

ROBUST DETECTION AND IDENTIFICATION OF PARTIALLY OCCLUDED CIRCULAR MARKERS

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Abstract: In this paper we present a pipeline for the robust detection of partially occluded circular markers. Compared to square markers, occluded circular tags can be tracked in a more robust way, since the camera pose is in this case computed from the whole contour instead of only the four corners. We introduce a new ellipse detection technique based on a constrained RANSAC algorithm and pre-ellipse fit outlier removal to detect tag candidates with damaged borders. Digital codes are used to identify the actual markers afterwards, since correlation based marker identification approaches are not capable of handling occlusion. The key to error detection and correction is a suitable Reed Solomon code together with a proper code layout on the marker. We show that markers covered up to 30% can be detected, our tracker moreover has a very low risk of false positive marker detection.

1 INTRODUCTION

In the context of computer vision and augmented reality, markers can be used to provide easily detectable visual cues for e.g. robot navigation (Sattar et al., 2007), indoor tracking (Naimark and Foxlin, 2002), marking important or interesting points in 2D/3D, and defining coordinate systems for placing augmentations (Fiala, 2004). The tags should be detectable within a certain distance to the camera and even in a simple, “tidy” scenario an object can quickly get between the camera and the tag, covering parts of it. Successful detection under partial occlusion is therefore an important use case (Figure 1). Most of the existing marker systems either use square- and/or circular markers. We believe that circular tags provide a higher robustness to occlusion, since the camera pose used for accessing the marker content can be computed from the whole elliptic contour. In case of square markers, the pose computation relies only on the four vertices. The tag can not be detected anymore as soon as a whole edge is covered, whereas the ellipse-shaped contour resulting from a circle still contains enough information to obtain a good pose estimation. The ellipse resulting from the perspective projection of the marker however yields two possible poses only one of which is correct. We use the error detection capabilities of the marker code to retrieve the correct pose, since the code cannot be read

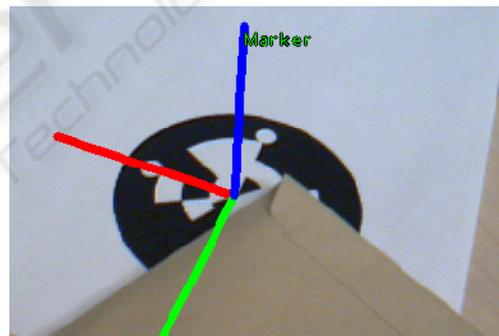


Figure 1: The successful identification of an occluded marker is visualized by rendering the coordinate frame it defines.

correctly from the wrong pose for most angles. Circular markers additionally need special features for determining their orientation, which is not naturally induced by the tag’s shape as it is the case with square markers. We address the degenerated ellipse contours resulting from occlusion with a RANSAC-based ellipse fitting technique that allows for successful fitting even if the ellipse’s contour contains large damages.

We assume that a total amount of 255 markers is sufficient for most AR applications and use a non-redundant digital ID composed of 8 bits on our markers together with a suitable Reed Solomon (“RS” in the following) code (Moon, 2005) for error correction and a CRC code for error detection, inspired by

ARTag (Fiala, 2004). Since RS codes are symbol oriented polynomial codes, we recommend a construction of the code over a small field, such that symbol-chunks on the marker do not contain too many bits. We also optimize the code to maximize the error correction capabilities.

The remainder of this paper is organized as follows: Section 2 reviews marker tracking and ellipse fitting approaches. Sections 3 and 4 cover error tolerant ellipse fitting and digital marker identification, the essentials of our processing pipeline. We finally conclude with an outlook to future work.

2 RELATED WORK

Robustness characteristics for a marker tracker have already been discussed in the context of the ARTag square marker system (Fiala, 2004): It should provide low false positive/ negative detection rates as well as not confuse the markers with each other. It was pointed out that correlation based marker tracking systems like the popular ARToolkit (Kato and Billinghurst, 2000) will not perform well in these areas, therefore ARTag made use of digital codes. Correlation based trackers are also not able to handle occlusions robustly, because the “fiducialness” of an observed ellipse is a threshold decision and the correlation measure cannot be used to identify and correct read errors. While ARTag performs well concerning the detection- and confusion rates, the used digital code however is only capable of correcting two bit errors out of 36 bits, which prohibits robust detection under larger occlusions. Other tracking systems also do not address the problem properly. The precise error correction capabilities of CyberCode were not mentioned in (Rekimoto and Ayatsuka, 2000), so we assume they are negligible. The tracker developed by (Naimark and Foxlin, 2002) has no read error protection. In (Sattar et al., 2007) possible protection methods are suggested but the developed system does not attempt to handle occlusions as well.

