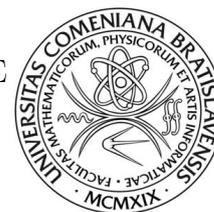




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Autoreferát dizertačnej práce

INTERACTIVE VIDEO FOR VIRTUAL ENVIRONMENTS

na získanie akademického titulu philosophiae doctor
v odbore doktorandského štúdia: 9.1.7 Geometria a topológia

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Dizertačná práca bola vypracovaná v dennej forme doktorandského štúdia na Katedre algebry, geometrie a didaktiky matematiky, Fakulty matematiky, fyziky a informatiky Univerzity Komenského v Bratislave.

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Oponenti:
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Obhajoba dizertačnej práce sa koná o h
pred komisiou pre obhajobu dizertačnej práce v odbore doktorandského štúdia vy-
menovanou predsedom odborovej komisie

9.1.7 Geometria a topológia

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Interactive video for virtual environments

1 Introduction

In these days more and more museums and galleries use World Wide Web for presenting their exhibitions or work. Most of web presentation consists of certain text, images and also some multimedia elements such as video or audio. Our goal is to provide presentation tool based on video to present cultural heritage, therefore our work is mostly oriented on virtual museums and galleries, but the solution we propose might be used in every virtual environment.

The simplest way to present a visual cultural or historical object is by using a photo gallery. However, for this purpose, pictures has some disadvantages. Firstly, they are static without any interaction and secondly they have only small angles of view. On the other hand, the advantage of using pictures and photo galleries as a presentation tool is that they do not take a lot of space and bandwidth. This type of presentation is used by many museums e.g. [Leo05] or virtual cities such as Rome [Ita11]. A more advanced way of presentation the exhibitions is to create panorama photos or object panoramas. The visitor can rotate his view or the object itself, so there is also interaction, but it is still an image. We can also find panoramas on the web pages of museum , e.g. [Mus11] and [Vir09].

On the other hand, we can create 3D models of objects for the presentation in the museum and also create a virtual walkthrough around them. This type of presentation is interactive and visitors can move and rotate the objects. However, it takes a lot of time and effort to create realistic model, because some of the historical objects are very complex. On the other hand we can reconstruct also objects which were destroyed or damaged. Then the visitor gets the idea how the object looked before damage. 3D models as a presentation of museum is used, e.g. in [FBF⁺07] or [Mus11].

Another way how to present a museum or a gallery is to show a video tour around the exhibition. The author or curator of the exhibition can present its most interesting parts. This type of presentation is dynamic and mostly the visitor can control it by using standard elements like Rewind or Fast forward. Although the visitor can control the walkthrough and jump from one position in video file to another, he is not as free as in virtual 3D space. Majority of the videos has also an audio track, which can be for example some commentary, sound or music.

2 Goal and tasks

The goal of our work was to propose and create an interactive system for virtual environment with cultural heritage based on video playback with real content extended by the virtual objects. The users should have the opportunity to interact with this objects and choose their own walkthrough. We can define four main tasks to achieve proposed goal. The first task is to create interactive system based on video. The second task is to represent the camera positions and object positions in form of parametric curve to decrease the needed memory. The next task is to propose a solution for two or more way video for video walkthrough. The last task is to create an augmented reality for this video by extending the content with virtual objects.

To test our work we created multiple video sequences in different settings. The global solution was tested on a case study consisted of three videos from the faculty, where we demonstrated the non-linearity of the walkthrough. For the testing of our results we used quantitative research, in which we asked questions about the interface and the number of test subjects is larger than the in qualitative testing.

3 Background and related work

First, we define important terms for our work and also we mention work which is related to ours. Also we discuss background for interaction and camera parameters to better understand our algorithm.

