Design of a Distributed Tracking System for Camera Networks

Final Report

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Abstract

Tracking systems are useful for medical applications such as the Information Technology for Assisted Living at Home (ITALH) project. One of the goals of the ITALH project is the design of a tracking system based on camera networks to monitor elderly people allowing them to live at home in safety. In this application it is especially important to have a robust and reliable system and to conserve the privacy of the user. That is why, the considered tracking algorithms deals with privacy and security issues by performing local processing and by distributing the information. To make the system reliable and robust, it is necessary to consider and understand occlusion issues. This report presents a classification and analysis of the different types of occlusion, and the transitions between them. These transitions are the basis for an algorithm to find the location of the occluding objects, and are used in a tracking algorithm to interpolate regions that are occluded to camera views.

1 Introduction

Tracking is one the main applications of camera network. It is useful in medical applications, like in the project Information Technology for Assisted Living at Home (ITALH). In ITALH, a tracking system based on camera networks will be used to monitor elderly people so they can live at their home without the need of a nurse. For this application we want to balance the amount of monitoring to be done while maintaining the privacy of the individual.

One of the main problems of a tracking system based on camera networks is that there can be occluding objects between the camera and the object of interest, like walls or people. If that happens, you lose track of the object. A robust tracking system must be capable of determining when an object is been occluded and deal with this situation.

There is a difference between the occlusion caused by walls and the occlusion caused by people. The occlusion produced by objects for which their positions do not vary with time, such as a wall or a bookcase, is referred to as static occlusion. On the other hand, the occlusion produced by people is called dynamic occlusion because position varies with time [7]. Most of the recent researches study dynamic occlusion [4],[5] or tried to deal with static occlusion without making an adequate analysis. Although dynamic occlusion does not allow us to predict certainly when and where occlusions will occur, the constancy of static occlusion let us know for sure where occlusion occurs and we can take advantage of this knowledge. Most of the current algorithms do not make used of this information.

The localization of occluding objects can be useful, especially when the tracking is performed in the interiors of building. For example, furniture can be consider static occlusion but its location can change after a long period of time.

This document presented a geometrical analysis and characterization of occlusion, Section 2.2. This analysis is later used to find some of the discontinuities in the visibility function of each camera and to combine each camera's information to find the location of occluding objects.

Another problem of tracking systems based on camera networks are security and privacy issues. Most of the tracking systems are made in a centralized way [6] in which all the information is sent without previous processing to a base station. The fact that all the information is sent to the base station can cause security problems since someone that has access to the base station can collect all the information. The security of the system increases if a distributed system is used. The information is distributed between the nodes and to collect all the information the person needs to have access to all the nodes. It is also important to preprocess the information in each one of the nodes to reduce transmission cost and to keep the privacy of the individual by not transmitting pictures but instead some features.

This document describes a tracking algorithm, Section 2.4, that only needs specific information of each camera. We assume that preprocessing as background subtraction is performed locally for each camera. After been processed, the information obtained for each camera is combined to find the path followed by the target.

2 Method

2.1 Model

A two dimensional model is used to analyzed and represent the environment, the camera network, targets and occluding objects. The use of a 2D model simplifies the analysis and it still is a good representation of the real environment. We can represent the occlusion and performed tracking in a two dimensional way.

It is assumed that the calibration parameters of the cameras are known [1]. This is used to triangulate the location of the target. It is important to say that since we are interested in applications where the size of the environment will be comparable with the objects size, the targets are represented as ellipses and not as points which is the usual representation of the targets [2], [3].

2.2 Occlusion Analysis

In order to characterize occlusion we study the transition between different types of occlusion. The types of occlusion are:

- Total occlusion: the target is totally occluded by the occluding object. The camera can not see the target.
- Partial occlusion: part of the target is occluded and part of the target is visible to the camera.
- Visible or no occlusion: the object can be totally seen by the camera.

Unless the target is a point, we can only pass from partial occlusion to one of the other types of occlusion and vice versa. These are the transition detected on the boundaries of the target:

- Total-to-partial: is the moment in which the target was not seen by the camera and the camera starts to see it.

- Partial-to-total: the camera detects part of the object and suddenly it totally disappears.
- Visible-to-partial: the object was completely seen by the camera and it starts to disappear.
- Partial-to-visible: the camera only detects part of the target and it starts to completely detect the target.

