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Review Article

Forensic image analysis – CCTV distortion and artefacts

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ABSTRACT

As a result of the worldwide deployment of surveillance cameras, authorities have gained a powerful tool that captures footage of activities of people in public areas. Surveillance cameras allow continuous monitoring of the area and allow footage to be obtained for later use, if a criminal or other act of interest occurs. Following this, a forensic practitioner, or expert witness can be required to analyse the footage of the Person of Interest. The examination ultimately aims at evaluating the strength of evidence at source and activity levels. In this paper, both source and activity levels are inferred from the trace, obtained in the form of CCTV footage. The source level alludes to features observed within the anatomy and gait of an individual, whilst the activity level relates to activity undertaken by the individual within the footage. The strength of evidence depends on the value of the information recorded, where the activity level is robust, yet source level requires further development. It is therefore suggested that the camera and the associated distortions should be assessed first and foremost and, where possible, quantified, to determine the level of each type of distortion present within the footage. A review of the 'forensic image analysis' review is presented here. It will outline the image distortion types and detail the limitations of differing surveillance camera systems. The aim is to highlight various types of distortion present particularly from surveillance footage, as well as address gaps in current literature in relation to assessment of CCTV distortions in tandem with gait analysis. Future work will consider the anatomical assessment from surveillance footage.

Contents

1. Introduction

Surveillance is defined as 'the practice of monitoring, recording, watching and processing the particular conduct of events, locations and persons for the purpose of governing activity' [1]. The importance of surveillance as an intelligence- and investigative-gathering tool cannot be over-estimated, and the number of cameras installed across various types of locations (both public and private) are increasing, thus proving to be a strong for activity level inference. The source level addresses the question of the identity of the person present on the CCTV footage, while the activity level focuses on the activity of this person [2]. However, the poor quality

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of the footage captured limits the amount of information recovered. The primary objective of installing surveillance cameras is to deter crime, as well as extracting both source and activity information following an effective detection, tracking, recognition, and identification of individuals. However, it has been determined that in some areas such as Newark, New Jersey, CCTV cameras are less effective at deterring crime than other areas such as Newcastle, England [3], thus questioning whether some places have lost their effect at deterring crime, possibly due to the recorded individual's awareness of limited source level analysis due to poor quality of footage [4].

Cameras are placed across multiple sites at airports, car parks, shopping centres, train stations, motorways and stores [5,6], and other public places, as well as an increasing proliferation in the private sphere. The purpose of surveillance cameras is to monitor an area continuously, and collect information for later use. The public commonly believe that criminal or deviant acts will be brought to a premature close once the camera is noticed, although crime rates do not support this assertion [7]. Although cameras are installed to deter the act of crime, or potentially reduce the amount of crimes committed, this does not appear to hold true based upon the increase of crime rates observed.

Between the years 2014 and 2015, an increase of 2% in varying types of crime was documented in Australia (i.e. theft and violent crimes) [8]. This equates to 411,686 offenders that were proceeded against by authorities [8]. To combat this, strategically placed 'open-street'[1] surveillance systems act as a crime deterrent through the continual monitoring of public crime 'hot spots' [9,10].

In NSW Australia alone, 45 open street camera systems have been strategically installed across crime hot-spots [10,11]. NSW Train Systems provide a good example of the large scale of some open street camera networks, as it includes 10,070 individual cameras within one system [11–13]. The purpose of such a network is to deter criminal activity and to capture the activity and identify individuals involved in this activity. Surveillance cameras have the capability to record continuously, however without a forensic image practitioner to examine the footage and infer the identity and the activities of the persons (victims or offenders), the footage remains of limited value, especially at the source level due to the limitations of the camera quality obstructing source level features. The determination of whether gait is able to be analysed from footage depends on whether the properties of the following can be satisfied, including: [1] feature set, [2] distinctiveness, [3] permanence, [4] universality, [5] collectability and [6] performance [14]. For more information, the gait analysis component will be further discussed in a future paper.

As aforementioned, the main limitations of CCTV cameras revolve around poor quality of the footage, thus limiting the availability for source level inference. Furthermore, camera distortion, aspect ratio distortion, high point of view of the camera, pan-tilt-zoom cameras, and time lapse recordings present obstacles commonly found in surveillance footage [15]. This paper reviews the types of distortion present in particular those that are commonly observed within surveillance cameras, and highlights the elements that need to be considered prior to the suitable analysis of a trace within the images for identification characteristics.

