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TESIS DOCTORAL

Geotecnologías láser y fotogramétricas aplicadas a la modelización 3D de escenarios complejos en infografía forense

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Geotecnologías láser y fotogramétricas aplicadas a la modelización 3D de escenarios complejos eninfografía forense

Tesis Doctoral presentada por Sandra Zancajo Blazquez

Informe de los Directores de Tesis

La Tesis Doctoral "*Geotecnologías láser y fotogramétricas aplicadas a la modelización 3D de escenarios complejos en infografía forense*", presentada por Sandra Zancajo Blázquez, se inserta en la línea de investigación de seguridad y aplicación de técnicas no destructivas en siniestros utilizando para ello técnicas fotogramétricas, sistemas láser escáner y gamingsensors.

Se trata de una línea muy activa y relevante en la Comunidad Científica Internacional y más concretamente en el marco europeo Horizonte 2020, lo que está permitiendo avanzar en la verticalización de las geotecnologías en el campo de la lucha contra el crimen y el terrorismo (H2020 FCT2-2015-Fight againstcrime and terrorism) y campos más concretos (Forensictopic 2: Advancedeasy to use in-situ forensictools at thescene of crime).El trabajo desarrollado se sitúa de forma significativa y eficaz en la incorporación de técnicas modernas en el contexto de la investigación criminal, haciendo frente de manera eficaz a los retos y desafíos de esta sociedad del siglo XXI y donde los problemas por terrorismo representan una de las principales preocupaciones a nivel mundial.

Se trata asimismo de una línea de investigación promovida y desarrollada por un Grupo de Investigación reconocido TIDOP (http://tidop.usal.es) de la Universidad de Salamanca, que viene investigando y desarrollando herramientas software y hardware en el seno de Proyectos de Investigación competitivos y en colaboración con otros grupos y empresas punteras a nivel nacional e internacional.

La Geomática y en particular las geotecnologías láser y fotogramétricas vienen experimentando una serie de innovaciones de gran alcance que han transformado profundamente su contexto de aplicación frente a las aplicaciones más clásicas (Cartografía y Topografía) en las que se venía trabajando años atrás. Estas innovaciones se articulan fundamentalmente en torno a la potencia en la captura masiva de información, la hibridación de sensores y la automatización de determinados procesos para generar productos de calidad con propiedades métricas.

Además, en los últimos diez años, las geotecnologías láser y fotogramétricas han demostrado que más que competir han venido a complementarse, lo que las ha situado en un horizonte muy prometedor y competitivo en todos los contextos y más concretamente en el campo de la Seguridad.

La Tesis aborda un adecuado Estado de la Cuestión de manera que permite identificar claramente la oportunidad estratégica de la aportación que se realiza como lo demuestra el hecho de que la Tesis se articula en torno a la modalidad de compendio de artículos publicados en revistas científicas y tecnológicas con impacto reconocido.Dos de ellos pertenecientes al primer cuartil-Q1 y alto factor de imacto (IEEE TransactionsonInformationForensics and Security; PlosOne) y otra perteneciente al tercercuartil-Q3 (ForensicSciences).

Estos artículos han verificado los correspondientes procesos de evaluación críticay revisión por parte de expertos internacionales de trayectoria reconocida. Estas contribuciones se centran en:

- Una solución, basada en la integración de la fotogrametría de rango cercano y la visión computacional, como una alternativa eficiente a la reconstrucción 3D de objetos y escenarios complejos para infografía forense, garantizando flexibilidad (trabajar con cualquier tipo de cámara), automatismo (paso del 2d-imágenes al 3d-nubes de puntos) y calidad (resoluciones superiores a los sistemas láser) en los resultados.

- Una solución tecnológica sencilla y de bajo coste basada en los dispositivos activos de escaneado “GamingSensors” que permite el análisis dimensional y el modelado tridimensional de la escena forense a pequeñas distancias.

- Un sistema novedoso de cartografiado de espacios interiores mediante láser móvil (“Indoor Mapping”), ideal en aquellos escenarios forenses complejos y de grandes dimensiones.

- Una estrategia que permite progresar en el paso de las nubes de puntos, ya sean láser y/o fotogramétricas, a los modelos CAD (ComputerAidedDesign), a través de la segmentación de dichas nubes de puntos en base al análisis de componentes principales (PCA-Principal ComponentAnalysis), lo que supone una contribución directa al campo de la infografía forense.

La Tesis concluye con el correspondiente apartado de Conclusiones en el que de forma precisa y concreta se especifican las principales aportaciones realizadas de tal manera que puedan ser objeto de crítica y de proyección hacia el desarrollo de futuros trabajos integrados en línea de investigación.

En Ávila, a 23 de febrero de 2015,

Diego González Aguilera David Hernández López

La presente Tesis Doctoral corresponde a un compendio de tres artículos científicos previamente publicados en revistas internacionales de impacto y que se especifican a continuación:

1. **An automatic image-based modelling method applied to forensic infography**

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2. **Application of Kinect gaming sensor in forensic science**

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3. Segmentation of indoor mapping point clouds applied to crime scenes reconstruction

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Lo que con mucho trabajo se adquiere,

más se ama.

Aristóteles.

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RESUMEN

El estudio de la reconstrucción tridimensional de escenas y objetos para su posterior análisis es un tema objeto de investigación por diferentes disciplinas. Una de las disciplinas en las que se hace necesaria la obtención de modelos 3D es en la ingeniería forense, y más concretamente en el campo de la infografía. La infografía forense es una técnica que permite la reconstrucción virtual de diferentes hechos a través de la informática y el manejo de imágenes digitales.

La gran ventaja que ofrecen las geotecnologías láser y fotogramétricas para la modelización de escenarios complejos en infografía forense es que son técnicas no invasivas y no destructivas. Es decir, a través de ellas quedará constancia documental de los indicios y evidencias presentes en el escenario, sin alterar en ningún momento sus posiciones espaciales ni sus propiedades físicas, además de dotar de rigor, exhaustividad y realismo a la reconstrucción del suceso.

En esta Tesis Doctoral se ha demostrado que la aplicación de diversas geotecnologías tales como, las cámaras digitales convencionales (incluyendo los propios “Smartphones”), los escáneres “Gaming Sensors” y los sistemas de cartografiado de interiores móviles (“Indoor Mapping”), son idóneas en la inspección ocular del delito para su posterior representación gráfica tridimensional. Más concretamente, en esta Tesis Doctoral se presentan las siguientes contribuciones:

- Se propone una solución, basada en la integración de la fotogrametría de rango cercano y la visión computacional, como una alternativa eficiente a la reconstrucción 3D de objetos y escenarios complejos para infografía forense, garantizando

flexibilidad (trabajar con cualquier tipo de cámara), automatismo (paso del 2d-imágenes al 3d-nubes de puntos) y calidad (resoluciones superiores a los sistemas láser) en los resultados.

- Se desarrolla y valida una solución tecnológica sencilla y de bajo coste basada en los dispositivos activos de escaneado “Gaming Sensors” que permite el análisis dimensional y el modelado tridimensional de la escena forense a pequeñas distancias.
- Se testea y valida un sistema novedoso de cartografiado de espacios interiores mediante láser móvil (indoor mapping), ideal en aquellos escenarios forenses complejos y de grandes dimensiones.
- Se avanza en una estrategia que permite progresar en el paso de las nubes de puntos, ya sean láser y/o fotogramétricas, a los modelos CAD (Computer Aided Design), a través de la segmentación de dichas nubes de puntos en base al análisis de componentes principales (PCA-Principal Component Analysis), lo que supone una contribución directa al campo de la infografía forense.

Palabras clave: Infografía forense, escena forense, fotogrametría, nubes de puntos, reconstrucción 3D, modelado 3D, smartphone, laser escáner, gaming sensor, indoor mapping, automatización, segmentación, CAD, PCA.

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CAPÍTULO 1

INTRODUCCIÓN

1. INTRODUCCIÓN

La infografía forense es una técnica que permite la reconstrucción virtual de diferentes hechos a través de la informática y el manejo de imágenes digitales. Las técnicas infográficas de vanguardia se están aplicando en la inspección ocular del escenario del delito. A través de ellas se llevan a cabo tareas de observación y documentación minuciosas, cuyo propósito es recabar todo tipo de datos que permitan relacionar los indicios entre sí para descubrir y demostrar la verdad y sus circunstancias.

La primera fase de investigación criminal, y quizás la más crítica, está representada por la exploración a pie de la escena forense. El objetivo de esa tarea es ubicar todas las evidencias útiles para la reconstrucción de la escena y de la dinámica del evento, de acuerdo a los protocolos precisos y aplicando técnicas de medición adecuadas (James et al., 2003). Estas operaciones deben ofrecer una documentación completa, no invasiva y objetiva de la escena, y deben suministrar una base válida de investigación para su posterior análisis dimensional. Las técnicas clásicas no son suficientes para satisfacer por completo estos requisitos. Por ejemplo, las fotografías, cintas métricas y dibujos sólo pueden proporcionar una descripción bidimensional de la escena, lo que provoca la disminución del nivel de integridad de la representación. Concretamente, el uso de técnicas manuales para medir distancias se caracteriza por ser de precisión limitada y puede contaminar la escena, debido al contacto natural de la medición sobre los objetos. Además, las desventajas de este tipo de soluciones son bastante destacables, como la de depender de la habilidad del operador, emplear mucho tiempo y ser muy subjetiva (Thali et al., 2003).

En los últimos años, las geotecnologías láser y fotogramétricas de adquisición remota y no-intrusivas están empezando a incorporarse en el campo de la infografía forense, ya que permiten preservar la escena de una forma objetiva, sin alterar en ningún momento sus posiciones espaciales ni sus propiedades físicas, además de dotar de rigor, exhaustividad y realismo a la reconstrucción del suceso, manteniendo la posibilidad de volver virtualmente a la escena para reconstruir indicios siempre que sea necesario. En este sentido, las dos geotecnologías más aplicadas en el campo de la infografía forense son la fotogrametría de rango cercano (Pastra et al., 2003), (D'Apuzzo y Mitchell, 2008) y (Gonzalez-Aguilera y Gomez-Lahoz, 2009) y el escaneado láser (Docchio et al., 2006), (Kovacs et al., 2006), (Cavagnini et al., 2009) y (Sansoni et al., 2009), permitiendo ambas, con sus ventajas e inconvenientes, el análisis dimensional y la reconstrucción 3D del escenario total o parcialmente. Ambas técnicas son complementarias, lo que en ocasiones se traduce en que se combinen (Docchio et al., 2006). Sin embargo, es más frecuente hacer uso de la fotogrametría cuando el escenario u objeto a reconstruir no es demasiado complejo desde el punto de vista geométrico (formas simples parametrizables), mientras que la técnica de escaneado láser era la idónea para aquellos casos en los que la geometría de los objetos presentan formas complejas (formas cóncavas y convexas no parametrizables) y de difícil modelización y/o automatización por parte de los métodos fotogramétricos (Rönnholm et al., 2007) y (El-Hakim et al., 1995).

Entre los principales inconvenientes de los sistemas láser se pueden citarel elevado coste unido, en ocasiones, a su difícil movilidad y disposición en escenarios reducidos donde se hace inviable su utilización. De este modo, la técnica del láser escáner terrestre exigirá de espacios lo suficientemente amplios para permitir el manejo del aparato, no siendo apto para escanear a muy cortas distancias. Asimismo, el procesamiento de los datos exigirá del manejo de un software específico no siempre sencillo y de fácil interpretación por parte del usuario no experto. Otro inconveniente de los sistemas láser es, en el caso de que lleve cámara integrada, normalmente ésta es de baja resolución, por lo que la calidad de las fotografías capturadas para texturizar no es muy buena; aún mayor inconveniente es si no captura fotografías.

Por su parte, los sistemas fotogramétricos y en concreto las cámaras digitales, aun siendo mucho más manejables y asequibles, han presentado el inconveniente de tener que ser calibradas para garantizar resultados de calidad (Remondino y Fraser, 2006), lo que siempre representaba un impedimento para las personas no expertas en fotogrametría. Además, la fotogrametría exigirá de unas condiciones de iluminación aceptables así como del cumplimiento escrupuloso de un protocolo de toma de imágenes, que de no ser cumplido no deparará resultados satisfactorios.Cabe destacar que una ventaja de las cámaras digitaleses que el propio conjunto de datos representado por las imágenes adquiridas suponen un gran valor documental.

Por último, y no menos importante, las nubes de puntos, tanto fotogramétricas como láser, aun siendo de alta resolución y conteniendo información radiométrica en forma de la propia textura del objeto, no incluían información semántica ni topológica asociada, siendo entidades geométricas inconexas y desordenadas. Por ello, algunos autores (Tang et al., 2010) han tratado de avanzar en el paso de las nubes de puntos a los modelos CAD, de forma que las propias nubes de puntos pudieran tener una utilidad real, máxime en el campo de la infografía forense donde la mayor parte de las herramientas software toman como datos de entrada modelos CAD.

Desde hace una década, la Policía Científica evalúa la utilidad de entornos virtuales a partir de modelos CAD para análisis de escenas forenses, investigaciones forenses e información del cumplimiento de la ley. La construcción de entornos virtuales “a mano”, incluso con herramientas CAD, es un proceso muy laborioso. Es por esto, por lo que se hace necesario emplear técnicas de modelado CAD semiautomáticas para la obtención de los modelos 3D permitiendo construir entornos virtuales de alta fidelidad que simulen escenas forenses particulares de la vida real lo más precisas y realistas posibles. (Howard et al., 2000).

A continuación se realizará un breve recorrido a través de las diversas geotecnologías aplicadas en esta Tesis Doctoral en el campo de la infografía forense.

1.1. Fotogrametría de rango cercano y visión computacional

La hibridación de la fotogrametría y la visión computacional en el campo de la ciencia forense es uno de los recursos más eficaces y de menor coste disponibles en la actualidad para la obtención de datos espaciales del escenario forense. La Policía Científica emplea mucho tiempo en la inspección y la exploración in situ de la escena forense tomando fotografías y mediciones, para posteriormente dedicar aún más tiempo frente al ordenador recreando manualmente la escena. Sin embargo, las escenas forenses son perecederas y después de ser examinadas deben regresar a su estado original. Por este motivo, los profesionales tienen que registrar toda la información tan meticulosamente como sea posible, ilustrando la mayor cantidad de datos para su posterior análisis, lo que implica hacer mediciones detalladas y tomar fotografías y vídeos en el lugar del suceso. En este sentido, y en vista de las necesidades, el binomio "fotogrametría-visión computacional" representa una alternativa como método de reconstrucción 3D a partir de imágenes permitiendo obtener las dimensiones, posiciones y formas (paramétricas y no paramétricas) del escenario y objetos que constituyen la escena forense.

La combinación del conocimiento y calidad de los métodos numéricos fotogramétricos con la robustez, rapidez y automatismo de los algoritmos procedentes de la visión computacional, permite obtener el análisis dimensional y reconstrucción de cualquier escenario u objeto de forma automática, sencilla, con bajo coste y sin renunciar a la calidad de los resultados.

Desde hace más de una década, se ha implementado la *reconstrucción interactiva* de entornos virtuales a partir de fotografías, con aplicación al análisis de escenas forenses. Estos escenarios simulados se construyen a través de métodos semiautomáticos de manera rápida y eficiente utilizando métodos de reconstrucción de visión artificial basados en la explotación de las características de las imágenes, es decir, mediante el uso de relaciones matemáticas establecidas en la geometría proyectiva y en la visión estereoscópica. Estos métodos semiautomáticos tienen la ventaja frente a los totalmente automáticos de poder modelar con precisión un entorno real a cualquier nivel de detalle requerido, ya que al interactuar el usuario, se mantiene la jerarquía de los objetos, aumentando la robustez del proceso de reconstrucción de la escena (Gibson y Howard, 2000).

Desafortunadamente, en muchas situaciones no es posible o práctico, garantizar un muestreo apropiado de todas las superficies de la escena. Por ejemplo, las oclusiones y las limitaciones de accesibilidad a determinadas regiones de la escena pueden provocar que algunas áreas no sean visibles, resultando modelos incompletos o reconstruidos de manera incorrecta, lo que plantea la necesidad de implementar algoritmos procedentes de la visión computacional a partir de información incompleta disponible por las imágenes de rango, para así mejorar la modelización de la escena (Wang y Oliveira, 2002). Algunos de estos algoritmos aplican la transformada de Hough para identificar la simetría aproximada en las nubes de puntos (Yip, 2000) y para reemplazar las áreas grandes planas por polígonos de textura mapeada, ya que son algoritmos robustos al ruido y a datos incompletos (Efros y Freeman, 2001). Otros algoritmos identifican de manera automática las regiones que necesitan mejorar la reconstrucción mediante la explotación de redundancias presentes en objetos simétricos incompletos (Gopi y Krishman, 2002).

En otras situaciones la única información que se tiene del escenario forense es a través de imágenes (Wen y Chen, 2004). En algunos exámenes forenses prácticos no se puede obtener toda la información de una sola imagen. Por esto se ha venido implementando la técnica de *fusión de imágenes de multirresolución* para combinar información de varias imágenes de la misma escena. Estas imágenes pueden provenir de un sensor o sensores múltiples (ej. imagen pancromática de alta resolución de niveles de gris y la imagen multiespectral de baja resolución en color). El resultado es una nueva imagen que contiene una mejor descripción de la escena, ya que integra la información y las características más destacadas de cada imagen de entrada. Para implementar la fusión de imágenes multi-resolución, una de las técnicas utilizadas es la Transformada Wavelet (Transformada en funciones de onda) ya que permite descomponer la información de cada imagen en la localización de ambos dominios espacio y frecuencia. Esta técnica, por tanto, permite la eliminación de ruido o la compresión y extracción de bordes (detalles diagonales, verticales y horizontales en las imágenes digitales). Mediante la integración y fusión de todas las características extraídas de las imágenes se reduce la dimensionalidad, dando como resultado un almacenamiento más eficiente y más rápido para la interpretación de las imágenes. Un ejemplo de empleo de esta técnica es en aplicaciones médicas y/o forenses a través de la tomografía computarizada y la resonancia magnética para mostrar toda la estructura del estudio.

Otro aspecto de la aplicación de la fotogrametría para las investigaciones penales (Lewis, 2014) es a través de imágenes tridimensionales, es decir, a través de la formación de imágenes panorámicas de la escena forense ya que proporcionan la capacidad de analizar y reconstruir espacialmente una escena más allá de la fase inicial de documentación. Las tecnologías de formación de imágenes panorámicas complementan técnicas tradicionales de documentación de la escena forense a través de la grabación integral y eficiente de imágenes de 360º de alta resolución. Este tipo de imágenes son utilizadas para evaluar la escena antes y después de la recogida de datos, para el desarrollo de exposiciones más convincentes en salas de audiencia y para la gestión de la propiedad y cadena de custodia. A través de la captura panorámica de datos se puede dar un paseo “virtual” a través de una escena forense después de que se haya procesado, lo que es muy valioso para los investigadores, jueces y jurados.

En los estudios biométricos también se aplican tecnologías fotogramétricas y de visión computacional para sus análisis forenses. (Bagchi et al., 2014). La biometría es el estudio de métodos automáticos para el reconocimiento de humanos basados en características morfológicas únicas que nos diferencian a cada individuo. Desde hace tiempo la medición biométrica se ha venido estudiando y actualmente se considera como el método ideal para la identificación humana. En el campo forense, los estudios biométricos para reconocimiento facial es una forma de visión por computador que utiliza la cara para intentar identificar a una persona o verificar su la identidad declarada. El reconocimiento tridimensional de la cara se hace necesario, pero es una tarea difícil. Cabe destacar que el registro perfecto de los datos faciales es muy necesario para una buena reconstrucción y permitir que el reconocimiento para la identificación de las características fundamentales en el estudio forense. Hasta hace unos años, esta labor era más complicada, debido al limitado desarrollo de métodos tridimensionales, ya que el reconocimiento de la cara en dos dimensiones conlleva variaciones de la pose, y cambios de iluminación y expresiones del rostro, reduciendo la probabilidad de éxito en él reconocimiento. El mayor problema es cuando hay variación de la pose, especialmente cuando la variación es extrema, ej. 90º, por lo que las imágenes tridimensionales tienden a reducir las deficiencias de las imágenes bidimensionales. Las imágenes tridimensionales no se ven tan afectadas por la iluminación y poseen información de la profundidad, por lo que el reconocimiento facial es más robusto. Durante la última década, ha habido un gran volumen de investigación científica en el reconocimiento facial (Bronstein et al., 2005) y (Paysan et al., 2009) entre otros. También destaca la reconstrucción a través de imágenes faciales de los cráneos de los esqueletos y para saber la edad de las víctimas desaparecidas a través de fotografías (Wilkinson, 2004). Además (Park et al., 2008) y (Ricanek y Tesafaye, 2006) han aplicado técnicas de reconocimiento facial para el estudio de la edad y evolución de rasgos físicos en las personas.

Otros autores, (Campomanes et al., 2014), utilizan la visión computacional en antropología, para modelar cráneos y superponer la cara. Este proceso implica la superposición de un cráneo con una serie de imágenes previa a la muerte de un individuo y el análisis de su correspondencia morfológica. A pesar de que la superposición cráneo-facial ha estado en uso durante más de un siglo, todavía se aplica por medio de un enfoque de ensayo y error, sin un método automático. Por lo tanto, es una técnica subjetiva, propensa a errores y que exige mucha dedicación. A través de fotografías y herramientas de visión computacional se puede llegar a automatizar el proceso, reduciendo drásticamente el tiempo empleado y obteniendo un resultado imparcial de superposición cráneo-cara.

Por otra parte, (Luostarinen y Lehmussola, 2014) combinan métodos fotogramétricos y de visión computacional para el reconocimiento de huellas de calzados a través de métodos automáticos. La finalidad es que a través del reconocimiento automático de huellas de calzado se detectan los correspondientes modelos de zapatos, previamente almacenados en bases de datos. Este reconocimiento es resultado de la implementación de descriptores locales y algoritmos basados en la transformada Fourier-Mellin y detección de puntos de interés locales con RANSAC.

Queda de manifiesto que son numerosas las técnicas de fotogrametría combinadas con la visión computacional aplicables al campo de la ciencia forense, y que actualmente están en continuo auge debido a la gran evolución de las tecnologías.

1.2. Gaming Sensors

En los últimos años, la proliferación de los dispositivos "Gaming Sensor" y sus increíbles capacidades de reconocimiento y modelado están abriendo nuevos usuarios que nada tienen que ver con la industria del entretenimiento. El principal motivo radica en su bajo coste, sencillez de manejo y capacidad de obtener resultados de modelizado 3D y reconocimiento bastante aceptables, lo que está provocando su utilización en diferentes disciplinas. Una de ellas, la infografía forense, es la que se toma como base en esta Tesis Doctoral.