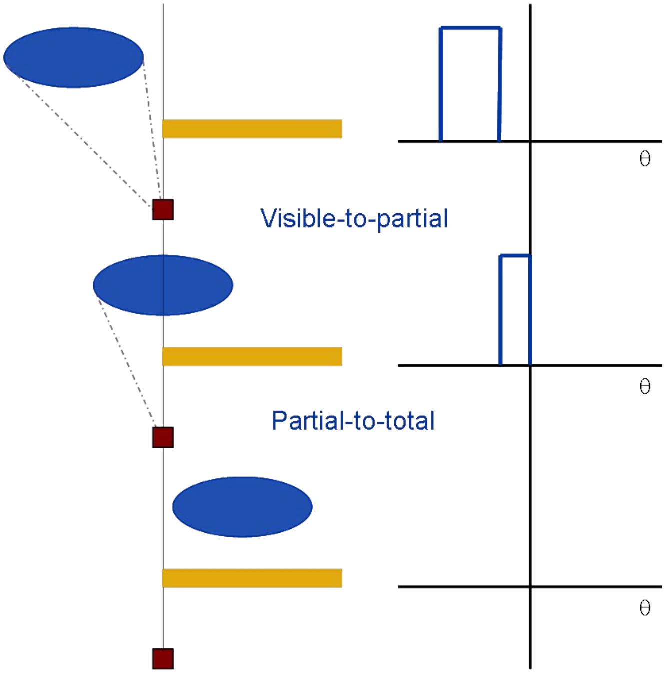

Figure 1. Example of occlusion transitions

A basic example of these types of transitions is shown in Figure 1.

There is an especial case of partial occlusion in which the occluding object is smaller than the target and the camera detects two different blocks that belong to the target. The transition of this type of occlusion can be represented as combination of the transitions mentioned above.

Each one of the different transitions have specific characteristic that allow us to identify them in a time analysis of the detections. These transitions are used in the next section to identify the location of the occluding objects.

2.3 Localization of occluding objects

The objective of this section is to identify regions where the occluding objects are found. The cameras take a reference picture which is used as a background image and then they use this to identify what is new in a different frame. Hence only the target is detected; the occluding objects can not be identified directly by the camera. The target moves in the environment and the detection from each camera is recorded. We used the fact that the target appears or disappears when an occluding object is present to determine the boundaries of the occluding object. This data is analyzed for each one of the cameras and then it is combined to find the location of occluding objects. The steps followed in this algorithm are:

- A visibility function is created.

- The function is analyzed and used to find the occluding angles for each camera.
- The angle information is combined to find the occluding object's location.

This process is explained in more details next.

2.3.1 Visibility function

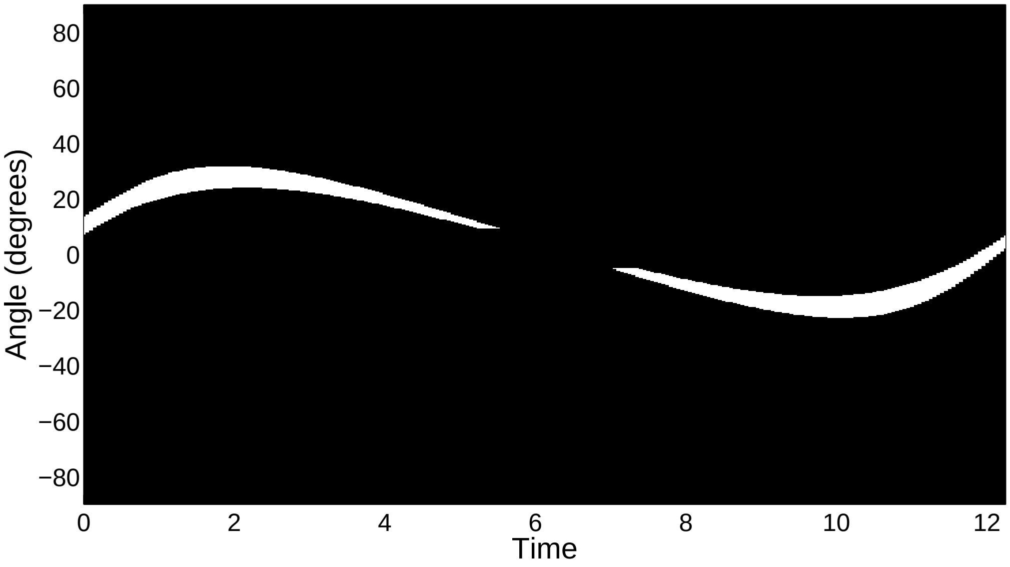

Figure 2. Example of visibility function

A visibility function is created for each camera. This function depends on time and the angle in which the target is detected with respect to the camera. The function presents a series of discontinuities, some of them have specific characteristic that let us identify the transitions between different types of occlusions. Figure 2 shows an example of this function.

There are two types of discontinuities that appear when the target is occluded with an object. Cusps appear in the point where the target totally disappears (partial-to-total occlusion) and in the point where target starts appearing (total-to-partial occlusion). For the case of an object disappearing, we notice flat edges in the visibility function during the period in which there is partial occlusion. This edge ends as a cusp when the target disappears. Something similar is observe at the transition from total-to-partial occlusion. These features can be used to determine the location of the occluding objects. However, flat edges can be ambiguous because other events can cause similar types of discontinuities. For instance, flat edges occur when the targets position remains constant in time. On the other hand, cusps are not ambiguous, these discontinuities only occur when the target is totally occluded.