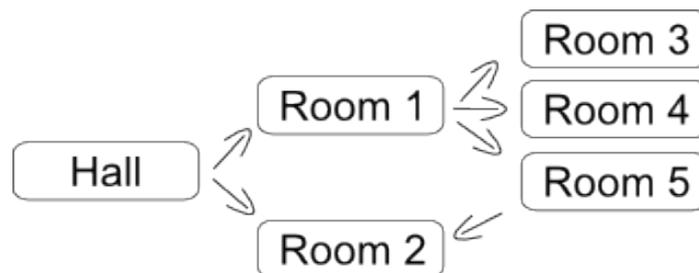


Figure 1: Non-linear video scheme organized into an oriented graph.

The first term we have to define is **object**, because we use this term to represent already captured object, so it is an object within the video. The **object representation** is an virtual representation of an object, for example bounding box. Last important term is **non-linear video**, which is a set of video files. This video sequences are organized into oriented graph as you can see on fig. 1. As the fig. 1

shows we have video sequence for hall, and for rooms 1 to n. At the end of the hall visitor can decide where he will continue his visit. Therefore the visitor has choice how to continue, If he choose the Room 1, the video which represents Room 1 will be played. At the end he can decide where to continue now.

3.1 Interaction

Our definition of interaction is based on [Qvo01]. From the 21 defined virtual interaction combination is for our case useful just two of them. First the interaction between user and avatar, where we think about user as the visitor of our exhibit and avatar is represented with the graphical user interface. The second interaction is held between user and the objects. In this case we think about interaction between visitor and our object representation.

Basically there are three groups of common interaction elements in standard video players. Firstly, the player has some buttons such as PLAY, PAUSE, STOP and FAST-FORWARD to control the video. Second element is a time line to make a linear jump in video content. This interaction element is linked to time position in video and the user can control the video in 1D space, but the only aspect he controls is time. The last common element is a slider to control the volume of the commentary, sound or music. The standard interaction with video does not provide interaction with the content of the video.

There can be found a lot of research in area of interaction and interactive graphics design. Most of the work is in 3D graphics. The authors of [WW10] presented solution for interaction inside CAVE. Also companies as [Mic10] use interaction with video. They add the advertisements inside the video frame and you can find more information about products. In [CM02] authors from Microsoft presented the Microsoft Kinect as a device to interact with 3D world. We take inspiration from this solution for our video based interaction. But also in 2D world of video and images we can find extended interaction, like in work of Kwiatek and Woolner, who have presented story-telling in images and videos of cultural heritage in [KW09].

3.2 Camera parameters

As we mentioned before our goal is to extract some data from video sequence. We need to get the camera positions from uncelebrated video sequence. This part of our work is some kind of preprocessing and we will use the research of Marc Pollefeys,

mostly the paper [PVG⁺04]. As we will mention much of the terms from this papers and also terms defined in [HZ03], we will explain some of them also here.

The camera capture process is represented by pinhole camera model. In this model is the camera represented by M , 4x3 projective matrix. This matrix represents all the camera parameters, intrinsic and extrinsic. The extrinsic parameters are translation and rotation of camera, so the position and the view vector can be computed. The intrinsic are often written in calibrating matrix. In our work we are focusing on the camera position. We will follow the solution from [PVG⁺04], although we know the calibration matrix.

There are several other researchers, which are solving the problem of structure and motion reconstruction. In work [CPV⁺01] authors added an virtual object inside a video which was not calibrated. In paper [GCHH02] authors propose a solution to calibrate camera if there is no real-time condition.

4 Interactive video

In this part we offer our algorithm to create a video presentation from a non-linear video together with our solution for parametric curve representing the camera position. However, we have to add some additional constrains on the video sequences. Each video sequence we will process has to be continuous in mean of camera position. Therefore the video should not consist of any cuts fade-outs, fade-ins etc. So the camera movement for one sequence should be continuous curve. We also require that the focal length is constant for whole video sequence. In places where the non-linear video is connected the end and the start frame of the next sequence should be similar as much as possible. This condition is only to detect video connections and it is not necessary. It is possible to make the connections also later in the process manually.