Kinect es un dispositivo de detección desarrollado por Microsoft para la consola de videojuegos Xbox. Permite a los usuarios la interacción con Xbox sin necesidad de un controlador de juego especial, a través de una interfaz de usuario natural utilizando gestos y comandos de voz. Kinect fue lanzado en noviembre de 2010 y en febrero de 2013 se habían vendido 26 millones de unidades.

El sensor Kinect contiene un sensor CMOS para obtener imágenes RGB y otro para detectar la profundidad y medición de coordenadas 3D (geometría). El sensor de profundidad, también utiliza un proyector láser (luz infrarroja: 830 nm) y la geometría es obtenida por el principio de triangulación. Los escáneres de triangulación combinan una luz proyectada con una cámara digital para localizar la posición de la luz incidente sobre la superficie del objeto. Dependiendo de la distancia entre el escáner y el objeto, la imagen de la luz reflejada aparece en diferente posición en el sensor de la cámara. La distancia y el ángulo entre el sensor y la luz proyectada son conocidos para realizar los cálculos. El campo de visión es de 57 º x 43 º y la resolución de la imagen es de 640 x 480 en 30 imágenes por segundo. El rango del sensor de profundidad es de 1,2 m - 5 m, que es suficiente para muchas escenas forenses. Las dimensiones del sensor son 27.9 cm x 6.3 cm x 3.8 cm y un peso de 1,36 kg. Kinect incluye un servomotor que permite el posicionamiento remoto del dispositivo. Todos los sistemas requieren fuente de alimentación de ACDC, aunque puede ser reemplazado por baterías. Microsoft lanzó el kit de desarrollo de software de Kinect para Windows 7 en junio de 2011 y permite a los desarrolladores escribir aplicaciones de Kinect en C + +, C # o Visual Basic.NET. Para la toma de datos en las escenas forenses de este estudio, se ha utilizado la biblioteca de código abierto llamado PCL (Point Cloud Library - Librería de nube de puntos).

En la actualidad, el sensor de videojuegos se presenta como una opción de bajo coste para el análisis dimensional y modelado 3D de la escena forense. El sistema es muy útil para la ciencia forense, ya que los laboratorios forenses y criminalísticas necesitan realizar mediciones en la escena forense. Normalmente estas mediciones se realizan utilizando cintas, barras de escala y fotografías. Aunque en los últimos años se están empleando instrumentos más tecnológicos como las ya reseñadas geotecnologías fotogramétricas y láser, ambas tienen sus desventajas, es por lo que este tipo de sensores ("Gaming Sensor") evitan las deficiencias citadas de las técnicas fotogramétricas y de escaneado láser.

En este sentido los "Gaming Sensors" (Microsoft Kinect, Asus Xtion Pro, Structure Sensor of Apple) están recibiendo mucha atención por el bajo coste, la fiabilidad y la rapidez de las medidas proporcionadas (Correa et al., 2012) y (Jia et al., 2012). Kinect está siendo el principal dispositivo de medición 3D robótica y de interior, reconstrucción de la escena 3D y reconocimiento de objetos (Martín et al., 2012) y (Csaba et al., 2012).

En el campo forense son diversos los autores que han utilizado este tipo de dispositivos de bajo coste. Algunos autores (Chow et al., 2012), han analizado el potencial del sistema Microsoft Kinect para realizar medidas del cuerpo humano con el fin de hacer estudios biométricos, es decir, aplicación de métodos automáticos para el reconocimiento de humanos basados en rasgos físicos intrínsecos. Otros autores (Urschler et al., 2014) han utilizado este sensor para registrar datos forenses generando modelos 3D anónimos y personalizados del paciente que son utilizados como visualizaciones de referencia con el fin de proporcionar un contexto intuitivo para documentación de lesiones de modalidades arbitrarias.

Es importante destacar que estos dispositivos sólo pueden emplearse en interiores, ya que en exteriores, al proyectar luz infrarroja, el sensor que detecta el patrón, se satura.

1.3. Sistemas de cartografiado móviles (“Indoor Mapping”)

La evolución de las tecnologías láser y fotogramétricas junto con los dispositivos de navegación (GNSS-Global NavigationSatelliteSystem / IMU-InertialMeasurementUnit) han permitido avanzar hacia soluciones de cartografiado móvil tanto en exteriores como en interiores. Estos sistemas son idóneos cuando el escenario forense a documentar es de interior, complejo y requiere materializar un elevado número de estacionamientos. En este caso, los sistemas “estáticos”, tanto láser cómo fotogramétricos, no aportan la solución idónea, siendo necesarios sistemas móviles y dinámicos que permitan la captura en movimiento. Desafortunadamente, no son muchos los sistemas móviles láser, fotogramétricos o híbridos existentes para interior y menos aún en el campo de la ingeniería forense. Algunos autores (Canter et al., 2010) han desarrollado sistemas “Indoor Mapping” para la creación de cartografía de interiores a través de información geoespacial precisa. La ventaja de estos sistemas es que integran GNSS de precisión con tecnología inercial avanzada (acelerómetros y giróscopos) para la georreferenciación del edificio a partir de medidas realizadas en el exterior del mismo, además de un sistema de posición y orientación para proporcionar mediciones ininterrumpidas de la posición, balanceo, cabeceo y rumbo verdadero del vehículo en movimiento en el interior. Con estos métodos, el tiempo de recopilación de datos equivale a lo que tarda una persona en recorrer caminando el área de interés, por lo que esta notable reducción de tiempo, comparada con otros sistemas, está acompañada de una destacable reducción de costes.

Otros autores (Boulanger y El-Hakim, 1999) han apostado por realizar sistemas móviles pasivos compuestos por cámaras de diferentes tipologías (panorámicas, compactas y réflex). Estos sistemas pasivos destacan por su bajo coste y sencillez de manejo, sin embargo se requiere de un elevado número de cámaras que den cobertura a los 360º de la escena junto con la aplicación de potentes y robustos algoritmos de procesamiento fotogramétrico (Oliensis, 2000) que permitan obtener con una calidad mínima la nube de puntos resultante. Otros, en cambio, han desarrollado sistemas indoor híbridos que integran los sensores activos y pasivos bajo una misma plataforma (Naikal et al., 2009). Estos, a pesar de reunir las ventajas de ambos, presentan como inconveniente más importante el tener que hacer frente a procesos de registro complejos y nada sencillos entre los sistemas láser y fotográficos.

Por otra parte, existen contribuciones de cartografiado móvil de exterior (outdoor mapping) a través de investigaciones geoespaciales de la escena del crimen (Wolf y Asche, 2009) desde análisis de situaciones a visualizaciones 3D interactivas basadas en SIG. De este modo se obtienen análisis de zonas urbanas donde quedan identificados los lugares frecuentados por delitos, contribuyendo como un sistema de gran ayuda para los organismos de seguridad y autoridades relacionadas con la planificación urbana.

Existen estudios sobre la reconstrucción y segmentación de escenas de rango cercano de mapas de nubes de puntos 3D a través de manipulaciones móviles en entornos domésticos (Rusu et al., 2009) que son perfectamente aplicables a escenas forenses. Otros análisis (Puente et al., 2013) hacen una revisión de tecnologías de cartografiado móvil y topográficas, que también se pueden destinar para estudios y reconstrucciones en la ciencia forense.

En el caso de la ingeniería forense, los sistemas "Indoor Mapping" destacan por su idoneidad para el registro de las escenas más complejas, pues desempeñan de forma automática múltiples pasos como el escaneado dinámico (en movimiento), junto con la determinación de la trayectoria autónoma que sigue el propio vehículo. La información 3D con carácter métrico se consigue prácticamente en tiempo real una vez realizado el recorrido con el propio vehículo.

1.4. Paso de las nubes de puntos a modelos CAD

A pesar de los inconvenientes reseñados en la fase de adquisición, no hay duda de que la mayor dificultad asociada al empleo de los sistemas de escaneado láser y/o fotogramétricos radica en la manejabilidad y conversión de las nubes de puntos masivas y desordenadas (sin topología) en modelos geométricos CAD que permitan su posterior explotación y análisis por parte de todos los agentes involucrados (Remondino, 2003). Uno de los primeros hitos en este reto se asienta en las estrategias de segmentación de la nube de puntos (Woo et al., 2002), (Schnabel et al., 2007), (Sithole y Vosselman, 2003), (Rusu et al., 2009), (Vosselman et al., 2004) y (Rabbani et al., 2006). El objetivo de las mismas no es otro que clasificar de forma semiautomática la información de la nube de puntos, llevando a organizar, parametrizar y postprocesar, esta información en elementos identificables, para conseguir la modelización tridimensional del escenario forense. Esta segmentación y organización de los objetos de la escena se basa en las características homogéneas de las nubes de puntos, con respecto a una serie de criterios (Biosca y Lerma, 2008). Dicha homogeneidad se refiere generalmente a la posición de los puntos en el espacio junto con una serie de restricciones geométricas asociadas tales como la profundidad, las normales y las curvaturas de las superficies. Algunos autores (Schnabel et al., 2007) han aplicado un algoritmo automático que hace uso de RANSAC (RAndomSAmpleConsensus), para detectar formas básicas en las nubes de puntos no organizadas. Se trata de un estimador robusto que es capaz de extraer una gran variedad de tipos de primitivas básicas, siendo idóneo para aplicarlo al campo de la infografía forense. (Shen et al., 2006) y (Li, 2011). No obstante, uno de los mayores inconvenientes asociados a RANSAC está en el coste computacional, ya que su propio principio de votación unido al elevado número de puntos existentes podría deparar costes computacionales inadmisibles.

Algunos autores (Bosche y Haas, 2008) han automatizado la recuperación robusta de objetos 3D/CAD a partir de datos obtenidos con escáner láser. Estos investigadores lo han implementado en la construcción y gestión de infraestructuras en ingeniería, aunque su aplicación puede ser perfectamente empleada para análisis forenses y legales a través de consultas automatizadas en bases de datos de imágenes 3D, ya que permite recuperar automáticamente los objetos CAD/3D en rangos de nubes de puntos.

Otros autores (Bels y Jain, 1988) han utilizado el análisis de componentes principales (PCA- Principal Component Analysis) para la segmentación de nubes de puntos. Cabe destacar que una de las ventajas de este método frente a otros ya existentes radica en la capacidad de detectar superficies con todas las orientaciones posibles y diferenciarlas de formas irregulares. Esta última característica es de vital importancia en la infografía forense, pues implica la extracción de información del escenario total de la escena, separando elementos como pueden ser el cuerpo de la víctima, restos de ropa y otros efectos personales, el arma empleada, etc. El modelo segmentado resultante permite avanzar hacia la simplificación inteligente de nubes de puntos y su conversión a modelos CAD, constituyendo la mejor “radiografía tridimensional” del escenario forense susceptible de ser utilizado por parte de la Policía Científica en las herramientas de infografía forense.

El Análisis de Componentes Principales (PCA) se aplica en diversos estudios en el campo de la infografía forense. Una aplicación es para la reconstrucción cráneo-facial basada en la diversidad estructural local de los cráneos (Pei et al., 2008). Se genera un mapa exacto de registro a través de los datos de reconstrucción, obteniendo como resultado un mapa de profundidad que permite examinar las características faciales del cráneo. Otra utilidad de PCA (Berar et al., 2005) es a través de un método de reconstrucción con el fin de estimar, a partir de un modelo estadístico, la forma tridimensional de la cara de un sujeto a partir de datos conocidos del cráneo.Otras aplicaciones de PCA (Exline et al., 2003) han sido destinadas sobre imágenes químicas para la detección de huellas dactilares, ya que a través de la técnica de PCA se exploran los datos y se reduce la dimensionalidad, lo que sirve para acentuar las diferencias entre las huellas y poder distinguir unas de otras.En general, las aplicaciones de PCA al campo forense sirven para investigar datos tomados sobre la escena forense y destacar las diferencias encontradas entre ellos para facilitar los análisis, tal y como muestran (Thanasoulias et al., 2002), (Muehlethaler et al., 2011) y (Virkler y Lednev, 2011), entre otros.

En otro aspecto, el diseño asistido por ordenador en tres dimensiones (CAD 3D) apoyado por la fotogrametría desempeña un papel importante en el campo de la documentación de lesiones forenses relevantes, sobre todo cuando es necesaria una reconstrucción 3D detallada. Un ejemplo de esta aplicación es en (Thali et al., 2003) y (Brüschweiler et al., 2003) donde se toman fotografías de las lesiones para crear modelos 3D y posteriormente, comparar en CAD/3D el modelo de la lesión contra el modelo virtual 3D del posible instrumento causante de la herida. La coincidencia entre ambos modelos demuestra cuál es el instrumento que ha causado la lesión.

También la ingeniería inversa se integra con el diseño CAD en el campo forense a través del procesado y toma de datos de modelos de cuerpo humano basado en sistemas de cámaras tridimensionales (Tan et al., 2010). La Ingeniería inversa utiliza dispositivos electrónicos para recoger datos crudos de superficie, luego calcula las coordenadas espaciales de los datos por software profesional y establece el modelo CAD tridimensional de los objetos. Es un método práctico y simple para operar y cuyo resultado es un modelo del cuerpo humano. Igualmente, existen técnicas de ingeniería inversa aplicadas a cráneos humanos para la reconstrucción 3D CAD y para la obtención de réplicas físicas por prototipado rápido. (Galantucci et al., 2006).

CAPÍTULO 2

HIPÓTESIS DE TRABAJO Y OBJETIVOS

2. HIPÓTESIS DE TRABAJO Y OBJETIVOS

2.1. Hipótesis

En el apartado anterior se ha mostrado una visión general de la aplicación de las diversas geotecnologías en el campo de la infografía forense. La base de esta investigación es que la aplicabilidad de dichas geotecnologías es idónea en la inspección ocular del delito para su posterior representación gráfica tridimensional. Para dar respuestas a esta investigación que se pretende verificar, se plantean las siguientes hipótesis:

- La incorporación de las geotecnologías láser y/o fotogramétricas en el campo de la infografía forense son un medio no destructivo y no invasivo ideal para la obtención de datos tridimensionales fidedignos y con propiedades métricas de las escenas forenses.

- La reconstrucción 3D a partir de imágenes demuestra la utilidad y la integración de la fotogrametría de rango cercano y la visión computacional como una alternativa eficiente para modelar objetos complejos y escenarios de infografía forense. Un escenario interior complejo puede ser automáticamente reconstruido en 3D utilizando múltiples imágenes adquiridas con cualquier tipo de cámara, incluyendo "Smartphones" y "Tablets".

- Los dispositivos del tipo "Gaming Sensor" se presentan como una opción sencilla y de bajo coste para el análisis dimensional y modelado en 3d de la escena forense en interiores y a cortas distancias, garantizando análisis dimensionales precisos.

- El uso de sistemas dinámicos de escaneado de interiores, "Indoor Mapping", se presentan como una solución rápida, eficaz y de bajo coste para la captura de datos en infografía forense. En aquellas escenas forenses grandes y complejas permite reducir el número de estacionamientos necesarios en comparación con otras geotecnologías (láser o fotogramétricas), lo que implicará una gran reducción de tiempo y una menor propagación de errores.

- La segmentación de nubes de puntos láser basado en PCA permite avanzar hacia la generación de modelos parciales CAD, de gran interés por parte de los agentes involucrados en las tareas de infografía forense.

2.2. Objetivos

El **objetivo general** de esta Tesis Doctoral es el estudio metodológico y validez de aplicación de geotecnologías de bajo coste fotogramétricas (cámara digital convencional y “Smartphones”) y láser (“Gaming Sensor” e “Indoor Mapping”) en escenarios forenses.

Este objetivo general se concreta en los siguientes **objetivos específicos**:

- Obtención de nubes de puntos a escala a través de la hibridación de técnicas fotogramétricas y de visión computacional que garantizan automatismo (en el paso del 2D al 3D), flexibilidad (admitiendo la utilización de cualquier tipo de cámara) y calidad (garantizado resoluciones superiores a los sistemas láser). Para ello, se utilizará una herramienta propia denominada PWF (Photogrammetry Workbench Forensic).

- Evaluación metrológica de la exactitud de la nube de puntos fotogramétrica, a través del análisis dimensional de primitivas básicas (distancias, esferas y planos).

- Análisis dimensional y modelado 3D de escenarios forenses de interior y a cortas distancias con técnicas “Gaming Sensor”. Para ello, se utilizará un software propio GSMod (Gaming Sensor Modelling).

- Estudio de la precisión y exactitud metrológica del dispositivo “Gaming Sensor” mediante el análisis de la desviación estándar de primitivas (e.g. planos), perfiles y medidas de objetos conocidos.

- Cartografiado tridimensional de escenarios forenses de interior mediantes sistemas dinámicos, “Indoor Mapping”.
- Segmentación en planos y aristas de las nubes de puntos adquiridas con un sistema láser móvil “Indoor Mapping” a partir del análisis de componentes principales (PCA).
- Conversión de la nube de puntos obtenida por dicha segmentación en un modelo 3D propio del diseño CAD, mediante estrategias de modelado paramétricas.
- Evaluación de la exactitud metrológica del sistema “Indoor Mapping” y validación del modelo CAD obtenido.

CAPÍTULO 3

ARTÍCULOS CIENTÍFICOS

3. ARTÍCULOS CIENTÍFICOS

A continuación se mostrarán los tres artículos científicos previamente publicados en revistas internacionales de impacto. Antes de cada artículo original se describe un pequeño resumen que recoge el trabajo de investigación de cada uno de ellos.

3.1. Método de modelado automático basado en imágenes aplicado a la infografía forense.

En este artículo se comprueba la utilidad e integración de la fotogrametría de rango cercano y la visión computacional a través de un nuevo método basado en la reconstrucción 3D a partir de imágenes, demostrándolo como una opción eficaz para la modelización de objetos y escenarios complejos en infografía forense.

Esta nueva técnica, desarrollada por los propios autores, se ha llevado a cabo a través de una herramienta software llamada PWF , en la que, siguiendo una metodología adecuada, se reconstruye la escena forense a través de imágenes, permitiendo hacer un análisis dimensional de la misma. La toma de fotografías para el procesamiento debe hacerse siguiendo unas directrices específicas. El modelo resultante es de alta resolución y con propiedades métricas, representando una "radiografía" de la escena forense lo que permite volver a visitar de manera virtual la misma para extraer datos métricos siempre que sea necesario.

La herramienta PWF procesa íntegramente todas las imágenes para la obtención del modelo 3D, de forma sencilla y automática. La interfaz del software oculta todos los procesos matemáticos necesarios para la reconstrucción de la escena, por lo que su utilización es muy sencilla para usuarios que no dominan la fotogrametría ni la visión computacional.

La Policía Científica de Madrid ha examinado y validado favorablemente esta herramienta empleándola para la modelización de diversos escenarios forenses simulados, tomando uno de ellos como caso de estudio en este artículo. Además, para asegurar la validez y exactitud del método, se ha establecido una "verdad terreno" a través de un sistema de escaneado láser terrestre.

Se concluye que PWF garantiza tres cualidades hasta ahora difíciles de integrar por parte otros softwares comerciales: automatización, flexibilidad y calidad. La automatización se logra porque la herramienta permite el paso de 2D a 3D sin interacción del usuario. La flexibilidad se consigue porque permite el uso de cualquier tipo de cámara e incluso pudiendo realizar las tomas con cámaras no calibradas y de bajo coste ("Smartphones" y "Tablets"). La calidad se alcanza al generar modelos densos con una resolución equivalente al GSD de la imagen y con una calidad métrica centimétrica. Por último, no debe ser olvidado el bajo coste y la sencillez de uso de la herramienta desarrollada. Por tanto, PWF es claramente, una herramienta totalmente válida para la Policía Científica y una alternativa a la toma de datos en infografía forense frente a los procedimientos expeditos clásicos e incluso frente a los modernos y costosos sistemas de escaneado láser.

An automatic image-based modelling method applied to forensic infography

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ABSTRACT: This paper presents a new method based on 3D reconstruction from images that demonstrates the utility and integration of close-range photogrammetry and computer vision as an efficient alternative to modelling complex objects and scenarios of forensic infography. The results obtained confirm the validity of the method compared to other existing alternatives as it guarantees the following: (i) flexibility, permitting work with any type of camera (calibrated and non-calibrated, smartphone or tablet) and image (visible, infrared, thermal, etc.); (ii) automation, allowing the reconstruction of three-dimensional scenarios in the absence of manual intervention, and (iii) high quality results, sometimes providing higher resolution than modern laser scanning systems. As a result, each ocular inspection of a crime scene with any camera performed by the scientific police can be transformed into a scaled 3d model.

KEYWORDS: forensic infography; crime scene; image-based modelling; photogrammetry; computer vision.

1. Introduction

Forensic infography is a technique that facilitates the virtual reconstruction of different facts through computer science and digital image management. Currently, cutting edge infographic techniques are applied to ocular inspection in crime scene investigations. These techniques consist of thorough tasks of observation and documentation, the purpose of which is to obtain information in order to relate all the signs so as to determine and demonstrate the facts [1]. However, its determinant role in scientific investigations has been relegated to the support of inspection and visual analysis for years. In recent years, geomatics and non-intrusive techniques based on remote data acquisition have been incorporated into the domain of forensic infography because they allow for the scene be remain unchanged, without altering either its spatial position or physical properties. In addition, this method provides the metric reconstruction of the incident with rigor, thoroughness and accuracy, facilitating a return to the crime scene in order to reconstruct its signs. In this regard, the two most applied geomantic techniques in the field of forensic infography are close-range photogrammetry [2-4] and laser scanning [5-8], both of which (considering advantages and disadvantages) permit a dimensional analysis and 3D reconstruction of the crime scene. Even if both methods complement each other and can be coordinated, they are applied with different purposes [9]. Photogrammetry is mostly used when the scene or the object to be reconstructed from a geometric point of view is not too complex (i.e., simple parametric forms); in contrast, the laser scanning technique is ideal for those objects with complex geometric shapes (i.e., non-parametric forms) that are difficult to model and/or automate through photogrammetric methods (i.e., textureless objects) [10, 11]. Nonetheless, occasionally it is not viable to use a laser scanner system due to its high costs and its mobility and layout difficulties in reduced scenes. Alternately, photogrammetric systems (digital cameras specifically), even though they are much more manageable and affordable, present the disadvantage of having to be calibrated to ensure high quality results [12], which is an impediment to those users inexperienced in photogrammetry.

In this respect, and considering the limitations remarked above in the field of forensic infography, this paper aims to contribute to the development of a 3D reconstruction method from images using the Open Source tools Apero-MicMac [13] and Cloud Compare [14]. These tools have been previously used in other studies [15, 16]. The advantages of the proposed solution in comparison with the contributions remarked above, including the authors' method [4], is that any indoor complex scene could be automatically reconstructed in 3d using multiple images acquired with any type of camera, including smartphones or tablets. In particular, the proposed approach integrates computer vision and photogrammetric algorithms in a smart manner that allows us to overcome the recording and modelling of complex objects (e.g., victims and facial models) and scenarios (e.g., indoor scenes with the presence of shadows and occlusions). The key to its success is the combination of the last generation of algorithms for the correspondence and orientation of images, the combination of several lens calibration models for the self-calibration process, and the combination of multiple stereo vision algorithms that enables coping with complex scenarios. As a result, it provides the field of forensic infography with a tool to obtain simple, automatic, low-cost, and outstanding quality dimensional analyses.

