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Errors and Mistakes in Automated Player Tracking *

Janez Perš[1], Marta Bon[2], and Stanislav Kovačič[1]

[1] Faculty of Electrical Engineering,
University of Ljubljana
Tržaška 25, SI-1000 Ljubljana, Slovenija
{janez.pers},{stanislav.kovacic}@fe.uni-lj.si,
WWW home page: http://vision.fe.uni-lj.si

[2] Faculty of Sport,
University of Ljubljana
Gortanova 22, SI-1000 Ljubljana, Slovenija
marta.bon@sp.uni-lj.si

Abstract This paper examines errors, which can affect the accuracy of computer vision based people tracker. After a successful development of an automated player tracking system for use in team sports, the set of experiments was designed to investigate its accuracy. The authors take advantage of the controlled environment they use to obtain the "ground truth" information. This information is used to measure the accuracy of the tracking system. The results obtained are analyzed, and conclusions, including specification of the overall tracker accuracy, are given.

1 Introduction

Use of computers in gathering and analyzing the sport data is an established practice in sport science [1,2]. One of important aspects of football, handball or basketball match analysis is the information about player movement [3]. To address the problem of computer-assisted acqisition of player trajectories during the handball match, an automated player tracking system using video recordings [4,5] has been developed in our laboratory in collaboration with the Faculty of Sports at the University of Ljubljana. As the development is nearly complete, a request from sport scientists for throughout verification of the system has been made, before the system will be put to routine use.

The research in the fields of people tracking and analysis of sports-related video has flourished in past several years [6,7,8,9,10]. However, the emphasis is still on development of tracking methods and improvement of reliability of the tracking itself. Only a few authors (for example [10]) examined the accuracy of their tracking systems.

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This paper is organized as follows: first, the main sources and types of errors in video-based automated tracking are presented. Next, several parameters which have influence on tracker accuracy are described. Four experiments designed to evaluate the influence of different parameters on overall tracker accuracy are described and hypotheses about their influence are given. Then, results are presented and finally some conclusions about overall accuracy of the system are drawn.

2 Sources and types of errors

There are several sources of errors that can influence the overall accuracy of the tracking. The input of our system consists of video recordings of the match, and the results are spatio-temporal trajectories of the players. The influence of errors on tracking process in shown in Fig. 1.

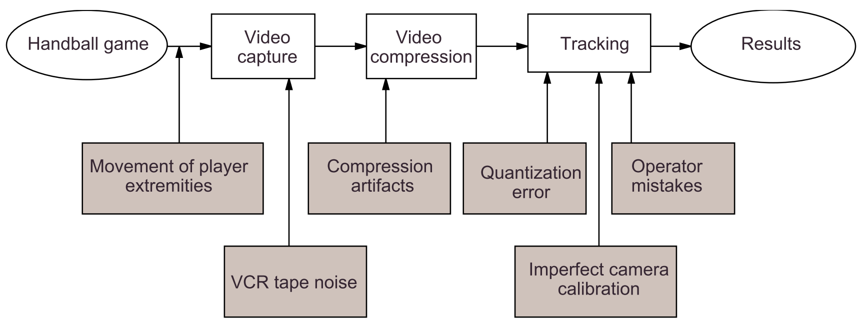

Figure 1. The tracking process in detail. Gray boxes represent sources of errors.

Errors have been grouped into the following categories:

• **Movement of player extremities.** We track *global movement* of the handball players in the court plane. Ideally, their acquired positions would not change, unless they walk or run from one point to another. But, due to the limitation of our setup (we are observing a large 3D space and assuming 2D motion) their acquired positions change due to movement of their extremities and their vertical movement. This effect is categorized as an error of our tracking system.

• **VCR tape noise and compression artifacts** degrade image quality. There are several thresholds built into our tracking system, and in some cases the "decision" taken by our tracking system can be influenced by such artifacts.

