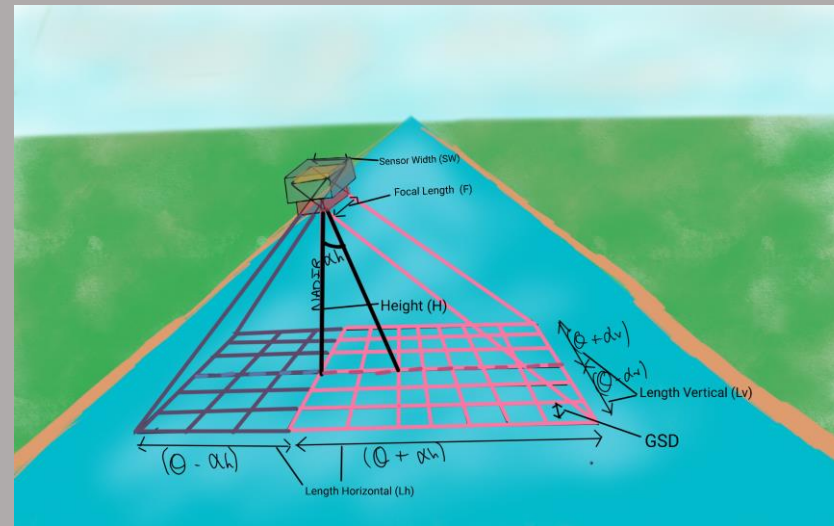


Figure 7: GSD example at an angle off of Nadir

**Spreadsheet tool available here:**

[https://github.com/MJolley1/GSDCalc/blob/main/MJ\\_Oblique\\_CamAngle\\_Est\\_V2.xlsx](https://github.com/MJolley1/GSDCalc/blob/main/MJ_Oblique_CamAngle_Est_V2.xlsx)

# Part one: Capture optimisation

- **GSD**

## Camera at angle

- Creation of GSD angle tool
  - Enter known parameters
    - Height, focal length, sensor width, average capture angle etc.

		Typical Values	
AlphaH	20	= angle of camera in horizontal direction (deg)	
AlphaW	10	= angle of camera in vertical direction (deg)	
Sw	53	= the sensor width of the camera (millimeters)	5mm (mobile phone), 53mm (medium format detailed)
Fr	100	= the focal length of the camera (millimeters)	11mm (180D FOV), 300mm (9D FOV), 28-50mm Ave.
H	50	= the camera height (meters)	
imW	1920	= the image width (pixels)	
imH	1060	= the image height (pixels)	
<b>GSD (Nadir)</b>	<b>1.380208333</b>	<b>= Ground Sampling Distance (centimeters/pixel) (ignore if not Nadir)</b>	
<b>Ave. GSD (Tilt)</b>	<b>5.541050993</b>	<b>= Ground Sampling Distance (centimeters/pixel)</b>	
Dw	106.3881791	= width of single image footprint on the ground (meters)	
DH	58.73514053	= height of single image footprint on the ground (meters)	
theta	27.92358972	= angle of capture [ATAN(Sw/Fr)] (deg)	
			1 Enter the tilt angles in both directions (0,0 for nadir)
			2 Enter sensor width and focal length of camera
			3 Enter the height of the camera
			4 Enter your resolution (pixel width and height) [HD=1920x1080]
			5 Let the spreadsheet calculate the average GSD in each quadrant
LH+	55.38191755	= length of H direction from nadir with positive AlphaH (m)	--> 10.44941841 = Average Ground Sampling Distance (centimeters/pixel)
LH-	6.959056828	= length of H direction from nadir with negative AlphaH (m)	--> 1.31302959 = Average Ground Sampling Distance (centimeters/pixel)
LW+	70.56364109	= length of W direction from nadir with positive AlphaW (m)	--> 7.350379281 = Average Ground Sampling Distance (centimeters/pixel)
LW-	29.29321629	= length of W direction from nadir with negative AlphaW (m)	--> 3.051376697 = Average Ground Sampling Distance (centimeters/pixel)
Total LH	62.34097438	m	
Total LW	99.85685738	m	
AREA	6225.173788	m <sup>2</sup>	
Ave. Density	0.032693063	pixels per cm	
Sqrt Dens.	0.180812232	square pixels per cm	
		If any of these values are negative, it would indicate the angle of the camera is not capturing a certain quadrant. For example, an AlphaH value of 50 and Sw=15, Fr= 20, H=15, would give us a LH- of -3.5m. This means that it is not capturing any of the LH direction, and is missing 3.5m from nadir into the LH+ direction.	

