Towards plan-based automatic exploration of virtual worlds

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ABSTRACT
In order to efficiently explore unknown virtual worlds with a camera, the camera has to be as autonomous as possible, in order to take decisions whenever it is necessary. In this paper, we present a formalisation of the automatic virtual world exploration problem, together with a technique allowing on-line incremental external intelligent exploration of a virtual world by a camera. This technique is based on an evaluation function which takes into account scene's covering and quality of points of view, together with a small number of positions that should be reached by the camera and tries to make exploration plans in order to reach them using incremental determination of the next camera position.

Keywords
Virtual worlds, camera's movement, heuristic search, good view, evaluation function, incremental exploration, on-line exploration

1.INTRODUCTION
Automatic exploration of virtual worlds becomes more and more necessary because of development of virtual reality applications on computers. This technique is especially useful to give elegant solutions in two kinds of problems: scene understanding and guided visits of a virtual world. When an unknown scene is found on the Internet, the user would like, generally, to know what it represents. In order to see the scene, he (she) must display it on the screen but the chosen point of view can be poor. It is difficult to look for a good point of view for a scene displayed on the screen because the screen is bidimensional while the scene is tridimensional. The problem becomes more complex when the found scene is very complex. In such a case, a single point of view is clearly not sufficient. How to find other interesting points of view? How to use them in order to better understand the scene? Unlike the user, the computer has a complete knowledge of the scene's geometry and topology. So, it should be able to propose interesting points of view, according to some view quality criteria, and even to intelligently explore the scene, because a set of views of the scene, without a good transition between these views, does not assure a good knowledge of it.

A guided visit of a virtual world is quite different. The virtual world can be a virtual representation of a museum, a particular building or a (part of a) city. Geometry and topology of the virtual world are not sufficient for the guided visit. The designer of the virtual world would like to show a set of interesting places in the world and the guided visit should take into account the designer's wishes. Again, in such a case, the computer has more information on the virtual world to visit than the visitor and it should be able to propose a guided exploration of the world, taking into account the desires of the world designer.

In section 2, the problem of virtual worlds exploration will be discussed. Authors conception of heuristic search-based scene exploration and the corresponding implemented techniques will be proposed in section 3. In section 4, plan-based improvements of heuristic search-based scene exploration will be presented, while in section 5 results, obtained by those of the proposed techniques which are currently implemented, will be presented and discussed. Section 6 will conclude the paper.

2.THE PROBLEM OF VIRTUAL WORLDS EXPLORATION

There are two possibilities when one wishes to explore a virtual world with a camera. The first kind of exploration is *global exploration*, where the camera remains always outside the world to be explored. The second one is *local exploration*, where there is immersion of the camera inside the world.

Global exploration is based on a camera which moves around the scene and tries to give the user a good general knowledge of it by exploring first the most interesting parts of the scene. Having a global knowledge of the world to be explored is always necessary and, for a great part of scenes, global exploration gives the user sufficient knowledge of the scene.

The purpose of local exploration is a more precise knowledge of a scene, or of a part of it, by immersion of the camera inside the scene. The camera is now a part of the world and it must take into account possible obstacles which could obstruct its movement. Local exploration is rarely sufficient to give the user a good knowledge of the explored world. However, this kind of exploration could be seen as a complement of global exploration whenever global exploration does not allow to see some details.

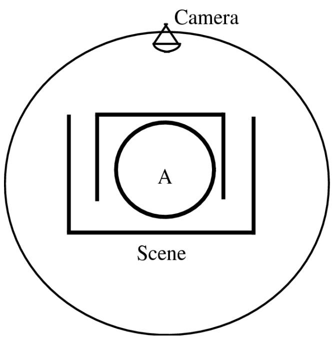

Figure 1. The camera cannot see object A

Let us consider the case of figure 1, where the scene is represented in 2 dimensions in order to make the problem easier to understand. The object A of the scene cannot be seen by a camera which moves around the scene. In such a case it is necessary to add local exploration, with immersion of the camera in the scene, in order to give the user a complete knowledge.

In some cases, the two scene exploration approaches can be combined. Let us consider the case of a virtual city. It is important to have sufficient knowledge of the general structure of the city before choosing to visit a particular place in it.

On the other hand, virtual world exploration may be *on-line* or *off-line* exploration.

On-line virtual world exploration may occur when the user discovers a new virtual world and would like to understand it as soon as possible. In such a case the camera path has to be determined in an incremental way, in real time, with only local knowledge of the world to explore.