Currently, forensic research revolves around the attempt to answer who the trace originally belongs to; through the inference of the source level by identification (investigation), individualisation (evaluation), and association (intelligence) [2]. These three processes are the results of the comparison of generally a trace, and a reference image. Although less attention has been provided for reconstruction at the activity level, the questions of 'how and when the traces are made' remain the primary focus [2]. CCTV technology was primarily designed for the activity level inference, which is effective for capturing information based on activity of individuals. However, when criminal activity is detected, the source level inference is then questioned. This paper focuses on distortions and artefacts that impact upon the trace material (CCTV footage) – which in turn may affect the analysis of the source level inference.

1.1. The age of surveillance technology

Proliferation of surveillance technology began in the UK in the 20th century, followed by rapid worldwide dispersion [1]. The number of camera systems have increased so significantly since that time that it is estimated that the average person in London will be captured by 300 different cameras in a single day [16]. As a result of the terrorist attacks on the World Trade Center in New York in 2001, security requirements were reassessed worldwide (particularly USA) to combat similar threats [17]. Thus, surveillance systems currently include video providing 'remote eyes' as a security measure [17]. The recording feature of surveillance technology and its capability to record in various conditions (colour, monochrome, night vision, heat detection, and infrared) allows police and border security to capture footage of persons of interest (offender and/or victim) [17]. Although still limited for source level inference, the presence of surveillance systems has been effective in reducing certain types of crimes [18]. For example, incidents of theft and other property crimes in general have reduced following the installation of surveillance cameras, however the number of violent crimes have not gone down [18].

Following a crime occurring, police obtain relevant footage of criminal activity/traces captured by CCTV, which are then passed to expert image analysts. The forensic practitioner is then required to assess the footage containing information about the presence and presence of individuals, often being asked to provide an expert comparison between the Person of Interest and a suspect, followed by the ACE-V protocol of Analysis, Comparison, Evaluation and Verification. CCTV can be invaluable within investigation or intelligence for instance, in circumstances when tracking the last movements of a missing person or that committing a crime, which in turn may lead to further evidence – including fingerprints and/or DNA. The benefit of CCTV revolves around its availability and capability to record continuously even from a distance the footage generally is readily accessible, due to the vast amount of surveillance cameras present; albeit limited in quality. As a result of the proliferating CCTV cameras, and how easy it is to capture footage of crime, once developed further and limitations addressed, this technique is thought to be very beneficial within modern society [7,19].

The accessibility to surveillance footage and its use have been demonstrated in a number of cases, however more importantly, scientific validation is not yet accomplished within the courtroom and is necessary. For example, in *Murdoch v The Queen ([2007] HCATrans 321* and *[2007]) NTCCA)* [20,21], an offender was convicted on the basis of 'morphometric mapping' of the body. The term 'morphometric' refers to the combination of both anthropometric and morphological analyses, whereas 'body mapping' is a comparison technique assessing the CCTV camera, followed by a comparison of the trace (person of interest) and reference (suspected person) [22]. Therefore, this case is an example where surveillance footage was used as a powerful tool [1,23]. However, it is hotly debated within the relevant forensic disciplines as to whether such evidence should be admissible in court without meeting the *Daubert* standards (as established in

[1] 'Open-street' surveillance systems are defined by the placement of an array of cameras within the public to monitor and deter acts of crime 9.

Daubert v Merrell Dow Pharmaceuticals, in 509. [1993], U.S. 579 and other relevant US cases [24]) and without a significant population database, frequency statistics and standardised protocols. Australian case law does not have an equivalent to the Daubert standard, however reliability of the evidence is essential prior to admission in court and requires scientific validity [25,26]. To a degree, this is somewhat similar to admissibility of evidence in Europe where the practitioner, or expert must provide quantifiable evidence and report the strength of evidence to the judge [27]. Both *Daubert* and Frye standards [28] require the expert to demonstrate that they have attained an adequate level of study, training and experience in order for their evidence to be admissible in that case [29]. Demonstration of expertise is a necessary requirement, however, it does not reflect the performance of the method and its limitations. Therefore, the expert witness' claim must have been tested, error rates of the method in conditions similar to the case and standardised protocols established, peer reviewed and published, and finally, the relevant scientific community must generally accept the technique [30,31]. An error rate or a strength of evidence does not characterise a method, but rather a method in a specific set of circumstances. Therefore, in the courtroom, the *Daubert* criteria should be met, scientific validity established, the performance of the method tested, and the limitations of such evidence should be highlighted [16,22,29,30]. In Europe for instance, the approach is to validate and accredit a method via a validation report (ISO 17025) [32]. Beside legal considerations, the strength of any forensic evidence depends on the intrinsic quantity of information present in the CCTV footage and how this information can be analysed compared and evaluated forensically. Therefore, it is suggested that surveillance footage should be assessed for distortion, prior to the assessment of the individual.

