ON-SITE 3D VISION TRACKING OF CONSTRUCTION PERSONNEL

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ABSTRACT

Open construction sites are highly complex environments for onsite tracking. The large amount of items present along with the amounts of occlusions/obstructions, make efficient onsite personnel tracking very difficult. Current tracking methods rely mostly on Radio Frequency technologies, such as Radio Frequency Identification (RFID), Global Positioning Systems (GPS), Bluetooth and Wireless Fidelity (Wi-Fi, Ultra-Wideband, etc). These technologies require manual deployment of tags and record keeping of the people they are placed on. In open construction sites with numerous people working simultaneously, sensor installations and maintenance increases the cost and time needed to implement these tracking methods. This paper presents a new, less obtrusive method for open site tracking of personnel using video cameras. Video feeds are collected from on site video cameras and presented to the user. The user can then select the person that is to be tracked. The person is subsequently tracked in each video using 2D vision tracking. In each frame, epipolar geometry is used to calculate the depth (3D position) of the person. This method addresses the limitations of radio frequency methods since it uses existing construction site equipment (security cameras) to perform tracking. The method has been implemented in a C++ prototype and preliminary results show effective 3D positioning of personnel in construction sites.

KEY WORDS

3D location, personnel tracking, image alignment

INTRODUCTION

Effective tracking of personnel has a wide variety of uses in the construction industry. It can be used for productivity calculations, activity sequence analysis, detecting travel path conflicts, and enhancing site safety. In addition, real time tracking can identify critical personnel and activities instantly. This allows for adequate flow of project information and increases the management's control and decision making capabilities, reducing the total cost of the construction project.

Real-time tracking existing solutions are based on Radio Frequency technologies. These include Global Positioning Systems, Radio Identification, Wireless Networks and Ultra Wideband technologies. These technologies all work under the same principle of having a sensor installed on the entity and an externally placed reader to acquire the tracking information. These technologies have proven accurate when tracking entities

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in certain types of construction projects such as building construction (Azo 2008). Some examples of construction related applications of these technologies include tracking prefabricated materials (Song et al 2006), equipment, inventory (Caldas et al 2004) and personnel (Teizer 2007). These applications have allowed the development of automated progress schedules and the creation of logistic systems.

However in open construction sites (e.g. highway construction), due to the large amount of personnel involved, trackers that require attaching sensors to each person have additional time and cost burden associated with performing sensor installations. This sensors need to be installed on each entity which means that by nature, these systems are intrusive, needing actual physical interaction between the entity and the sensor. Such intrusive methods are not favored by Construction Unions due to the lack of privacy they provide the worker (Juels 2005). Additionally, the user has to know which tag is attached to which person. This task is necessary in order to distinguish between individuals present at the construction site. Having to correlate and organize each entity's tracking information with each sensor becomes a time consuming task that requires trained personnel and increases the overall cost of onsite tracking. In open construction sites, tracking methods should be able to adapt to varying day-to-day construction tasks without interfering with said operations.

The research presented in this paper proposes an alternate tracking methodology based on vision tracking. Under this method, several video streams are collected from the construction site and simultaneously presented to the user. The user has the ability to select the person he wants to track in all of the views. Using the Lucas Kanade (Baker and Matthews, 2002) 2D tracking algorithm, the 2D location of the entity is recorded. Using epipolar geometry, the centroid of the entity is calculated in each frame which provides the 2D location of the entity. Afterwards, the depth value of the centroid is calculated using the fundamental matrix of the images. This provides the 3D aspect and allows the user to retrieve 3D location information in real time. Preliminary results were obtained by testing the method on an actual open construction site at the University of Michigan. The results indicate that the method can effectively provide accurate localization of an entity's 3D position from two or more different views.

Successful tracking can identify on site waste and can be used for activity flow diagrams. By tracking the location of workers and materials, activity path diagrams and pull flow mechanisms can be developed to enhance current site layout and processes, allowing for better localization of tools and materials and reducing layout complexity in order to increase worker productivity and reduce safety hazards, it can also be used to accommodate and manage waste as efficiently as possible. Tracking can also be used for developing safety measures in direct response to risk levels. Using the Pull Flow concept (Womack and Jones 2003) actual demands rely mostly on construction workers safety and overall site safety.

RADIO FREQUENCY BASED TRACKING

There is a wide variety of technologies that use the principle of radio frequency to calculate position and provide tracking information. Some of the most commonly used in construction sites includes GPS, RFID, Bluetooth and Wireless Fidelity (Wi-Fi, Ultra-Wideband, etc). These methods rely mainly on a tag and a reader. A tag is attached to the items of interest and a reader is set up and calibrated to receive the item information. These methods can record positions across time, paths, velocity and acceleration among other information.