Our ellipse fitting technique is composed of 3 other methods. (Cai et al., 2004) use a RANSAC based approach which computes a test model from 5 random contour points. They introduced the fitting factor for deciding if the model fits the data well. (Song and Wang, 2007) reduced the amount of contour points to 3 which decreases the amount of needed iterations. Both approaches however did not make use of an error tolerance as it is common in RANSAC. We found out that the fitting factor is occasionally high for a poor fit when the points are chosen randomly and solved this problem using a separation idea found

in (Zhang and Liu, 2005). Other ellipse fitting techniques are either too slow (genetic algorithms, e.g. (Yao et al., 2004)) or can not cope with defects to a desired extend (optimization based approaches, e.g. (Fitzgibbon et al., 1999)).

3 ELLIPSE DETECTION

Ellipses found in an image are the first indicator for the presence of a circular marker. We first detect closed contours in the thresholded, binary input image, which serve as a region of interest (ROI) and narrow the search scope (remark: These ROIs do not necessarily need to be closed, in fact we delete certain parts from them). Our ellipse detection method applied to each of the found contours is based on the method of (Song and Wang, 2007). Their algorithm roughly performs the following steps:

For each input contour do:

1. Select 3 contour points P_1, P_2, P_3 .
2. Compute a tangent T_i at P_i using a least squares fit of a line to the contour points found within a 5×5 -raster around P_i .
3. Compute the potential ellipse center C from the tangents.
4. Compute an ellipse E using C and P_i .
5. Accept E if its fitting factor F is adequate.

We found several problems in this approach. First, no error tolerance was used during the point hit test which slows down the computation. We use a cross-shaped mask allowing an error of 2 pixels in each positive and negative x/y direction.

Second, a 5×5 raster for tangent computation can cause tangent distortions when outliers are captured by the raster. Since our input contours are sequenced, connected pixels, we can use the previous and succeeding pixels with respect to an index for tangent computation for higher robustness.

Third, Ellipses fitting the contour poorly can nevertheless score a high fitting factor. This results from the fact, that the model (test ellipse) is compared against the data (input contour) (refer to (Cai et al., 2004) for details) and not vice versa as it is usually done in a RANSAC algorithm. While sparing the costly computation of the geometric distance of every contour pixel to the test ellipse (see (Forsyth and Ponce, 2003), p.338), this enforces only local fitting in the area covered by the test ellipse. When the randomly chosen tangent indices are close to each other, the resulting test ellipses are often stretched and small



Figure 2: Green: part of the correct ellipse, blue: P_i , red: derived model evaluated in a RANSAC-iteration. It scores a high fitting factor but does not fit the contour well.

and therefore can produce a high fitting factor (Figure 2).

To resolve this problem, we use the tangent separation idea mentioned in (Zhang and Liu, 2005). We enforce it in our approach with the evenly distributed tangent (EDT)-constraint:

$$P_i = P_{i-1} + \left(\left(\frac{1}{3} + x \right) \cdot cs \right) \bmod cs \quad (1)$$

Where $x \in [-0.1..0.1]$ is chosen randomly, cs is the size of the input contour and P_i , $i \in \{2, 3\}$ are point indices referring to the input pixel array. P_1 Is chosen randomly. This assures an appropriate size of the test ellipse.

Our goal is to detect occluded markers. In this scenario the ellipse-shaped contour resulting from the marker border will be broken. When applying a contrast enhancement to the input image, the occlusions cause outlier parts in the form of convexity defects in most cases (Figure 3). To prevent the choice of

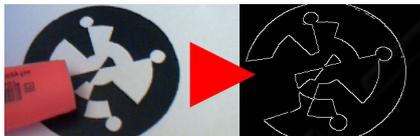


Figure 3: Broken contour caused by occlusion.

tangent indices from outlier parts we remove these defects from the contours. The direct least squares method of (Fitzgibbon et al., 1999) is used to obtain the final ellipses from from the consensus sets.