We can form the proposed algorithm into followed steps. As an INPUT for our algorithm we have the non-linear video, the ground plan of the building where is the museum and calibration matrix for each video sequence. On the OUTPUT we have virtual walkthrough based on video, ready to be published on Internet. The steps of the algorithm are in algorithm 1.

Algorithm 1 Global algorithm to create video based walkthrough with cultural heritage content using curves to represent camera motion.

INPUT: non-linear video, building ground plan, calibration matrix

OUTPUT: extracted camera positions for all video sequences in non-linear video

- 1: Choose one not processed video from a set of videos in non-linear video.
 - 2: Process the video as follows:
 - 3: **loop**
 - 4: Select two key frames, which are not too similar.
 - 5: Find corresponding points between two key frames.
 - 6: Based on corresponding key frames estimate the fundamental matrix.
 - 7: Add additional frames.
 - 8: With help of calibration matrix get the metric reconstruction.
 - 9: Extract the rotation and translation matrices.
 - 10: Save the camera position points.
 - 11: Save the first and last frame for further processing.
 - 12: **end loop**
 - 13: Determine the best curve which will approximate the camera movements
 - 14: Save the control points for the curve and another information about it
 - 15: Try to connect video with already processed videos with help of saved frames.
 - 16: Repeat the steps for all video sequences.
 - 17: Change curves size and position and rotation according the ground plan (user input needed).
 - 18: Save the recalculated control points into XML structure.
 - 19: Load the structure in video player.
 - 20: Draw the curve and create the interactive element.
-

4.1 Preprocessing

The preprocessing part is based on [PVG⁺04] and [oHB99] and we implemented the algorithm with library OpenCV [Ope13]. First we find the relation between frames when we track feature points in frames, then we get the fundamental matrix. Then we compute projective matrices for selected frames and we create initial frame. After that we update the reconstruction with addition frames. With help of the calibration matrix, which we had as input, we extract essential matrix between two frames and calculate the relative translation between camera positions.

Video sequence connection

Next step is to connect the video sequences, if it is possible. This method will help the author of the video presentation to place the curves inside ground plan. We used

our stored first and last frames of video sequences to compare if the scene is the same. We find the features in last frame of the previous video and we try to track the same points in the second image. If this fail we decided that this two videos are not connected. If we find the correspondence, we compared the vectors direction and length. We assumed that if we are looking on the same scene the vectors will have similar direction and similar length, therefore we count the error function of vectors with different properties. If the error is under a threshold we mark these two videos as continuous.

Curve approximation

From previous steps we have camera positions, which we are going to approximate with a cubic b-spline. We use Gauss's method of least squares implemented in library called GeometricTools [Geo12]. We are looking for minimal amount of control points that will approximate the points with minimal error. That means we set an error function that measures the sum of distances between camera positions and the point on the curve for the same time. In the next step we present the results to the user and he have to arrange the curves into the background. If he is satisfied he could save curves into an XML schema in the form of the control points.

XML schema

All these data and relations are stored in our data model. This is represented by an XML file which is the input for the final video player on web page. The XML stores also the paths to the video files, the path to the ground plan with the size of the image. In the same XML file we stored also another information for video based virtual walkthrough, for example interactive objects in video, or how and when to display metadata. With all these sources we can extend the video. For example we have text information which can be displayed external or internal, internal means in the video player itself and external means near the player in the web page and we are going to display this text in time specified by author.

4.2 Interaction

The main part of our work is to use the extracted camera positions with the previous techniques and use this information to create the element for different interaction with video. With help of the camera position we introduce a new type of interaction based

on camera movement. Therefore the visitor can change his position in walkthrough according to camera position during capture process and not only according to the time as in standard video. This interaction is based on interactive element called *virtual path*, which can be seen on fig. 2. The user is doing the same as the author of the video did. He was changing the position of camera.