2.3.2 Determining Occluding Angles

We want to determine the angles where the occluding object is located with respect to each camera. These angles are given by the cusps in the visibility function and the flat edges at the same angle. We could use the

Figure 3. Template used to find cusps

edges but it can cause ambiguities. Correlation is used to determine the position of the cusps in the visibility function. A template with the pattern of a cusp is designed and correlated with the function to determine the points that fits the template. This is a local analysis and hence uses little data from the visibility function. The templates used to find the cusps are show in Figure 3. Two different templates are used; the reason for this is that it is important to take time into account. The first template is used to determine partial-to-total occlusion, which marks the beginning of the occluding object. The second one is used to determined total-to-partial occlusion, which marks the ending of the occluding object.

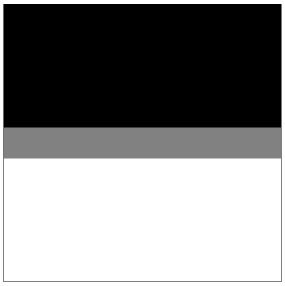

Figure 4. Template used to find flat edges orientation

It is important to determine the direction in which the target is moving. For this, the flat edges due to occlusion are useful. After knowing the location of the cusp we use a template in a neighborhood around the cusp to determine the orientation of the flat edges. This analysis is performed locally in time and space. Figure 4 shows the template that is used to determine the edges orientation.

2.3.3 Combining information to localize the object

After finding the angles that form the cusps, we can pair them considering if they come from cusps due to partial-to-total or due to total-to-partial occlusion and considering the orientation of their edges. The angles of occlusion from each camera determine conic regions. By intercepting these regions we mark the location of the occluding object.

2.4 Tracking

This section presents a tracking algorithm for a single target considering static occlusion. To do the tracking it is assumed that the data is processed and only the detection angles are known per time frame. This determines the visibility function.

The center angle of the object is determined. This is done to each time frame and for all the cameras. The center is determined by finding the average between the minimum and maximum angle of detection. This process can lead to reconstruction errors in regions that contain partial occlusion since part of the target can not be seen by the camera.

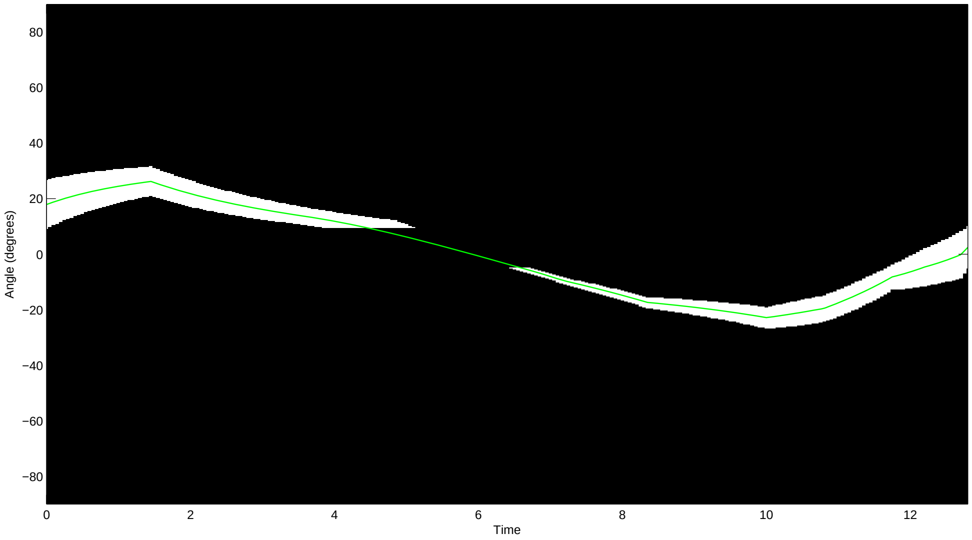

Figure 5. Center function computation

Occlusion causes problems in the computation of the center function for each camera. We can not determine the center of the object in regions with partial occlusion since, as it was mentioned before, it yields misleading results. In order to avoid these problems, we determine the regions of partial occlusion and eliminate those values from the center angle calculation. After that, we perform cubic interpolation for the points with partial and total occlusion. An example of the final center function is shown in Figure 5.

Finally, the information of each camera is combined using triangulation to determine the target's position over time. Triangulation consists on drawing lines from the cameras with slopes determined by the center angle calculations and looking for the interception of these lines. Notice that this is the only step that uses the calibration parameters, that is, the position and the orientation of the camera. The rest of the process is independent of the calibration information.