**Spreadsheet tool available here:**

[https://github.com/MJolley1/GSDC/blob/main/MJ\\_Oblique\\_CamAngle\\_Est\\_V2.xlsx](https://github.com/MJolley1/GSDC/blob/main/MJ_Oblique_CamAngle_Est_V2.xlsx)

Figure 8: GSD spreadsheet tool available on Github

# Part one: Capture optimisation

## • Tracers



Figure 9: Visible tracers that can be used to track surface velocity between two frames, 1s apart (high flow, roughly around 1.7m/s)

- 10-30% of the surface should be traceable throughout the process

(Meselhe et al., 2004)

- Can use artificial tracers where natural is sub-optimal

- Passive to flow
- Easily distinguishable
- No effect on water quality

(Detert & Weitbrecht, 2015)

- Size/shape should be stable over time

(Tauro et al., 2017, Tsubaki et al., 2011)

- Tracers should be larger than 1px

(Dal Sasso et al., 2020)

- Artificially placed tracers

- ellipsoidal particles of 2-5 pixels in size perform well

(Wu Tang et al., 2008)

# Part one: Capture optimisation

- **Environmental conditions**
  - Presence of wind, rain, and glare within imagery
    - Wind
      - False tracers
      - Tracer disruption
    - Rain
      - Blurring of imagery
      - False vectors?
      - Tracer disruption
    - Glare
      - Impact of brightness variation
      - Loss of tracers

(Fujita et al., 2007; Hauet et al., 2008; Le Coz et al., 2010; Zhang et al., 2013)