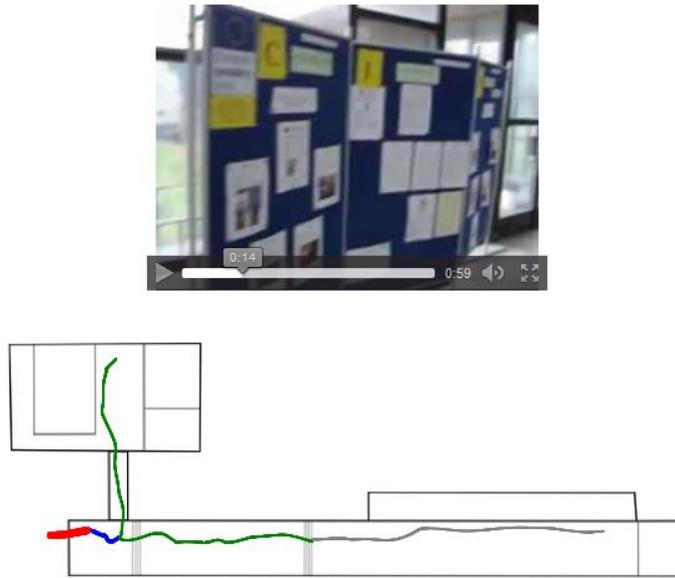


Figure 2: Proposed element called *virtual path* displays the camera positions during the capturing video. This novel approach gives the possibility to change the position in video according the camera position during capturing.

Curve interpretation

In our approach the web based video player loads first the XML file presented before and it prepare objects to represent the camera positions. Then it loads all the camera position parametric curves, which will be displayed in the right position over the ground plan. The curve are also connected with the corresponding video and during the playback it will control the position of the video. The *virtual path* element is therefore a new control element in video player.

With the change of the time in video we also draw over the curve positions we have already seen. If we change the time in video let's say from t_0 to t_1 , where $t_0 < t_1$, we will not draw curve over the camera positions representing this time segment (t_0, t_1) . Fig. 3 represents the highlighted and not highlighted part. Therefore we draw only the past from visitor's point of view and unvisited parts by user are not be highlighted.

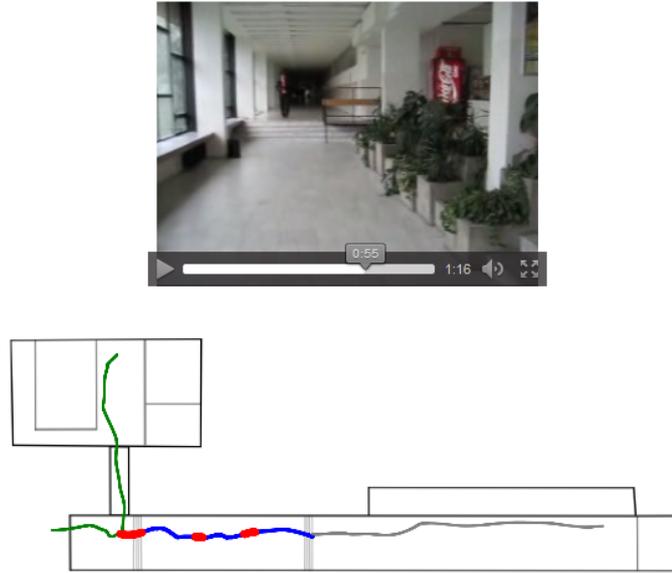


Figure 3: Not visited part in active video (blue), visited part in active video (red).

The active curve is also clickable, therefore the user can select the position he wants to see. The video will change time according the parameter of the selected position. This interaction gives us also the information about actual position inside the museum. If the visitor clicks on a curve, which is not currently active, appropriate video sequence becomes active. Therefore the visitor can also jump from one room to another. With the non-linear video, where the user can select his next step from more than one video sequences, we presented a novel approach to interaction with video.

Video connection

At the end of the video sequence we also display arrows to continue watching the exhibition if there is connected video sequence. For example from the fig 1 at the end of the hall video sequence our video player will display two arrows to continue to room 1 and room 2. Similar example is on fig. 4 where at the end of the first video, we have arrows representing the direction of following videos.