2. The ultimage goal: to determine the limitations presented by distortion and artefacts

The type and extent of and artefact or distortion affecting a CCTV camera can be determined if the correct information is provided about the camera. Certain characteristics of each type of distortion are present in the footage and may be used to identify the underlying distortion. Additionally, CCTV cameras generally contain not one, but a combination of multiple artefacts, distortions or a combination of the two. This presents further challenges to determining the types of distortion present within the footage/camera.

2.1. Artefact and distortion analysis

The examination of images as part of criminal investigations is known generally as 'forensic image analysis' [33], first stage of which often includes the evaluation of image quality and levels of artefacts (information and influences that impact upon and image) and distortion within CCTV footage. Once the distortion affecting the footage has been determined, morphometric analysis of any persons can proceed with the application of biometric technology [2]. Examples of features that contribute to distortion include: poor camera maintenance and placement (introduced before the camera is even turned on, due to the viewing angle the camera is placed at; for example, an extremely high or low angle), distortions due to the camera lens, perspective distortion, and external/environmental influences (e.g., direct sunlight, condensation) [9,23,34]. These factors combine and contribute to poor-quality surveillance footage.

Measurement of the height of known structures within the scene [15], such as trees, architecture details or non-removable objects, may be used to determine the corrected height and geometry of the individual from CCTV footage where the known structure can be measured with less than 2 cm error; as shown by a study undertaken by Andersen et al. [35]. Furthermore, comparative measurements between the individual on the surveillance footage and a known person (a specific police officer for example) of a pre-recorded height placed in the same location as the individual from footage helps with the assessment of correct height and geometry [15]. This analysis of the scene allows vital information to infer the approximate distance and sizes of subjects and objects, which increases the accuracy of height estimation [15]. Another study by Neves (2015) however, showed the performance of the height estimation to vary in an individual (true height of 168 cm) by between 0.1 cm and 14.7 cm [36]. Therefore, strength of evidence of the height remains limited, except from extreme cases; for that reason, increasing the pool of features observed within the anatomy and gait provides further useful information. However, this analysis has the potential for subjective interpretation, highlighting the importance for standardised protocols to be established. This is one of the three requirements as highlighted in the Australian case of *Regina v Dastagir [2013] SASC 26*, (the other two being the development of population databases and publication of frequency statistics) [15]. Once all three of these components are achieved and meet the *Daubert* standards, it is thought that a more accurate analysis can be achieved.

Various techniques have been applied to assess and/or correct geometric distortion, with one being photogrammetry. This method is defined as the attainment of dimensional information by application of perspective geometry to an image; a process that has an extended history, having been applied as early as the 15th century by Leonardo De Vinci to allow accurate representation of objects in paintings [15]. Today, in the analysis stage of CCTV footage, it is theorised that through accurate application of these techniques and assessment of distortion, relevant information can be extracted successfully from video evidence. However, problems are introduced when applying photogrammetry to CCTV video footage due to the distortions that are common amongst various cameras and subsequent footage (such as geometric distortion as a result of the high positioning of the camera and the downward angle tilting) [15].

2.1.1. Extrinsic artefact and distortion analysis

Distortion can be divided into 'extrinsic' and 'intrinsic'. Extrinsic artefact refers to external factors that influence the camera – i.e. weather conditions and maintenance; and intrinsic artefact will be detailed in Section 2.1.2. The various types of extrinsic artefact can be categorised to represent the different components of a CCTV camera that can be affected. Table 1 lists the specific types of extrinsic distortion and provides accompanying definitions, which can also be used as a checklist upon assessment of distortion.

Target classification – Is referred to the target object or subject within the image that is being analysed, including the determination of the number of targets, their positions, their total speed (velocities), and acceleration [37]. Furthermore, the 'Field of View' is taken into consideration upon assessment of the target where the environment is monitored to detect the presence of crime or a particular person from footage. Human activity is observed through camera systems by the footage produced, however the purpose of the footage being viewed varies from crowd control to the recognition of a particular individual. Therefore, five categories have been developed by Cohen (2009), [38] for the simplification of the purpose of monitoring. This is subcategorised into monitor and control, detection, observation, recognition, and identification [38] and activity and source level inference can be extracted based upon the aforementioned categories. For monitor and control the crowd is monitored so each target occupies 5% of screen height

Table 1
Extrinsic factors/distortion affecting CCTV footage.