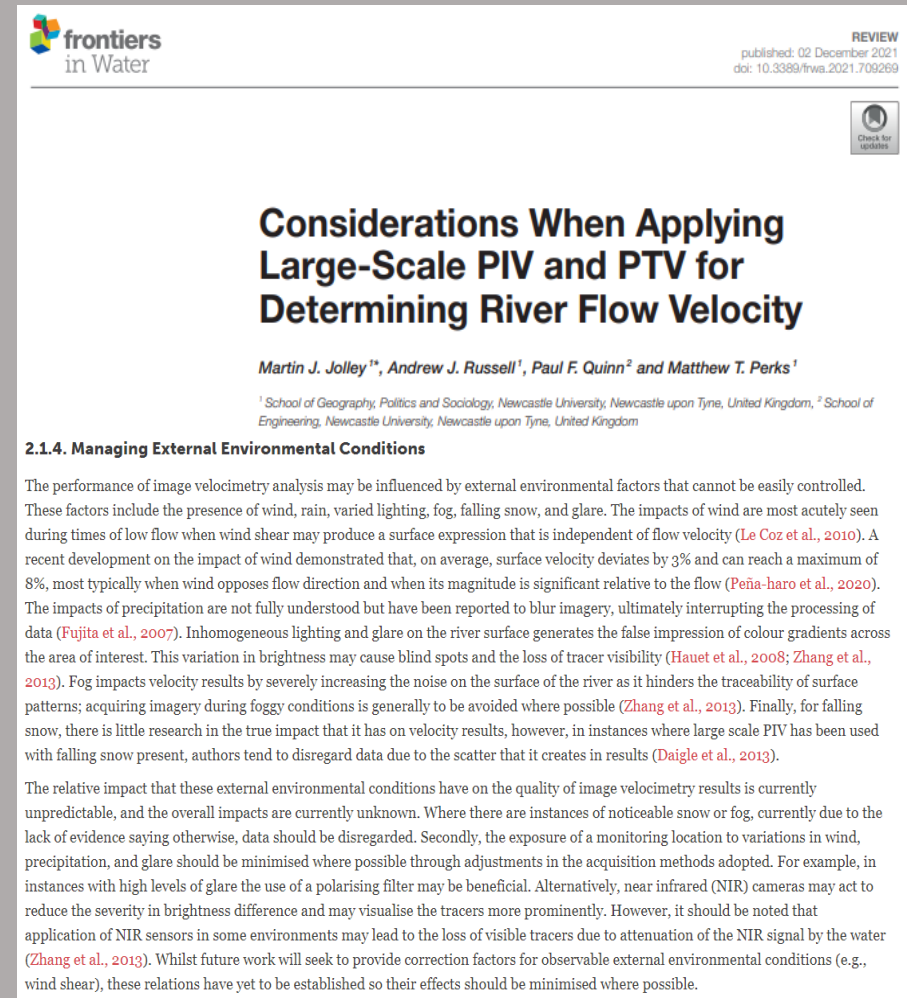


Figure 10: Chapter on environmental conditions within the review

# Part Two: Pre-Processing

- Image Stabilisation
  - Critical for mobile platforms
- Orthorectification
  - Associating pixels with lengths
- ~~Image Manipulation~~