• **Quantization error.** Due to severe radial distortion of our input images, the quantization error becomes significant at locations near the court boundaries. Fig. 2 illustrates the problem of radial distortion and non-uniform quantization. Assuming the input image resolution of 384-by-288 pixels, one pixel near the optical axis of camera covers the area of 4-by-4 centimeters in our setup. At the court corners, one pixel covers the area of 20-by-20 centimeters.

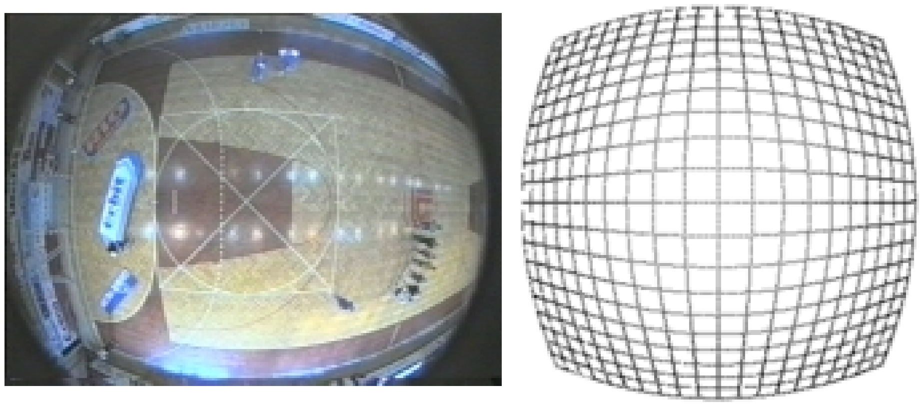

Figure 2. Effect of the radial distortion on the quantization error. Left: acquired image. Right: transformation of the 1-by-1 meter grid on the court plane to the camera sensor.

• **Imperfect camera calibration.** Camera calibration is a difficult task in the case of significant radial distortion. It involves obtaining both the parameters of the non-linear radial distortion model and the parameters of the linear transformation from the court plane to the image plane. In our case, no special calibration grid was used, and calibration was done entirely with a help of court boundary lines and other marks already present on the court.

• **Operator mistakes.** The developed tracking system needs human operator supervision. Although capable of tracking players autonomously through several seconds of the match, it needs a certain amount of human operator interventions to maintain error-free tracking [4,5]. It is up to operator to stay alerted during the tracking process and to intervene when intervention is needed, otherwise the results, provided by the tracker, will not be accurate. In the rest of this paper we will assume that results of the tracking were acquired *without* operator mistakes.

Following an established categorization of measuring errors to random and systematic [11], the movements of player extremities, tape noise, compression artifacts and quantization error can be classified as *random* errors. On the other hand, imperfect camera calibration is *systematic* in its nature (and could be measured and compensated for, provided there would be a strong need for such compensation).

Influences of above described errors can be combined in certain situations (for example, movement of player extremities near the court boundaries will be more significant due to a larger quantization error than similar movement near the court center). Thorough analysis of error propagation would be complicated in our case. Therefore, the decision has been made to plan and perform a series of experiments to measure the overall uncertainty of the tracking system instead of a deeper theoretical analysis.

3 Tracking parameters

The performance of the tracking system depends on several variables:

• **Tracking method used.** The tracker can use one of the three methods to obtain position of the players [4,5]. In this paper, we tested only two of them: Image subtraction from image of the empty playing court (this method will be referred to as "method A"), and the combination of color and template tracking algorithms (method B). Preliminary tests have shown that these two methods contain acceptable amount of jitter.

• **Position of the players.** Due to radial distortion, and subsequently larger quantization error in remote parts of the playing court, the position of the players which are near the court boundaries will be acquired with less precision than the position of players directly underneath the camera.

• **Activity of the players.** Due to movement of the player extremities during the various activities that are part of the game, acquired positions of those players may be less accurate that the positions of the players that are not performing such activities.