This paper has the following layout and structure: after this introduction, section 2 explains in detail the method developed; section 3 shows experimental results for several case studies performed in collaboration with the forensic infography group of the Scientific Police in Madrid; and the final section outlines the most relevant conclusions together with possible future work areas.

2. Method

The method developed for 3d reconstruction should be understood in regards to the accomplishment of two main steps: (i) the automatic determination of the spatial and angular position of each image taken at the crime scene, regardless of the order in which the images were taken and without requiring initial approximations; (ii) the automatic computation for each pixel in the image of its 3D scene position, which determines the generation of a dense and scaled 3d model.

From a general point of view, the originality of the proposed approach lies in the ability of combining photogrammetric and computer vision algorithms adapted to the reconstruction of crime scenes, opening their use to non-experts in these disciplines. From a specific point of view, the method developed is based on a simple and specific protocol for its application in forensic scenarios, ensuring completeness and quality of the final model. Additionally, various robust algorithms for the extraction and correspondence of features (i.e., points or lines) between images have been implemented and tested, including a variation of SIFT (Scaled Invariant Feature Transform) [17], ASIFT (Affine Invariant Scale Feature Transform) [18], that exhibits the best results in these types of situations where geometric (e.g., presence of objects at different distances, occlusions) and lighting (e.g., shadows, textureless materials) variations are very common. Last but not least, several camera calibration models (e.g., radial basic, radial extended, Brown and Fraser basic) have been integrated, allowing us to work with any type of camera, including inexpensive smartphones and tablets. Therefore, camera calibration is not mandatory since the tool developed incorporates a self-calibration approach which includes the remarked camera calibration models. Anyway, if the user decides to calibrate its camera these parameters can also be added as fixed and known parameters in the camera orientation process.

The following graphic (Figure 1) illustrates the different steps performed in the development of the modelling method based on images. It includes a control of the quality during the process (accuracy assessment) through a laser scanner system, which acts as the “ground truth”.

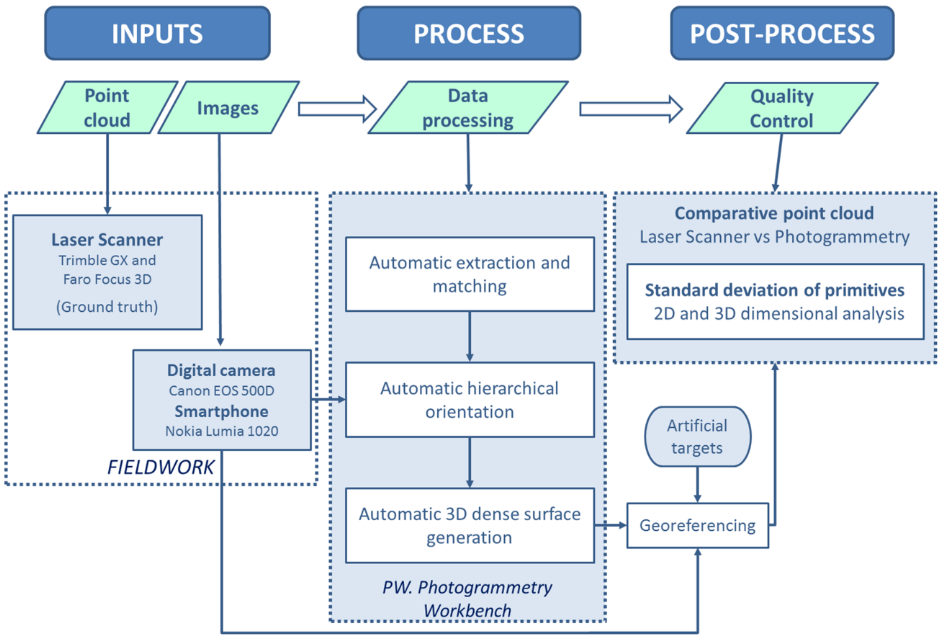

***Figure 1**. Workflow developed for automatic reconstruction from images in forensic infography.*

2.1. Data acquisition protocol

The data acquisition, in the form of images, is the key to the success of the developed process because they represent the input data for the correspondence and orientation of images. Previously, and apart from the geometric conditions required for the image acquisition that are detailed below (see Figure 2), the context must be exhaustively analysed, including the lighting conditions of the scene as they will determine the shot strategy and the values of exposure, aperture and shutter speed of the camera. To this end, images should be acquired without critical illumination variations, avoiding overexposed areas and ensuring sharpness, together with an analysis of possible occlusions due to the presence of obstacles that, in the end, will affect the protocol of multiple image acquisitions and the multiple overlaps between adjacent images.

The shortest available focal length of the camera must be chosen and must remain constant throughout the image acquisition process. Nevertheless, for certain detailed shots, a different focal length could be used due to the proximity of the object of interest.

In relation to the geometric conditions of the photographic shot, the objective is to establish a multiple image acquisition protocol to reconstruct the object or scene of interest, guarantying the highest completeness and accuracy of the resulting 3d model. The optimal image acquisition can be complex, in particular for scenes with strong depth variations and occlusions. Therefore, the key is to establish a guideline, based on simple geometric constrains, for the acquisition of imagery at the crime scene (Figure 2).

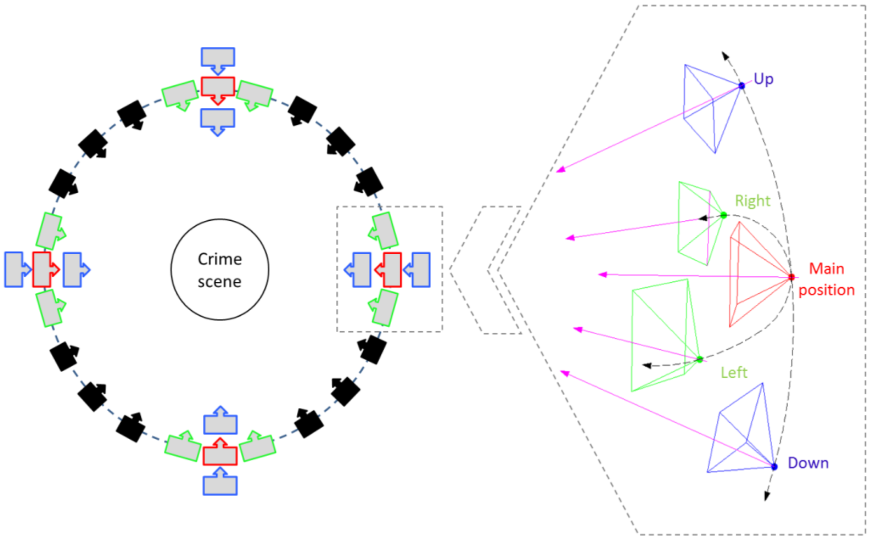

Figure 2. *Protocol for image acquisition following a multiple convergent shooting ("ring" configuration) to fully reconstruct a crime scene (Left). Five specific images acquired from, at least, four stations of the ring at the crime scene (Right).*

Specifically, the photographs must be taken following a "ring" around the object (Figure 2), maintaining a constant distance to the object (depth) and a specific separation (baseline) between stations. Regarding the depth, this should be chosen according to the image scale or the resolution desired. With respect to the baseline, a small separation between stations leads to high completeness of the 3d model due to the high image similarity and the good correspondence performance. As a general rule, and to ensure the correspondence of images during the orientation phase, the separation between two stations should guarantee small intersection angles (e.g., 15º).

Five images (one master and four slaves) have to be taken from, at least, four stations of the ring, following the sketch outlined in Figure 2, right. In particular:

- The master image represents the origin of the coordinate system and should focus on the object of study. This image must be taken from the front and frame the principal part of the object of study or, if possible, including the entire object.

- Two slave images are taken by moving the camera slightly horizontally (right and left).
- Two slave images are taken by moving the camera slightly vertically (up and down).
- The percentage of overlap (i.e., common area) between the slaves and the master image must be high (80-90%). In addition, the slave images should be acquired by turning the camera towards the centre of the object focused on in the master image, so that it assures the geometric reconstruction of any point on the object and thus the automatic reconstruction of the scene (see Figure 2, right).

2.2. Correspondence between images

One of the most critical steps in this process is the extraction and correspondence of an image's features (lines and points) with high accuracy and reliability because they constitute the framework that supports the entire process as they provide the necessary information to indirectly resolve spatial and angular position of images (orientation), including the camera self-calibration. Because crime scenes usually present variations in scale (e.g., objects at different distances, depth variations) and illumination (e.g., occlusions and shadows), classical algorithms based on grey levels, such as ABM (Area Based Matching) [19] and LSM (Least Square Matching) [20], are useless. To this end, more sophisticated and robust algorithms have been tested: SUSAN (Smallest Univalue Segment Assimilating Nucleus) [21]; SIFT (Scale Invariant Feature Transform) [17]; MSER (Efficient Maximally Stable Extremal Region) [22] and SURF (Speeded Up Robust Features) [23]. Unfortunately, all of these algorithms become ineffective when considerable scale and rotation variations exist between images.

In this sense, a variation of the SIFT algorithm, called ASIFT (Scale Invariant Affine Transform) [18], has been incorporated into method developed. As the most remarkable improvement, ASIFT includes the consideration of two additional parameters that control the presence of images with different scales and rotations. In this manner, the ASIFT algorithm can cope with images that have a high scale and rotation difference, common in indoor crime scenes. The result is an invariant algorithm that considers the scale, rotation and movement between images.

This result provides the next expression:

$$A = \begin{bmatrix} a & b \\ c & d \end{bmatrix} = H_\lambda R_1(\kappa) T_1 R_2(\varpi) = \lambda \begin{bmatrix} cos\kappa & -sin\kappa \\ sin\kappa & cosk \end{bmatrix} * \begin{bmatrix} t & 0 \\ 0 & 1 \end{bmatrix} * \begin{bmatrix} cos\varpi & -sin\varpi \\ sin\varpi & cos\varpi \end{bmatrix} \quad (1)$$

where **A** is the affinity transformation that contains scale, λ , rotation, κ, around the optical axis (swing) and the perspective parameters that correspond to the inclination of the camera optical axis, φ (tilt) or the vertical angle between optical axis and the normal to the image plane; and ϖ (axis), the horizontal angle between the optical axis and a the fixed vertical plan.

The author's main contribution in the adaptation of the ASIFT algorithm is its integration with robust strategies that allow us to avoid erroneous correspondences. These strategies are the Euclidean distance [20] and the Moisan-Stival ORSA (Optimized Random Sampling Algorithm) [24]. This algorithm is a variant of Random Sample Consensus (RANSAC) [25] with an adaptive criterion to filter erroneous correspondences by the employment of the epipolar geometry constraints.

2.3. Hierarchical orientation of images

The correspondence points derived from the ASIFT operator are the input for the orientation procedure, which is performed in two steps. In the first step, a pairwise orientation is executed by relating the images to each other by means of the Longuet-Higgins algorithm [26]. In the second step, this initial and relative approximation to the solution is used to perform a global orientation adjustment between all images by means of the collinearity equations [27], which could include the determination of the camera parameters (self-calibration).

Additionally, ground control points (GCP) belonging to the crime scene or a known distance (KD) could be incorporated to permit an absolute georeferenciation of the images. These GCP or KD will be added to the orientation process as artificial targets (optional) located around the crime scene.

2.4. 3D model generation

Starting from the robust orientation of images, a process for 3D model reconstruction has been developed. It is based on the semi-global matching technique (SGM) [28], and, by applying the projective equation [29] (2), it permits the generation of a dense 3D model resulting from the determination of a 3D coordinate for each pixel.

$$x_k = C\left(D\left(R_i(X_k - S_i)\right)\right) \qquad (2)$$

where X is the 3D point, x is the point corresponding to the image, **R** is the rotation matrix of the camera, S is the projection centre of the camera, C is the function of internal camera calibration, D is the lens distortion function and the subscripts k and i are related to the point and image, respectively.

The SGM process consists of minimising an energy function (3) throughout the eight basic directions that a pixel can take (each 45º). This function is composed of a function of cost, **M** (the pixel correspondence cost), that reflects the degree of the similarity of the pixels between two images. x and x', together with the incorporation of two restrictions, P_1 and P_2, show the possible presence of gross errors in the process of SGM. In addition, a third constraint has been added to the process of SGM; it consists of the epipolar geometry derived from the photogrammetry [30], and it can enclose the search space of each pixel in order to reduce the enormous computational cost. In that case, it will generate a dense model with multiple images, obtaining more optimal processing times.

$$E(D) = \sum_x \left(M(x, D_x) + \sum_{x' \epsilon N_x} P_1 T[|D_x - D_{x'}| = 1] + \sum_{x' \epsilon N_x} P_2 T[|D_x - D_{x'}| > 1] \right) \quad (3)$$

where $E(D)$ is an energy function that must be minimised on the basis of the disparity (difference of correspondence) through the counterpart characteristics, the function M (the pixel correspondence cost) evaluates the levels of similarity between the pixel x and its counterpart x' through its disparity Dx, while the terms P_1 and P_2 correspond with two restrictions that allow for avoiding gross errors in the dense matching process for the disparity of 1 pixel or a larger number of them, respectively.

2.5. Accuracy assessment

The quality of the results must be validated to certify the accuracy of the method. Therefore, a terrestrial laser scanner sensor has been incorporated (previously calibrated) as the “ground truth” in the process of data acquisition. This provides high accuracy measurements that will be contrasted with those obtained from the developed method. More specifically, a metrology analysis of the spatial invariant is proposed to test the accuracy of the method.

3. Experimental results

The experimental results were obtained through two simulated crime scenes at the Headquarters of the Scientific Police in Canillas (Madrid-Spain). Both scenes try to emulate real situations, including evidence that provides the hypothesis required in order to evaluate and analyse the crime scene. Two different sites and sensors were chosen to undertake the experiments, with the purpose of adapting the method to a threefold requirement proposed by the Scientific Police: (i) to cope with scenes with textureless objects (the first crime scene); (ii) to allow the possibility of using smartphones (the second crime scene); and (iii) to guarantee enough accuracy for forensic infography. Although the cameras used in forensic investigations are digital single lens reflex (DSLR) cameras, the lens used are different than those used in this study. In particular, forensic investigations make use of macro lens and/or fisheye lens and the acquisition of individual images which allow a qualitative analysis of the crime scene.

The material used in the experiment includes two different digital cameras: a DSLR camera, the Canon EOS500D, and a smartphone, the Nokia 1020, both used for image acquisition. In addition, two terrestrial laser scanner systems, the Trimble GX and Faro Focus, were used for providing accuracy assessments of the method proposed.

The table below (Table 1) illustrates the technical characteristics of the four sensors used:

Table 1. *Technical characteristics of the sensors used.*

Terrestrial Laser Scanner	**Trimble GX**	Laser type: Time of flight with a wavelength of 532 nm (green) Range: 2 – 350 m, with a nominal accuracy of 6 mm at 50 m range Scanning speed: up to 5000 points per second Spot size: 3 mm at 50 m Scanning speed: up to 5000 points per second Field of view: 360° (horizontally) x 60° (vertically) Minimum vertical angular step-width 0.0014º and minimum horizontal angular step-width 0.0012º
	Faro Focus 3D	Laser type: phase shift with a wavelength of 905 nm (Infrared) Range: 0.6 – 120 m, indoor and 0.6-20 m outdoor, with a nominal accuracy of 2 mm at 50 m range Scanning speed: up to 976000 points per second Field of view: 360° (horizontally) x 305° (vertically) Minimum vertical angular step-width 0.009º in horizontal and vertical
Digital Cameras	**Digital Camera Canon EOS500D**	Sensor type: APS-C CMOS (22.3 x 14.9 mm) Resolution: 15.1 MP Image size: 4752 x 3168 pixels Focal length: 17 mm
	Smartphone Nokia Lumia1020	Sensor type: BSI CMOS (8.8 x 6.6 mm) Resolution: 38 MP Image size: 7712 x 5360 pixels Focal length: 26 mm

In the following, the results obtained in each phase of the developed methodology will be illustrated and analysed.

In the first simulated crime scene, *the suicide*, the protocol of data acquisition provided 67 images that present the top distribution below (Figure 3, top). For a detailed study of the scene, 23 images corresponding to the nearest ring of interest were used. The second simulated scene, *the homicide*, used 26 images (Figure 3, bottom).

Both crime scenes were scanned with the laser scanner from a single station point (Figure 3) in order to be able to work with the best ground truth that would reflect the quality of the developed process.

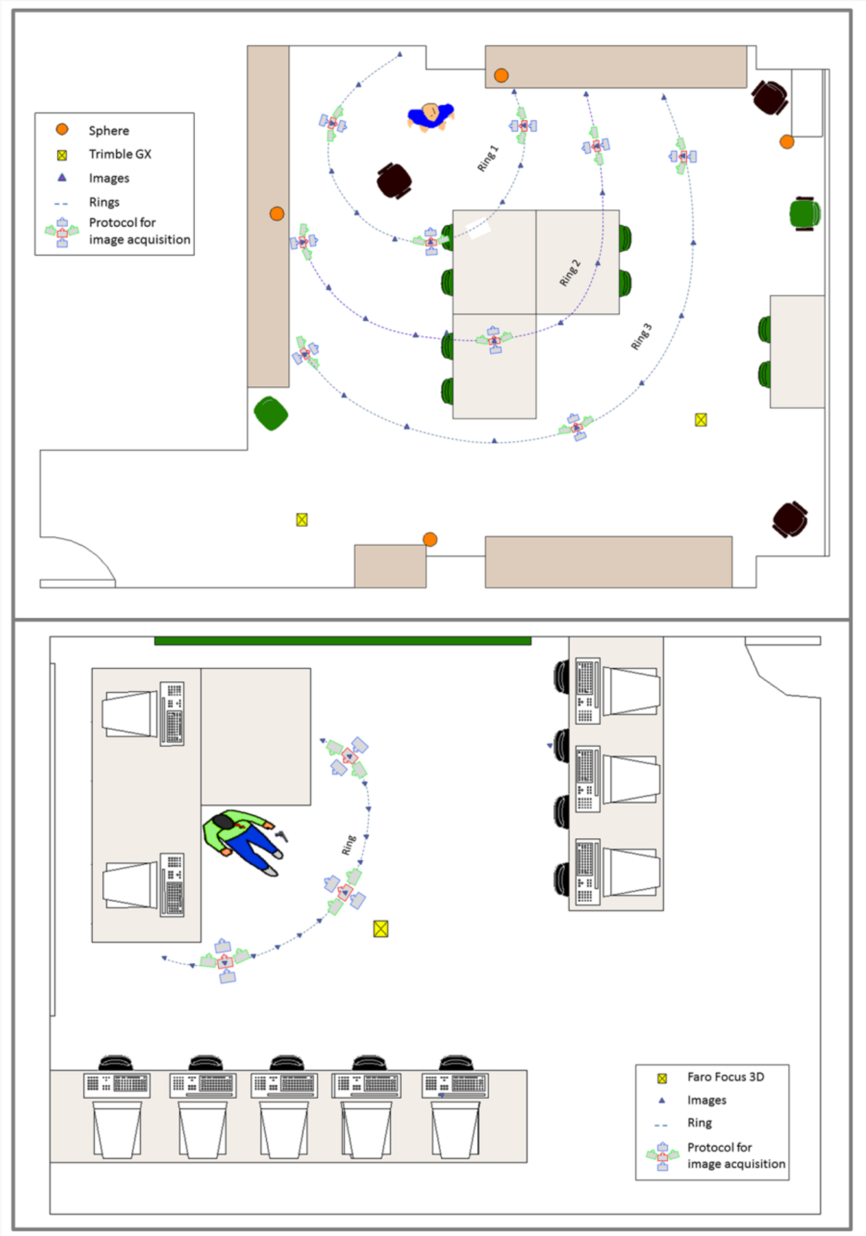

Figure 3. *Plant view of image acquisition and of the laser scanner. First simulated crime scene, the suicide (Top). Second simulated crime scene, the homicide (Bottom).*

It is worthwhile to highlight that the protocol followed in data acquisition is simple and fast, as it did not require more than 5 minutes for image acquisition. In the first crime scene, *the suicide*, images were taken with a short fixed focal length, diaphragm aperture of f/5.6, exposure time of 1/10 s and ISO of 200. The point cloud captured with the scanner laser Trimble GX has provided 2581272 points and was acquired from an approximate distance of 3 m with a resolution of 3 mm.

In the second crime scene, *the homicide*, 26 images were taken with a fixed focal length, aperture of f/2.2, exposure time of 1/17 and ISO of 400. The point cloud captured with the laser scanner Faro Focus 3D gives 3020648 points at a distance of approximately 2 m and a resolution of approximately 2 mm.

Prior to the image and laser acquisition, artificial targets (optional) were placed in the crime scene with a double function: first, they serve as GCP for georeferencing and scaling the scene, and, second, they set stable and defined references to control the accuracy of the three-dimensional model that has been reconstructed.

Once the data acquisition process is finished, we need to determine the position (spatial and angular) from where the images have been taken to transform 2D (the images) into 3D (the three-dimensional model). This process is automatically completed through the correspondence of interest points. The ASIFT algorithm obtained a total of 83754 points of interest with approximately 6442 image points for the first simulated crime scene (Fig. 4, left), whereas 276682 points of interest were matched for the second crime scene with approximately 18445 image points (Fig. 4, right).

Figure 4. *Matching results based on the ASIFT algorithm for a couple of images corresponding to the first crime scene, the suicide (Left) and to the second crime scene, the homicide (Right). These images show the matched points joined with a "white" line.*

When the matching points between images have been determined, the relative orientation of images must be calculated (the spatial and angular position of the cameras in the arbitrary reference system, with no georeferencing or scaling). Afterwards, it will be refined and calculated in absolute form with respect to a scaled reference system established by ground control points or known distances in the form of artificial targets.
After the points from where the images were taken are determined, the next phase is to resolve the reconstruction problem, that is, to obtain any 3D point for each pixel of the image and thus generate a dense 3D model of the crime scene. The following figure (Figure 5) illustrates the quality and resolution of the 3D model in the form of a point cloud resulting from the process. A total of 1,520,315 points were obtained for the first simulated crime scene and 6992230 points for the second crime scene, with an equivalent ground sample distance (GSD) or resolution of 0.8 mm and 0.3 mm, respectively. If we establish a quantitative comparison with a laser scanner point cloud, we realise that photogrammetric models provide a better resolution than laser scanner systems, which is something that was unthinkable a few years ago.

The point cloud coming from the images includes photorealistic texture and that each *XYZ* point also includes components of *RGB* true colour (Figure 5).