4 MARKER IDENTIFICATION

Those Ellipses observed in an image that did not originate from a marker must be excluded according to the data found in their interior. To uniformly access this data we hypothesize 2 possible camera poses, following (Chen et al., 2004). The distinction of the 2 poses is described later in this section. We chose a marker identification based upon a digital code, since this provides higher robustness compared to a correlation based identification (Fiala, 2004). Read errors can also be corrected, which is desired in case of occlusions. Our markers carry 32 bits on 3 rings, 12 bits on the 2 outer- and 8 bits on the inner ring. The reasoning for this layout is described at the end

of this section. To uniformly access these bins the marker must first be properly oriented, respectively the unknown camera rotation around the normal vector at the marker's center must be computed. While a square naturally induces 4 possible orientations, a circular marker needs special features for this. We therefore placed 4 spots on the outer marker border to obtain 4 possible orientations (Figure 4). The symmetry of these points guarantees that the rotation can be determined even when other bright spots were found, which is the case under occlusion. The correct among the 4 possible rotations is determined by the decoding properties of the bit sequence read at the respective rotation. Only a single sequence must be allowed to correctly decode. This idea originates from ARTag (Fiala, 2004).

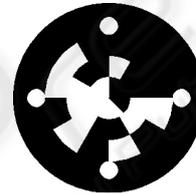


Figure 4: One of our new, digital markers.

Thus our processing steps are similar to ARTag: Read 4 permutations, correct errors (RS stage), accept the code word which passes the CRC check (CRC stage). Because our goal is to find markers under occlusion, the error correction abilities of the code must be significantly higher. To achieve this we use a long FEC- (a Reed Solomon (RS) in our case) and a short CRC code, inversely to ARTag. This is possible since we found that about 55% of all permutations scramble the code word such that the RS code can not recover it. It is discarded after the RS-stage. The CRC-code distinguishes only between the remaining ambiguities and is variable with respect to this objective. Since it cannot be computed analytically (Rice et al., 2004), testing revealed that using the generator polynomial $0x8D$ (CRC-8-CCITT, (Moon, 2005)), no other than the 0-codeword must be excluded for ambiguities. We moreover assume a marker will not carry more than 60 bits and thus construct primitive RS codes over $GF(16) = GF(2^4) = GF(q^m)$. The RS code words then have a maximal symbol length of $n = q^m - 1 = 15$ with 4 bits per symbol. Our FEC-redundancy length is 16 bits = 4 symbols. With standard decoding 2 symbols = 8 bits can be corrected.

In order to obtain valid permutations of the code and therewith predictable decoding results, a bin count divisible by 4 is necessary for each ring as illustrated in Figure 5. When this is not the case, invalid bins are sampled and we can not be sure of the

obtained value. For these reasons the final code used on our markers is 32 bits long, composed of an 8 bit non-redundant ID, an 8 bit CRC code and a 16 bit RS code, stored in 3 rings with 12 bits (outer rings) and 8 bits (innermost ring) (Figure 4). ARTag markers use a 36 bit code with 10 bit ID, 16 bit CRC code and 10 bit FEC code.

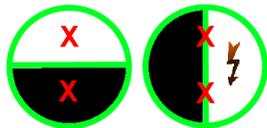


Figure 5: Exemplary innermost code ring, 2 bins. When rotated by 90° the result of the sampling is unclear - the value might oscillate between black and white due to small errors in the pose estimation.

The symbols must be placed on the marker such that they fit to occluding objects well (Figure 6). We therefore distribute the first 6 symbols of a code word (= the first 24 bits) to the outer rings as seen in Figure 6 (right) and the remaining 2 symbols (= 8 bit) on the innermost code ring.

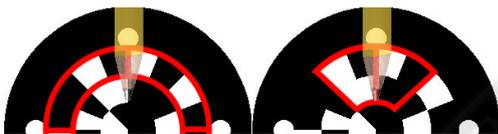


Figure 6: Left: bad layout (2 symbols), recovery not possible. Right: good layout (2 symbols), recovery possible.

After successful identification we use the read error information to distinguish between the 2 pose estimations. We moreover use composites consisting of 2 coplanar markers or 3 markers in different planes. The a priori information of the planes the markers lie in can be used to recompute the camera pose after successful marker identification. For 2 markers we complete the approach that yielded the initial estimation (Chen et al., 2004). For 3 markers in different planes we use the approach found in (Kannala et al., 2006).