In off-line virtual world exploration the user, having discovered a new virtual world, cannot explore it immediately. In such a case a camera path determination module may compute an optimised path for the camera, which may be used by the user for later exploration. In off-line virtual world exploration, camera path determination is more precise but it may be time consuming. This is not really a drawback, as the user decided to understand the virtual world later.

In this paper, only incremental global on-line exploration is concerned. Techniques for off-line exploration, as well as techniques to improve local exploration have been presented in other papers [Sok06a, Sok06b, Sok05, Sbe05, Jau06].

3.HEURISTIC SEARCH BASED VIRTUAL CAMERA'S MOVEMENT AROUND A SCENE

What are the main requirements for a good on-line global exploration of a virtual world with a camera? All that we need is :

- a criterion of “good view”,
- some general purpose rules on the camera’s movement,
- an evaluation function allowing the camera to choose its next position.

It is admitted that the camera’s direction of view relies the camera to the centre of the scene and that the camera’s cone of vision contains the whole scene. In the following lines we will explain how the three main requirements: “good view” criterion, evaluation function and camera’s movement rules are chosen for heuristic search-based scene exploration.

3.1.The “good view” criterion

What can be a “good” view for a virtual world? If the virtual world is completely unknown, the only possible criterion would necessarily be a geometry-based one because the geometry of the world is the only thing the computer knows. If the virtual world to be explored is sufficiently known and the purpose of the exploration is to show some important or interesting places of this world, the criterion should take into account the view of these selected places.

Some authors have worked to find a criterion of “good view” and methods to locate good points of view for a scene [Col90, Kk88, Ple91, Ple96]. Other

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authors are working to define a criterion of good point of view based on information theory [Sbe02]. A review of virtual world exploration techniques can be found in [Ple03]. More recently, some work was made to define more accurate viewpoint quality criteria [Sok06, Ple06, Lee05, Vaz03].

In this paper, we use a geometry-based criterion [Bar99], even if the proposed virtual world exploration method works with other criteria as well.

The used “good view” criterion is a combination of two notions: the notion of “number of visible details” and the notion of “importance of a detail”. More precisely, considering that a scene is a set of surfaces, the good view criterion is a combination of two quantities:

- number of visible surfaces,
- area of the projected visible part of each surface.

More precisely, the importance of a point of view will be computed using the following formula:

$$I(V)=\frac{\sum_{i=1}^{n}\left\lceil\frac{P_i(V)}{P_i(V)+1}\right\rceil}{n}+\frac{\sum_{i=1}^{n}P_i(V)}{r}$$

where:

- I(V) is the importance of the view point V,
- Pi(V) is the projected visible area of the polygon number i obtained from the point of view V,
- r is the total projected area,
- n is the total number of polygons of the scene.

In this formula, ⌈e⌉ denotes the smallest integer, greater than or equal to e, for any expression e.

The problem with automatic computation of good view directions is that it is a time consuming process, hardly compatible with a real time smooth movement of a camera. So, in order to reduce the time cost of this task, we apply a computation technique using image analysis. Based on the use of the OpenGL graphical library and its integrated z-buffer, the used technique is described in this section.

If a distinct colour is given to each surface of the scene, displaying the scene using OpenGL allows to obtain a histogram which gives information on the number of displayed colours and the ratio of the image space occupied by each color.

As each surface has a distinct colour, the number of displayed colours is the number of visible surfaces of the scene from the current position of the camera. The ratio of the image space occupied by a colour is the area of the projection of the visual part of the corresponding surface. The sum of these ratios is the projected area of the visible part of the scene. In this manner, the two good view criteria are computed directly by means of an integrated fast display method.

With this technique, the same formula as above is used to compute the importance of a point of view but now:

Pi(V) is the number of pixels corresponding to the polygon number i in the image obtained from the view point V and,

r is the total number of pixels of the image (resolution of the image),

The main advantages of the used technique are the following:

- Approximated computing of the number of visible surfaces and of the projected area of each visible surface by image analysis is very easy. The total time cost of the technique is O(d) + O(m+n), where O(d) is the image computing cost, m is the number of pixels of the image and n the number of polygons (surfaces) of the scene.
- The display cost with a hardware acceleration based z-buffer is not important and a large number of polygons can be displayed very quickly.

To determine the starting point of the scene exploration process, that is, a point of view with a high probability to be the best one, the following technique is used:

The surface of the sphere where the camera is moving is divided in 8 spherical triangles. The best spherical triangle is determined by positioning the camera at each intersection point of the three main axes with the sphere and computing its importance as a point of view. The best intersection point on each axis is selected. These three points on the sphere determine a spherical triangle, selected as the best one.