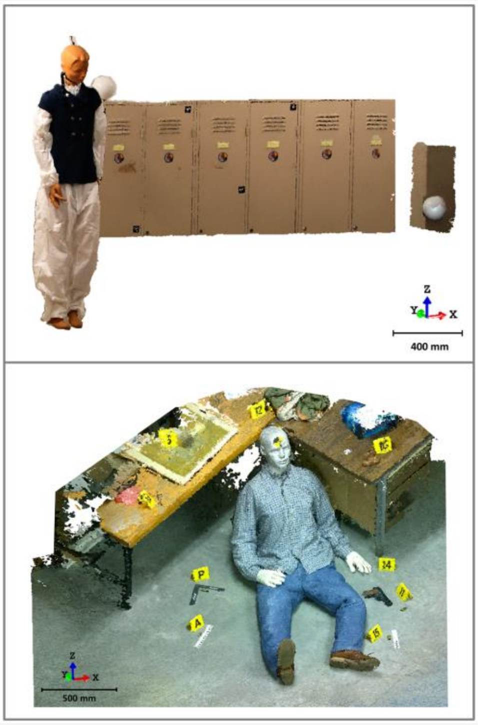

Figure 5. *Photogrammetric dense model resulting from the first crime scene analysed, the suicide (Top) and the second crime scene, the homicide (Bottom). Number of total points: 1520315. Resolution: 0.8 mm (Top). Number of total points: 6992230. Resolution: 0.3 mm (Bottom).*

Finally, to validate and assess the accuracy of the method developed, the Scientific Police decided to establish a ground truth provided by two different laser scanning systems, a time of flight, Trimble GX, and a phase shift, Faro Focus (Table 1). During the process of accuracy assessment, a dimensional analysis of geometric invariants has been carried out in the form of distances and standard deviations associated to best-fit planes and best-fit spheres for the point clouds of the crime scene. Table 2 and Table 3 illustrate the results of the accuracy assessment process, and Figure 6 and Figure 7 reflect distances, spheres and planes analysed for the first and second crime scenes, respectively.

Table 2. *Results of accuracy assessment process from the first crime scene (the suicide) analysed and recorded with the camera Canon EOS500D. The values correspond to the dimensional analysis of distances (d), their errors (δ_{d1}) and standard deviations derived from the best-fit plane (σ_p) and best-fit sphere (σ_s) with the dimensional errors of diameter spheres(δ_{s2}) .*

		Method proposed Canon EOS500D	**Trimble GX**
Distances	d_1 (mm)	1283.3	1292.6
	δ_{d1} (mm)	9.3	
	d_2 (mm)	976.58	985.86
	δ_{d2} (mm)	9.3	
	d_3 (mm)	1479.00	1471.74
	δ_{d3} (mm)	-7.29	
	d_4 (mm)	707.45	713.59
	δ_{d4} (mm)	6.14	
Spheres	s_1 (mm)	148.70	145.35
	δ_{s1} (mm)	-3.35	
	σ_{s1} (mm)	8.6	0.7
	s_2 (mm)	148.57	145.95
	δ_{s2} (mm)	-2.62	
	σ_{s2} (mm)	9.3	0.5
Plane	σ_p (mm)	5.9	1.7

Figure 6. *Dimensional analysis based on distances measured between ground control points (artificial targets) and basic primitives (spheres and planes) fitted in the first crime scene.*

Table 3. *Results of accuracy assessment process from the second crime scene (the homicide) analysed and recorded with the smartphone Nokia 1020. The values correspond to the dimensional analysis of distances (d), their errors (δ_{d1}) and standard deviations derived from the best-fit plane (σ_p).*

		Method proposed Nokia 1020	Faro Focus 3D
Distances	d_1 (mm)	187.56	185.92
	δ_{d1} (mm)	-1.64	
	d_2 (mm)	32.29	34.00
	δ_{d2} (mm)	1.71	
	d_3 (mm)	152.32	155.22
	δ_{d3} (mm)	2.90	
	d_4 (mm)	1333.29	1329.78
	δ_{d4} (mm)	-3.51	
	d_5 (mm)	87.80	88.25
	δ_{d5} (mm)	0.45	
	d_6 (mm)	309.03	310.95
	δ_{d6} (mm)	1.92	
Planes	σ_{p1} (mm)	0.82	1.71
	σ_{p2} (mm)	5.21	1.92

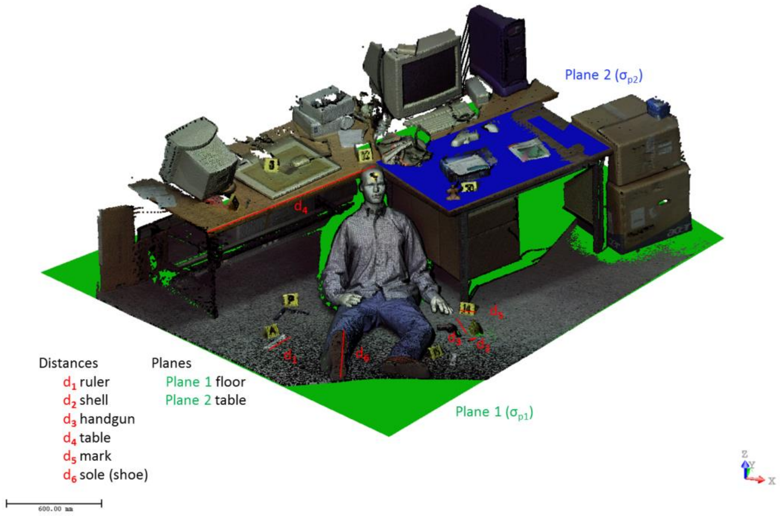

Figure 7. *Dimensional analysis based on the distances measured and basic primitives (planes) fitted in the second crime scene.*

Table 2 and Figure 6 outline the measure of two distances in each of the point clouds (Our image-based modelling method and Trimble GX). It can be verified that the values of distances obtained in the point cloud of the method proposed reveal results with discrepancies lower than 1 cm, so the method guarantees that the results are completely acceptable for forensic infographics studies, which usually only require centimetre accuracies. The spheres, which were distributed homogeneously and in various heights, are calibrated, and their diameter is known, 145 mm. Table 2 presents the standard deviation of the spheres generated by the two point clouds (Method proposed and Trimble GX), with the lowest standard deviation for the laser Trimble GX because it functions as a ground truth. Finally, the standard deviation of a plane generated by the two point clouds has been studied. Again, the lowest standard deviation appears in the cloud of points captured with the Trimble GX system; this fact confirms and assures its accuracy. However, the method proposed shows a very acceptable standard deviation. This value is higher because the cloud of points obtained by the Trimble GX scanner generates less noise than the one obtained by the method proposed. Table 3 shows the measurement of six distances (Figure 7) in the point cloud obtained from the method proposed (the Faro Focus 3D point cloud is used as ground truth). It is confirmed that the method proposed provides acceptable results for forensics engineering studies with errors lower than 1 cm. Table 3 also shows the standard deviation in plane fitting. In some cases, for example, the plane fitted from the floor, the standard deviation obtained from the method proposed is even lower that those obtained from the Faro Focus 3D.

4. Conclusions

This paper has provided a methodology using Open Source tools [13,14] that allows the 3d reconstruction and dimensional analysis of crime scenes using only images. Once the data acquisition process is finished, following the guidelines specified, the processing of images provides an “as built” 3d model of the crime scene. This model is high resolution with metric properties, representing a "radiography" of the crime scene, allowing one to return to the crime scene whenever necessary and to extract data with metric properties. The process described is performed easily and automatically. The tool has been favourably tested and validated by the Scientific Police of Madrid through simulations of a number of diverse crime scenes, some of which have been taken as case studies in this paper. The tests outlined in this paper have been motivated according to the Scientific Police’s feedback. The exemplary selected scenes are very common in forensic science, and the authors think that the experimentation zone provides sufficient reliability to verify the method and technology. The ground truth established with the laser scanner systems permits the ensuring of the validity and accuracy of this approach even when we cope with complex scenes and smartphone cameras, showcasing this approach as an efficient and acceptable solution for the Scientific Police. The image-based modelling method proposed is clearly an alternative tool for data acquisition in forensic infography compared to classical expeditious procedures and even opposite to modern and expensive laser scanner systems. The method guarantees three characteristics that are difficult to integrate: automation, flexibility and quality. Automation is achieved because the tool allows for passing from 2D to 3D without user interaction. Flexibility is achieved because the tool facilitates the use of any type of camera, even taking photographs with non-calibrated and low-cost cameras (e.g., smartphones and tablets). Quality is achieved because the tool generates dense models with a resolution equivalent to the image GSD and centimetre accuracy. Finally, the low-cost and simplicity of use that the developed tool represents should not be forgotten.

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3.2. Aplicación de Gaming Sensor Kinect en la ciencia forense.

En este artículo se avanza en la documentación y análisis dimensional de escenas forenses utilizando para ello un instrumento tan actual, como son los sensores de videojuegos “Gaming Sensor”.

El “Gaming Sensor” Kinect se presenta como una opción de bajo coste para el análisis dimensional y modelado 3D de la escena forense. Para comprobar la aplicación de este tipo de sensores en el campo de la ciencia forense, en este artículo se han realizado pruebas de precisión y fiabilidad comparándolo con dos escáneres láser terrestre, que se disponen como “verdad terreno”.

Una vez obtenidos los datos en nubes de puntos por las tres tecnologías láser empleadas se han estudiado los conjuntos de datos, mostrando los datos capturados por Kinect, una desviación estándar que aumenta con el rango entre el sensor y el objeto de estudio. Se ha comprobado que este resultado obtenido está de acuerdo con soluciones bibliográficas consultadas previamente, además de verificar los resultados de ruido conseguidos a través de la obtención de perfiles desde las nubes de puntos. Por estas consecuencias, es importante planificar cualquier medición en la escena forense antes de capturar los datos.

Se ha hecho otro estudio para datos tomados a diferentes distancias entre el sensor y los objetos, comprobando la resolución de las nubes de puntos. Para las medidas de detalle en la escena (e.g. la cara del maniquí, los casquillos, la pistola, etc.) la resolución del sensor disminuye bruscamente con el aumento de la amplitud, por eso es adecuado colocar el sensor cerca de señales de puntería. Sin embargo, las medidas de distancias más generales pueden obtenerse en este rango con errores menores al 10%. Por otro lado, los conjuntos de datos Kinect tomados a distancias cortas (alrededor de 1.5 m.) muestran buenos detalles de los objetos.

En conclusión, el sensor Kinect aparece como un escáner láser de bajo coste con aplicabilidad a la ciencia forense para la adquisición de medidas dimensionales de la escena forense. Sin embargo, el límite en el rango de medida y la falta de precisión con el incremento de rango deben tenerse en cuenta para planificar el estudio, por lo que es recomendable, combinar diferentes rangos de medidas según el detalle y el tipo de las mediciones a realizar e incluso combinar con otras técnicas, como la fotogrametría.

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TECHNICAL NOTE

DIGITAL & MULTIMEDIA SCIENCES

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Application of Kinect Gaming Sensor in Forensic Science*

ABSTRACT: Kinect sensor appears as a low-cost option for 3D modeling. This manuscript describes a methodology to test the applicability of Kinect to crime scenes. The methodology includes the comparison versus well-established scanners (Faro and Trimble). The parameters used for the comparison are the quality in the fitting of primitives, a qualitative evaluation of facial data, the data quality for different ranges, and the accuracy in the measurement of different lengths. The results show that the Kinect noise level increases with range, from 5 mm at 1.5 m range to 15 mm at 3 m range. It is considered that for detail measurements the sensor must be placed close to the target. A general measurement of a sample crime scene was analyzed. Errors in length measurements are between 2% and 10% for 3 m range. The measurement range must be limited to *c.* 3 m.

KEYWORDS: forensic science, laser scanner, gaming sensors, crime scene, Kinect, photogrammetry

Metrology is the science of measurement, and it is applied to forensic science as forensic metrology. Forensic and criminalistics laboratories perform numerous measurements to support both criminal and legal actions. Some examples are the measurement of the presence of a substance (e.g. cocaine, alcohol), DNA analysis, or crime scene measurements. Crime scene measurements are typically performed using tapes, scale bars and photographs, especially for small distances (victim body, gun, and bullet), and topographic instrumentation as electro-distance measurement indicators, total stations, and levels for longer lengths (room of the crime, bullet trajectory, car accident trajectory). During the last years, more technological instruments are being used that usually consist of photogrammetry and laser scanning and allow obtaining an accurate representation of the crime scene (1,2). In addition, the information is completely digitalized in 3D coordinates (point clouds) and CAD programs can be used to complete the research process of the crime.

Laser scanners used in the surveying of crime scenes are typically divided in two types, terrestrial laser scanners (3) and triangulation scanners (4–6). The terrestrial laser scanners are used for medium ranges (2–100 m) and intermediate accuracy (around 1 cm), while the triangulation scanners are preferred for short ranges (<2 m) and high accuracy (<0.5 cm). The first type allows a clear reconstruction of the complete scene, while the second one is used for details.

The main problem of using laser scanning techniques is the high cost involved that makes difficult to extent to many forensic units, in addition to the required laser calibration and the license of the software to manage the point clouds. Therefore, alternative low-cost solutions are welcomed. During the last years Kinect (Microsoft Corporation) is becoming and important 3D sensor. It is receiving a lot of attention for the low-cost, reliability, and speed of the measurements provided (7,8). Kinect is currently one of the primary 3D measurement devices in indoor robotics and mapping, 3D scene reconstruction and object recognition (9,10). The use of these sensors in applications beyond entertainment is of great interest, being forensic science one of the applications fields with main possibilities.

This work presents a metrological study about the applicability of Kinect to forensic science. For this purpose, a crime scene was simulated in a room using a dummy together with some objects (e.g. gun, bullets, and clothes). The metrological verification is performed by comparison against a reference provided by two terrestrial laser scanners: Focus 3D (Faro Technologies Inc, Trimble Nabigation Ltd, Los Angeles, CA) and GX (Trimble Navigation Ltd). The metrological comparison consists of four main tests. The first test is related with the fitting of primitives to certain geometric characteristics in the scene. The second one shows the qualitative evaluation of the facial data of the body. The third one measures the noise of two profiles of data at different ranges. Finally, the fourth one consists of the estimation of five different lengths to determine the accuracy in length measurements.

Materials and Methods

The crime scene (Fig. 1) was measured using standard Kinect sensor. In addition, it was also measured by Faro and Trimble

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FIG. 1—*Simulated crime scene.*

laser scanners to assess the metrological accuracy and reliability of the Kinect device. Figure 2 shows the different sensing systems.

Instrumentation

Kinect is a sensing device developed by Microsoft Corporation for the Xbox video game console. It enables users the interaction with the Xbox without the need of a special game controller, through a natural user interface using gestures and spoken commands. Kinect was launched in November 2010. A total of 26 million units of the Kinect sensor had been shipped in February 2013.

The Kinect sensor contains one CMOS sensor for RGB imaging and another one for depth sensing and 3D coordinate measurements (geometry). Depth sensing also uses a laser projector (infrared light: 830 nm), and geometry is obtained from the triangulation principle. Triangulation scanners combine a light projector with a digital camera to locate the position of the incident light on the object surface. Depending of the distance between the scanner and the object, the imaging of the reflected light appears in a different location on the sensor of the camera. The distance and angle between the sensor and the light projector is known to perform the calculations. The field of view is 57° × 43°, and the image resolution is 640 × 480 at 30 frames per second. The depth sensor range is 1.2–5 m which is enough for many crime scenes. The dimensions of the sensor are 27.9 cm × 6.3 cm × 3.8 cm, and its weight is 1.36 kg. The Kinect includes a servo-motor that enables the remote device positioning. All the system requires an ACDC power supply, although it can be replaced by batteries. Microsoft Corporation released the Kinect software development kit for Windows 7 on June 2011 and allows developers to write Kinect apps in C++, C#, or Visual Basic.NET. The open source library called PCL (point cloud library) was used for the digital recording of the measurements in this study (11).

The Trimble scanner is based on the time of flight principle and has a laser source that emits pulses with a wavelength of 532 nm. This system measures distances in the range of 2–350 m, with a nominal accuracy of 6 mm at 50 m range. The field of view is 360° horizontally and 60° vertically. The minimum vertical angular step width is 0.0014°, and the horizontal one is 0.0012°. The diameter of the laser beam is 3 mm at 50 m. The measurement rate is 5000 points per second.

The Faro is a phase shift scanner with a laser wavelength of 905 nm. The system measures distance in the range of 0.6–120 m indoors and 0.6–20 m outdoors, with a nominal accuracy of 2 mm at 50 m range. The field of view is 360° horizontally and 305° vertically. The minimum vertical angular step width is 0.009° in horizontal and vertical. The measurement rate is 976,000 points per second. Table 1 summarizes the main technical characteristics of the systems.

Methodology

The workflow for this study is divided into three main phases: fieldwork to generate input point cloud data, data processing, and quality control in postprocessing (Fig. 3). During field work several scans were acquired from different positions with Faro and Trimble to generate the input reference data. The scanners were placed on topographic tripods leveled using the digital levels of the systems. Data were saved in a SD card for the Faro system and in a laptop for the Trimble. Faro uses embedded software for the management of the data acquisition, while Trimble needs Trimble software in the laptop for the acquisition. The data from

TABLE 1—*Technical specifications of Faro, Trimble and Kinect.*

	Faro	Trimble	Kinect
Wavelength (nm)	905	532	830
Field of view (°)	360 × 305	360 × 60	57 × 43
Accuracy (mm) – 50 m range	2	6	–
Measurement range (m)	0.6–120	2–350	1.2–5
Angular resolution (°)	0.009	0.0014 H 0.0012 V	0.09
Measurement rate (Hz)	976,000	5000	9,216,000

FIG. 2—*Laser scanners used for the experiment. From left to right: Kinect, Trimble, and Faro.*

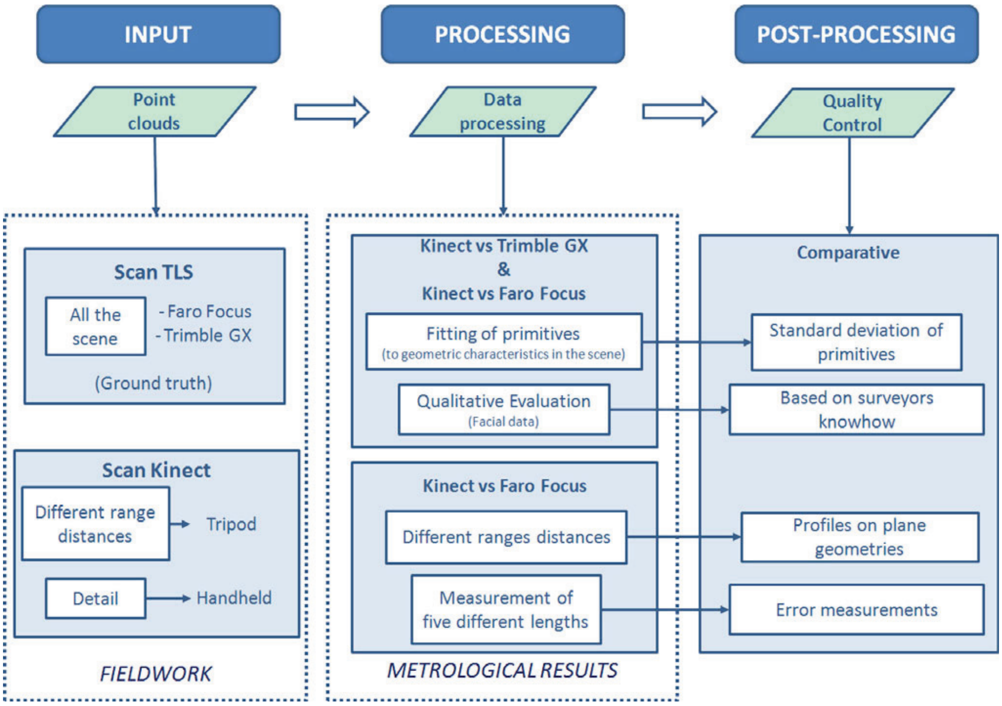

FIG. 3—*Workflow.*

the single scan positions were registered with the aim to represent the entire crime scene and avoid data gaps. In addition, two different Kinect datasets where obtained from the case study. The first one covers approximately all the scene. The Kinect was placed on a photographic tripod to make the measurements stable. The tripod was leveled using the two leveling bubbles. Different range distances will be evaluated. The second one was made with the purpose of obtaining more details about the face of the dummy. In this case, it was not possible to position the tripod, so the sensor was handheld. Figure 4 shows a scheme with the scan positions used during the survey. The open source Point Cloud Library was installed in a laptop to acquire the Kinect data.

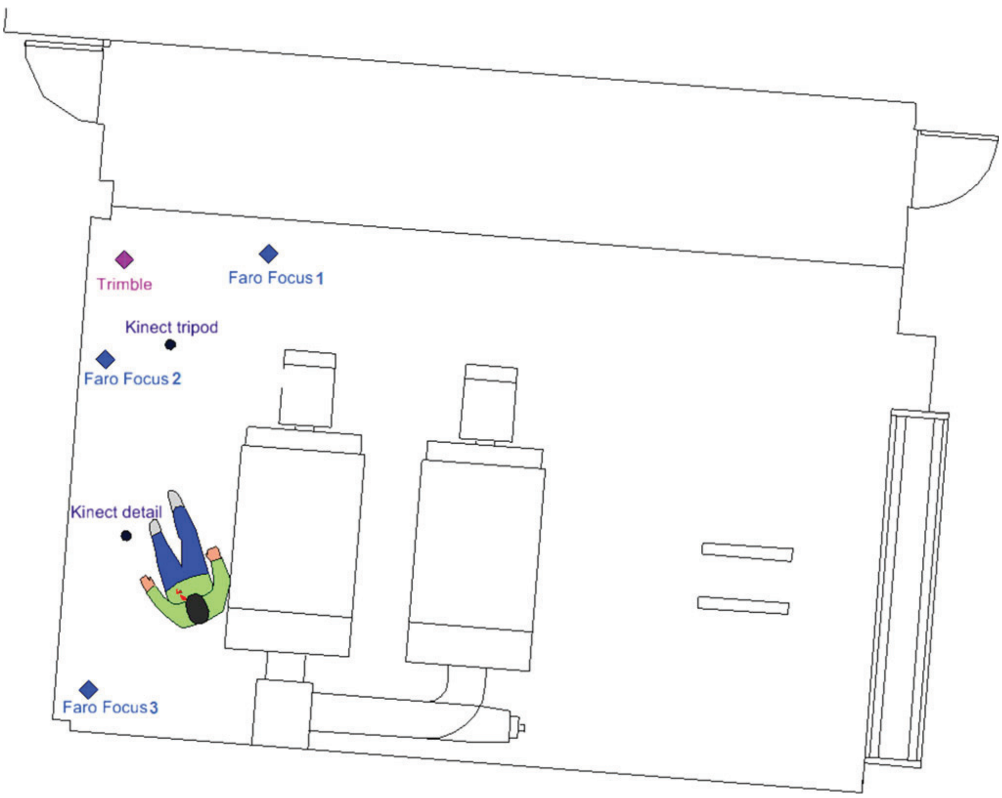

FIG. 4—*Scan positions.*

Data processing involves the preparation of results obtained from the Kinect (in both configurations) and those obtained for the Trimble and Faro laser scanner for the metrological comparison (quality control) in postprocessing.