4.3 Results

The presented solution for interactive video has been tested in two different ways. The first way was the implementation testing, where we use the solution to create the virtual walkthrough based on video. However, this part is based on known algorithms

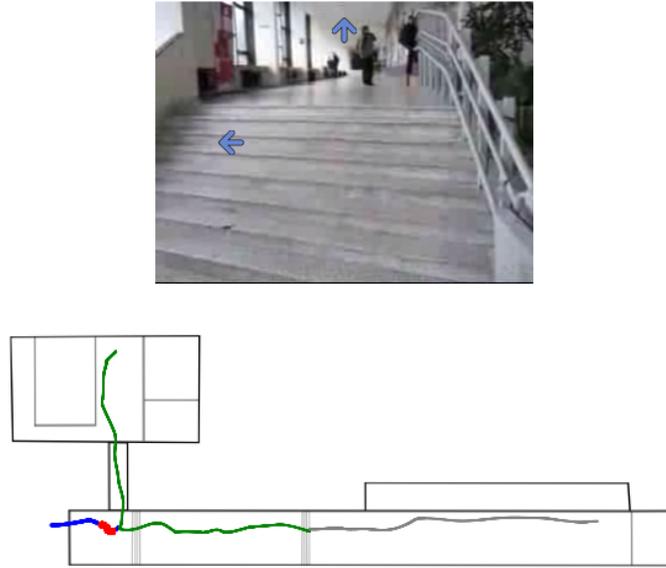


Figure 4: Arrows over video represent connecting video sequences.

and open libraries, therefore we tested the global solution. The preprocessing steps were quite slow, it takes 1 to 2 frames per second to extract the camera positions from the video. But this is not a problem, because the extraction needs to be done just once. The correspondence step and tracking step results were accurate. The fundamental matrix computation had problems if the video have been still between two selected key frames. Therefore, if the fundamental matrix was not found properly, we selected another key frame, until it was found. For the testing solution we used the pre-computed calibration camera matrix.

The process of finding the connection between video sequences gave us also satisfying results. Our algorithm detected over 90 percent positive connections of the testing video sequences. If the algorithm did not find the connection the author can create one manually directly in the XML describing the virtual exhibition.

The main part of testing was based on the user experience with the interface and with the interactive elements provided within our solution. We created a survey, where we presented our case study and we ask the questions about the user experience with interactive video. We got 120 usable answers for the questions. First we ask general questions about gender, age, experiences with virtual museums etc. The second part of the questions were about the user experience with the proposed solution for video based virtual walkthrough divided into interaction with *virtual path* element and the interaction with video connection arrows. For the *virtual path* element we wanted to know if the interface is intuitive and if the control elements are usable. Almost 95%

of all users think that *virtual path* element is intuitive. However, the assumption, that only the visited part of the camera position curve should be highlighted was supported only by 75% of asked users. The rest thinks that we should highlight all camera positions before the actual points. Our conclusion is that some users are used to look at the past in video as the standard time line does, so all positions before the current one are already behind. The change between video sequences was intuitive for more than 95% of users.

The comments from the users suggested, that the blue and red color is not the best option to colorize this element. Also the width of the curves is small and the area where the user can actively click could be wider. Except this suggestion the comments gave us a positive feedback, so our conclusion is that from the user perspective the *virtual path* element can be a good asset for virtual exhibitions based on video, where we can get the camera path and display it on the building or city ground plan.

We also asked questions about the interactive arrows to continue with the exhibition in the selected direction. Almost all (95%) of the responders think that the arrows placed in the video is a useful interactive element. The difference was in the placement of this element. From the comments we get some suggestion, for example to add perspective to this element or rotate the arrows according the actual direction of the following video. Our conclusion from the answers and comments is that also this element increases the experience satisfaction with the player.