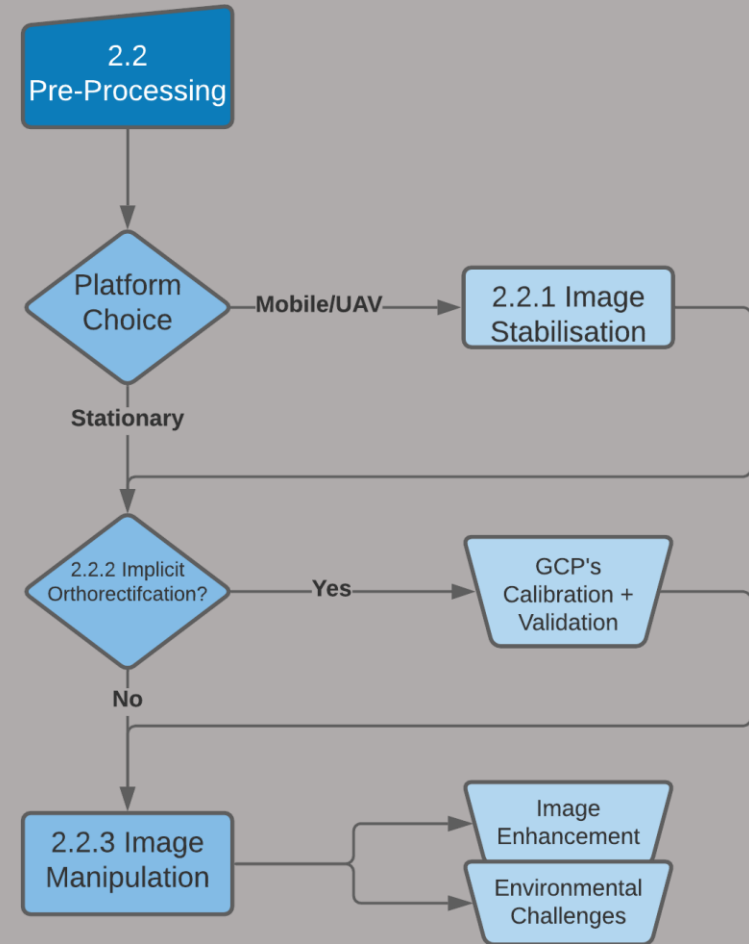


Figure 11: Generalised processes of pre-processing data

# Part Two: Pre-Processing

## • Image Stabilisation

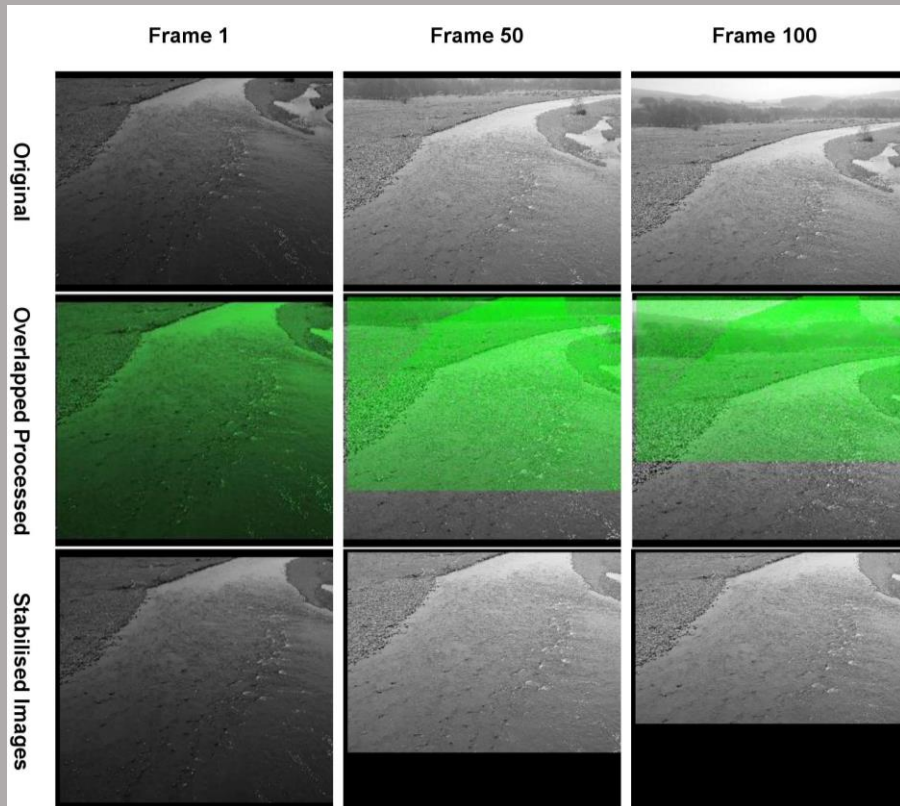


Figure 12: Simple stabilisation code impact in MATLAB used on drone footage

- Manual or Automatic
  - Manual methods → manual selection → automatic displacement
  - Automatic methods → automatic selection and displacement
    - Binary feature matching techniques, e.g.
      - Harris Corner Detection