The first step in data processing includes the fitting of primitives (sphere, cylinder, and plane) to geometric characteristics in the scene. The sphere data are obtained from a topographic sphere introduced in the scene, the cylinder from a pipe, and the plane from the floor (Fig. 5). The quality control compares for all the systems involved the standard deviation of least square fitting algorithm applied to the primitives previously cited.

The second step in data processing consists of a qualitative evaluation of the facial data obtained from the Kinect sensor and of a comparison of the results with the data obtained by the Faro and Trimble scanners. The quality control is performed based on the surveyors know-how.

The third step analyzes the behavior of the Kinect at different ranges. The quality control is performed by measuring the noise of four profiles of data obtained from two different locations. Each location provides two profiles, one for Kinect and another one for Faro. Figure 6 shows the location of the profiles.

The fourth step consists of the estimation of five different segments for length comparison between the Faro (the most accurate system) and Kinect sensor (Fig. 7). The quality control is performed by means of error measurements.

The experimental results were performed in a simulated crime scene located in a room at the Polytechnic School of Avila (University of Salamanca). The room includes machinery for the central heating of the building. A dummy was used for the simulation of the crime scene. In addition, some other objects where placed in the scene to provide more realism. These objects were clothes, a gun, a brush, and some bullets.

Results and Discussion

Figure 8 depicts the standard deviation of the primitives sphere, plane, and cylinder fitted to representative geometries in the scene. The lowest standard deviation value appears for the Faro system that confirms it as the reference for all the experiments. This behavior is in agreement with the technical specifications provided by the manufacturer that give and accuracy of

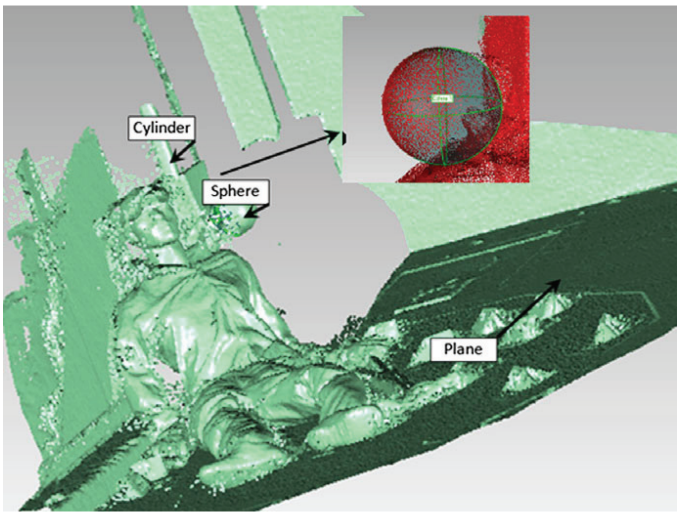

FIG. 5—*Primitives fitting: sphere, cylinder, and plane. Zoom is performed to sphere fitting to exemplify the process.*

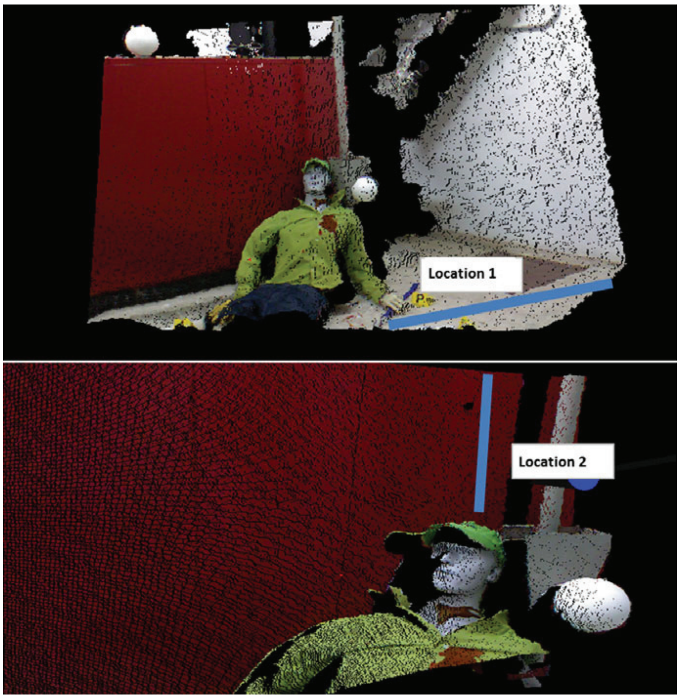

FIG. 6—*Horizontal and vertical profiles used for noise evaluation with scanners Kinect and Faro. Dataset for the figure was provided by Kinect scanner.*

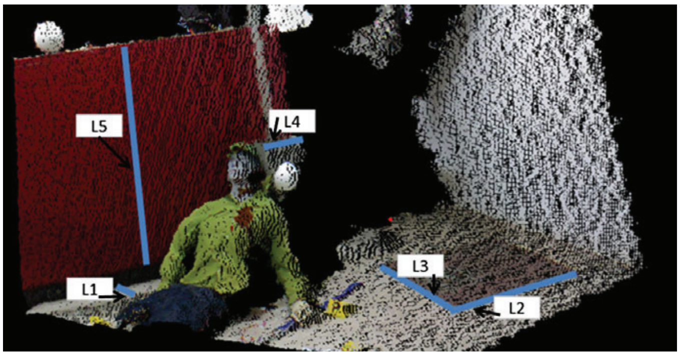

FIG. 7—*Segments for length comparison between Faro and Kinect. Dataset for the figure was provided by Kinect scanner.*

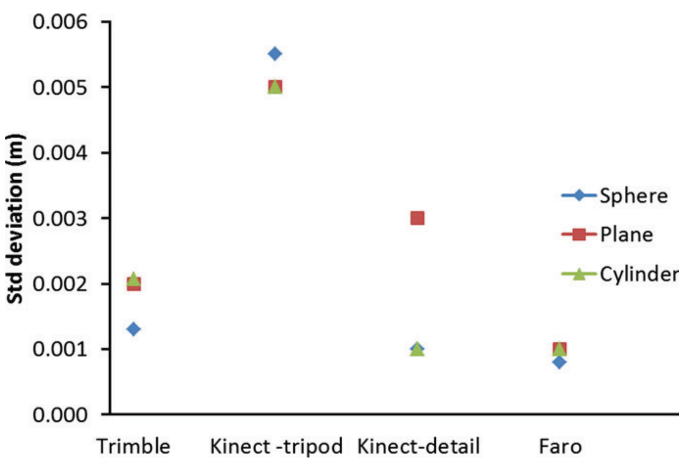

FIG. 8—*Standard deviation of the fitting primitives: sphere, cylinder, and plane.*

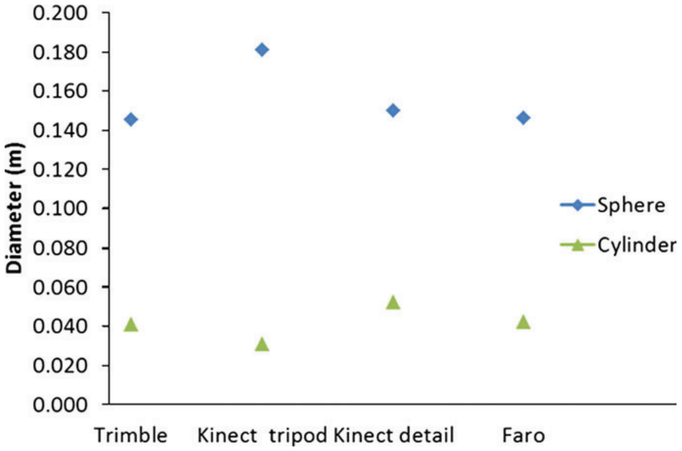

FIG. 9—*Comparison of the diameters measured from the fitting primitives: sphere and cylinder.*

2 mm in range measurement. The Trimble scanner shows a behavior similar to Faro, although the results are a bit poorer.

The Kinect data obtained at close ranges (Kinect detail; around 1.5 m distance between sensor and objects) show higher standard deviations than those obtained from Faro and Trimble. However, in all cases the values appear acceptable for crime scene documentation, being all below 5 mm. In the case of the Kinect data at large ranges (Kinect on a tripod; around 3 m) all values increase in comparison with those with detailed measurements. The behavior obtained with Kinect sensor in this study is in agreement with those obtained in previous works (12), where the precision of the Kinect sensor decreases with range according a second order polynomial.

Figure 9 shows the resulting diameters obtained from the sphere and cylinder fitting. In this case, the Kinect data for close ranges show results very close to those obtained from the professional measurement systems Trimble and Faro. At the higher measurement range (Kinect – tripod), the Kinect shows poorer results.

Figure 10 compares the Kinect data (1.5 m range and 3 m range) of the dummy face to the Faro measurements. Results

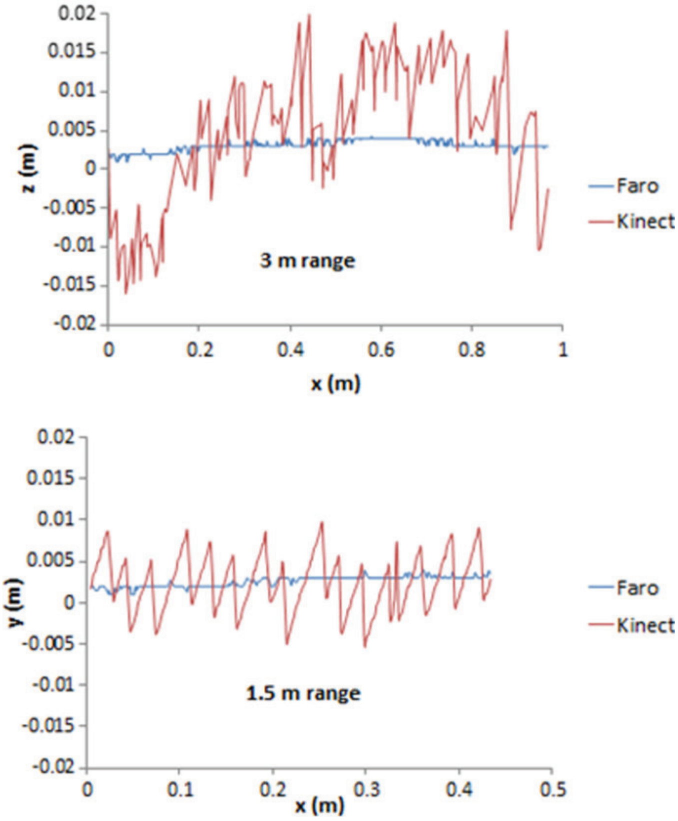

FIG. 11—*Comparison between two profiles (horizontal and vertical), each one obtained from Kinect and Faro scanners.*

show that detailed measurements of the face can be only performed at closer range, where resolution of Kinect is higher and details from the face of the dummy can be measured. The nose, eyes, and mouth of the dummy are as well detected from the Kinect point cloud as from the Faro data. The detection allows differentiating the main elements of the face and raw measurements of its position.

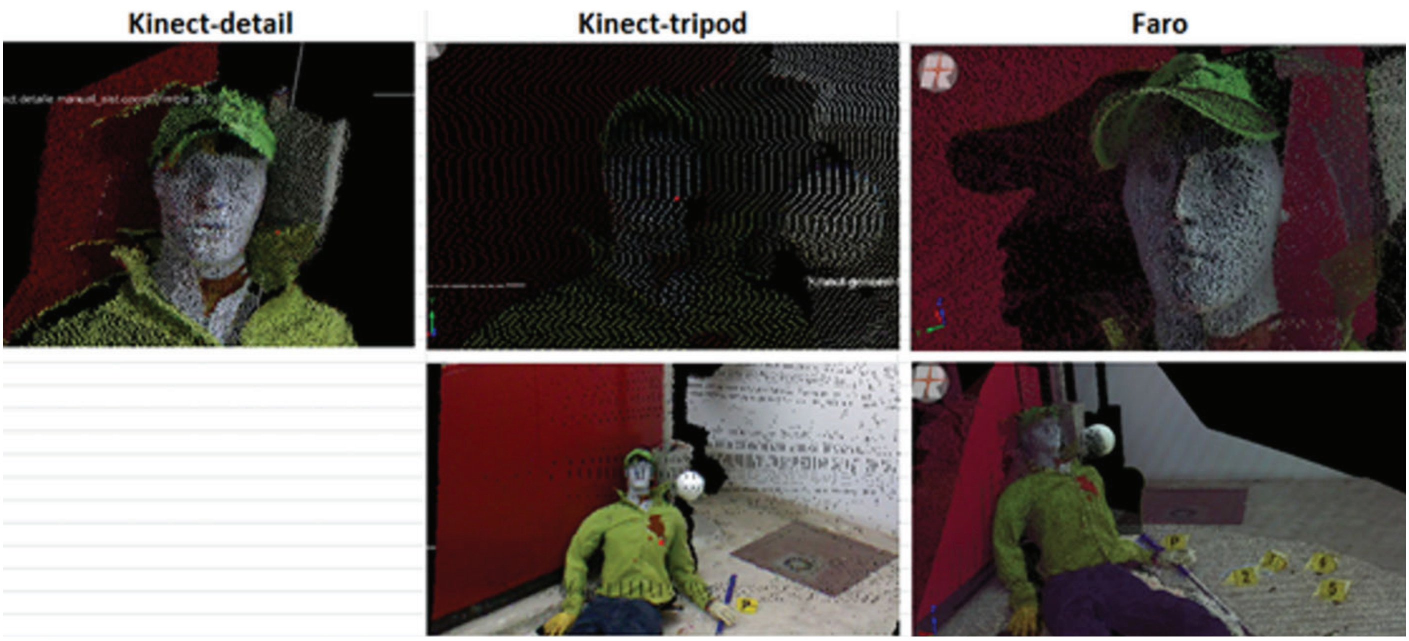

FIG. 10—*Qualitative comparison between the point clouds obtained at different ranges from Kinect and Faro.*

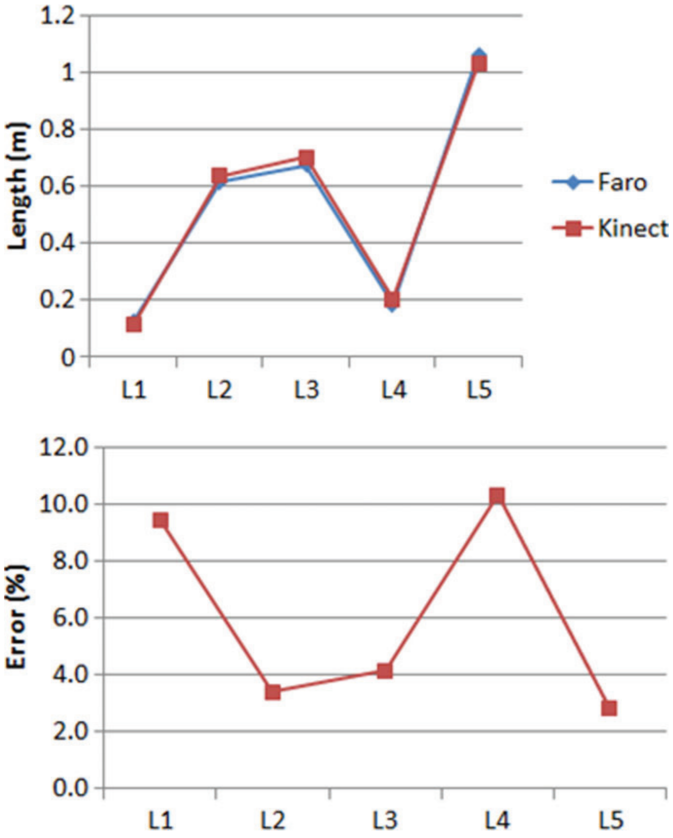

FIG. 12—*Comparison of length measurements between Kinect and Faro.*

Figure 11 shows two profiles (horizontal and vertical) obtained from Kinect and Faro data on plane geometries (see also Fig. 6). As must be expected Faro data shows noise levels lower than Kinect, especially for closer ranges. Kinect also depicts a noise increasing with the increasing of range that it is in agreement with the previous results of primitive fitting and the bibliography.

Finally, a comparison between Faro and Kinect data is performed for long range measurements (3 m; Fig. 12). Length measurements are in agreement in all cases with the reference, especially for longer lengths. The error changes between 2% for longer lengths under study (around 1 m) and 10% for the smaller ones (around 10 cm). The Faro scanner is taken as the reference. The error is calculated as the difference between the Kinect and Faro data. Percentage values are depicted to make it more understandable. An inverse trend between error and length of the measured segment is observed. This is a common behavior in dimensional metrology where short length measurements always represent poor values.

Conclusion

In this study, a step forward for crime scene recording and dimensional analysis based on low-cost gaming sensors has been provided. The Kinect sensor is evaluated for its application in crime scene measurements. It is compared against well-known and reliable commercial scanners (Faro and Trimble).

Kinect shows a standard deviation that increases with range between sensor and target object. This result is in agreement with previous results obtained from the bibliography and must to be taken into account to plan any measurement in a crime scene. These results are also in agreement with noise results obtained from some profiles obtained from point cloud data.

The Kinect datasets taken at larger ranges (around 3 m) show low resolution which is not enough to take detailed measurement from the scene parts (e.g. detail from face of a dummy cannot be obtained). However, more general distance measurements can be obtained at this range with errors typically below of 10%. The Kinect datasets taken at close distances (around 1.5 m) show good details of the objects.

In conclusion, the Kinect sensor appears to be a low-cost laser scanner with applicability to forensic science for the acquisition of dimensional measurements from crime scenes. However, the limited measurement range and the lack of precision with the increasing of range must be taken into account to plan the survey. It seems recommendable to combine different measurement ranges depending on the detail and type of the measurements to perform.

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3.3. Segmentación de nubes de puntos de sistemas de escáner láser móvil “Indoor Mapping” aplicado a reconstrucción de escenas de crimen.

El empleo de sistemas de escaneado láser móviles, o “Indoor Mapping”, en comparación con los sistemas estáticos, tanto láser cómo fotogramétricos, es una solución ideal en la captura de datos en infografía forense de manera rápida y eficaz, para la reconstrucción de escenarios grandes y complejos en los que se requiere un elevado número de estacionamientos y gran dedicación de tiempo.

Desarrollar una herramienta que permita el paso de las nubes de puntos capturadas por un sistema “Indoor Mapping” a modelos CAD manejados por la policía científica en sus análisis es el objetivo principal de este estudio.

A lo largo de este artículo se presenta una metodología de segmentación de las nubes de puntos capturadas por este sistema de escaneado móvil, basado en formas geométricas paramétricas y no paramétricas tanto del escenario como de los objetos que constituyen la escena forense. Para ello, se ha obtenido un modelo segmentado en planos y sus correspondientes bordes junto con la víctima en nube de puntos. A la segmentación de estos datos se ha incorporado la descomposición en componentes principales debido a que las nubes de puntos capturadas con este sistema son masivas y desorganizadas. Concretamente, se ha automatizado la extracción de planos y bordes, lo que representa de gran utilidad en infografía forense para pasar de las nubes de puntos a los modelos CAD en aquellas formas paramétricas.

El modelo híbrido resultante de la segmentación basado en análisis de componentes principales (PCA) permite una manejabilidad ágil y sencilla por parte de cualquier programa CAD, constituyendo la mejor “radiografía tridimensional” del escenario forense susceptible de ser utilizado por parte de la Policía Científica como herramienta en las técnicas de infografía forense.

Otraparte de este estudio es la modelización CAD, proceso que ha requerido la asistencia manual por parte del usuario en la definición de extrusiones, si bien el procedimiento es muy rápido y productivo ya que se dispone de los contornos segmentados automáticamente, así como la dirección de la normal.

Como conclusión, cabe destacar la importancia del sistema de bajo coste de cartografiado móvil ("Indoor Mapping"), desarrollado íntegramente por la Universidad de Vigo, para la documentación de este tipo de escenarios y en especial de escenas interiores grandes y complejas, ya que es idóneos para desplazarse por pasillos y diversas habitaciones, deparando un modelo en nube de puntos continuo, métrico y perfectamente georreferenciado.

Segmentation of indoor mapping point clouds applied to crime scenes reconstruction

Sandra Zancajo-Blázquez , Susana Lagüela-López, Diego González-Aguilera and Joaquín Martínez-Sánchez

Abstract— **Data acquisition in forensics science must be performed in a fast and efficient way, so that the data acquired is maximized at the same time that disturbance and time on the scene are minimized. For this reason, the use of indoor mapping systems appears as a key solution, in contrast with static systems, either laser or photogrammetry based, in which representing big and complex scenes requires acquisition from a high number of positions, and long-time dedication for data processing.**

This paper presents a methodology for the segmentation of point clouds acquired with a mobile indoor mapping system, and their conversion to 3D models in CAD format, based on parameterized geometric elements from the scene. This way, all the information required in forensic sciences is stored in an adequate digital format, enabling its availability in the future and minimizing time dedication in both data acquisition and processing steps.

Index Terms— **Crime scenes, indoor mapping, segmentation, CAD, PCA, point clouds.**

I. Introduction

THE use of geomatic techniques, with remote acquisition and not intrusive, in the field of forensics science is the way of obtaining three-dimensional data with metric properties in the form of point clouds automatically.[1] The two most common geomatic techniques nowadays are photogrammetry [1-3] and laser scanning [4-6]. They provide a detailed register of the crime scene, standing as a complete representation of the data needed for the investigation of the event and its posterior modelling. In the last two years, photogrammetry has reached the level of results provided by laser scanners [7], due to the incorporation of computer vision techniques to the photogrammetric process.

However, both laser scanning and photogrammetry present serious limitations when the scene of the event is indoors, with complex geometry and requires the performance of the acquisition from numerous positions. In these cases, static systems, either laser or photogrammetry based, do not provide a worthy solution, making necessary the use of mobile and dynamic systems that allow capture in motion. Unfortunately, there are not many mobile laser scanners, photogrammetric or hybrid systems for indoor scenes available in the market [8, 9], even less specific for the field of forensic engineering. Some authors as Canter & Stott [10] have developed indoor mapping systems for the generation of indoor cartography from accurate geospatial information. The main advantage of these systems is that they integrate high-precision GNSS with advanced inertial technology (accelerometers and gyroscopes) for the georeferenciation of the building using measures from its exterior, apart from an Applanix POS system for positioning and orientation that provides uninterrupted measurements of the true position, roll, pitch and yaw of the vehicle moving indoors. With these methods, time needed for data acquisition is equal to the time a person needs to walk through the area of interest; this noticeable time reduction regarding other systems implies an important cost decrease.