4.4 Summary

We proposed our algorithm to create a video based walkthrough from captured video sequences. We limited the sequences, for example they should be without cuts and also the focal length should be constant. We also need calibrated camera so we know the intrinsic camera parameters. We process the video files one by one and create XML file with all information about interactive video. This XML file is then input to our proposed web based video player and displayed as the video itself and the *virtual path* element, displaying the camera positions during the capture. The proposed element is a novel approach for interaction with this kind of virtual walkthrough, where the user is able to change the video position also according the camera position during capturing process and not only according time.

5 Multiple way video

As the non-linear video is organized into oriented graph we can come to a point where all paths end and no new path begins, so the user can only jump to another position and continue from there. In reality this is not possible, but it is not a problem, because in real museum he can move freely. In most of the video based virtual walkthroughs the visitor has strict path to follow and he can only jump forward and backward. However, in our solution we are giving freedom to our visitors and therefore they can choose where to continue. We add another condition for better experience with the exhibition, the multiple way condition:

Each end point of a way is also a beginning of another way or the same way and we can find a loop path in the graph.

We will explain the condition further. For each data segment (room, hall, or street) with two end points A and B, we will have at least two ways. One way from point A to point B and second way from point B to point A. We can also have a segment with only one end point, then we have only one way from point A to point A, but this is a trivial case, when we need only one video with one direction. With the new condition we have to answer how to store video sequences for both ways from point A to B and from B to A and how to represent this on element *virtual path*.

In our work we present five possible solution for this request:

- **Backward playback** – is the solution where we use the same video also for opposite direction. We can capture the video in one direction and then we can also play it backwards from t_{max} to t_0 . However this solution has multiple disadvantages, first the standard compress algorithm like H.264 or MPEG-4 Part 10 [Ric03] are not prepared to run video in the opposite order of frames. And also the human perception can distinguish that the camera is moving backwards. This assumption was confirmed by participants, where all users detected the backward movement.
- **Video panorama** – is a continuous video with wide field of view composed from more separately taken videos from a single viewpoint stitched together [Lac10]. In video panorama the user can rotate his view and therefore if we play the video backwards we can rotate it so that the user will have the experience as he moves forward. However, the problem with order of frames and decompression in reverse order remains. The advantage of this approach is that we have captured

also another parts of the exhibition and the user can have better experience when he can see also artifacts from other positions.

- **Two video tracks** – is the solution based on two video sequences stored in one file. In general, these tracks can have different length and also different position curve. However, we would like to represent both directions with a single curve, if it is possible. Therefore we propose a simple prototype to capture the video for both directions at once. We had two cameras on one line, with opposite view as close as possible. Then we were capturing both videos together, the camera could be rotated freely, but the position of both cameras were still. But with this setting we have to capture all interesting objects long time enough from both cameras. After we have both videos, we have to change the direction of the backward one.
- **Two images** – is similar solution than the previous one, but it stores both way in one video with two frames side by side. This approach is also based on the same settings from previous, where we have two cameras. We capture both videos, then we rearrange the backward video to be in the correct order and then we created a new video with frame of size $2m * n$. This means we created new frame from two frames, that one (from first camera) is next to the second one (from second camera but opposite order). From the case study we can conclude, that this approach is better than the backward playback, but still has some drawbacks, mostly with the blind places when one camera is focusing on the object and the second one is capturing unimportant parts of the scene.
- **Two video files** – is a trivial solution for the two way video problem is to use different video files for each direction of the walkthrough. In this case we will have only that part of the scene captured which we are interesting into. The disadvantage of this approach is that we do not have correlation between this two video sequences. We need for each sequence separate curve representing the camera movement and in case of changing direction we have to change the displayed curve and also we have to compute the correct position in the opposite video sequence.