GPS is a satellite based radio-navigation system. Based on the amount of time that the radio signal travels from a satellite to a receiver, GPS receivers determine, with great accuracy, locations in terms of longitude, latitude and altitude, (Oloufa et al, 2003). GPS has been used for common construction practices such as positioning of equipment and surveying (Caldas et al 2004). It has also been proven effective in managing, tracking and controlling earth-moving and mining operations, in open areas (Lu et al, 2006).

RFID's can be used for tracking entities using RFID tags embedded on the entities that can be read by RFID readers. RFID technology has proven to be effective in tracking equipment and materials in a construction site. Song et al (2006) used RFID chips to track pre-fabricated pipe spools for usage in industrial construction projects. Other applications include generating automated progress schedules and inventory monitoring (Kamashi and Varghese, 2007) and to developing construction logistics systems (Kanekoi et al, 2007).The RFID transponders placed on objects can be easily identified and tracked, which is ideal for a person with an RFID receiver in close proximity to the transponders (Song et al, 2006).

Positioning based on a wireless network (Wi-fi) relies on the existence of at least 3 Wi-Fi devices in the environment to act as beacons, the strength of the signal is then used to identify the location of the entity. Castro et al (2006) presented a Wi-Fi network to create task allocation protocols. Field positioning data was obtained by pinpointing the Wi-Fi tags attached to construction materials, or by manually pinpointing the location of materials that cannot have tags attached due to limitations in size, shape or type of surface and pinpointing their location.

Ultra Wideband (UWB) is another radio technology that can be used at very low energy levels for short-range communications using high-bandwidth (Fontana, 2004). UWB is used as a part of location systems and real time location systems. Its capabilities for acquiring precise data as well as the low amount of power it needs, make its application useful for certain sensitive environments (such as hospitals). In construction, Teizer et al (2007) used UWB for real time material location and tracking system. The system, similar to RFID has advantages over the aforementioned, since it can provide real time data.

Nevertheless, all of these technologies have several limitations which limit their applicability in open construction sites. RFID tracking is a near sighted approach that requires a reader to move in order to identify a person (the person is not tracked continuously). This becomes a problem when trying to achieve real time tracking. In these cases, far-sighted methods (e.g. vision racking) that can provide real time tracking are preferred. When using UWB technology, in order to feed adequate positioning data to the system, a Total Station must be used prior to its implementation. This increases the time and cost needed to apply this method large areas. On the other hand, GPS systems can only be used outdoors and rely on the greater satellites for system acuracy, whereas in construction a more localized approach provides a higher degree of control over the efficiency of the system (Oloufa 2003).

In addition, these technologies are based on the same tag and reader principle which means that amsensor has to be installed in each entity before any type of tracking information can be acquired. Not only does this mean that additional equipment (tags and readers) is needed, but in order to identify who or what it is that the system is tracking, each sensor must be classified according to the specific type of entity in which it is installed. The information collected by the sensor must be associated with a specific person or item since tracking information is used differently for each entity. Managing and organizing this information involves a significant amount of time and trained personnel, which increases the overall cost of using such methods. Furthermore, the methods create other types of concerns, especially in workers who believe they do not take benefit from wearing tracking sensors. They argue, and, it is debatable, that these sensor installations are a violation of their privacy.

VISION TRACKING

Vision tracking fuses video cameras and computer vision algorithms to perform several measurement tasks. This tracking approach is highly regarded for its capability to measure a large number of particles with a high level of accuracy (Gruen, 1997). According to Coifman et al 1998, several types of vision tracking methods are available such as:

- Model Based Tracking, which relies on detailed geometric objects.
- Region Based Tracking, which identifies a blob (region) associated which each object and tracks it using a cross correlation measure.
- Active Contour Based Tracking, which is a representation of the bounding contour of the object and keeps dynamically updating it.
- Feature Based Tracking which tracks object sub-features.