In the case of forensic engineering, indoor mapping systems stand out for their suitability for the capture of the most complex scenes, as they perform automatically multiple processes such as dynamic scanning (in motion) and the auto-determination of the autonomous trajectory of the vehicle. 3D information with metric nature is obtained in real time as the vehicle completes its tour.

Other authors as El-Hakim [11] have chosen passive mobile systems consisting on cameras of different typologies (panoramic, compact, and reflex). These passive systems are characterized by their low-cost and handiness, although a high number of cameras is required for covering the 360º of the scene, together with the application of

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powerful and robust SfM (Structure from Motion) algorithms [12], which allow obtaining the point cloud with acceptable quality. On the other hand, other authors have developed hybrid indoor systems integrating active and passive sensors in the same platform [13]. These systems, despite collecting the qualities of the previous two, present the great disadvantage of requiring the performance of complex registration processes between laser and photographic systems.

In spite of those drawbacks highlighted for the acquisition phase, the greatest difficulty associated to the use of laser scanning and/or photogrammetric systems lies in the handiness and conversion of massive and disorganized point clouds (with no topology) in CAD (Computer Aided Design) geometric models, with the aim at their posterior exploitation and analysis from all the agents involved [14]. One of the first landmarks in this challenge consists in the strategies for the segmentation of the point cloud [15-20]. Their objective is to classify in a semiautomatic way the information of the point cloud, organizing, parameterizing and post-processing this information in recognizable elements, and leading to the three-dimensional modelling of the crime scene. This segmentation and organization of the objects of the scene is based on the homogeneous characteristics of the point clouds with respect to a series of criteria [21]. This homogeneity generally refers to the position of the points in the space, and to a series of associated geometric restrictions such as depth, normal vectors and surfaces curvature. Some authors as Schnabel, Wahl and Klein [16] have applied the automatic algorithm of RANSAC (RANdom SAmple Consensus) [22], to detect basic shapes in disorganized point clouds. RANSAC is a robust estimator able to extract a high variety of basic primitive types, being suitable for its application in forensic sciences [23-24] as most real objects can be defined through a sum of primitives. However, one of the greatest disadvantages associated to RANSAC is found in the computing cost, given that its own voting principle united to the high number of existing points could bring unacceptable computing time periods.

This paper presents a methodology for the generation of 3D models of building interiors destined to their use in forensics sciences; consequently, the building interiors consist of crime scenes. This methodology consists on the segmentation of laser data coming from an indoor mapping system developed in the University of Vigo, and the data conversion to 3D models for CAD design and forensic science based on Principal Component Analysis (PCA). One of the advantages of this method regarding existing methods lies in its capacity of detecting surfaces with all possible orientations, and differencing them from irregular shapes. This last characteristic is of vital importance in forensic science, as it implies the extraction of information of the crime scene from the complete scene, separating elements such as the corpse, clothes and other personal effects, and the weapon used. The paper is structured as follows: after this introduction, section 2 describes the methodology developed in detail putting special attention in how existing methods can be applied in a practical forensic case using a well-equipped acquisition unit, section 3 is included as a demonstration of the practical application of the presented methodology, showing the experimental results obtained in different case studies. Section 4 includes the quality evaluation of the methodology, whereas section 5 includes the most relevant conclusions and possible future lines.

II. Methodology

The analysis and detailed record of the crime scene are very important during forensic investigations. The first and most important steps in criminal investigation are the inspection and examination of the crime scene. Therefore, it is necessary to register all the information, as detailed as possible, following the measurement protocols and using precise and non-destructive techniques. In this regard, the segmentation method for laser point clouds based on PCA can be used in order to obtain CAD models demanded by the forensic infographic agents involved. These models correspond to parametric shapes of the scene, and include the objects that constitute the crime scene. The following graphic (Figure 1) illustrates the process developed.

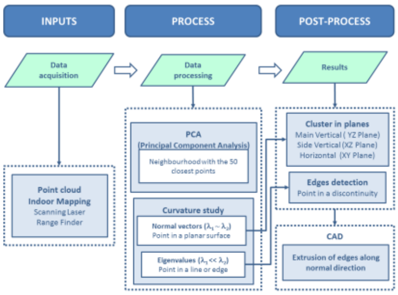

Fig. 1. Workflow developed for the transformation of the point cloud obtained by the indoor mapping system to CAD model.

A. *Data acquisition system*

The geometric data acquisition is made with a mobile system designed for the indoor mapping of buildings (Figure 2). This system is equipped with positioning and geomatics sensors to provide directly three-dimensional point clouds of the inspected areas. In particular, the positioning systems used are an IMU (Inertial Measurement Unit) of the kind Advanced Navigation Spatial and two odometers Kübler. The IMU is composed by an accelerometer, a gyroscope and a magnetometer, all these have three axis, in addition to a pressure sensor that measures height. The angular accuracy in the movement is 0.5º for heading and 0.2º for roll and pitch turns. This IMU has a GPS sensor, which enables the positioning of the crime scene if the global coordinates have been previously captured from an external location. The odometers produce 1024 ppr (pulses per revolution). As the mobile system has two odometers, it can work in differential configuration to get both the value of the distance travelled and the angles of the trajectory [25].

Regarding geomatic sensors, the mobile unit is equipped with a time of flight laser Hokuyo UTM-30LX. This laser has a range of 30 m and an angular resolution of 0.25º, with accuracy in measurement of point of 30 mm. This sensor measures each 25 ms an arc of 270º. Under these conditions, points in a profile perpendicular to the displacement are acquired in each measurement, and the area of 90º where measurements are not made is located towards the ground. This way, the information of the walls and ceiling of the inspection area is not lost. Figure 2 shows a detailed picture of the system.

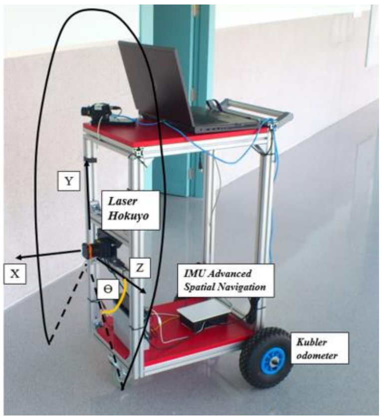

Fig. 2. Schematic representation of the indoor mapping system, including the position of the sensors, and the axis assigned to the different components of the movement

Both the laser sensor and the positioning sensor are regulated by a microprocessor of the type Arduino Mega, so that measurements are done simultaneously. Furthermore, each 2D profile is associated to a time stamp which links the profile with the positioning settings of the mobile unit in every instant.

Data acquisition is performed during the movement of the system in a trajectory designed trying to cover all the corners in the room. There are two possibilities for the configuration of the trajectory: doing a loop, or a back and forth displacement. The selection of one or the other comes as a consequence of the area inspected, since objects on the floor will have to be avoided by the system in order to have a continuous path. If the latter is not possible, data will have to be acquired in different sequences, and then a registration procedure will put all the sequences in the same coordinate system, provided there are overlapping areas within consecutive sequences.

When data acquisition is finished, the position of each profile in the point cloud is calculated based on the data of the trajectory of the mobile unit, as done in [26], but without GPS support, and the complete 3D point cloud of the inspection area is obtained.

B. Data segmentation based on PCA

Once data acquisition is done and the point cloud is generated based on data from the trajectory, the next step is the segmentation of the point cloud. In the case of point clouds, the process is identical to the one followed for the segmentation of surfaces from range images [27]. The segmentation focuses on the search of methods and techniques for grouping points with similar geometrical properties, such as normal vectors and curvatures [28]. There are many papers about this subject, most of them dealing with the segmentation of point clouds through an analysis of curvature [29-31].

In this study, the analysis of curvature is made through the calculation of the normal vector of each point of the point cloud. The process developed is the PCA with the covariance method [32] and the computation of the eigenvalues and eigenvectors. These vectors are related to the normal vector through the fact that the eigenvector associated to the lowest eigenvalue can be considered as the normal vector of the point. For this study, a neighborhood of the points surrounding each point is used for the estimation of the principal components through the covariance matrix (1). The size of the neighborhood depends on the density of each point cloud and the size of the surfaces of interest, in such a way that the highest the density and greatest the size of the surfaces of interest, the more populated the neighborhood. Analogously, low density point clouds required the use of smaller neighborhoods, so that the study of each point is not based on dispersed values. As an initial value, neighborhoods of the 50 closest points are considered, following the study of [33].

The covariance matrix for a neighborhood surrounding a point of interest is determined with the following expression:

$$\Sigma = COV(X) = \begin{bmatrix} \sigma_x^2 & \sigma_{xy} & \sigma_{xz} \\ \sigma_{xy} & \sigma_y^2 & \sigma_{yz} \\ \sigma_{xz} & \sigma_{yz} & \sigma_z^2 \end{bmatrix} \quad (1)$$

Where the main diagonal contains the variance data of the variable $(\sigma_x^2, \sigma_y^2, \sigma_z^2)$ and the other cells contain the statistics of the covariances for each pair of variables.

Given the entities in the covariance matrix, for a group of *k* neighborhoods, the size is defined as:

(2)

$$\sigma_x^2 = var(x) = E(x^2) - E(x)^2 = \frac{1}{k}\sum_{i=1}^{k}(x_i - \bar{x})^2$$

(3)

$$\sigma_{xy} = cov(x, y) = E(xy) - E(x)E(y) = \frac{1}{k}\sum_{i=1}^{k}(y_i - \bar{y})(x_i - \bar{x})$$

Where *var(x)* and *cov(x)* are variance and covariance respectively, *E(x)* is the expected value (arithmetic mean) for the coordinate *x*, which can also be defined as . Finally, we denote as (x_i, y_i, z_i) the spatial coordinates of the i-th point of the neighborhood that surrounds the point of interest.

Consequently, through the covariance analysis the eigenvalues (λ_i) and eigenvectors (e_i) associated to the covariance matrix are evaluated. They give information about the vector perpendicular to the surface in the point of interest.

Once the covariance analysis is finished, the resulting value of the normal vector of each point is weighed using the vectors of all points in its neighborhood, using the distance between the point of interest and the points in the neighborhood as weight. This way, more consistent results are obtained, smoothing the curvature values so that all points contained in the same plane present similar normal vectors, minimizing the effect of isolated points and the lack of precision in the computation of the principal components. Smooth curvature values are calculated using the following expression:

$$\bar{v}_N = \frac{\sum_{i=1}^{neigbors} \frac{v_i}{d_i}}{\sum_{i=1}^{neigbors} \frac{1}{d_i}} \quad (4)$$

Where is the normal vector after weighing with distance to its neighbors, process known as curvature smoothing; is the normal vector to the plane at each point contained in the neighborhood of the point of interest, and is the distance to point *i* from the point of interest.

C. Plane detection

After the computation of the smoothed normal vectors of every point, these are classified as a function of their direction, with the following procedure: planes parallel to the main walls (planes YZ), planes parallel to the lateral walls and perpendicular to the main walls (planes XZ) and horizontal planes (planes XY). The latter include the floor, ceiling and other horizontal surfaces, such as furniture.

Points contained in a planar surface identified with PCA are composed of three eigenvalues ($\lambda_0 \leq \lambda_1 \leq \lambda_2$) and three eigenvectors (v_0, v_1, v_2), which can be seen as a correlation ellipsoid. Points contained in a plane, the first eigenvector, v0, is the approximation of the normal vector and its corresponding eigenvalue λ_0, is small, approximately zero ($\lambda_0 \sim 0$), whereas the eigenvalues (λ_1, λ_2) present similar values. This way, all points fulfilling the requirement of presenting the lowest eigenvalue with a value close to zero, and much smaller than the other two eigenvalues are classified as "belonging to a plane", and continue to the following classification step, where they are distinguished as planes parallel to the main wall, or planes YZ; planes perpendicular to the main wall, or planes XZ; and horizontal planes, or planes XY. This step is performed analyzing the angle between each normal vector and the normal vector of the planes of each wall (Figure 3). If this angle is below a threshold-value, the point is classified as a point of this or a parallel wall. This angular threshold is user-adaptable in order to avoid incorrect classifications in certain constructions that contain walls forming angles different to 90º; although the values of general application are thresholds between 45 and 60º.

Once all points are classified in their corresponding planes given their different orientations, parallel walls are differentiated based on their position (coordinates of their forming points) and the orthogonal distance between them using the threshold established by the user as a function of the configuration of the scene: the threshold is commonly set in twice the scan resolution.

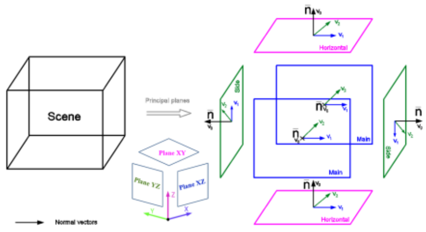

Fig. 3. Main planes with their normal vectors.

Following this procedure, not only the different walls of the scene are segmented, but also the biggest furniture pieces, such as shelving and tables.

D. Edges detection

The eigenvalues calculated in the curvature analysis are also used for the detection of edges in the segmented point cloud. This information is of great interest because it allows the extraction of the structural support (edges/discontinuities) defining the scene from a massive and disorganized point cloud. This support is the basis of the conversion of the point cloud to CAD model.

Contrary to plane segmentation, edges detection is based on points containing significant variations between the eigenvalues λ_2 and λ_1, being $\lambda_2 >>> \lambda_1$. In particular, the quotient between λ_2 and λ_1 is used as a probability measure of a point belonging to an edge or discontinuity in a certain surface. In other words, if $\lambda_2 / \lambda_1 > \varepsilon$ the point is located in an edge. After the study of a high number of point clouds and the examination of existing bibliography [28], the optimum value for ε lies between 1.5 and 2. The analysis for edge detection is performed for every point in each surface for its classification.

Steps from B to D are all developed in Matlab®, as a previous step to its final implementation in the open source library PCL (Point Cloud Library) [34].

E. CAD model generation

CAD modeling is performed using parametric modeling strategies that allow the application of an extrusion process based on the edges segmented by PCA. Extrusion is a 3D modeling procedure consisting on giving volume to an object by sliding its wall along a trajectory until it presents a closed shape. This trajectory can be both straight and curved. In the presented methodology, the normal vectors calculated for the walls are used as trajectory for the extrusion of the walls: walls are extruded, or extended, following the directions of the normal vectors until their intersections complete a closed scene. This process results in the generation of the geometry of the parametric solid that better describes the scanned scene.

Therefore, the final CAD model contains "plane objects" in the walls, and "line objects" in the intersections between walls.

Those shapes that cannot be parameterized, such as the corpse and its surroundings, are kept in their original structure of point cloud, given that existing non-parametric strategies, such as triangular mesh, would distort the results and cause a loss of precision.

III. Experimental Results

Different case studies were developed in order to test the results obtained after the application of the proposed methodology. Figure 4 shows the floor distribution and the point cloud acquired with the indoor mapping unit for three case studies: one of them consists on a cluttered room, with square floor; the second is an L-shaped room, with two adjoining storage spaces; the last case study is a square room, with no furniture and a semi-demolished wall.

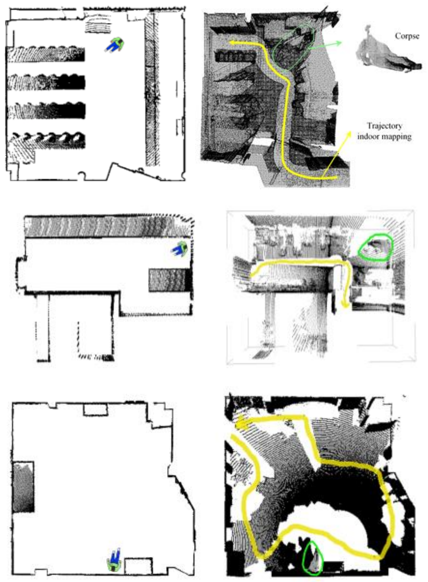

Fig. 4. Floor distribution of the area acquired with the indoor mapping system (left). View from above of the point cloud, including the trajectory of the indoor mapping system in yellow (right). Each case study is shown in the same row; cases 1 and 2 present a back and

The aim of these tests is to describe the methodology through a proof of concept, where the process follows these steps: an acquisition unit (indoor mapping) is used to capture laser measurements and other geospatial references, producing as output a cloud of points in the 3D space. Starting from this cloud, authors propose the use of an existing method based on PCA that follows these steps: for each point, the normal vector is determined using the smaller eigenvector. Then, points sharing the normal vector are grouped according to three main planes. Following, edges within each plane are determined by thresholding the ratio of eigenvalues, so to distinguish parallel planes belonging to different objects. Finally, knowing the position of the planes and edges, an extrusion procedure is used to convert the segmented points into a CAD structure.

Results are shown in Figure 5 and Table 1

TABLE I
NUMBER OF POINTS CLASSIFIED IN EACH OF THE MAIN ORIENTATIONS OF THE SCENE

Main planes	Points per plane		
	Case 1	Case 2	Case 3
Total number	4,447,073	239,985	623,788
Main (*YZ*)	1,279,303	89,776	119,479
Side (*XZ*)	955,492	43,127	129,312
Horizontal (*XY*)	2,212,273	107,082	374,997
Edges	1,388,185	78,120	162,038

Other results obtained are the identification of points belonging to the edges of each plane. The union of these points results in the defining vectors of the point cloud. The number of edge points in each plane is shown in Table 2

TABLE II
NUMBER OF POINTS IN THE EDGES FOR EACH MAIN PLANE

Edge	Number of edge points		
	Case 1	Case 2	Case 3
Main (*YZ*)	253,889	14,849	39,216
Side (*XZ*)	279,702	12,867	22,255
Horizontal (*XY*)	183,965	9,254	18,513

Once the main parametric components of the scene: planes and edges, are segmented, the CAD model of the crime scene can be determined. As described in the methodology, the extrusion of the edges is performed along the direction of the normal vector of the containing plane. Figure 6 shows the resulting CAD models.

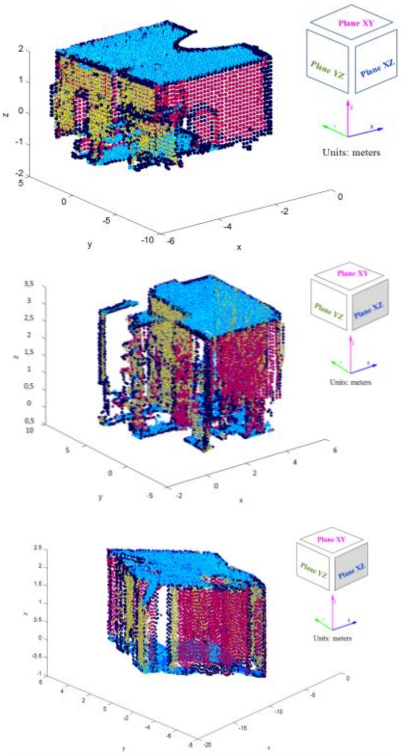

Fig. 5. Results obtained from the classification of planes depending on their orientation: in blue, horizontal planes; in red, planes perpendicular to the main wall; in yellow, planes parallel to the main wall; and in black, points belonging to the edges in the point cloud.

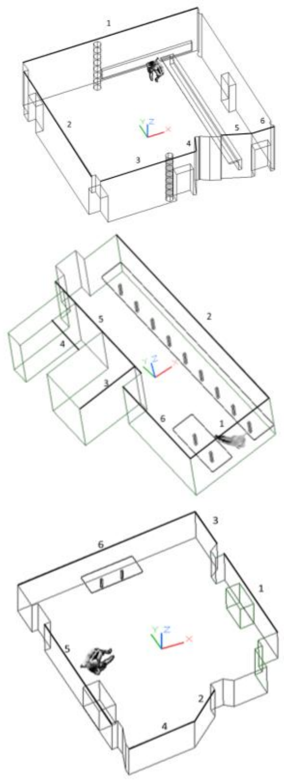

Fig. 6. Resulting CAD models of the crime scene scanned with the indoor mapping unit through the application of extrusion procedures on the 3D edges segmented with PCA. Numbers make reference to the distance measurements included in Table 3.

IV. VALIDATION OF THE METHODOLOGY

In order to assess the accuracy of the indoor mapping system and the proposed methodology, the scenes have been scanned with a terrestrial laser scanner system, Riegl LMS Z-390i, which is considered as provider of the ground truth, as in [35]. This laser system is based in the measurement of the time of flight, that is, it determines the distance between the laser and every point in the scene by measuring the time of the round trip of a pulse of laser light (to the object and back). Its precision in the point measurement is 6 mm, with an accuracy of 2 mm, providing high-quality values for the study proposed. This high quality regarding the metric measurement motivates the use of a terrestrial laser scanner as ground truth; for this reason, the scanning of each room is performed from one position only, maximizing accuracy in the measurement and minimizing time and processing error.

For the analysis of the crime scene, the point clouds acquired with the terrestrial laser scanner Riegl LMS Z-390i (Figure 7) are reduced in a filtering step for noise elimination and discard of redundant information.

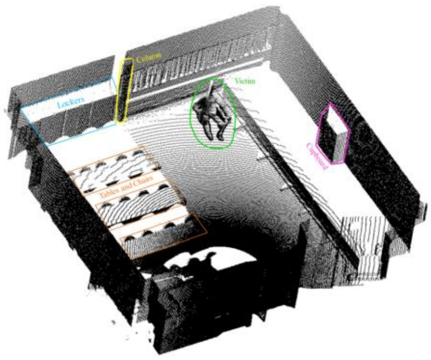

Fig. 7. Example of the crime scene scanned with the terrestrial laser scanner Riegl LMS Z-390i, belonging to case of study no. 1.

The accuracy assessment is performed through the comparison of the coordinates of the corners of the room in the CAD model resulting from the methodology and the Riegl point cloud, as well as through the measurement and comparison of different distances. Results are shown in Table 3, where the column "Difference" shows the discrepancy between the measurements performed on the CAD model with the measurements made on the point cloud from the Riegl LMS Z-390i.

The highest difference is 5,5 %, as shown in Table 3. This value is tolerable especially taking into account that we are comparing values obtained directly from the Riegl laser scanner with values obtained after acquisition and processing. That is, our reference only presents the nominal error from the measurement with the laser, which is 6 mm according to the Riegl manufacturer; whereas the result of the methodology presents the error of the Hokuyo laser (30 mm), plus the error in the trajectory, and the error in the segmentation procedure. Regarding all this, the quality results of the proposed methodology are acceptable for forensic applications. What is more, if the case study is taken into account, it can be seen that the highest error appears in an element with no influence in the crime, the roof, so its importance is more limited.

On the other hand, if the focus is not only set on the quality of the results but also on the procedure itself, the proposed methodology requires about 5 minutes for the data acquisition of a room, whereas data acquisition with the terrestrial laser scanner requires from 20 minutes for case studies 1 and 3, where only one position of acquisition is required, to 80 minutes for case study 2, which requires a minimum of 4 positions for the complete acquisition of the main room and the two storage spaces.