The next problem to resolve is the selection the best point of view on the best spherical triangle. The following heuristic search technique is used to resolve this problem:

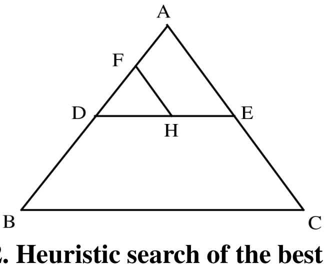

Figure 2. Heuristic search of the best point of view by subdivision of a spherical triangle

If the vertex A (figure 2) is the vertex with the best evaluation of the spherical triangle ABC, two new

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vertices E and F are chosen at the middles of the edges AB and AC respectively and the new spherical triangle ADE becomes the current spherical triangle. This process is recursively repeated until the quality of obtained points of view does not increase. The vertex of the final spherical triangle with the best evaluation is chosen as the best point of view.

3.2.The general rules guiding the camera's movement

The problem of virtual world exploration by a camera is a very interesting and useful problem but, surprisingly, very few authors have been interested in it [Fou96, Mou96, Jar98, Bar99, Bar00a, Bar00b]. In the following lines our conception of the rules guiding the camera's movement is presented.

During its movement, the camera has to explore the scene as well as possible. So, the camera's movement must apply some intuitive heuristic rules insuring a good exploration. The more important rules are the following :

- It is important that the camera moves along positions which are good points of view.
- The camera must avoid fast returns to the starting point or to already visited points.
- The camera's path must be as smooth as possible in order to allow the user to better understand the explored scene. A movement with brusque changes of direction is confusing for the user and must be avoided.

The first and second rules will be taken into account by the camera's position evaluation function which will be presented below. In order to always apply the third rule, the following technique is used.

Once the supposed best point of view has been computed on the surface of the sphere, the camera is set on this point and the movement of the camera starts by a decision for the camera's initial movement direction. Initially, all directions are plausible and eight movement directions are considered.

For each possible new position of the camera on the surface of the sphere, corresponding to a movement direction, the view direction from this point is evaluated and the chosen position is the one corresponding to the best view direction value.

After the first movement of the camera, a movement direction is defined by the previous and the current position of the camera. As blunt changes of movement direction have to be avoided, in order to obtain a smooth movement of the camera, the number of possible new directions of the camera is reduced and only 3 directions are considered for each new movement of the camera (figure 3).

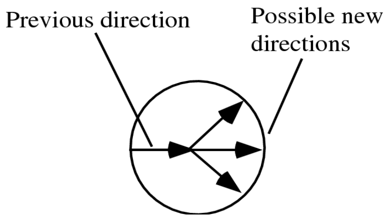

Figure 3. Only 3 directions are considered for a smooth movement of the camera

One of the three possible directions will be chosen by the position evaluation function which will integrate heuristic rules taking into account the first and second heuristic rules presented above, at the beginning of this section. This position evaluation function will be presented in the following sub-section.

3.3.The camera position evaluation function

The purpose of the virtual camera's movement around the scene is to give the user a good knowledge of the scene's properties. To do this, a maximum of interesting regions of the scene must be seen by the camera, with a minimum displacement from the starting point.

The three heuristic rules presented at the beginning of this section must be taken into account for the camera's movement. The third rule is already integrated as explained in sub-section 3.2. In the following lines we will explain how the first and second rules will be integrated in the evaluation function of the camera's position.

In order to avoid a fast return of the camera to the starting point, because of attraction due to the fact that this point determines a good view position, a weight is assigned to each position of the camera. The weight of a position is proportional to the distance of the virtual camera from the starting point. What is the distance of a point on the surface of a sphere from the starting point? We define this distance as the length of the arc of the circle obtained by the intersection of the sphere by the plane defined by the starting point, the current position of the camera and the centre of the scene.

In fact, we must consider two kinds of distance.

- The length of the path traced by the camera's movement (figure 6a). The length of this path can be computed as the sum of the chords of elementary arcs obtained by decomposition of the path.
- The minimal length arc between the starting point and the current position of the virtual camera, that is, the distance of the current position from the starting point (figure 4).