The interpolation can cause some problems due to the possibility that the path passes over the occluding object. To correct this error we want to take into account the regions that contain the occluding objects. We want to make a cost function to make a trade off between the occluding objects position and the smoothness of the center curve. This will be part of future work. Other problems can occur if there is a lack of information due to total occlusion, however there is nothing that we can do about this situation.

3 Results

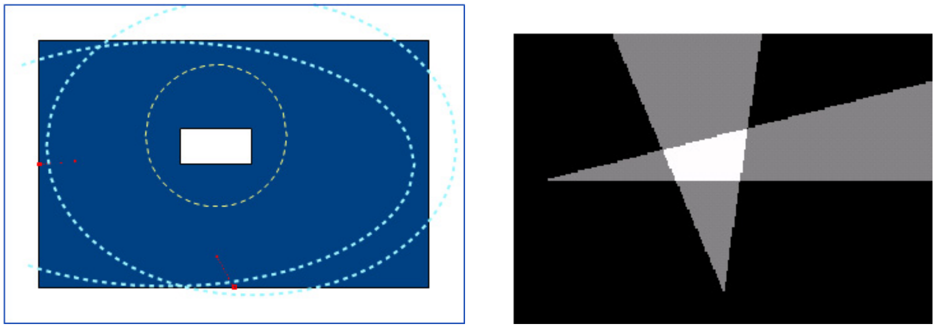

Figure 6. Environment with single occluding object (left) and corresponding reconstructed region (right).

A simulation environment was developed to test the different algorithms. Various tests were run to reconstruct an occluding object using the localization algorithm presented in Section 2.3. Figure 6 shows an example of the localization of an object. In the left side, the simulation environment is presented; and in the right side, the object location due to the interception of the projections is presented.

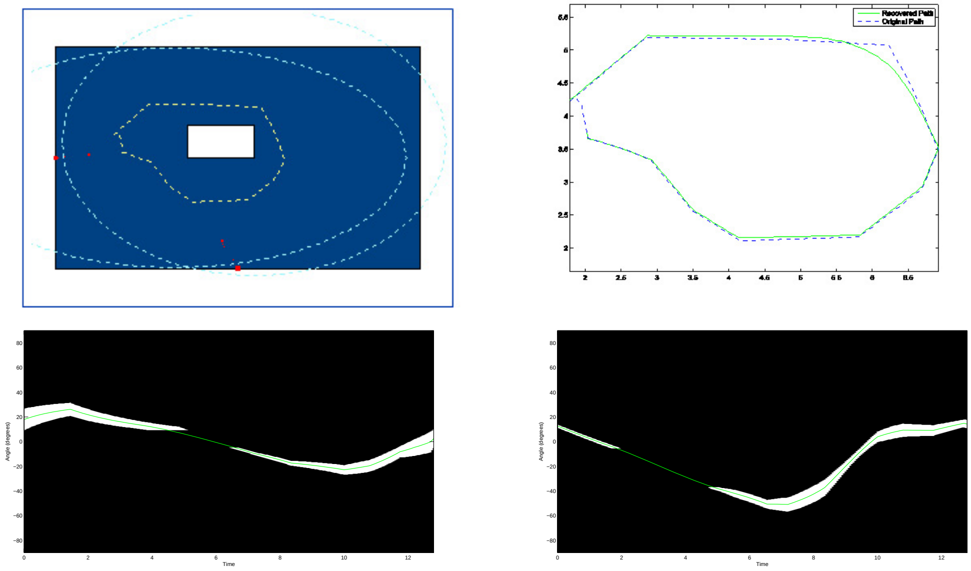

Figure 7. Environment with original path (top left),Original and recover path (top right), Center functions for corresponding cameras (bottom).

Tests were performed to find the path of a single target in an environment that contains two cameras and one occluding object. The results of these tests are show in Figure 7.

4 Conclusions and Future Work

In this research we used a geometrical approach to solve the occlusion problems present in tracking systems base on camera networks. We made a deep analysis of the types of occlusions and designed an algorithm to localize occluding objects. Discontinuities with particular characteristic were identified and used to determine the location of the occluding object. This analysis was tested in an environment that contained only one occluding object, in future work we want to extend and test this analysis in an environment with multiple objects.

We designed a tracking algorithm that does not need to have access to all the data of the camera; it just needs to know some features of the image. This tracking algorithm uses the discontinuities due to occlusion to interpolate the missing or unreliable information. The analysis is performed locally for each camera and then combined together. This algorithm was tested in cases with only two cameras and one occluding object. In the future work we want to generalize this algorithm to multiple occlusions, cameras and more than one target.

We hope to combine the algorithm to localize occluding objects with the tracking algorithm to make a more robust tracking system.

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