      - FAST

(Liu & Cheng, 2008; Mingkwan & Khawsuk, 2017; Muja & Lowe, 2012; Rodriguez-Padilla et al, 2019)
- Four point pairs → full projective transformation
  - Perspective deformation

(Ljubičić et al., 2021)
- Excessive movement = Updated grid per  $n^{\text{th}}$  frame?

# Part Two: Pre-Processing

## • Orthorectification

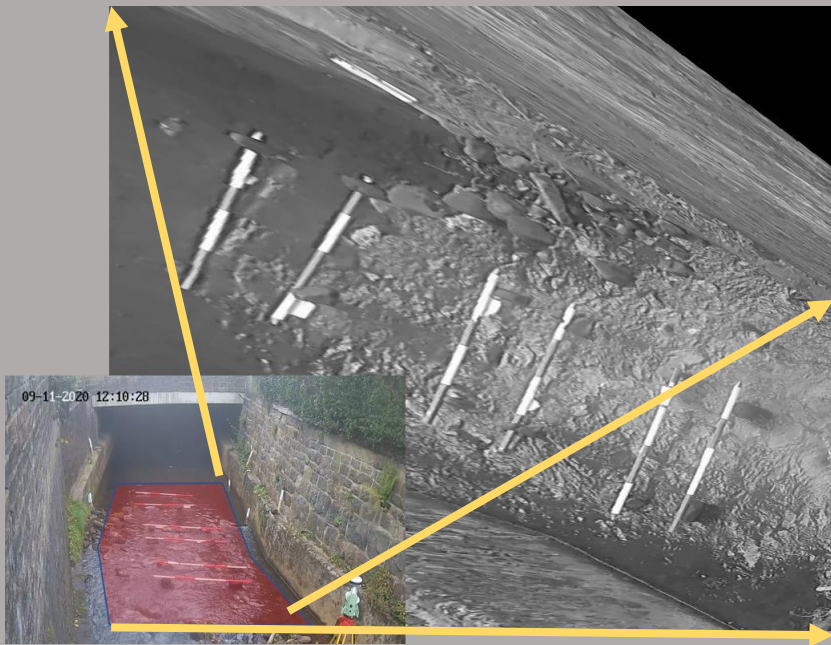


Figure 13: Orthorectification of a fixed camera station using KLT-IV software (Perks, 2020)