A more recent approach, called image alignment, consists of moving and deforming a template to minimize the sum of squared errors between two images: the template and the image. This tracking method was the preferred method to use in this research since it is based on gradient descent, currently the defacto standard numerical algorithm for performing image alignment tracking (Baker and Matthews, 2002). Image Alignment is preferred for any application where pixels in a local area are expected to move in way which can be modeled by a function of position; for example, for tracking rigid objects of known surface in 3D (Molton et al 2004). The algorithm's methodology is presented in the following steps:

1. Video streams and video properties are collected from the input data. The frame size the frame rate and the numbers of frames must be identified since they are used throughout the tracking process. Finally, the image size (width and height) in terms of pixels is arranged in matrix form.
2. Calculation of the error image: The image is warped (distorted) and the result is subtracted from the image template, providing the error image.
3. Arrangement of single matrix – A single bock matrix is created, each frame is queried using the frame rate and the duration of the data. A total of 40 iterations are realized in which the warped image with the current parameters is computed.
4. Calculation of parameter updates –The steepest descent and warp parameters are updated in each frame to match the tracked image points.
5. Second Warping – Warping is applied and the matrixes are multiplied. The system creates a number of possible vectors identifying the point's probable location in the next frame. Once one of the points is matched, the rest of the points that create the surface are automatically updated to their new position.

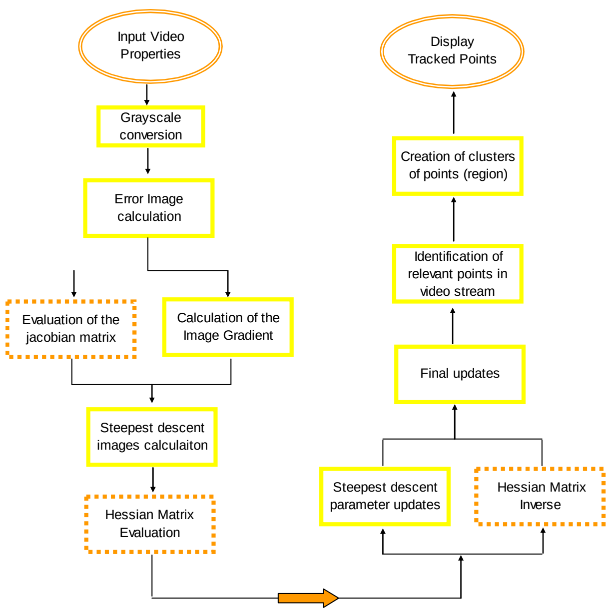

Figure 5 – 2D Tracking Methodology (Baker and Matthews 2002)

METHODOLOGY

The long term objective of this research is to accurately acquire the 3D location (spatial coordinates) of distinct project related entities, such as construction equipment, personnel, and materials of standard sizes and shapes. The primary research objectives are to:

- Create a user friendly interface in which a user can select one entity by marking an area that corresponds to it.
- Effectively calculate the centroid of the selected area to represent the entity's location.
- Use the Lucas-Kanade 2D tracking method to precisely compute each entity's 2D tracking location.
- Use epipolar geometry to give the 3D perspective (3D location) of the entity's centroid.
- Interactively visualize the resulting tracked entities and their 3D tracking information.

The research presented in this paper is part of a larger framework which is not limited to tracking only personnel. Additional tracking applications include construction materials and equipment. In this paper however, the main focus is on the method's ability to tracking construction-related personnel.

This personnel tracking methodology consists of a computer receiving video feeds collected from on site self calibrated video cameras. The method can be used with several cameras connected simultaneously. These cameras must have at least partially overlapping views of the entity (personnel) that is to be tracked in order to calculate the 3D location of the entity. After receiving the video feed, the cameras' views are projected in the user's window simultaneously. The method allows the user to select an entity of interest in both of the views. Selecting an area corresponding to the entity (e.g. uniform or hardhat) is enough to perform the tracking. After selecting the entity that is to be tracked, the method calculates the selected area's centroid, which will be used in calculating the 2D location across the image frame. The method then uses the Lucas Kanade (Baker and Matthews, 2002) tracking algorithm to track the areas identified in all of the views. The tracking of the entity, in this case personnel, is performed simultaneously and independently in each camera. This feature allows the user to locate and track personnel in real time across the entire site simultaneously. Epipolar geometry is used to calculate the depth of the centroid of the area and give the 3D location of the entity in each frame. The system records the tracking information and displays the 3D coordinates of the entity in the user's window. The methodology for this algorithm is presented in Figure 2.

Entity Selection and 2D Tracking

When the user is presented with the video feeds, he has the ability to interactively select the person he wishes to track. It is not necessary to select the entire person, but a distinguishable characteristic of the entity. For example, a hardhat or uniform is a distinct characteristic of personnel in construction sites. By selecting the hardhat or the uniform, the tracking information of the personnel can be easily acquired. The user selects the same entity area in both of the views by marking a rectangle on top of it.