Property	Distortion variance			Definition	Source
Functional classification	Field of view	Monitor and control		Monitoring the environment to determine the number, direction and speed of people within a wide area. Image of the subject is a very minor percentage of approximately 5% of the screen height.	Cohen et al. [38]
		Detection		Monitoring the environment to detect presence of subject within a large field of view. Image of subject occupies small percentage 10% of the screen height.	
		Observation		Monitoring activities of moving subject(s) to detect specific action(s) and/or movement(s). Image of subject occupies approximately 25% of the screen height.	
		Activity level inference		To capture noticeable features for subject recognition. Image of subject occupies approximately 50% of the screen height.	
		Source level inference		To capture detailed images of high clarity for subject identification. Image of subject occupies more than 100% of the screen height.	
Maintenance	Physical condition of camera lens	Sun damage to housing	Present	Damage to sensitive camera housing by direct exposure to intense sunlight.	Jones and Arnold [42]
			Absent	No sun damage to lens surface.	
			Indeterminable	Not evident.	
		Dirty	Yes	Camera lens free of dust and/or pollutant.	Canty (1990) [43]
			No	Dust and/or pollutant present on camera lens.	
			Indeterminable	Not evident.	
	Physical condition of camera housing	Damage	Present	Camera housing damaged (i.e. broken or cracked).	Chow et al. [39]
			Absent	No damage to camera housing.	
			Indeterminable	Not evident.	
		Dirty	Yes	Camera housing free of dust and/or pollutant.	
			No	Dust and/or pollutant present on camera housing.	
			Indeterminable	Not evident.	
Environment	Environment (time of day)	Day time		Sunrise to sunset (i.e. daylight).	Nawrat and Kus [44]
		Night time		Sunset to sunrise (i.e. nightfall).	
		Indeterminable		Not evident.	
	Weather conditions	Dry		Dry weather conditions is visible in environment.	Nawrat and Kus [44]
		Wet		Wet weather conditions is visible in environment.	
	Light source	Natural lighting (sun)		Field of view is illuminated by sunlight.	Nawrat and Kus [44]
		Artificial lighting (lamp)		Field of view is illuminated by man-made light source (e.g. street lamps).	
		Both natural and artificial lighting		Field of view is illuminated by sunlight and man-made light source.	
		Absent lighting		Field of view is void of light (i.e. pitch-black).	
		Indeterminable		Not evident.	
Camera placement	Height camera is placed	High placement		Camera in elevated position.	Cathey and Dailey [45]
		Medium placement		Camera in position.	
		Low placement		Camera positioned low.	
		Indeterminable		Not evident.	
	Angle (focal plane) of camera	Tilted downwards		Focal plane tilted downwards for maximum coverage of target area (i.e. large field of view).	
		Neutral		Focal plane is at the same plane as the intended field of view of the subject(s).	
		Tilted upwards		Focal plane tilted upwards to target area.	
		Indeterminable		Not evident.	
	Camera distance to subject(s)	Large		Camera positioned far from subject(s).	Grgic et al. [46]
		Medium		Camera positioned moderate distance from subject(s).	
		Small		Camera positioned close to subject(s).	
		Indeterminable		Not evident.	
Target subject (and/or object)	Motion velocity of target subject (and/or object)	Motion blur	Present	Image display apparent streaking of rapidly moving subject(s) (and/or objects). Motion Blur dependent on velocity of the subject(s) and/or objects (i.e. the faster the subject/object, the greater the distortion).	Jin et al. [47]
			Absent	Image free of *motion blur*.	
			Indeterminable	Not evident.	

[38]. For detection, the individual or target object occupies 10% of screen height, whilst observation is 25%, recognition is 50%, and identification is 100% [38]. The purpose of target classifications was to develop a specification for monitoring and to meet the specific requirements for that purpose [37]. It does not aim to set a minimum standard, nor does it suggest that identification can be achieved based purely on the accurate screen height of the person achieved – rather showing activity of the person and suggesting a categories for monitoring a person through CCTV. Factors including the resolution and other artefact and distortion types may alter each classification based on the clarity and condition of the footage.

Maintenance – Refers to the condition and upkeep of the camera and housing to determine whether any damage or dirt is obstructing the view of the camera [39]. For the purpose of this section within the table, the housing and the camera are separated into their own categories, since maintenance may only be undertaken for either camera, housing, or both.

Environment – Relates to the environmental conditions that may impact upon the camera [40]. Weather conditions and light source are the two main components within this classification. Weather conditions (for instance rain) may cause water droplets on the camera housing, consequently obscuring parts of the footage. If the camera is not placed in an ideal location, sun damage can also occur over a span of time. Lighting on the other hand is essential to view the occurrences within the footage, the absence of which (unless the camera is night vision) would limit the camera of its use.