In conclusion, the indoor mapping device and the segmentation methodology stand as a practical and low-cost system with applicability to forensic sciences for dimensional measurement acquisitions within the crime scene.

TABLE III
COMPARISON OF THE DISTANCES MEASURED ON THE CAD MODELS WITH THE DISTANCES OF THE POINT CLOUD ACQUIRED WITH RIEGL LMS Z-390I LASER SCANNER. UNITS IN METERS.

Case	Distances analyzed	CAD distances	Riegl point cloud distances	Difference (%)
Case 1	1	10.051	10.009	**0.42**
	2	8.618	8.593	**0.29**
	3	0.563	0.596	**-5.49**
	4	5.535	5.591	**-0.99**
	5	1.389	1.368	**1.55**
	6	10.051	10.009	**0.42**
Case 2	1	3.999	3.910	**2.28**
	2	9.480	9.500	**-0.21**
	3	2.776	2.750	**0.94**
	4	3.093	3.071	**0.72**
	5	5.314	5.404	**-1.66**
	6	4.166	4.019	**3.66**
Case 3	1	4.899	4.950	**-1.03**
	2	1.947	1.910	**1.93**
	3	2.012	2.044	**-1.56**
	4	3.242	3.234	**0.25**
	5	6.128	6.092	**0.59**
	6	8.886	8.630	**2.97**

V. CONCLUSIONS AND FUTURE PERSPECTIVES

The main objective in this study is the development of a tool for the generation of digital models of crime scenes, starting from point clouds acquired with an indoor mapping unit and finishing with CAD models used by the Scientific Police in their analysis. With this purpose a model segmented in planes and their edges is obtained, as well as the corpse in point cloud form. The parametric modeling of the corpse has been considered, as well as a non-parametric meshing strategy, but the results are low-quality and lack of detail, so it has been decided to model the scene in CAD format and include the corpse and the auxiliary objects as a point cloud, with maximum resolution. The resulting hybrid model presents ease of use in any CAD software, being the best “three-dimensional radiograph” of the crime scene available for its use by the Scientific Police, among all forensic infographic tools.

The low-cost indoor mapping unit developed in the University of Vigo is a key component for the documentation of this type of scenes, especially for big and complex indoor scenes, given that it is suitable for the displacement along corridors and different rooms, resulting in a continuous, metric and georeferenced point cloud. The decomposition of the point cloud captured by the indoor mapping unit in its principal components has allowed the automatic segmentation of massive and disorganized laser point clouds. What is more, the automation of the plane and edge extraction is of great utility in forensic infography for the conversion from point clouds to CAD models in parametric form.

Although the CAD modeling process requires the user’s intervention in the definition of the extrusions, the whole procedure, that can be defined as “semi-automatic” presents high productivity: working time can be divided in two, acquisition time and processing time, both depending on the complexity and size of the scene. Acquisition time with this methodology only implies the time required to walk along the crime scene, at a pace of 1m/s; processing time presents dependence also on the computing machine: a computer with Intel 5 processor and 4GB RAM requires 3 minutes for the complete segmentation of the point cloud, assuming it contains 1,000.000 points. These facts imply a great advantage regarding static laser scanners, which take about 20 minutes per scan-station, in addition to the preparation time for the arrangement of targets needed for the posterior registration of the different scan positions in one unique coordinate system. What is more, while the generation of a point cloud of a complete scene after data acquisition can take in the order of 5-10 seconds, registering point clouds of two different scan positions takes this time, increasing correspondingly with the number of scan positions.

Despite the great number of advantages, the methodology presents one limitation: the modelling of rooms with furniture covering most of the walls. If the walls are too occluded, the methodology will consider as walls the main surface of the furniture, consequently resulting in a CAD model with smaller dimensions than reality. However, this same limitation appears when the point cloud is acquired with a static laser scanner, not being a solved problem yet.

Future lines are set on the quality segmentation of more complex and non-parametric shapes and the corpse. Nowadays, the best alternative is the direct use of the point cloud, as it is the product that better describes such a complex geometry. Approaches based on triangular meshes have not finished in good results, distorting the shape of the corpse and presenting low quality measures

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CAPÍTULO 4

CONCLUSIONES Y PERSPECTIVAS FUTURAS

4. CONCLUSIONES Y PERSPECTIVAS FUTURAS

En esta Tesis Doctoral se ha demostrado que la aplicación de diversas geotecnologías, tales como, la fotogrametría de rango cercano, la visión computacional, los “Gaming Sensor” y los dispositivos “Indoor Mapping”, son idóneas en la modelización tridimensional de escenarios forenses para su posterior explotación en labores de inspección y extracción de información cualitativa y cuantitativa con rigor métrico. La gran ventaja que ofrecen las geotecnologías láser y fotogramétricas propuestas (“Gaming Sensor”, “Indoor Mapping”, Cámara digital y“Smartphone”) es su bajo coste además de ser técnicas no invasivas y no destructivas. Es decir, a través de ellas quedará constancia documental de los indicios y evidencias presentes en el escenario, sin alterar en ningún momento sus posiciones espaciales ni sus propiedades físicas, además de dotar de rigor, exhaustividad y realismo a la reconstrucción del suceso.

En general, se concluye que los sensores activos (“Gaming Sensor” e “Indoor Mapping”) y pasivos (Cámara digital y “Smartphone”) empleados para la investigación son claramente herramientas alternativas para la adquisición de datos en infografía forense en comparación con procedimientos expeditos clásicos e incluso opuestos a los sistemas láser actuales y costosos.Además, respecto a los sensores activosutilizados, cabe destacar la versatilidad que ofrecen los “Gaming Sensor” para la obtención de detalles de la escena y la idoneidad del sensor “Indoor Mapping” para documentación deinteriores grandes y complejos.

A continuación, tras la consecución de los objetivos propuestos en esta investigación, se desarrollaran en profundidad las conclusiones obtenidas correspondientes a cada uno de los artículos científicos, además de preverunas líneas de trabajo futuras basadas en la ampliación del estudio realizadoque permitan seguir avanzando en estas geotecnologías variables y en constante evolución.

4.1. Conclusiones

Esta Tesis Doctoral es el resultado de un compendio de tres artículos científicos publicados en revistas de impacto especializadas. A continuación se reseñarán las conclusiones obtenidas relacionadas a cada una de las investigaciones realizadas.

En primer lugar, a través de la adquisición de datos con los sensores pasivos propuestos y de la aplicación de una metodología y un software propio (PWF), se ha conseguido la reconstrucción tridimensional de manera automática y el análisis dimensional de escenas forenses utilizando sólo imágenes. Una gran ventaja de esta herramienta es que las imágenes realizadas para su procesamiento pueden estar tomadas con cualquier tipo de cámara, incluso con cámaras no calibradas y de bajo coste (“Smartphones” y “Tablets”), lo que permite una gran flexibilidad para aquellas personas no expertas. Además, el modelo obtenido mediante esta herramienta es de alta resolución y con propiedades métricas, pudiendo extraer datos metrológicos en cualquier momento después del suceso. La calidad en los resultados se consigue a través de los modelos de nubes de puntos de alta densidad que se han generado con una resolución equivalente al tamaño del pixel en la escena (GSD-GroundSampleDistance), superior a la de los sistemas láser escáner y con niveles de precisión centimétrica.

Por todas estas razones, se concluye que PWF es una alternativa sencilla y de bajo coste ideal para adquisición de datos en infografía forense en comparación con procedimientos expeditos clásicos e incluso los modernos y costosos sistemas de escaneado láser.

En segundo lugar, se ha probado e implementado una técnica de escaneado de bajo coste basada en “Gaming Sensors” y que ha permitido realizar un análisis dimensional y modelado 3D de la escena forense. Estos sensores activos, muestran un buen comportamiento en distancias cortas (nunca superiores a 3 m) y en espacios interiores, siendo muy recomendable para el análisis de los detalles que conforman el escenario o en escenas de reducidas dimensiones, sobre todo en combinación con otras técnicas, como por ejemplo las fotogramétricas.

En tercer lugar, cabe destacar la importancia del empleo de otro sensor activo, el sistema de bajo coste de escaneado móvil, “Indoor Mapping”, para la documentación de escenas interiores grandes y complejas. El modelo tridimensional obtenido en nubes de puntos es continuo, métrico y perfectamente georreferenciado.

Por último, se ha avanzado en el paso de las nubes de puntos, tanto fotogramétricas como láser, a modelos CAD. Para ello, se han implementado procedimientos de segmentación automáticos de las nubes de puntos en entidades básicas paramétricas (i.e. planos y aristas) en base a la descomposición en componentes principales (PCA). En base a estas entidades se han desarrollado procedimientos semi-automáticos de extrusión que han permitido la generación de modelos CAD parciales de los escenarios forenses. Estos procedimientos aunque han demostrado ser rápidos y productivos (al disponer de las aristas, planos y dirección de las normales), requieren de la asistencia manual por parte del usuario. Los modelos CAD de escenarios de forenses son de gran utilidad y necesarios para la Policía Científica en el campo de la infografía forense, ya que la mayor parte de las herramientas software empleadas se apoyan en archivos CAD. Asimismo, los modelos CAD permiten avanzar hacia modelos semánticos susceptibles de ser explotados y conectados por bases de datos utilizadas por parte de la Policía Científica.

Concluyendo de manera general la investigación, se verifica que las geotecnologías fotogramétricas y láser arrojan resultados métricos aceptables en gran parte de las aplicaciones forenses relativas a escenas de crímenes y siniestros, lo que implica la utilidad de estas herramientas e instrumentos una alternativa eficiente para aplicar a diversos casos de estudio en infografía forense.

4.2. Perspectivas futuras

Dada la incipiente evolución de las líneas, así como la propia obsolescencia de la tecnología, a continuación se proponen las líneas futuras de investigación vinculadas a todos los contenidos considerados durante el desarrollo de esta Tesis Doctoral:

- En el contexto de la *fotogrametría y la visión computacional* quedan abiertas nuevas líneas de investigación tales como:
    - En lo que se refiere a la herramienta PWF desarrollada, incorporar acciones que permitan el escalado y el georreferenciado de las nubes de puntos obtenidas (Galantucci et al., 2006)de manera automática, de manera que no sea el propio usuario el que requiera introducir una distancia conocida.
    - La extracción de puntos de interés en zonas homogéneas sin textura (e.g. paredes lisas, materiales acristalados, brillantes, etc.), a través de la incorporación de algoritmos de última generación "textureless objects".
    - La posibilidad de la reconstrucción de escenarios tridimensionales a partir de imágenes panorámicas, tomadas con objetivos gran angulares del tipo "ojo de pez" y que requerirán de calibraciones específicas.
    - La explotación y utilización del canal no visible infrarrojo de los sistemas activos láser desde el punto de vista cualitativo y de clasificación de patrones o indicios no visibles.
- En el contexto de dispositivos "Gaming Sensors" el principal avance sería mejorar en alcance, ya que para largas distancias entre el objeto y el sensor (mayores a 3 metros), la calidad de los datos decrece por el ruido y la baja resolución de las medidas de profundidad.

- En el contexto del paso de nubes de puntos a modelos CAD quedan abiertas las líneas de investigación que permitan:
  - Una segmentación de calidad de formas complejas del tipo no paramétrico, como la propia víctima.
  - Acercamientos de mallado avanzados que permitan la modelización simplificada y de calidad de formas complejas (e.g. la propia víctima)

CAPÍTULO 5

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ANEXO

FACTOR DE IMPACTO DE LAS PUBLICACIONES

ANEXO. FACTOR DE IMPACTO DE LAS PUBLICACIONES

I. An automatic image-based modelling method applied to forensic infography

Descripción del factor de impacto y documentación de la revista:

Nombre de la revista:	**PLOS ONE**
URL:	**http://www.plosone.org/**
Editorial:	**PUBLIC LIBRARY SCIENCE**
ISSN:	**1932-6203**
Factor de impacto (2013):	**3.534**
Ranking de la revista:	**8/55**
Cuartil:	**Q1**

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2013 JCR ScienceEdition

Journal: PLoSOne

Mark	Journal Title	ISSN	Total Cites	Impact Factor	5-Year Impact Factor	Immediacy-Index	Citable Items	Cited Half-life	Citing Half-life
	PLOS ONE	1932-6203	226708	3.534	4.015	0.416	31496	2.5	7.4

Cited Journal | Citing Journal | Source Data | Journal Self Cites

CITED JOURNAL DATA | CITING JOURNAL DATA | IMPACT FACTOR TREND | RELATED JOURNALS

Journal Information

Full JournalTitle: PLoSOne
ISO Abbrev. Title: PLoSOne
JCR Abbrev. Title: PLOS ONE
ISSN: 1932-6203
Issues/Year: 0
Language: ENGLISH
Journal Country/Territory: UNITED STATES
Publisher: PUBLIC LIBRARY SCIENCE
Publisher Address: 1160 BATTERY STREET, STE 100, SAN FRANCISCO, CA 94111
SubjectCategories: MULTIDISCIPLINARY SCIENCES — SCOPE NOTE — VIEW JOURNAL SUMMARY LIST — VIEW CATEGORY DATA
Journal Rank in Categories: JOURNAL RANKING

***Eigenfactor*® Metrics**
***Eigenfactor*® Score**
0.78
***Article Influence*®Score**
1.55

JournalImpact Factor

Cites in 2013 to items published in:		Number of items published in:	
	2012 = 67956		2012 = 23447
	2011 = 63607		2011 = 13782
	Sum: 131563		Sum: 37229

Calculation: $\frac{\text{Cites to recent items}}{\text{Number of recent items}} \quad \frac{131563}{37229} = \mathbf{3.534}$

5-Year JournalImpact Factor

Cites in {2013} to items published in:			Number of items published in:		
	2012 =	67956		2012 =	23447
	2011 =	63607		2011 =	13782
	2010 =	35009		2010 =	6724
	2009 =	23135		2009 =	4403
	2008 =	15342		2008 =	2717
	Sum:	205049		Sum:	51073

Calculation: $\frac{\text{Cites to recent items}}{\text{Number of recent items}} \; \frac{205049}{51073} = \mathbf{4.015}$

Journal Self Cites

The tables show the contribution of the journal's self cites to its impact factor. This information is also represented in the cited journal graph.

Total Cites	226708
Cites to Years Used in Impact Factor Calculation	131563
Impact Factor	3.534

Self Cites	29805 (13% of 226708)
Self Cites to Years Used in Impact Factor Calculation	17872 (13% of 131563)
Impact Factor without Self Cites	3.054

JournalImmediacyIndex

Cites in 2013 to items published in 2013 = 13099
Number of items published in 2013 = 31496

Calculation: $\frac{\text{Cites to current items}}{\text{Number of current items}} \; \frac{13099}{31496} = \mathbf{0.416}$

JournalCitedHalf-Life

The cited half-life for the journal is the median age of its items cited in the current JCR year. Half of the citations to the journal are to items published within the cited half-life.

CitedHalf-Life: 2.5 years

Breakdown of the citations ***to the journal*** by the cumulative percent of 2013 cites to items published in the following years:

CitedYear	**2013**	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003-all**
# Cites from 2013	13099	67956	63607	35009	23135	15342	6938	744	49	16	813
Cumulative %	5.78	35.75	63.81	79.25	89.46	96.22	99.28	99.61	99.63	99.64	100

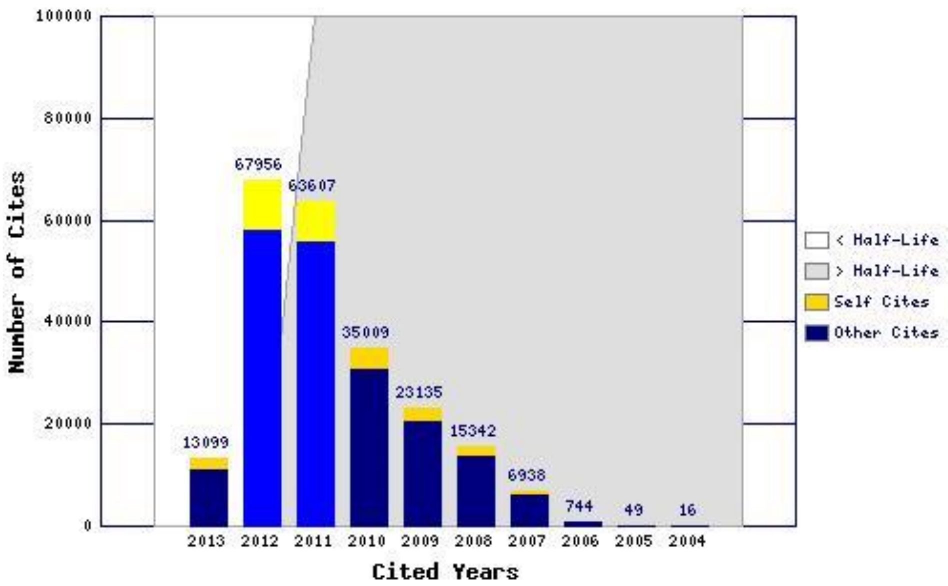
Cited Half-Life Calculations:
The cited half-life calculation finds the number of publication years from the current JCR year that account for 50% of citations received by the journal. Read help for more information on the calculation.

Cited Journal Graph

Click here for Cited Journal data table

This graph shows the distribution by cited year of citations to items published in the journal PLOS ONE.

Citations to the journal (per cited year)



- The white/grey division indicates the cited half-life (if < 10.0). Half of the journal's cited items were published more recently than the cited half-life.
- The top (gold) portion of each column indicates Journal Self Citations: citations to items in the journal from items in the same journal.
- The bottom (blue) portion of each column indicates Non-Self Citations: citations to the journal from items in other journals.
- The two lighter columns indicate citations used to calculate the Impact Factor (always the 2nd and 3rd columns).

JournalCitingHalf-Life

The citing half-life for the journal is the median age of the items the journal cited in the current JCR year. Half of the citations in the journal are to items published within the citing half-life.

CitingHalf-Life: 7.4 years

Breakdown of the citations ***from the journal*** by the cumulative percent of 2013 cites to items published in the following years:

CitedYear	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003-all
# Cites from 2013	27622	114437	131387	125797	116797	106256	97771	87900	80247	72796	547928
Cumulative %	1.83	9.41	18.12	26.46	34.20	41.24	47.72	53.55	58.86	63.69	100

Citing Half-Life Calculations:

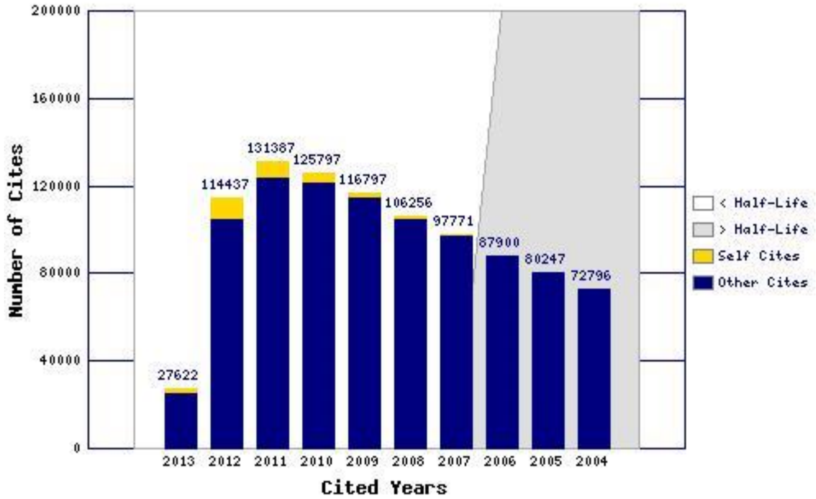
The citing half-life calculation finds the number of publication years from the current JCR year that account for 50% of citations in the journal. Read help for more information on the calculation.

Citing Journal Graph

Click here for Citing Journal data table

This graph shows the distribution by cited year of citations from current-year items in the journal PLOS ONE.

Citations from the journal (per cited year)



- The white/grey division indicates the citing half-life (if < 10.0). Half of the citations from the journal's current items are to items published more recently than the citing half-life.
- The top (gold) portion of each column indicates Journal Self-Citations: citations from items in the journal to items in the same journal.
- The bottom (blue) portion of each column indicates Non-Self Citations: citations from the journal to items in other journals.

JournalSource Data

	Citable items			Otheritems
	Articles	**Reviews**	**Combined**	
Number in JCR year 2013 (A)	31227	269	31496	2
Number of references (B)	1492677	16227	1508904	
Ratio (B/A)	47.8	60.3	47.9	0.0

Rank in Category: PLoS One

Journal Ranking

For **2013**, the journal **PLoS One** has an Impact Factor of **3.534**.

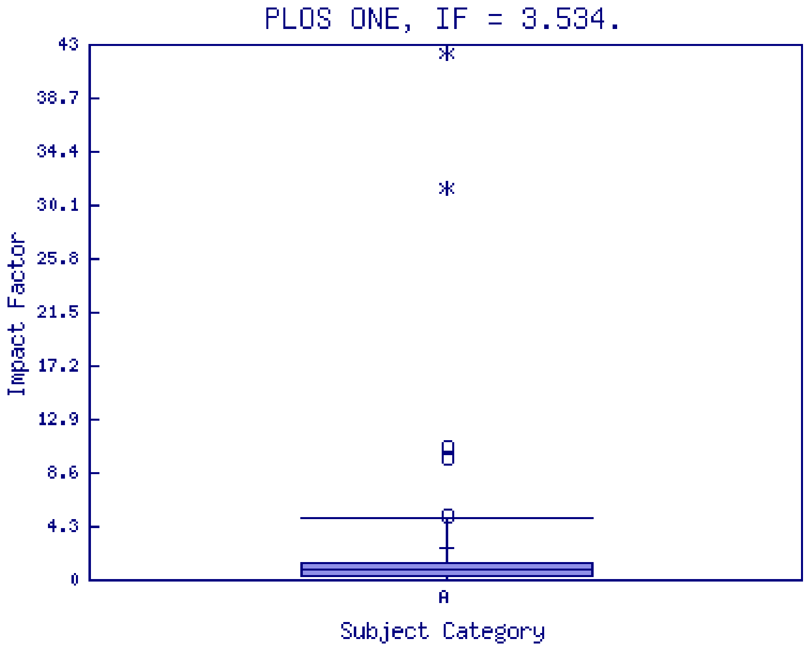
This table shows the ranking of this journal in its subject categories based on Impact Factor.

CategoryName	Total Journals in Category	Journal Rank in Category	Quartile in Category
MULTIDISCIPLINARY SCIENCES	55	8	Q1

Category Box Plot

For **2013**, the journal **PLoS One** has an Impact Factor of **3.534**.

This is a box plot of the subject category or categories to which the journal has been assigned. It provides information about the distribution of journals based on Impact Factor values. It shows median, 25th and 75th percentiles, and the extreme values of the distribution.