• **Post-processing of trajectories.** To reduce jitter, which is always present in the output trajectories of any tracking method, different filters may be used. The application of a particular filter to the player trajectory may affect the results of trajectory analysis - for example, player velocity and trajectory length.

4 Experiments

It is obvious that the possible combinations of variables that affect the performance of a tracking system form a large multi-dimensional space and it is impossible to explore it in full detail. Therefore, experiments examined several directions in that space: the influence of different tracking methods, the influence of various player activities to the method that performed best in the first test and influence of different trajectory filters to the results obtained with the best-performing method. Additional experiments were performed to get an insight into the accuracy of the results, which are usually derived from player trajectories - player velocity and trajectory length.

4.1 Ground truth

To make verification of the tracking system possible, a reliable reference in terms of player position is needed. Before the experiments were performed, several patterns were drawn on the playing court. Patterns were exactly measured with the measuring tape, and served as ground truth in all but the last experiment. Patterns are shown on Fig. 3 and can be also observed on the Fig. 2 (left).

The last experiment was designed to compare our tracking system to the manual video-based three-dimensional tracking system (Ariel Performance Analysis System - APAS) [2], widely used by sport scientists at the Faculty of Sports

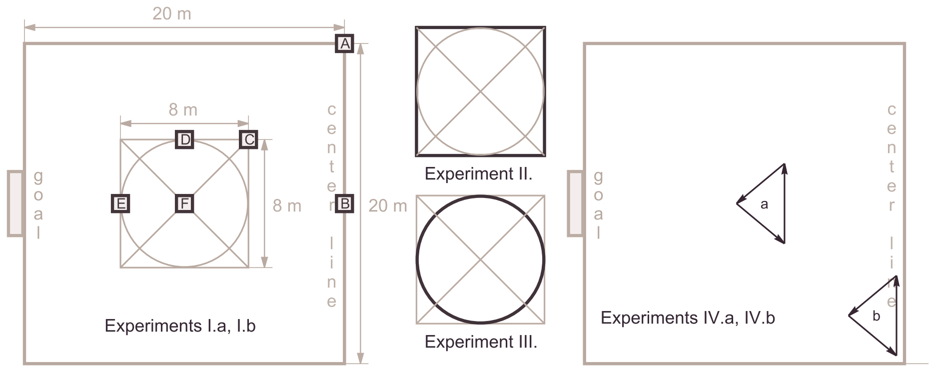

Figure 3. Setup for experiments I.-IV. on the one half of the handball court. Left: player positions during the experiment I. are marked with black boxes and labeled "A" through "F". Middle: Reference player trajectories for experiments II. and III, shown with thick lines. Right: Approximate player trajectories for the experiment IV.

of University of Ljubljana. APAS output served as the ground truth in that experiment.

Although two cameras are used in tracking players during the match (each camera covers its half of the playing court), the experiments were performed using only one camera, observing just one half of the playing court. Due to the symmetry of the court, the results can be generalized.

4.2 Experiment I.

The purpose of this experiment was to evaluate the influence of different tracking methods to the jitter in output trajectories. The setup is shown in Fig. 3 (left). Six players, marked "A" through "F", were instructed to stay at the marked spots. Two players ("A" and "B") were placed to the remote spots, far from the optical axis of the camera, the others were staying near the center of the court half. Experiment was split into two parts:

In the **first** part of experiment (I. a), players were instructed to stand still for 60 seconds. In the **second** part of experiment (I. b), players were instructed to perform various activities *without* leaving their designated position for 180 seconds. The activities included jumping, waving, passing ball and similar. We tested the following hypotheses during this experiment:

Hypothesis 1 *Use of different tracking methods results in different amount of jitter in resulting trajectories.*

Hypothesis 2 *Trajectories of the players placed far from the optical axis of a camera contain more jitter than trajectories of players, placed near the optical axis.*

Hypothesis 3 *Jitter in player trajectory increases if the player is actively participating in the various actions that are part of the game.*

Hypothesis 4 *Amount of jitter in the trajectory can be reduced by means of trajectory filtering.*

The following quantities were used in analysis of the results of experiment I.: Root Mean Square (RMS) error in player position, trajectory length and mean player velocity.