5 RESULTS

5.1 Ellipse Detection

We examined a series of intact ellipses with axis sizes from 150:150 to 10:150 pixels. Each ellipse was fitted with a pure random choice of points for tangent computation and our EDT-constraint, 100 times each. The ellipses were always successfully detected. Our EDT-constrained algorithm needs an average of 1.2-1.7 iterations per ellipse compared to an average of 3.0-5.1

iterations of the unconstrained RANSAC algorithm. Both algorithms handle intact ellipses well, the EDT-constraint shows out to be slightly better. The graph depicted in Figure 7 gives a first insight in how the algorithm performs in the presence of defects. A growing defect is added to an ellipse with axis sizes of 75 and 150 pixels. The defect is not removed from the detected contour. The algorithm stops trying to detect the ellipse after 100 iterations, so an amount of 100 iterations corresponds to a failed detection. The fitting factor is set to accept defects up to 40%.

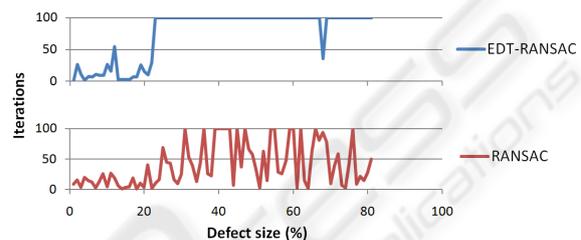


Figure 7: Fitting of an ellipse (axis sizes: 75 and 150 pixel) with a growing defect that is not removed.

We can see that neither the EDT-constrained nor a pure random choice of tangent candidate points produces reliable fits. If the defects are removed however, EDT-RANSAC performs as expected (Figure 8), the ellipse is not detected anymore at a defect size of 40% and a fairly low amount of iterations was needed. With a pure random choice however, RANSAC still detects an ellipse after the defect grew bigger than 40% although the demanded fitting factor can not be scored anymore. This behavior results from the problem described in Section 3 and is not desired.

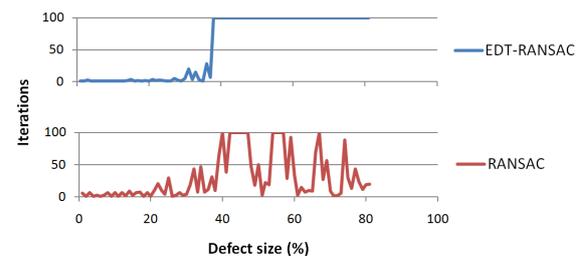


Figure 8: Fitting of an ellipse (axis sizes: 75 and 150 pixel) with a growing defect that is removed, the fitting factor allows a defect of up to 40%. Note the predictable behavior of the EDT-constrained RANSAC in contrast to the false fits detected by the previous RANSAC after the defect is larger than 40%.

Figure 9 shows the maximal defect size that still yields a successful detection with a feasible amount of 15 iterations for a series of ellipses with axis sizes from 150:150 to 20:150 pixels. The fitting factor is set to allow a total defect of 85% for this experi-

ment. When a consensus set was successfully computed from a test ellipse whose axes differed by more than 5% from the known correct ellipse the search is considered as failed (in this case the estimated ellipse would not fit to the contour). When no consensus set was found after 15 iterations the search is also considered as failed. The results are shown in Figure 9. This result shows that using defect removal, our al-

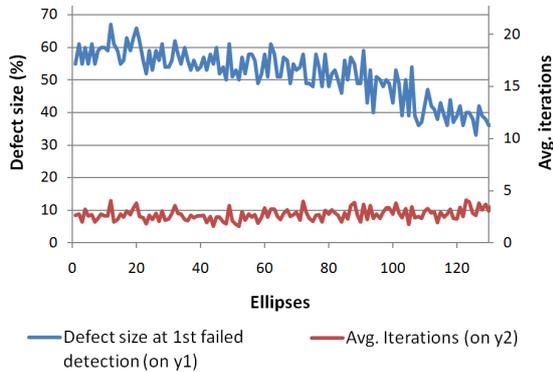


Figure 9: Maximal defect that could not be detected anymore using 15 iterations (blue); Average iterations until first failed detection (red).

gorithm can detect ellipses with large defects of 50% and higher with a fairly low amount of iterations. As a comparison the original P-RANSAC algorithm (Song and Wang, 2007) was used with an amount of 35 iterations to successfully recover ellipses in (Kaewapichai and Kaewtrakulpong, 2008). Compared to this we require only 40% of iterations to obtain good fits.

5.2 Marker Identification

In this section we present the detection rate of our marker tracker and the risk of a false positive marker detection.