Key

A - MULTIDISCIPLINARY SCIENCES

II. Application of Kinect gaming sensor in forensic science

Descripción del factor de impacto y documentación de la revista:

Nombre de la revista:	**JOURNAL OF FORENSIC SCIENCES**
URL:	**http://onlinelibrary.wiley.com/doi/10.1111/1556-4029.12565/abstract**
Editorial:	**WILEY-BLACKWELL**
ISSN:	**0022-1198**
Factor de impacto (2013):	**1.306**
Ranking de la revista:	**9/16**
Cuartil:	**Q3**

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2013 JCR ScienceEdition

Journal: JOURNAL OF FORENSIC SCIENCES

Mark	JournalTitle	ISSN	Total Cites	Impact Factor	5-Year Impact Factor	ImmediacyIndex	Citable Items	Cited Half-life	Citing Half-life
☐	J FORENSIC SCI	0022-1198	6456	1.306	1.508	0.248	310	9.3	>7.4

Cited Journal Citing Journal Source Data Journal Self Cites

CITED JOURNAL DATA CITING JOURNAL DATA IMPACT FACTOR TREND RELATED JOURNALS

Journal Information

Full JournalTitle: JOURNAL OF FORENSIC SCIENCES
ISO Abbrev. Title: J. Forensic Sci
JCR Abbrev. Title: J. FORENSIC SCI
ISSN: 0022-1198
Issues/Year: 6
Language: ENGLISH
Journal Country/Territory: UNITED STATES
Publisher: WILEY-BLACKWELL
Publisher Address: 111RIVER ST, HOBOKEN 07030-5774, NJ
SubjectCategories: MEDICINE, LEGAL SCOPE NOTE VIEW JOURNAL SUMMARY LIST VIEW CATEGORY DATA
Journal Rank in Categories: JOURNAL RANKING

***Eigenfactor*® Metrics**
***Eigenfactor*® Score**
1.16582
***Article Influence*®Score**
1.370

JournalImpact Factor

Cites in 2013 to items published in:		Number of items published in:	
	2012 = 274		2012 = 23447
	2011 = 486		2011 = 13782
	Sum: 760		Sum: 37229

Calculation: $\frac{\text{Cites to recent items}}{\text{Number of recent items}}$ $\frac{760}{582}$ = **1.306**

5-Year JournalImpact Factor

Cites in {2013} to items published in:			Number of items published in:		
	2012 =	274		2012 =	270
	2011 =	486		2011 =	312
	2010 =	427		2010 =	271
	2009 =	382		2009 =	235
	2008 =	420		2008 =	231
	Sum:	1989		Sum:	1319

Calculation: $\frac{\text{Cites to recent items}}{\text{Number of recent items}} \quad \frac{1989}{1319} = \mathbf{1.508}$

Journal Self Cites

The tables show the contribution of the journal's self cites to its impact factor. This information is also represented in the cited journal graph.

Total Cites	6456
Cites to Years Used in Impact Factor Calculation	760
Impact Factor	1.306

Self Cites	912 (14% of 6456)
Self Cites to Years Used in Impact Factor Calculation	95 (12% of 760)
Impact Factor without Self Cites	1.143

JournalImmediacyIndex

Cites in 2013 to items published in 2013 = 77
Number of items published in 2013 = 310

Calculation: $\frac{\text{Cites to current items}}{\text{Number of current items}} \quad \frac{77}{310} = \mathbf{0.248}$

JournalCitedHalf-Life

The cited half-life for the journal is the median age of its items cited in the current JCR year. Half of the citations to the journal are to items published within the cited half-life.

CitedHalf-Life: 9.3 years

Breakdown of the citations ***to the journal*** by the cumulative percent of 2013 cites to items published in the following years:

CitedYear	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003-all
# Cites from 2013	77	274	486	427	382	420	402	349	346	251	3042
Cumulative %	1.19	5.44	12.96	19.58	25.50	32.00	38.23	43.63	48.99	52.88	100

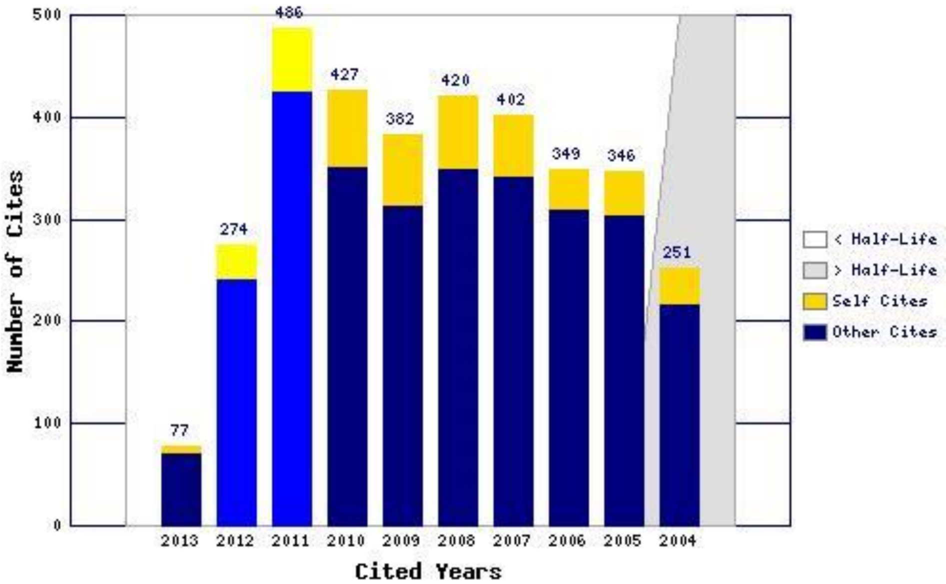
Cited Half-Life Calculations:
The cited half-life calculation finds the number of publication years from the current JCR year that account for 50% of citations received by the journal. Read help for more information on the calculation.

Cited Journal Graph

Click here for Cited Journal data table

This graph shows the distribution by cited year of citations to items published in the journal J FORENSIC SCI.

Citations to the journal (per cited year)



- The white/grey division indicates the cited half-life (if < 10.0). Half of the journal's cited items were published more recently than the cited half-life.
- The top (gold) portion of each column indicates Journal Self Citations: citations to items in the journal from items in the same journal.
- The bottom (blue) portion of each column indicates Non-Self Citations: citations to the journal from items in other journals.
- The two lighter columns indicate citations used to calculate the Impact Factor (always the 2nd and 3rd columns).

JournalCitingHalf-Life

The citing half-life for the journal is the median age of the items the journal cited in the current JCR year. Half of the citations in the journal are to items published within the citing half-life.

CitingHalf-Life: >10.0 years
Breakdown of the citations ***from the journal*** by the cumulative percent of 2013 cites to items published in the following years:

CitedYear	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003-all
# Cites from 2013	15	147	498	531	528	576	529	439	434	377	4397
Cumulative %	0.18	1.91	7.79	14.06	20.29	27.09	33.34	38.52	43.64	48.09	100

Citing Half-Life Calculations:

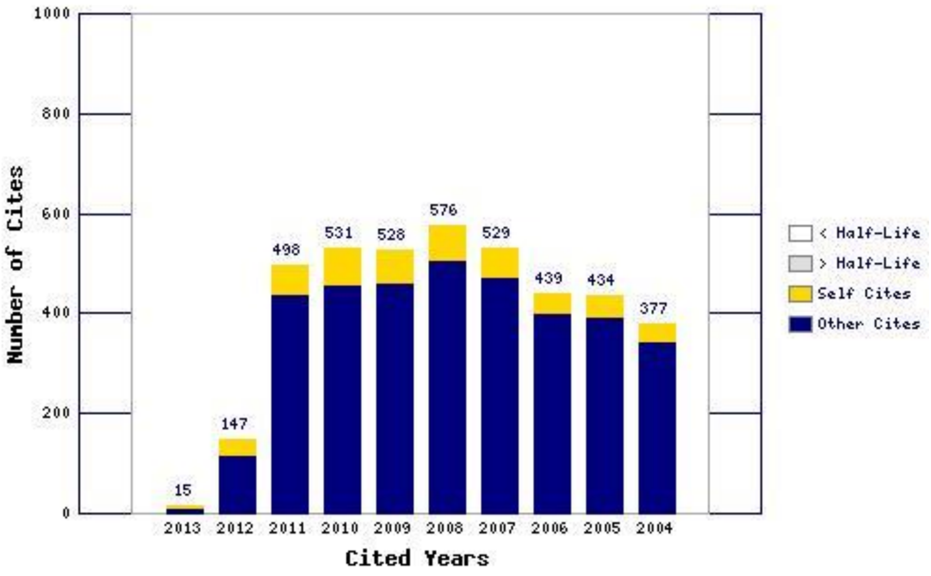
The citing half-life calculation finds the number of publication years from the current JCR year that account for 50% of citations in the journal. Read help for more information on the calculation.

Citing Journal Graph

Click here for Citing Journal data table

This graph shows the distribution by cited year of citations from current-year items in the journal J FORENSIC SCI

Citations from the journal (per cited year)



- The white/grey division indicates the citing half-life (if < 10.0). Half of the citations from the journal's current items are to items published more recently than the citing half-life.
- The top (gold) portion of each column indicates Journal Self-Citations: citations from items in the journal to items in the same journal.
- The bottom (blue) portion of each column indicates Non-Self Citations: citations from the journal to items in other journals.

JournalSource Data

	Citable items			Otheritems
	Articles	Reviews	Combined	
Number in JCR year 2013 (A)	310	0	310	32
Number of references (B)	8363	0	8363	0.0
Ratio (B/A)	27.0	0.0	27.0	0.0

Rank in Category: JOURNAL OF FORENSIC SCIENCES

Journal Ranking

For **2013**, the journal **JOURNAL OF FORENSIC SCIENCES** has an Impact Factor of **1.306**.

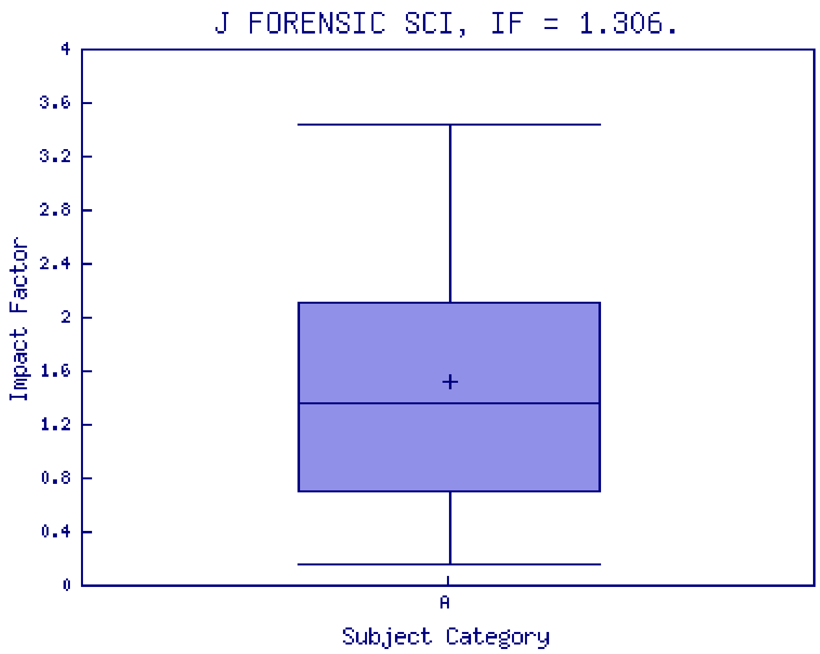
This table shows the ranking of this journal in its subject categories based on Impact Factor.

CategoryName	Total Journals in Category	Journal Rank in Category	Quartile in Category
MEDICINE, LEGAL	16	9	Q3

Category Box Plot

For **2013**, the journal **JOURNAL OF FORENSIC SCIENCES** has an Impact Factor of **1.306**.

This is a box plot of the subject category or categories to which the journal has been assigned. It provides information about the distribution of journals based on Impact Factor values. It shows median, 25th and 75th percentiles, and the extreme values of the distribution.



Key

A - MEDICINE, LEGAL

III. Segmentation of indoor mapping point clouds applied to crime scenes reconstruction

Descripción del factor de impacto y documentación de la revista:

Nombre de la revista:	**IEEE Transactions on Information Forensics and Security**
URL:	**http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=10206**
Editorial:	**IEEE-INST ELECTRICAL ELECTRONICS ENGINEERS INC**
ISSN:	**1556-6013**
Factor de impacto (2013):	**2.065**
Ranking de la revista:	**12/102 (COMPUTER SCIENCE, THEORY & METHODS)** **58/248 (ENGINEERING, ELECTRICAL &ELECTRONIC)**
Cuartil:	**Q1**

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Journal Citation Reports®

WELCOME | HELP | RETURN TO LIST | PREVIOUS JOURNAL | NEXT JOURNAL

2013 JCR ScienceEdition

Journal: IEEE Transaction on Information Forensics and Security

Mark	JournalTitle	ISSN	Total Cites	Impact Factor	5-Year Impact Factor	ImmediacyIndex	Citable Items	Cited Half-life	Citing Half-life
☐	IEEE T INF FOREN SEC	1556-6013	1598	2.065	2.379	0.227	176	3.7	6.5

Cited Journal | Citing Journal | Source Data | Journal Self Cites

CITED JOURNAL DATA | CITING JOURNAL DATA | IMPACT FACTOR TREND | RELATED JOURNALS

Journal Information

Full JournalTitle: IEEE Transactions on Information Forensics and Security

ISO Abbrev. Title: IEEE Trans. Inf. Forensic Secur

JCR Abbrev. Title: IEEE T INF FOREN SEC

ISSN: 1556-6013

Issues/Year: 4

Language: ENGLISH

Journal Country/Territory: UNITED STATES

Publisher: IEEE-INST ELECTRICAL ELECTRONICS ENGINEERS INC

Publisher Address: 445 HOES LANE, PISCATAWAY, NJ 08855-4141

SubjectCategories: COMPUTER SCIENCE, THEORY & METHODS

SCOPE NOTE | VIEW JOURNAL SUMMARY LIST | VIEW CATEGORY DATA

ENGINEERING, ELECTRICAL & ELECTRONIC

SCOPE NOTE | VIEW JOURNAL SUMMARY LIST | VIEW CATEGORY DATA

Journal Rank in Categories: JOURNAL RANKING

***Eigenfactor*® Metrics**

***Eigenfactor*® Score**

0.00766

***Article Influence*®Score**

0.905

JournalImpact Factor

Cites in 2013 to items published in:	2012 = 270	Number of items published in:	2012 = 157
	2011 = 300		2011 = 119
	Sum: 570		Sum: 276

Calculation: $\frac{\text{Cites to recent items}}{\text{Number of recent items}} \quad \frac{570}{276} = \mathbf{2.065}$

5-Year JournalImpact Factor

Cites in {2013} to items published in:			Number of items published in:		
	2012 =	270		2012 =	157
	2011 =	300		2011 =	119
	2010 =	270		2010 =	81
	2009 =	143		2009 =	81
	2008 =	221		2008 =	68
	Sum:	1204		Sum:	506

Calculation: $\frac{\text{Cites to recentitems}}{\text{Number of recentitems}} \quad \frac{1204}{506} = \mathbf{2.379}$

Journal Self Cites

The tables show the contribution of the journal's self cites to its impact factor. This information is also represented in the cited journal graph.

Total Cites	1598
Cites to Years Used in Impact Factor Calculation	570
Impact Factor	2.065

Self Cites	202 (12% of 1598)
Self Cites to Years Used in Impact Factor Calculation	72 (12% of 570)
Impact Factor without Self Cites	1.804

JournalImmediacyIndex

Cites in 2013 to items published in 2013 = 40
Number of items published in 2013 = 176

Calculation: $\frac{\text{Cites to currentitems}}{\text{Number of currentitems}} \quad \frac{40}{176} = \mathbf{0.227}$

JournalCitedHalf-Life

The cited half-life for the journal is the median age of its items cited in the current JCR year. Half of the citations to the journal are to items published within the cited half-life.

CitedHalf-Life: 3.7 years

Breakdown of the citations ***to the journal*** by the cumulative percent of 2013 cites to items published in the following years:

CitedYear	**2013**	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003-all**
# Cites from 2013	40	270	300	270	143	221	198	153	0	0	3
Cumulative %	2.50	19.40	38.17	55.07	64.02	77.85	90.24	99.81	99.81	99.81	100

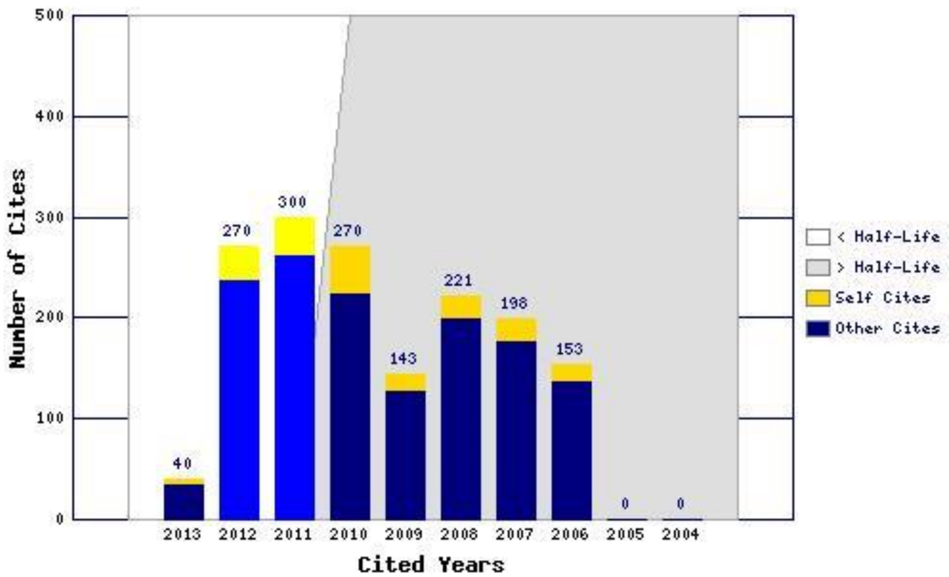
Cited Half-Life Calculations:
The cited half-life calculation finds the number of publication years from the current JCR year that account for 50% of citations received by the journal. Read help for more information on the calculation.

Cited Journal Graph

[Click here for Cited Journal data table]

This graph shows the distribution by cited year of citations to items published in the journal IEEE T INF FOREN SEC..

Citations to the journal (per cited year)



- The white/grey division indicates the cited half-life (if < 10.0). Half of the journal's cited items were published more recently than the cited half-life.
- The top (gold) portion of each column indicates Journal Self Citations: citations to items in the journal from items in the same journal.
- The bottom (blue) portion of each column indicates Non-Self Citations: citations to the journal from items in other journals.
- The two lighter columns indicate citations used to calculate the Impact Factor (always the 2nd and 3rd columns).

JournalCitingHalf-Life

The citing half-life for the journal is the median age of the items the journal cited in the current JCR year. Half of the citations in the journal are to items published within the citing half-life.

CitingHalf-Life: 6.5 years
Breakdown of the citations ***from the journal*** by the cumulative percent of 2013 cites to items published in the following years:

CitedYear	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003-all
# Cites from 2013	79	430	646	626	539	497	452	366	309	282	1822
Cumulative %	1.31	8.42	19.10	29.45	38.36	46.58	54.05	60.10	65.21	69.87	100

Citing Half-Life Calculations:

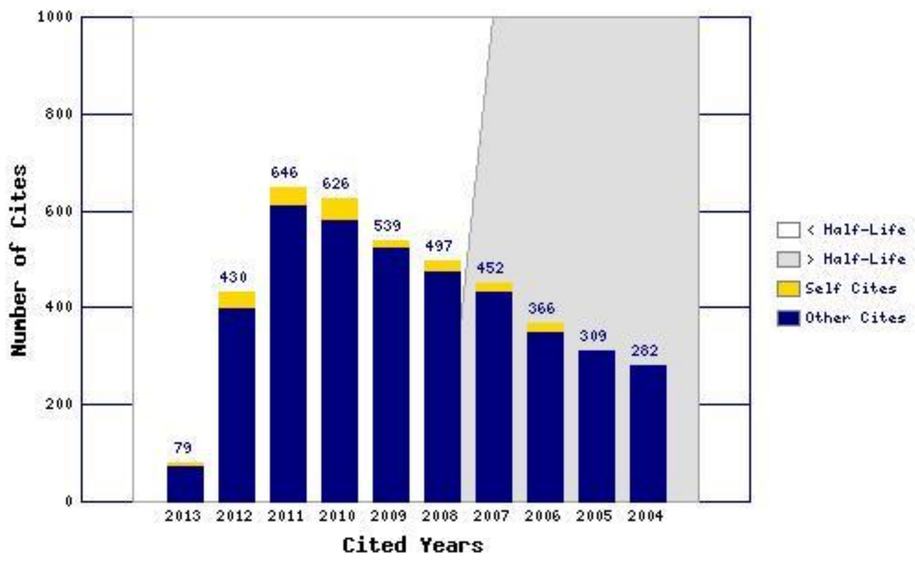
The citing half-life calculation finds the number of publication years from the current JCR year that account for 50% of citations in the journal. Read help for more information on the calculation.

Citing Journal Graph

[Click here for Citing Journal data table]

This graph shows the distribution by cited year of citations from current-year items in the journal IEEE T INF FOREN SEC.

Citations from the journal (per cited year)



- The white/grey division indicates the citing half-life (if < 10.0). Half of the citations from the journal's current items are to items published more recently than the citing half-life.
- The top (gold) portion of each column indicates Journal Self-Citations: citations from items in the journal to items in the same journal.
- The bottom (blue) portion of each column indicates Non-Self Citations: citations from the journal to items in other journals.

JournalSource Data

	Citable items			
	Articles	Reviews	Combined	Otheritems
Number in JCR year 2013 (A)	176	0	176	2
Number of references (B)	6048	0	6048	0.0
34.4	34.4	0.0	34.4	0.0

Rank in Category: IEEE Transactions on Informatiom Forensics and Security

Journal Ranking

For **2013**, the journal **IEEE Transactions on Informatiom Forensics and Security** has an Impact Factor of **2.065**.

This table shows the ranking of this journal in its subject categories based on Impact Factor.

CategoryName	Total Journals in Category	Journal Rank in Category	Quartile in Category
COMPUTER SCIENCE, THEORY & METHODS	102	12	Q1
ENGINEERING, ELECTRICAL &ELECTRONIC	248	58	Q1

Category Box Plot

For **2013**, the journal **IEEE Transactions on Informatiom Forensics and Security** has an Impact Factor of **2.065**.

This is a box plot of the subject category or categories to which the journal has been assigned. It provides information about the distribution of journals based on Impact Factor values. It shows median, 25th and 75th percentiles, and the extreme values of the distribution.

Key	
A -	COMPUTER SCIENCE, THEORY & METHODS
B -	ENGINEERING, ELECTRICAL & ELECTRONIC