Camera placement – Can be defined as the 'strategic' and 'non-strategic' placement of the CCTV camera [41]. 'Strategic' camera placement refers to the camera being placed with forethought and consideration of the environment; whereas 'non-strategic' camera placement is more random placement with no further consideration or thought to the surrounding environment – whether the camera placement be high/low or angled facing upwards/downwards [41]. These 'non-strategic' placements can more often than not, lead to geometric distortion as they are not parallel to the camera and not at a standardised level.

Target subject (and/or object) – The target subject/object is as the name suggests, where a particular person or object of interest is the aim of further monitoring [38]. One of the key components that is considered upon assessment, is the velocity. Therefore, the table directly relates to the speed at which the subject is moving. If the subject is moving at a quick pace, for instance, this may lead to a motion blurring distortion, which tends to be more prominent within the appendicular anatomy (arms and legs) of the subject as they swing forward for advancement in gait.

2.1.2. Intrinsic artefact and distortion analysis

Intrinsic distortion is a direct result of distortion caused by the camera itself and not from external factors that impact upon the camera, including the camera type, capture and recording for instance. The various types of intrinsic distortion can be categorised to represent the different components of a CCTV camera that can be affected. Table 2 lists the specific types of intrinsic distortion, and provides accompanying definitions, which can also be used as a checklist upon assessment of distortion.

CCTV camera – Can be defined as a system that captures (relates to optics and sensor) and records (pre-process, encodes, compresses and records) its surrounding area for surveillance purposes [48]. For the purpose of the table, the 'CCTV camera' category was subdivided into the camera type and specifications. Visibility of the camera to an individual captured on CCTV or members of the public is also considered, which assists to further determine its specifications. The first of these, camera types (monochrome, colour, infrared, night vision and thermal), can change the mode of footage produced. For instance an individual concealed within a bushland area may be concealed in footage from a monochrome camera, but easily observed with a thermal camera. The second factor, visibility of the camera, is important as if the individual can see the camera, this may affect their activity (they may keep their face averted, for instance).

Monitoring – Falls under video surveillance and, as the name suggests, refers to the direct visual monitoring of activities within any given premise [49]. Within the table, the operated or automatic movement of the camera is primarily highlighted, as upon said movement of camera, distortions may occur such as 'rolling shutter' (the distortion caused by the skewing of the image through movement of the camera while the shutter is open) [50]. Operated movement occurs under the control of a person, whereas automatic movement is the programmed movement of the camera itself.

Capture and recording – Can be defined as the recording and retention of footage captured by the camera, and the subsequent manner in which the footage is recorded [38]. The mechanics of recording involves Modulation Transfer Function (MTF), which is the optical transfer function, indicating the resolution properties by determining the transfer of contrast at a certain resolution when recording from object to image (resolution and contrast integrated into a single parameter) [51]. Electronic sensor of the camera supplies the digital image directly which can range between monochrome, colour, infrared, night vision and thermal [52]. Other components to consider are the signal-to-noise ratio (level of information [signal] against the interference [noise] in a ratio form) [53] and the dynamic range (ratio between minimum and maximum light intensities able to be measured at exposure) [54]. Following from the mechanism of recording, now this category is further divided into three subcategories; recording mode, frame rate, and interlacing. Recording mode within this particular table relates to whether the camera records continuously or is triggered to record through motion or at a pre-set time. Frame rate refers to whether the recorded frames are high (images captured to show a high level of information from video as a result of the increased number of frames captured per second) or low (video appears 'jumpy' or 'lagged' as only some frames are obtained to complete the footage). Interlacing is the distortion whereby two line-by-line fields (odd and even that forms a full frame) shift as a result of timing differences.

Playback – Refers to footage that is played back after the capturing and recording has been completed [55]. Time lapse is an example of this, where it is programmed to obtain a single image or a single still image at determined time gaps to capture a scene over the course of weeks or months – thus making it seem that the footage captured is 'fast forward' when it is played back.

System – Relates to the specifications that is held by the camera, including the manner in which data captured is stored; for instance, older systems are analogue and the contemporary systems are digital [56]. Analogue systems function by transmitting and recording video within analogue format and record to VHS, as opposed to digital cameras, which transmit and record digitally and are stored into hard drives [56].