4.3 Experiment II.

The purpose of this experiment was to evaluate the effect of trajectory filtering to the accuracy of player position, when player is in motion. Five players were instructed to move below the camera, exactly following the square pattern, drawn on the court. The square pattern is shown in Fig. 3 (upper-middle).

Hypothesis 5 *Intense filtering will distort player trajectories, especially when rapid changes in player direction are present.*

To analyze distortion of trajectories, we analyzed RMS radial distance from acquired player position to the square, drawn on the court.

4.4 Experiment III.

The purpose of this experiment was to evaluate the effect of trajectory filtering to the accuracy of player velocity, which is calculated from player trajectory. Five players were instructed to move with constant velocity under the camera, exactly following the circular pattern, drawn on the court. The circle pattern is shown in Fig. 3 (lower-middle). Mean velocity was used as a ground truth and was calculated from the time players needed to complete one round and from the length of the circular path.

Hypothesis 6 *If players are moving with constant velocity, the maximum difference between their velocity and calculated mean velocity would be small.*

Hypothesis 7 *The maximum difference between players velocity and calculated mean velocity will be affected by trajectory filtering.*

To evaluate results of this experiment, we analyzed RMS velocity error and RMS radial distance from the players to the circular trajectory.

4.5 Experiment IV.

The purpose of this experiment was to compare our tracking system to the APAS system, using it as the ground truth. Since the motion analysis using APAS is extremely time consuming, only two tests with duration of 3 seconds were done. Single player was instructed to run around three markers on the playing court. The two triangular patterns are shown in Fig. 3 (right).

Hypothesis 8 *It is possible to infer planar components of the 3D motion from the 2D image, captured using single camera.*

To evaluate results of this experiment, we analyzed RMS velocity error and path length error.

5 Results

5.1 Experiment I.

Fig. 4 shows results, obtained from *unfiltered* player trajectories in first experiment. Results of experiment I. are grouped according to player position: two players were assigned positions near the court boundary, the other four near the optical axis of camera. The measurements near court boundaries are less accurate than those in court center, as expected. Clearly, method B performed better than method A in every aspect. It produces more accurate measurements, less jitter (shorter trajectory length in case of stationary player) and subsequently allows for more accurate velocity calculation. However, it can be seen that some kind of trajectory filtering is necessary. We can also conclude that player activities adversely affect accuracy of measurements.

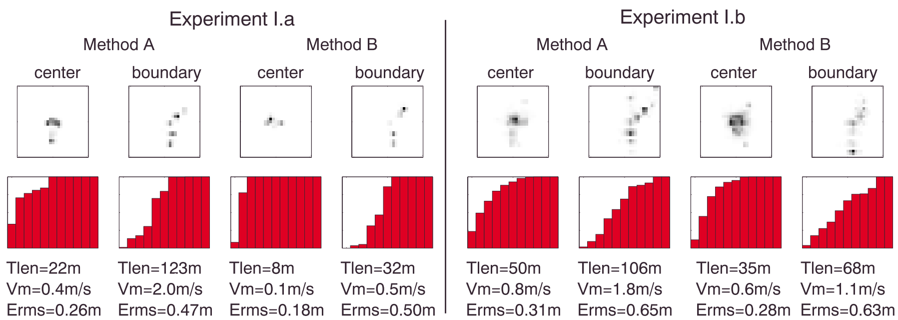

Figure 4. Top row: Scatter of measurements on area 2-by-2 meters, surrounding the expected player position. Second row: Cumulative histograms of absolute error in player position. Bin width was set to 10 cm. Bottom row: parameters, calculated from player trajectories: trajectory length per player per minute (Tlen), mean of absolute velocity (Vm) and RMS error in player position (Erms). Smaller values indicate better performance, as players were standing on the same spot all the time.