We implemented **Backward playback**, **Two images** and **Two video files** and for all of this solution we extended the *virtual path* element with arrows representing the current direction of video playback. In every moment during the playback the users have the option to change the direction with the blue arrow in *virtual path* element on fig. 5. The playback will continue in the opposite direction from the

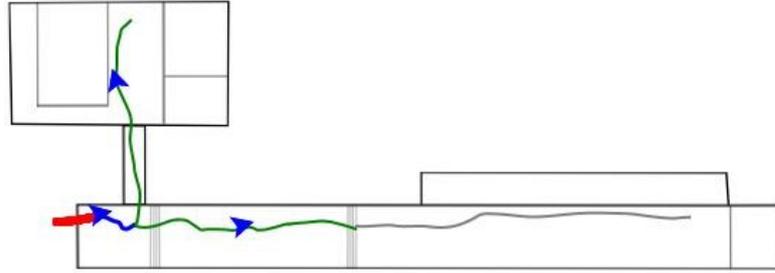


Figure 5: The blue arrows on the *virtual path* element represent the actual direction of the walkthrough.

actual position. With this solution we add another novel element, where the user can return continuously return to previous objects.

5.1 Summary

We have proposed solutions for the problem of two way virtual walkthrough based on video. We state five approaches based on one video file or two files for a segment. From the user study we can conclude, that the best solution is the use of two separate video files, each for different direction. If we have the setting for panorama video, we can combine this two solutions and get the video panorama for one direction and the second video panorama for backward way only by the changing the order of frames. This solution will bring up another possible interaction with the video, that the user can rotate his view in every moment.

6 Interaction with content

Beside the *virtual path*, we suggest to add additional information about the objects inside the video and extend the content with virtual objects. Although in the video we have a sound or commentary, we can still add some more information such as images, links or various texts that will introduce the nature of the object and hence attract the visitor.

6.1 Interaction with 2D video objects

Interaction with the video content can be found in multiple works, for example in Europeana [The12] interactive video (<http://remix.europeana.eu/>) or YouTube (<http://www.youtube.com/watch?v=dXcBjeoRqFY>). Most of these cases use static overlay over video and make the element clickable. This element is mostly rectangular and not always connected with video. In our solution we are going a little bit further and we will track important objects in video and make the element to follow the object. We will call the element object representation as we define it in previous section 3.

The additional information can be stored in extra files or database and are shown only on visitors demand. For this purpose we will use our object representation, which will be a bounding box of the object. With the help of the algorithms mentioned in preprocessing part and their OpenCV implementations, we can interactively select object and track it over the video sequence as the algorithm 2 describes. However, we are just tracking the bounding box of the object and we approximate this movement with another cubic b-spline. We also proposed an automatic approach based on input images and ORB [RRKB11] descriptor.

Algorithm 2 Algorithm to track manually selected objects in video for content interaction.

INPUT: video sequence

OUTPUT: extracted objects movement

- 1: Manually select the feature points of object to track
 - 2: Create the bounding box of the object
 - 3: **loop**
 - 4: Track the selected points between frames
 - 5: **end loop**
 - 6: Get the curve with minimal error for each bounding box point or for the center point
 - 7: Save the control points and add the additional information
 - 8: Repeat the steps 1 to 5 until all desired objects are tracked and represented
-

In the place of object representation we put a bounding box which is a clickable object and it will represent some additional data (fig. 6). If the visitor clicks on it, the content on demand will be shown in the same web page under the video player. Therefore he will not lose the context, he can still continue watching video.

In our solution we have to store just control points of the curve and the start time and end time, when should be the object visible. The additional data are sent only

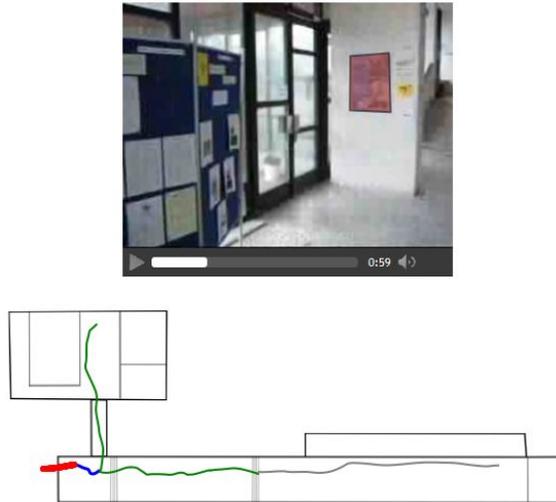


Figure 6: Object representation in video.

if the visitor requests them. In commercial video applications we can find similar approach to display advertisement over some part of object, which is clickable and you can get information where to buy the product. We transferred this approach also into museum presentation.