- Critical unless the image is being captured at nadir
  - + Image distortion has been removed
- Ground Control Points (GCPs)
  - Calibrate known coordinate points in the field of view  
(Tauro et al., 2014)
- 2D transformations:
  - 8-parameter plan-to-plan perspective projection
    - Four GCPs at the river free-surface elevation  
(Detert, 2020; Detert et al., 2017; Detert & Weitbrecht, 2015; Fujita et al., 1998)
- 3D transformations:
- Large variations of elevation between GCPs and the river surface
  - 11 unknown dimensions → Six or more GCPs  
(Jodeau et al., 2008)
- Minimum of four GCPs should be used in or immediately around the region of interest

# Part Three: Processing

- ~~Founding principles~~
- ~~Flow state~~
- Feature tracking scheme
  - PIV or PTV?

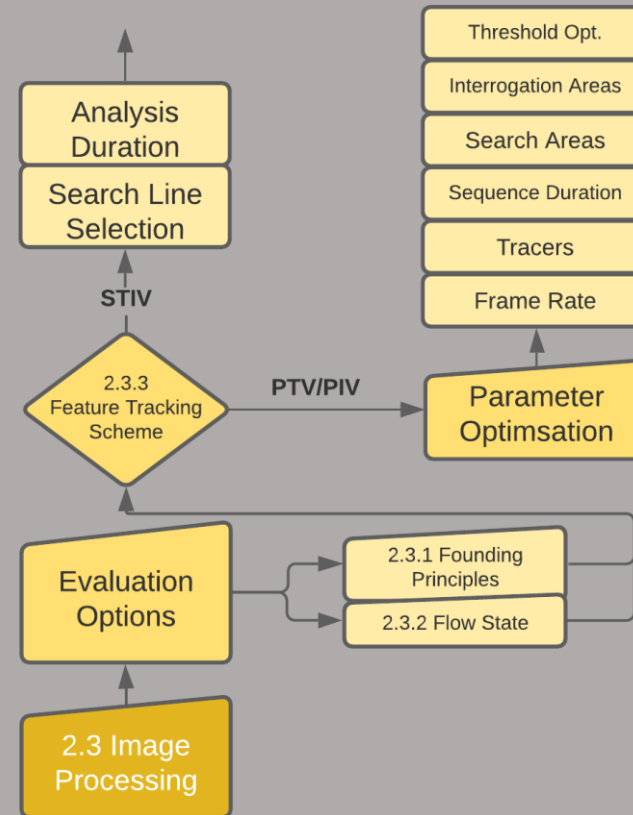


Figure 14: Generalised stages of processing data

# Part Three: Processing

## • Feature tracking scheme

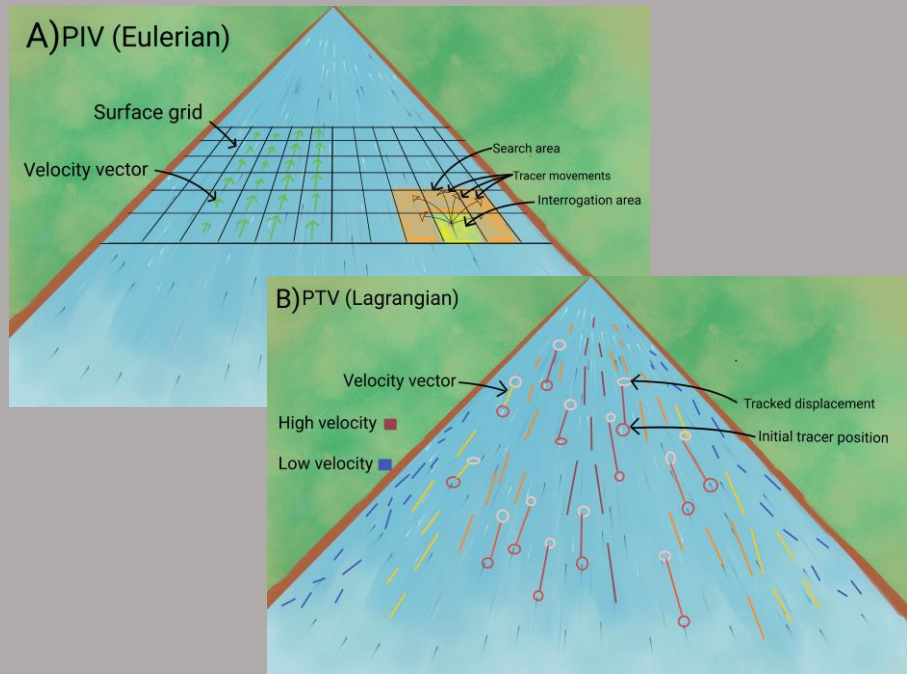


Figure 15: Lagrangian (PTV) and Eulerian (PIV) methods of tracking displacements

### • PTV based approaches:

- Tracks individual particles along a long-profile
- Perform well under low seeding density conditions

(Lloyd et al., 1995, Tauro et al., 2017)

### • PIV based approaches:

- Search and interrogation areas within an image
- Less sensitive to the transformation of individual features
- Inhomogeneity and discontinuity of tracers are critical issues that may negatively affect the quality of PIV analysis

(Muste et al., 2008; Tauro et al., 2016)

### • Feature detection:

- Good Features to Track (GFTT) (Shi & Tomasi, 1994)
- FAST (Rosten & Drummond, 2006)
- SIFT (Lowe, 1999)

### • For tracking algorithms:

- Cross-correlation can be used
- Kanade-Lucas-Tomasi (KLT) (Perks, 2020; Tomasi, 1991)
- Variations of the Nearest-Neighbour algorithm e.g. Tauro et al. (2019)

# Part Four: Post-Processing

- ~~Error Statistical Analysis~~
- Discharge Calculations
  - From surface velocity to flow/discharge