The effect of trajectory filtering to player position accuracy, trajectory length and player velocity was also evaluated. Although we performed this evaluation only on the set of data obtained by method B, the results can be generalized to both methods.

Trajectory filtering (smoothing) was done in post-processing phase, after a complete trajectory was obtained. A FIR filter with no time delay was used in x and y direction separately, as described in [5,12]. Filter coefficients were calculated from gaussian function, spanning from -3σ to 3σ. Width of the filter (5, 11, 25 or 51 samples) [1] is directly related to the intensity of filtering - wider filter yields smoother trajectories. Results are shown in Fig. 5. It can be observed that filter width played almost no role in position accuracy. On the other hand, filtering significantly reduces jitter that inflates trajectory length. From this point of view, wide filter is preferred for accurate measurements.

[1] Tracker outputs raw trajectory data at 25 samples per second.

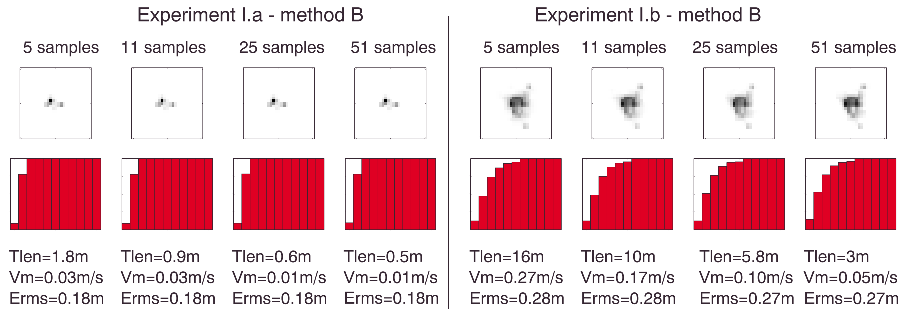

Figure 5. Effects of trajectory filtering, depending on filter width. See also Fig. 4 for the explanation of graphs. The results for players standing near the court boundaries are not shown due to the lack of space.

5.2 Experiment II.

Generalization of trajectory filtering results to a moving player is not straightforward. Preliminary tests have shown that wide filter will over-smooth the trajectory and hide the rapid changes in direction of fast moving players.

We simulated the rapid changes in player direction with the square trajectory, drawn on the court. Players were supposed to run over it and follow it exactly. From video recordings it was obvious that some failed to do so, and the results for those were discarded. For the rest five players, we calculated RMS radial difference $D_r = \sqrt{\frac{1}{n}\sum_{i=1}^{n} |d_i|^2}$ between the square and the resulting trajectories, processed using different filters. Trajectories of five players were linked together before analysis and n denotes total number of samples at a sampling rate of 25 samples per second. Trajectory distortion is illustrated in Fig. 6.

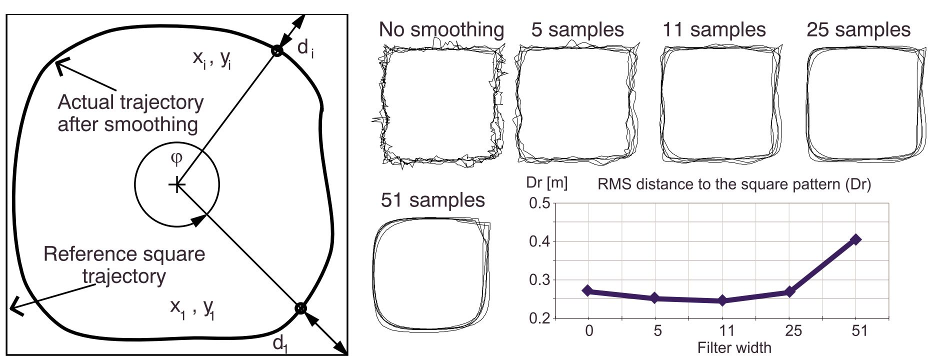

Figure 6. Left: evaluation of trajectory distortion due to filtering. Right: Effect of different filter width to square trajectory and to RMS radial difference D_r.