6.2 Augmented video

We extended the video with 3D objects projected into the video. With this approach we get the augmented video with 3D models created separately. In most of the papers [CPV⁺01], [GCHH02] where authors combine video and 3D objects the virtual objects were positioned into the video scene and then the user can observe them from the camera point of view. In our work we proposed to add also interaction with virtual objects.

The virtual object registration is done based on the results from interactive video part, where we know the relative change of the position and rotation of camera for each key frame. The process of placing virtual object into the scene is done manually. The object is placed in one frame and then the user has to check if in all other frames the object is in the right position and if all other properties are as he requires.

To render the virtual scene we used the WebGL API [Khr13] for HTML5 canvas element and we used this API also for video playback. We created two textures, one is the current video frame and the second texture is a frame buffer created texture from the virtual scene for given time. Next we blended these two textures so that

the virtual object is in front of the video. With this solution we do not need to have more layers, we have only one layer with WebGL window. The end user will not see the difference between the standard video player and our WebGL based video player with 3D virtual objects support.

The interaction with virtual object is started by clicking on it. After the pause of the playback the user can interact with the virtual object. The logic behind the interaction is that the user can rotate the object only or display it in separate window with additional information and full manipulation. The reason for this concept is to do not change the object position and scale inside the video context. However, if the user desires to interact with the object, zoom in or get another useful information about the object he can open the object in separate part of the web page.

6.3 Summary

We presented our solution for video object interaction when we separated the video object from the video itself and stored the bounding box in our XML file. Therefore we can easily extend the current interactive element with additional video object. For object detection and tracking we presented two methods, the manual approach depends on user selection of the interesting object. The approach based on descriptors like ORB is automatic based on input images of the object. The object representation is an interactive element, which can be clicked to get a further information about the object represented.

We also researched the 2D video and 3D virtual objects combination. We proposed a solution, where the virtual object is placed into a video and the user can interact with the object itself. If the user wants to interact with the object, the video is paused and he can rotate the object and view it from different side. Our solution can be extended for automatic placement of the object and the possible interaction can be extended further. In the field of virtual exhibitions and walkthroughs this combination is a novel approach and can extend the user experience.

7 Results and conclusion

We propose an algorithm, which will create a video presentation from calibrated non-linear video. The proposed solution extends the standard video functionality with multiple interactive elements. The main result of our work is the *virtual path* element, used for better orientation in virtual environment and for controlling the

video playback. This novel approach is more intuitive, because the visitor can select place where he wants to be transferred and not seeking the correct time. As we are in video based walkthrough for expected experience the visitor has to have the chance to move both directions. Our solutions provide also this novel approach and the user can change his direction in every moment. This option gives more freedom, which was a disadvantage for video based exhibitions.

The interaction with both 2D objects and 3D virtual artifacts extends the standard video functionality and changes the video a from passive into interactive media. The user is encouraged to click on content in video, so he gets additional information or metadata and content connected to the selected object. This approach can be also used for learning about the cultural heritage. We enhanced the Virtual museum [CK07] from visualization to activation category for dynamic (video) content.

As the Europeana already contains an interactive video, we can compare our solution with it. Our solution has the *virtual path* element with the camera positions instead of the Europeana, where only the timeline is used to control the position. Another difference is that they used 2D objects over the video, but without any context to the actual video content. On the other hand in our solution there is a connection about additional information and video content and the clickable element is moved along the video. Therefore our solution provide more interactive elements.

Our novel approach is an alternative way for museums and galleries to present their exhibitions. The visitor has less freedom than in 3D virtual walkthroughs, but it still provides more information than images or panoramas. Our results shows, that it could be used as educational tool to spread the information about cultural heritage.

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Research projects

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