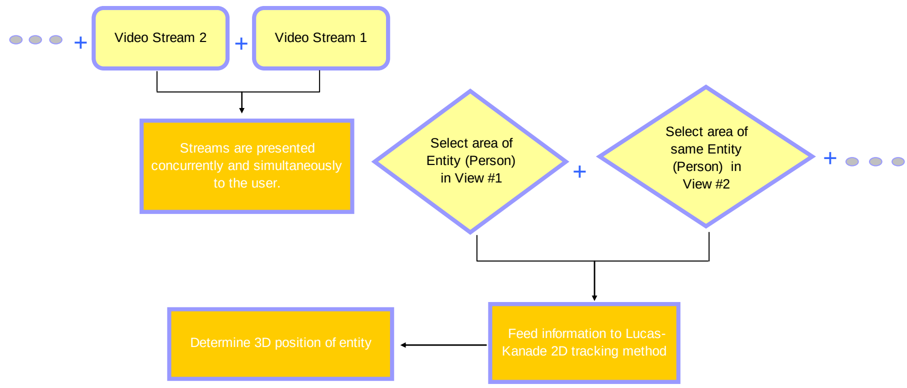

Figure 2 - Methodology Overview

The rectangle's coordinates on the image frame are stored and used as input data points, which are later used in the 2D tracking algorithm. After recognizing the pixel area of the marked rectangle, the centroid (center of gravity) of each marked region is computed. The centroid coordinates mark the 2D location (x,y) of the entity in the image plane. After determining the pixel area that is occupied by the entity, a 2D vision tracking code based on the Lucas-Kanade algorithm (Baker and Matthews 2002) is used to acquire tracking data. The 2D position of the entity's centroid is updated and recalculated in each frame as the marked entity moves.

3D LOCATION

The 2D tracking results of the selected entity in each of the camera's views are used to determine the real time 3D position of the person. The 8 point algorithm is used to calculate the fundamental matrix of the images. The fundamental matrix is important since it enables full reconstruction of the epipolar geometry. The fundamental matrix is used to find the epipolar lines of the image which can be located where the epipolar plane intersects the image plane (Figure 3). These epipolar lines are necessary to find the 3D location of the entity. Since the centroid of the entity is known on both camera views, the projection of that point across the epipolar plane in both of the views leads to an intersecting point in 3D space. This intersection point is the depth coordinate of the entity. This provides the 3D perspective and allows for the calculation of the 3D location of the image in every frame.

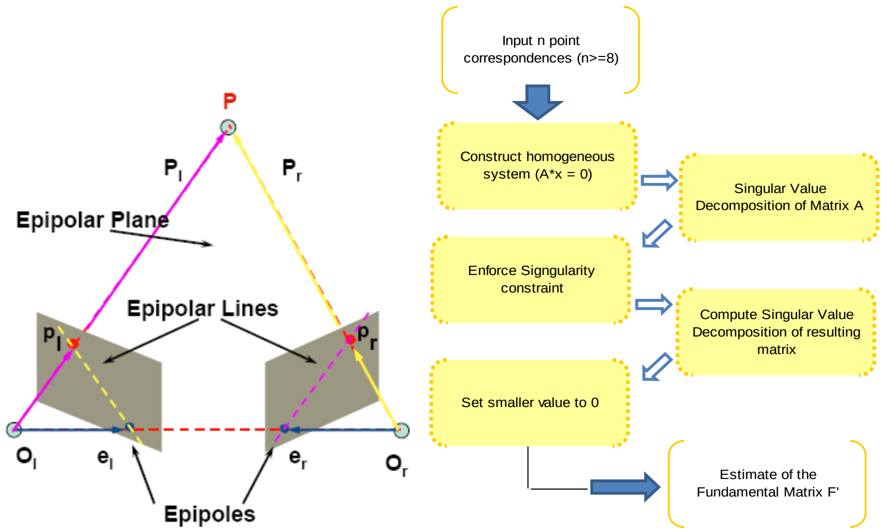

Figure 3 – Epipolar Geometry. Display of Epipolar Lines and Fundamental Matrix Calculation

RESULTS

The method was tested on an actual open construction site at the University of Michigan. The basic setup consists of 2 cameras connected to a Personal Computer. Although the method can be implemented with several cameras simultaneously, the basic example (2 cameras) has been used for experimental purposes. The user selects the entity he wishes to track in each of the cameras view by simply marking the area on the screen (clicking on the mouse to draw a rectangle on each of the presented screens). Figure 4 shows the view that is presented to the user. Both feeds are shown concurrently and simultaneously. Here the user selects the area in both views, in this case the worker, and the 3D position is calculated.