Images – Can be defined as the resulting footage (frames) produced by the camera recording, which are stored on either a memory card, hard drive, or other storage system [57]. This section in the table however, specifically refers to the colour and quality of the image recorded. It can be further categorised into colour specification, image resolution, and image quality. Colour specification determines whether the camera is monochrome or colour, whilst image resolution determines the number of pixels present within the frame and the overall quality of the image (whether it is high or low).

Camera lens – The camera lens works in tandem with the body of the camera to capture and recreate the surroundings recorded within the field of view of the CCTV camera and represents it on a 2D image depiction [58]. The camera lens can be fixed (distance of the field of view remains the same) or zoom (principle distance of zoom lens to changed so they 'zoom' in closer to an area of the camera field of view) [59]. For the table, 'Camera Lens' specifically refers to the different types of camera lenses available and the subsequent image variations as a cause of the lens type. These variations in lens use can lead to six further types of distortion; wide angle barrel, narrow pincushion, moustache, rectilinear, lens blur, and rolling shutter. Wide angle or 'barrel' is the most common type of distortion seen within a CCTV camera, whereby the image becomes mapped around the shape of a barrel, thus making straight objects appear curved. Pincushion distortion is when the image bows inward, and moustache distortion is the combination of both barrel and pincushion distortions. Rectilinear is when straight objects appear curved. Lens blur occurs when the full/part of the image is not in focus and appears blurred. Rolling shutter distortion transpires when the movement of the camera (either automatic or through operator) leads to the skewing of objects/subjects within the image.

Transmission – Is when signals are sent and received to obtain an image file [60]. Distortion that manifests is a result of the interference of signals within the camera. Both speckle (black granules within screen) and Gaussian noise (white granules within screen) occur when one signal interferes with another, consequently leading to a grainy appearance of the footage.

Outer frame – As the name suggests, the outer frame can be defined as the region comprising of some or all of the corner/edge of the image that is captured [61]. For the purpose of the distortion table, this is subcategorised into particular distortions or features that occur within the outer edge/corner of the frame, including

Table 2
Intrinsic factors/distortion affecting CCTV footage.

Property	Distortion variance	Definition		Source
CCTV camera	CCTV camera visibility	Visible (overt)	Camera is noticeable	Doyle et al. [48]
		Hidden (covert)	Camera is concealed (e.g. encased in dome or set behind panel in ATM)	
		Unknown	Camera visibility is indeterminate	
	CCTV camera type	Standard colour	Colour image output under optimum lighting	Nawrat and Kus [44]
		Standard monochrome	Black and white image output under optimum lighting	
		Infra-red (night vision)	Utilises infra-red technology for low light level and pitch black condition (e.g. at night). (B&W output)	
		Day/night vision	Compensate for varying light conditions to allow the camera to capture images. Primarily used in outdoor applications where the security camera is positioned (e.g. for an outdoor parking lot). Units are capable of having a wide dynamic range to function in glare, direct sunlight, reflections and strong backlight 24/7. (B&W Output)	
		Heat detection (thermal)	Camouflaged subjects are visible through heat detection	
Monitoring	Automatic monitoring	Stationary	Unmanned with constant directional view	Hong [62]
		Moving	Unmanned with changing directional view	
	Manual monitoring	Moving	Operator controlled changes of directional view	
		Moving and zoom	Operator controlled changes of directional view and zoom in/out	
Capture and recording	Recording mode	Active	Continuous (independent of moving subject (or object)	Freeman [63]
		Passive	Motion detected	
		Time pre-set	Time scheduled	
	Frame rate	High	High number of frames captured per second	Keval and Sasse [64]
		Low	Low number of frames captured per second	
	Interlacing	Present	Shifting of two line-by-line fields (odd and even that form a full frame) due to difference in timing	Busko et al. [65]
		Absent	Image free of *interlacing* distortion	
Playback	Time lapse	Present	Footage appears in *fast forward* (event captured at one frame rate per given time – subsequently making the appearance that time is passing quicker)	Reif and Tornberg [66]
		Absent	Image free of *time lapse*	
System	Data storage	Analogue (VCR)	Footage is recorded on videocassette by recorders (VCR) and to be viewed on TV screens	Keval and Sasse [64]
		Digital	Footage recorded digitally and stored onto hard drives. Data can be compressed to conserve storage space, which can lead to pixilation, loss of details and/or colour chromes.	
Images	Colour specification of images	Colour	Image output of actual colour(s) recorded	Nawrat and Kus [44]
		Monochrome	Image output in black & white (and shades of grey)	
		Other	Image output not of actual colour recorded and not in black & white	
	Image resolution	High	Image free of noticeable *pixels*	Cohen et al. [38]
		Medium	Image with slightly visible 'square shaped' *pixels*	
		Low	Noticeable individual 'square shaped' *pixel*	
	Image quality	High	Maximum or full clarity of details	
		Medium	Intermediate clarity of details	
		Low	Minimal or no clarity of details	
Camera lens	Wide-angle barrel	Present	Image mapped into a barrel shape thus straight line/object appears curved	Johnston and Bailey [67]
		Absent	Image free of *wide-angle barrel* distortion	
		Indeterminable	Not evident	
	Narrow-angle pincushion	Present	Centre of image appears bowing inward	Hugemann [68]
		Absent	Image free of *narrow-angle pincushion* distortion	
		Indeterminable	Not evident	
	Moustache	Present	Combination of both *barrel* and *pincushion* distortions	Nawrat and Kus [44]
		Absent	Image free of *moustache* distortion	
		Indeterminable	Not evident	
	Rectilinear	Present	Curved line/object appears straightened	Lucas et al. [69]
		Absent	Image free of *rectilinear* distortion	
		Indeterminable	Not evident	
	Lens blur	Present	Image appears blurred (whole or part of frame). Example is 'bokeh' blurring of distant object whilst close object appears in focus.	Reed [70]
		Absent	Image free of *lens blur* distortion	
		Indeterminable	Not evident	
	Rolling shutter	Present	Image appears skewed resulting from camera movement whilst shutter is open.	Meingast et al. [50]