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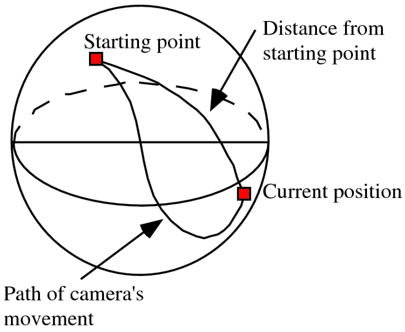

Figure 4. Distance of the current position of the camera from the starting point

In order to create a heuristic function guiding the movement of the camera, we can observe that the importance of the camera's distance from the starting point is inversely proportional to the length of the path traced by the camera.

Thus, our heuristic function computing the weight of a position for the camera on the surface of the sphere must take into account :

- The global evaluation of the camera's current position as a point of view (n_c).
- The path traced by the camera from the starting point to the current position (p_c).
- The distance of the current position from the starting point (d_c).

Finally, the main function we have chosen is the following :

$$w_c = \frac{n_c}{2}\left(1 + \frac{d_c}{p_c}\right)$$

where w denotes the weight and c the current position of the camera.

4.PRINCIPLES OF GOAL-BASED CAMERA MOVEMENT

The problem with the scene exploration techniques proposed in section 3 is that the choice of the camera's next position is based on local estimation of the position, trying only to push the camera far from the starting position. That is, there is not a real scene exploration strategy.

It would be interesting if the camera could elaborate exploration plans, with the purpose to reach interesting view positions.

Currently, we are only sure that the camera reaches a single interesting position, the starting position. With a strategy based on plan elaboration, reaching interesting positions should be considered as a permanent goal.

As a partial goal of scene exploration could be to reach an interesting position for the camera, it is possible to imagine three different plans:

1. Direct movement of the camera to the interesting point to reach, taking into account the general purpose rules on the camera's movement.
2. Progressive movement of the camera towards the interesting point to reach, taking into account the quality of the possible next positions of the camera.
3. Progressive movement of the camera towards the interesting point to reach, taking into account the quality of the possible next positions of the camera and the quality of the possible last positions before reaching the goal position.

In figure 5, P1 is the current position of the camera and P2 is an interesting position to reach. The first possibility is to choose the shortest path from P1 to P2, in order to reach P2 as soon as possible. The second possibility tries to reach P2 but the evaluation function determining the next position of the camera takes into account the quality as a point of view of every possible next position. So, the path of the camera is not always the shortest one from P1 to P2. Figure 8 illustrates above all the third possibility: here, the evaluation function is used to determine the next position of the camera, whose current position is P1, and the last position before the goal position P2, taking into account the quality as a point of view of each candidate position. If the determined next and last positions are respectively P3 and P4, the same process is applied to determine a path for the camera, where P3 is its current position and P4 the position to reach.

This determination of next and last positions can be made using a heuristic search at one level of depth or at many levels. The evaluation function computing the importance of a position must take into account, at each step, the current distance between the starting position and the position to reach.

So, the proposed goal-based strategy is made of two steps:

- Selection of a small number of interesting position for the camera. This number has to be small in order to allow on-line exploration.
- Virtual world exploration, using one of the three plans proposed above.

During exploration, only not yet seen polygons are taken into account to determine the quality of a camera position.

How to choose a small set of interesting positions to reach on the surface of the bounding sphere? An interesting position is a position being a good point of view. The chosen solution is to divide the bounding sphere in 8 spherical triangles and to compute a good

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point of view for each spherical triangle, using the technique described in section 3.1.

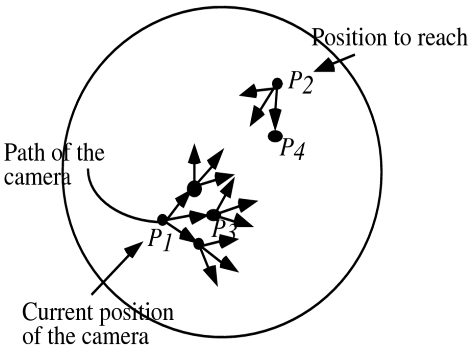

Figure 5. Plan elaboration using heuristic search from the starting position to the goal position

Now, given the current position of the camera and an interesting position to reach, the following strategy is used when applying the third, most general, exploration plan presented above. If I_P denotes the interest of the position P, n(P) the next position from position P, p(P) the previous position from the position P to reach, pv_P the quality as a point of view of the position P, d(P1, P2) the distance between positions P1 and P2 on the surface of the sphere and P_c and P_r respectively the current position and the position to reach, the next position of the camera can be evaluated using the following formula:

$$I_{n(P_c)} = \left(pv_{n(P_c)} + pv_{p(P_r)}\right) \frac{d(P_c, P_r)}{d\left(n(P_c), p(P_r)\right)}$$

In this formula, the next position of the camera is chosen in order to have the following conditions verified:

- The next camera position is a good point of view
- There exists a position, before the position to reach, which is a good point of view
- The distance between the next position of the camera and the position before the position to reach is minimal.