Figure 4– Experimental Results (Original Frame)

As can be seen from Figure 5, after the worker was marked the 3D location of the centroid of the entity is displayed. These values are updated in every frame to provide the real time aspect. The centroid is calculated using pixel location information.

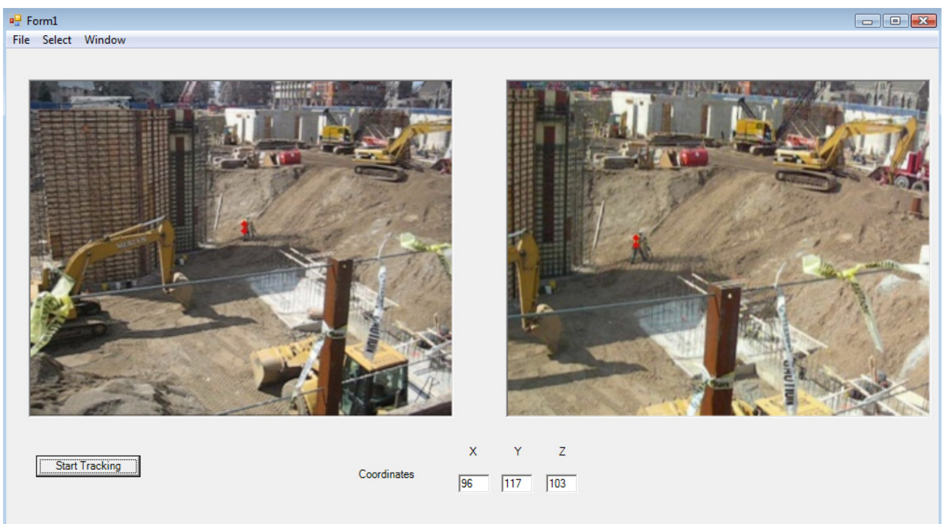

Figure 5 – Experimental Results (Subsequent frames)

2D tracking is performed continuously on the entity as it moves through the image frame. The 3D coordinates of the entity are modified accordingly depending on the entity's movement .Current 3D position is updated with every frame. Current streaming frame rate is one frame per second. Preliminary results indicate that the method is accurate and efficient in acquiring the 3D position of project entities. The presented research however, faces the limitation of needing a buffer time, while the calculation of the 3D position in the first frame is originally calculated

CONCLUSION

The use of onsite tracking applications in open construction sites can provide useful information for productivity calculations, activity sequence analysis, detecting travel path conflicts, and enhancing site safety among others. This makes possible ample and continuous flow of critical project information which increases the management's control over the project.

Current onsite tracking methods are mainly based on Radio Frequency technologies such as Global Positioning Systems, Radio Identification, Wireless Networks and Ultra Wideband. All of these technologies work under the same tag and reader principle. This principle faces the limitation of having increased cost and time associated with performing sensor installations on each entity present at the site. In busy, open construction sites, where there are hundreds of personnel spread over a large area, managing and correlating tracking information becomes a costly, time consuming task since trained personnel is required to perform data correlation. This data correlation is required since it is necessary to know which tag is attached to which person in order to distinguish between individuals present at the construction site. In addition these sensor installations have given arise to several personnel privacy issues, since workers dislike the idea of being tracked by a sensor and argue that these sensor installations violate their privacy.

These issues were addressed by using vision based tracking technology that can accurately determine the 3D location of an entity in an open construction site. This vision tracking method requires little or no additional equipment costs since owners currently demand the installation of video cameras on site. Under this method, several video streams are collected from the construction site and simultaneously presented to the user. The user selects the entity to be tracked in all of the views. Using the Lucas Kanade (Baker and Matthews, 2002) 2D tracking algorithm, the 2D location of the entity's centroid is acquired. Epipolar geometry is then used to calculate the depth value corresponding to the entity. This provides the 3D aspect and allows the user to retrieve 3D location information in real time. Preliminary results obtained from video feeds of actual open construction sites indicate that the effective 3D positioning of construction related personnel can be achieved.

Vision-based tracking can provide real-time visual information of construction job sites. This method is highly accurate and unobtrusive, which means that there is no need for tagging or installing sensors on the tracked entities. Additional advantages include the simplicity, commercial availability and low costs associated with video equipment (Caldas et al 2004). These attributes favor the method's use in open construction sites, where large numbers of items (such as equipment and personnel) are present. Although there are many methods that can be used for tracking, vision tracking offers great advantages mostly because of its accuracy, low cost and availability. The implementation of such methodology will provide owners, architects and engineers with real time information which enhances the decision making capabilities of the construction team.

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