It can be again observed that trajectory filtering reduces jitter in trajectory. However, using wide filter introduces distortion of trajectory in its "corners", where players made 90 degree turns. As the diagram in Fig. 6 shows, conservative smoothing slightly improves accuracy. Increase in filter width proves beneficial up to certain extent, where the distance D_r rises dramatically, indicating severe distortion of the trajectory. Based on these results, filter width of 11 samples seems optimal. However, differences between results obtained using 5, 11 and 25 samples wide filter are small.

5.3 Experiment III.

Setup for this experiment is explained in section 4.4 and shown in Fig. 3. The results were processed using a 12 and 25 sample wide filters, as they performed best in experiments I. and II. Separate results for each player are shown in Table 1. Results are consistent with previous experiments.

	11 samples wide filter					25 samples wide filter				
Player	A	B	C	D	E	A	B	C	D	E
D_r [m]	0.15	0.16	0.26	0.16	0.16	0.18	0.18	0.30	0.15	0.24
V_{ref} [m/s]	2.69	2.79	3.19	2.90	3.22	2.69	2.79	3.19	2.90	3.22
$V_{error}[m/s]$	0.30	0.35	0.21	0.28	0.24	0.15	0.19	0.18	0.07	0.20
V_{error} (%)	11%	12%	6.4%	9.5%	7.4%	5.7%	6.8%	5.7%	2.41%	6.19%

Table 1. Results of the experiment III. D_r - RMS radius difference between the player position and circular trajectory. V_{ref} - reference player velocity, obtained from time players needed to complete one round and the length of the reference circular trajectory. V_{error} - RMS error of measured velocity.

It is obvious that players were unable to move with *exactly* the same velocity during the whole round. Part of velocity variation can be attributed to the players themselves. Therefore, the accuracy of the tracker is as specified in Table 1 or better.

5.4 Experiment IV. a, b

The setup for this experiment is shown in Fig. 3 as well. Tracking was performed using method "A" to get the estimation of the worst case errors that are possible in the use of our system. The resulting trajectories were post-processed using 11 samples wide filter and compared to the output of the APAS system. Results are shown in Figure 7.

Errors in player position are consistent with previous experiments. However, measurements of player velocity seem inaccurate, when compared to the APAS output. The trajectories, obtained using APAS are calculated from numerous trajectories which describe motion of several body parts, and are far less filtered than trajectories, obtained using our tracking system. Therefore, velocity graph, obtained using APAS (Fig. 7, dotted line) shows changes in velocity due to

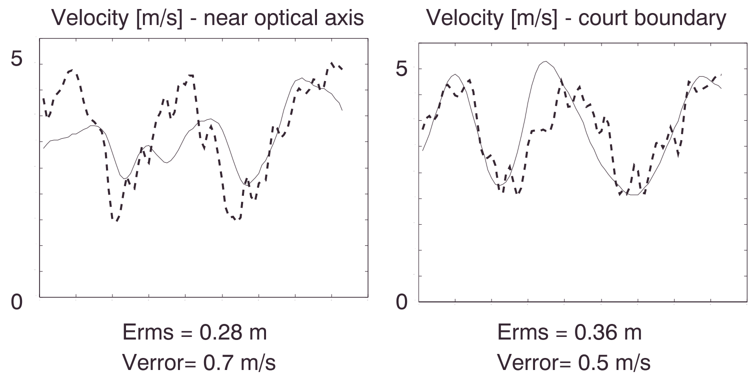

Figure 7. Results of the experiment IV. E_{rms} - RMS error in player position, V_{error} - RMS error in player velocity. Solid line - calculated velocity. Dotted line - velocity provided by APAS.

movement of player extremities - the feature that our system intentionally tries to avoid using heavy trajectory smoothing. This difference between our tracking system and APAS is especially noticeable, when observing acceleration graphs, shown in Fig. 8. Player acceleration was derived from velocity data, shown in Fig. 7 by simple differentiation $a = \frac{\triangle v}{\triangle t}$.