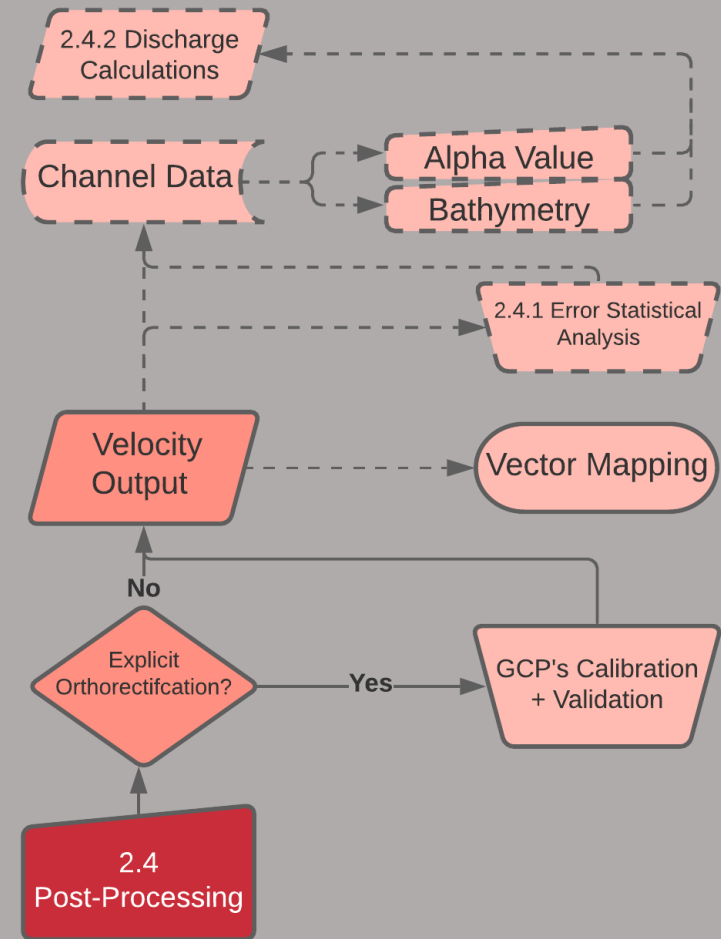


Figure 16: Generalised stages of post-processing of data

# Part Four: Post-Processing

- Discharge Calculations

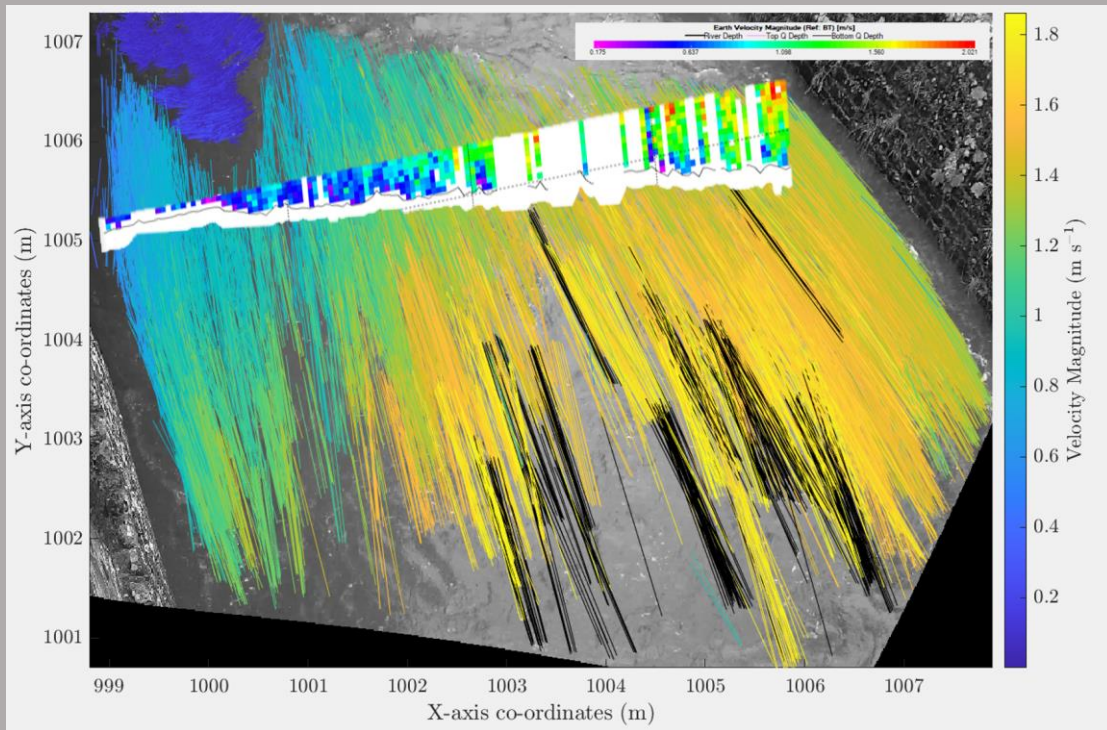


Figure 17: KLT-IV (Perks, 2020) output (PTV), aligned with a aDcp transect taken at the same time. One verifies the other and once an area of a transect is known, discharge can be estimated.

- Typically velocity-area method
  - Alpha value  $\approx 0.85$

(Creutin et al., 2003)

- Known & measured transects of the river within the camera field of view
- Good spread of tracers
  - Interpolate or extrapolate
    - Polynomial, cubic, or the constant Froude method

(Perks, 2020)

# Key Findings

1. Mobile platforms have very similar requirements to fixed platforms, with the added important of stabilising the imagery.
2. There is a vast amount of research regarding optimisation for most parameters, with tracers, angles, stabilisation and orthorectification being key considerations for reliable processing.
3. Most importantly for my research, there is a lack of information regarding how to process imagery that is heavily influenced by environmental factors (e.g. Wind, Rain, Solar Radiance/Brightness Variation).

# Using the Findings...

## 1. Handbook for SEPA

- Contents
- Choosing your sites

## 2. Begin to look at how environmental factors influence tracers

- Seeding Density Indexing (SDI)
- Dispersity

# The Handbook/Guidebook



## Handbook: On the creation of large-scale image velocimetry sites

Large-scale image velocimetry in rivers

Author: Martin Jolley

Institute: Newcastle University

Date: January 2022

Version: 1.1

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# Choosing a Site...