It is possible to transform the above formula in order to apply the second exploration plan presented at the beginning of this section. Here, only the next position of the camera has to be computed, the position to reach remaining the same (P_2). The new formula will be the following:

$$I_{n(P_c)} = \left(pv_{n(P_c)} + pv_{p(P_2)}\right) \frac{d(P_c, P_2)}{d\left(n(P_c), P_2\right)}$$

The main advantage of the second exploration plan is that exploration is faster. On the other hand, the control of the camera trajectory is less precise.

5.IMPLEMENTATION OF EXPLORATION TECHNIQUES AND RESULTS

A great part of the techniques presented in this paper and allowing intelligent exploration of virtual worlds has been implemented. In figure 6, one can see an exploration of a scene representing an office. The movement of the camera is represented by the dotted line. This exploration is based on the method described in section 3. The camera's motion is smooth and the scene is well understood after a relatively short exploration. In this kind of exploration, the camera's next position is computed in incremental manner but the exploration is not goal-oriented, as there are not goals to reach.

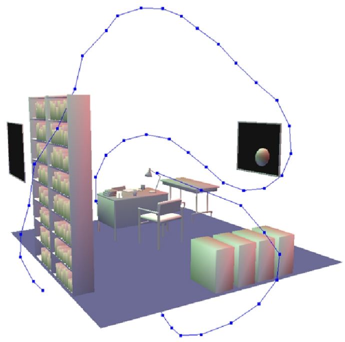

Figure 6. Exploration of an office by the techniques explained in the previous section

The first exploration plan described in section 4 was implemented but it is not very interesting, as smooth movement of the camera is not guarantied. The second exploration plan produces interesting results, which will be commented in this section. The third exploration strategy is under implementation.

We have chosen to comment on results of the proposed plan-based method, obtained with two scenes: The office scene, already seen in figure 6, and a sphere with 6 holes, containing various objects inside. This second test scene is very interesting because most of the scene details are visible only through the holes.

Four cases were studied, corresponding to variants of the second formula of section 4:

1. Only the distance between the current position of the camera and the position to reach is considered. The viewpoint qualities of positions to reach are not taken into account. See figure 7.
2. Only the viewpoint qualities of positions to reach are considered, that is, the next point to reach is the closest to the current camera position. See Figure 8.

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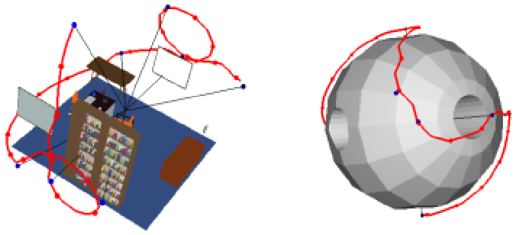

Figure 7. Only distance to the next position to reach is taken into account

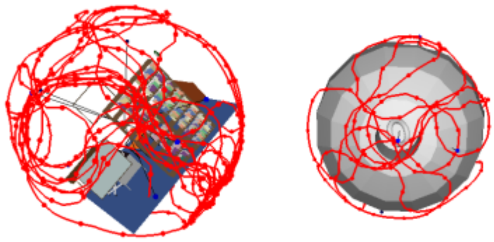

Figure 8. Only viewpoint qualities of the positions to reach is taken into account

3. Both distance and viewpoint quality of the position to reach are considered, with equal weights (ratio *viewpoint quality/distance* = 1). See Figure 9.

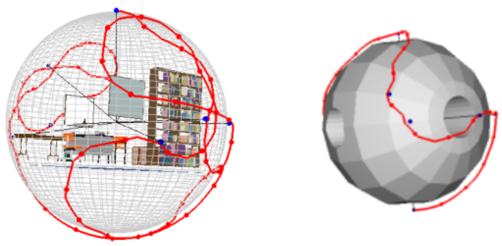

Figure 9. Both distance and viewpoint quality are equally considered

4. Both distance and viewpoint quality of the position to reach are considered, with the distance weight equal to twice the viewpoint quality weight (ratio *viewpoint quality/distance* = 1/2). See Figure 10.