The graphs in Figure 10 illustrate the detection rate of our marker tracker, which measures the minimal detectable pattern size. 9 different markers are filmed by a webcam (Microsoft LiveCam VC-6000 1.0) in top view at various distances with a resolution of 640x480. For each distance, the number of detected markers is recorded for a total amount of 20 frames. Division by the expected 180 markers then yields the detection rate. The rate will be plotted as function of minimal marker diameter inside the image. This experiment was accomplished for 9 intact as well as 9 partially covered markers (Figure 10). With both intact and occluded markers we can score a very good detection rate. In case of intact markers the graph has a steep ascend from no to constant detection between 12 and 17 pixels. When all of the 9 markers are partially occluded we obtain a first initial

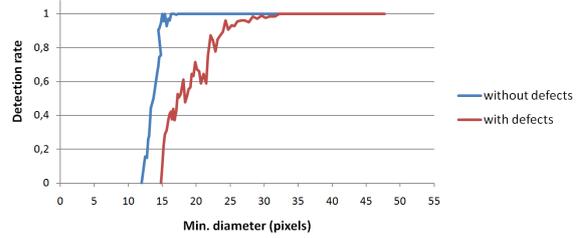


Figure 10: Detection rate for intact and covered markers.

detection at a tag size of 15 pixel and constant detection at a size of 32 pixel, this means damaged tags need to be approximately twice as big. The detection rates for intact markers of ARTag and ARToolkit are taken from (Fiala, 2004), p.32-35 for several camera types. The tag-size intervals from a first initial- to constant detection are found in Table 1. Although dif-

Table 1: Marker size intervals from initial to constant detection for ARTag and ARToolkit. A: Greyscale PGR Dragonfly 640x480, B: Color PGR Dragonfly 640x480, C: Intel Pro 640x480 webcam. “+” in case of ARToolkit means the value can be higher, depending on the confidence factor (c.f.) used. Refer to (Fiala, 2004) for more details.

-	A	B	C
ARTag	11-16	15-20	13-25
ARToolkit	10-30+	10-55+	15-26+

ferent camera types were used, it is obvious that the detection rate of our markers can compete with these results well. In case of intact markers we can score almost the same detection rate with our webcam as ARTag with the high-quality PGR Dragonfly camera. When the markers are occluded, our detection rate is slightly worse but still close to non-occluded ARTag markers and much better than ARToolkit, which is not able to handle occlusions of any kind.

The risk for a false positive marker detection is 0.0039% (Fiala, 2005) in case of ARTag. With higher error correction capabilities this risk grows since more false words are mapped to a correct code word. The risk in case of our markers is computed with equation 2.

$$\frac{(1 + \binom{8}{1} \cdot n + \binom{8}{2} \cdot n^2) \cdot (4 \cdot 255)}{2^{32}} = 0.153\% \quad (2)$$

where $n = \sum_{i=1}^4 \binom{4}{i} = 15$ are the possibilities to corrupt a 4 bit symbol. Although almost 40 times higher than in ARTag, this risk is still fairly low. In fact even a much higher risk does not yet pose a problem since the actual probability for a marker pattern to appear in a scene by chance is not involved in these considerations.

6 CONCLUSIONS AND FUTURE WORK

We presented a pipeline for the robust detection of circular markers. To accomplish this we use an error tolerant ellipse detection algorithm as well as error correcting codes together with a robust design of the marker. The RANSAC-based ellipse fitting algorithm is able to detect ellipses with defects $> 50\%$ with a fairly low amount of iterations. This is accomplished by pre ellipse fit removal of convexity defects from contour candidates and the use of the EDT-constraint. In the future this algorithm can be extended to robustly handle outward errors of the ellipses and occlusions that do not cause convexity defects, but lines.

The occlusion of the marker must also be handled after the successful fitting of an ellipse to its contour. We therefore introduced a robust, occlusion-tolerating rotation indicator. Error correcting Reed Solomon codes are used together with error detecting CRC codes to find and correct read errors caused by occlusions and to obtain the correct orientation and pose. Other than in ARTag, our goal was to minimize the code for a better readability, yet maintaining a high error correction rate. For this reason we also used the error detection features of the actual error correcting Reed Solomon code to filter out bad marker orientations. We found that more than half of all possible marker-rotation caused permutations of all possible codes can be filtered out in this way, allowing the use of a shorter CRC code. Compared to ARTag, our code therefore can correct up to 8 bit errors instead of 2 and the CRC generator polynomial has half the size. Thus approximately 30% of it can be covered. The risk of a false positive detection is nevertheless very low. In the future the markers can be extended with the more sophisticated erasure decoding method for the Reed Solomon codes to double the amount of corrected errors.

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