Table 2 (*Continued*)

Property	Distortion variance	Definition		Source
		Absent	Image free of *rolling shutter* distortion	
		Indeterminable	Not evident	
Transmission	Speckle noise	Present	Noise distortion occurs when one signal is interfered with by another signal, causing a distortion. Example is "speckling" on digital CCTV footage, which is determinable through black granules	Nawrat and Kus [44]
		Absent	Image free of *noise* distortion	
		Indeterminable	Not evident	
	Gaussian noise	Present	When white granular noise distortion is displayed on image	Ramirez-Mireles [71]
		Absent	Image free of *Gaussian noise* distortion	
		Indeterminable	Not evident	
	Salt and pepper noise	Present	When black and white granular noise distortion is displayed on image	Yi et al. [72]
		Absent	Image free of *Salt and Pepper noise* distortion	
		Indeterminable	Not evident	
Outer frame	Vignetting	Present	Image display darker tones on edges of the frame	Kim and Pollefeys [73]
		Absent	Image free of *vignetting* distortion	
		Indeterminable	Not evident	
	Chromatic aberration	Present	Image displays change of colour on edges of the frame	Boult and Wolberg [74]
		Absent	Image free of *chromatic aberration* distortion	
		Indeterminable	Not evident	
	Digital watermark	Present	Image displays a watermark (e.g. time, date, place and camera number)	Reed [70]
		Absent	Image free of *watermark*	
	Window framing	Present	Frame imprinting or 'a frame watermark' of the camera (frame of the camera viewed in tandem with field of view)	Amemiya et al. (1999)
		Absent	Image free of *window framing*	

vignetting, chromatic aberration, digital watermark, and window framing. When the outer edge is darker in tone, this is known as vignetting, whereas chromatic aberration is the change in colour tone within the outer edges and corners. A digital watermark comprises details of the camera placed within the frame including date, time, place, and camera number. Window framing is the frame imprinting with a specific colour (traditionally black) or area of the edges of the frame.

3. Artefacts and distortion within Australian and international courts of law

The assessment of a CCTV footage trace has been questioned by many researchers and practitioners, based on what is 'real' or 'distorted', as emphasised by Porter [16]. The District Court of NSW was the first Australian jurisdiction to declare facial mapping evidence currently inadmissible, and the first case that admitted face and body mapping evidence occurred in the Bidura Children's Court in NSW in 2005 [22]. Following the admittance of such evidence, the landmark case of *Regina v Jung [Regina v Jung* in *658*. 2006, NSWSC] [75] established that experts determining similarities and differences between a trace and a suspect from surveillance footage are also required to also have expertise in forensic imagery [76].

To provide an example, the case by *Regina v Jung, 2006* [75], focused on evidence of CCTV images obtained from a Westpac Bank ATM that were compared to images obtained from NSW Police Force. The level of expertise displayed by the expert in forensic photography was scrutinised by Justice Hall [16,76]. Hall [76] suggested that the expert's skills were limited to the forensic imagery field, and did not cover extensive knowledge of distortion – as seen by errors made in court. To provide an example of the skills lacking by the expert in this case, one example includes the 'similar perspectives' reference within the expert's evidence, where rather than image perspectives, the expert meant similar camera angles [16]. These are two separate concepts, as perspectives relate to perspective distortion in photography whereas camera angles refer to the angle of the camera in relation to the environment and trace. Without the extensive knowledge of forensic image analysis, assessment is prone to errors, thus making the photographic comparison questionable [16], as concluded by Justice Hall in this case.