- **Capture some initial video**
  - Doesn't have to be perfect
    - 30s max video
      - Stable video if possible
  - Can you see the movement easily by eye?
    - Are there floating tracers?
    - Are ripples evident
    - Is it too laminar?
  - Choose either PTV (KLT) or PIV (RIVeR)
    - PTV better for low particle seeding
    - PIV easier to obtain initial values
- **Make it easy for yourself**
  - Easy to access with equipment
- **Don't be afraid to get it wrong**
  - If a site isn't working, change the site
  - Set everything up before you go to site and have it running for a few days to trial
  - Try both KLT and RIVeR to see which works best for your site if you're not sure

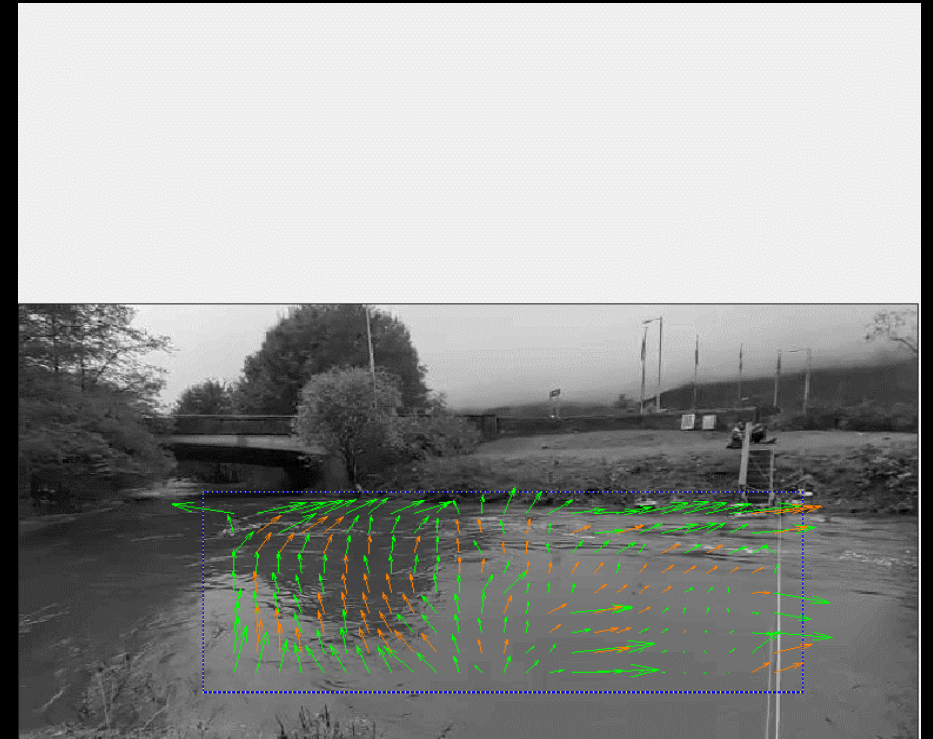


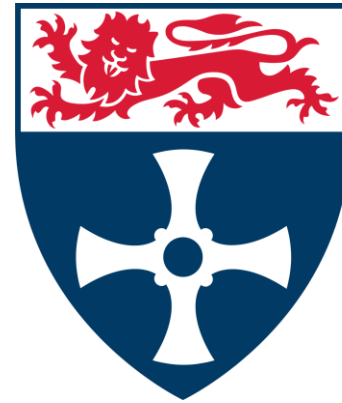
Figure 18: A video that was sent to me during site considerations to check the surroundings and tracer availability. Image has been stabilised and preliminarily processed through river

## CHAPTER 2 – SDI & ENVIRONMENTAL CONDITIONS

- The hypothesis of the study is initially :
  - Tracer SDI and dispersity significantly impact velocity results using KLT-IV (PTV)
- With the main question being:
  - To what impact does SDI and seeding dispersity have on surface velocimetry and consequently discharge when using PTV methods over a variety of flows?

Thank you for  
your time...

- Should you wish to know more about my work, please contact me at:
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