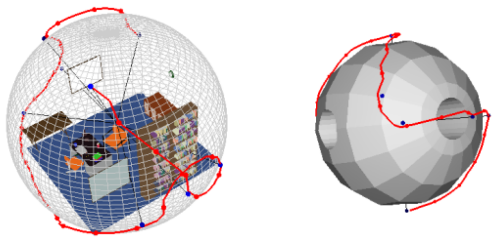

Figure 10. The distance is twice more important than viewpoint quality

One can see that the fourth case gives the best results with both test scenes. With the sphere test scene, the fourth case gives results very close to those of the first case (distance only), as it can be seen in figure 11.

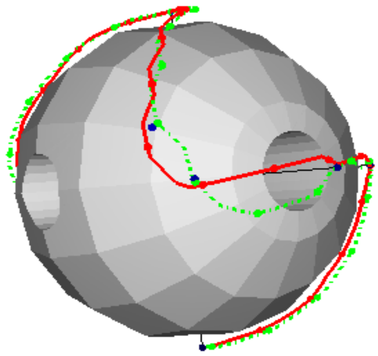

Figure 11. The distance-based path(in green) is very close to the best path(in red)

Graphic representations of results (Figures 12 and 13) show that, in all cases, more than 80% of the scene is seen when the last of the initially defined positions is reached by the camera. This proves that the chosen method for creating the small initial set of positions to reach is well adapted to the purpose of the plan-based automatic exploration. The number of positions to reach of the initial set is generally small (usually 8), so that the added extra time cost is negligible.

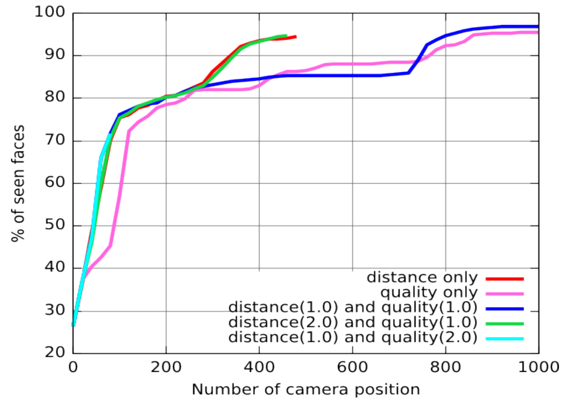

Figure 12. Graphic representation of results with the Office test scene

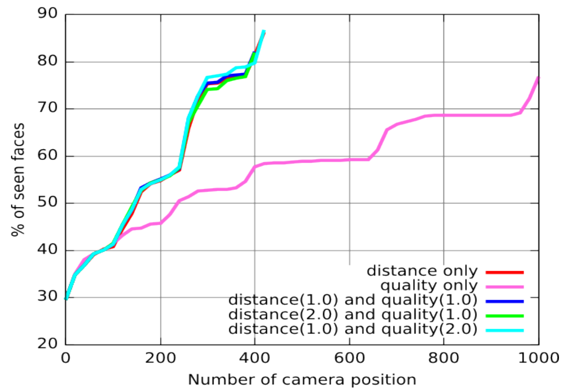

Figure 13. Graphic representation of results with the Sphere test scene

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6.CONCLUSION AND FUTURE WORK

In this paper we have presented techniques allowing external intelligent exploration of a scene by a virtual camera. In these techniques the camera is supposed to move on the surface of a sphere bounding the scene.

The presented techniques perform incremental determination of the next position of the camera and take into account both viewpoint quality and positions that should be reached by the camera and try to elaborate exploration plans in order to reach these positions when they try to determine the next camera position.

The study of obtained results shows that the distance of the current camera position from the position to reach is often more important than the viewpoint quality of the current position. In our opinion this fact can be explained by the mode of choice of the initial set of positions to reach. As they are chosen to be good viewpoints and well distributed on the surface of the surrounding sphere, it is natural to discover a big part of the virtual world by visiting the positions to reach only according to their distance from the current position. The optimal ratio viewpoint quality/distance is 1/2. Obtained trajectories with this ratio are always interesting and the used methods are not time consuming. In implemented techniques, the movement of the camera is smooth and the chosen camera paths interesting.

Taking into account that the implemented plan-based technique uses the second of the three possible camera's movement plans(see section 4), one can hope that implementation of the more accurate third plan will give much more interesting results. Our next work will be implementation of the remaining more elaborated plan of the plan-based technique. We are also trying to find an objective measure in order to evaluate the different scene exploration techniques.

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