Another case of *Honeysett v The Queen* [2014] HCA 29 [77], a robbery, which initially accepted, that the expert had 'specialised knowledge' based on both anatomy and viewing of CCTV footage [77]. Later however, the court accepted the expert's knowledge in anatomy during the appeal, but did not maintain his knowledge in viewing CCTV footage, thus allowing the appeal to be granted based on these grounds [77]. Therefore, it is imperative that the expert have both qualifications in anatomy and image analysis.

Moreover, it is very important that the *Daubert* standards [31] are met, the scientific validity achieved and any deficits acknowledged by the expert in court, to circumvent any potential miscarriage of justice [16]. Additionally Porter [16] highlights the prerequisite to implement scientific methods that will allow for the presentation of consistent, reliable, transparent, and replicable evidence based on the analysis of CCTV images. It is suggested that identification evidence should not be presented in court until misunderstandings surrounding photographic evidence, methods of photointerpretation error rates, and subjectivity in examination methods are addressed through additional research [16].

To assist in the evaluation of the strength that should be afforded to expert evidence in a particular case, experts were recommended to begin using the 'Bromby Scale' within British criminal courts in 2003, developed for the purpose of standardising the presentation of evidence [78]. The scale indicates the level of support that the evidence would offer, the highest being 'lends powerful support' and the lowest being 'lends no support' [78]. The Bromby scale however, was applied within the Australian courts in the matter of *R v Hien Puoc TANG [2006] NSWCCA 167* [79], where the expert produced a slightly different version of the Bromby scale. However, it was claimed that the evidence had 'no scientific basis' as quoted from *R v Hien Puoc TANG [2006] NSWCCA 167* [79], which led to the case being appealed and the forensic body mapping technique declared inadmissible. Evett (2009), stated that the four principles of balance, logic, transparency and robustness should be achieved, which should govern the decision of admissibility in the accusatorial system and inadmissibility in the inquisitorial system [80].

The cases aforementioned highlights the current development of the requirements of practitioners involving distortion analysis from body/gait assessment), within a legal setting and highlights the limitations and gaps that need to be addressed. Further development and research into the gait analysis is necessary, with the inclusion of implemented frameworks, reliable and reproducible results with the application of forensic statistics. Once the scientific requirements are achieved, cases can be admissible and processed within the court of law with minimal risk.

4. Conclusion

Surveillance cameras have become a powerful tool to capture footages of activities of people in public areas. While such footages have been increasingly used in investigations and in court proceedings, they have also been criticised for their lack of scientific validity in a legal setting. It is argued here that the forensic examination of such material ultimately aims at evaluating the strength of evidence at source and activity levels and that this strength is inferred from the trace, obtained in the form of CCTV footage. The strength of evidence therefore depends on the value of the information recorded which, itself, depends on the camera and the associated distortions. It is recognised that all artefacts and distortion cannot be eliminated and that they primarily and more critically affect the robustness of the inference at source level. However their impact on the strength of evidence can and should be studied. For example, pre-assessment of cases can be completed as well as providing a preview of the degree of magnitude of the likelihood ratio both at source and activity level, according to the nature and magnitude of the artefacts present within the trace material. In other words – whilst taking artefacts into account from the trace material, the likelihood ratio, evaluates the strength of evidence at source and activity level; thus, assessing the likelihood of a 'reference 'image, to that of the trace evidence.

This review paper took a step towards highlighting the requirements and limitations revolving around artefacts and distortion by determining the types of distortion present and their degrees of impact on the resulting footage. To improve the analysis of source level information, further research is necessary to fully understand the varying types of artefacts and distortion and their levels of severity (and therefore the potential impact on the reliability of the evidence produced from any forensic evaluation). Currently, not enough research has been conducted to accurately state that an identification can be made of a trace from CCTV images, but that does not mean that such information is not of any value. For instance, evaluation of an individual from CCTV evidence can be used as an exclusionary tool and/or can be extremely valuable information in investigations and even in court proceedings. Ultimately, it should be pointed out that the value of any technology, including CCTV, is relative to the questions being asked. Knowing the relevant questions, how fit this technology is to answer them and the value and limitation of such technology for the intended purpose would go a long way to address criticisms and challenges about CCTV. With this in mind, forensic gait analysis from surveillance footage will be discussed in a future paper.

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