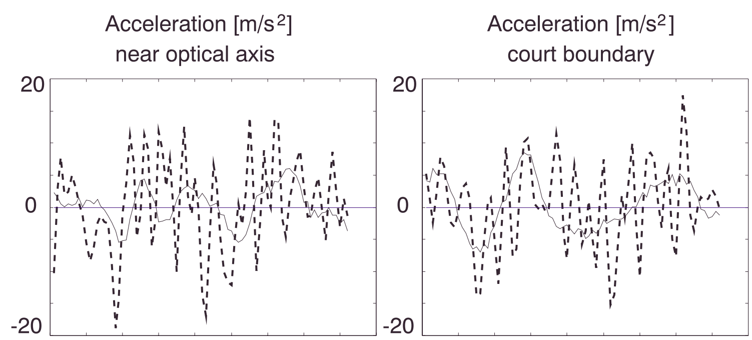

Figure 8. Player acceleration, calculated from velocity data, shown in Fig. 7. Solid line - acceleration, calculated by our tracking system. Dotted line - acceleration derived from velocity data, provided by APAS.

The difference between these results can be explained. It is clear that results, obtained by both systems describe actual motion of the player, but each one with different level of detail. Human body model used in APAS results in accurate description of acceleration of player's centre of gravity due to movement of his extremities and it is useful in applications where such level of detail is desired. Our system however works on a larger scale - acceleration graph, obtained by our system, shows the motion of the player in context of his movement across the court plane. That is, player accelerates after he changed his direction and decelerates when it is approaching the marker which requires him to make another turn to follow the marked trajectory. In context of a handball game analysis, the larger scale approach is more important, as it gives more information about actual gameplay.

6 Conclusion

Results, obtained by experiments I.-IV. confirmed hypotheses, set in section 4. These results can be summarized to give detailed specification of tracker accuracy, shown in Table 2. Effort has been made to examine the worst case scenarios - therefore the worst measurements were used, when available. However, we did not explore every parameter, which could influence accuracy. For example, accuracy analysis for players, moving at high speed has not been performed (and we are confident that it would be extremely difficult to do so, due to inability of human body to control its position and velocity at a high speed). Many other parameters that *could* affect the accuracy of the tracking were also not examined (for example the different lens selection and different types of illumination).

Recommended method:	Method "B"	
Recommended filter width:	11 or 25 samples	
Accuracy using:	11 samples wide filter	25 samples wide filter
Position, still player:	0.2 (0.5) m RMS	0.2 (0.5) m RMS
Position, active player:	0.3 (0.6) m RMS	0.3 (0.6) m RMS
Velocity, uniform motion:	0.4 m/s RMS	0.2 m/s RMS
Velocity, uniform motion (%)	12%	7%
Path length, still player:	+0.9 m/min	+0.6 m/min
Path length, active player:	+10 m/min	+6 m/min

Table 2. Tracker accuracy. Numbers in parentheses indicate accuracy for player position near the court boundary.

We are confident that the obtained accuracy does not hit the limits of our tracking system, but rather the limits of possible definition of player position, velocity and path length itself. This is especially evident from the results of the experiment IV.

From computer vision point of view, the handball players are large, non rigid objects and in many cases reporting player position with uncertainty as low as shown in Table 2 does not make any sense. We are aware that it would be possible to further increase the level of detail which our tracker acquires, by use of more sophisticated filtering, use of high-resolution, high-speed cameras, by increasing the number of cameras and similar enhancements to our initial setup, which would significantly raise the cost and complexity of the whole system.

The initial goal in our research was the development of the tracking system, capable of acquiring *global* motion of players across court plane during the handball game for the purpose of gameplay analysis. Developed system does satisfy these requirements.

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