Potential field based camera collisions detection in a static 3D environment

Adam Wojciechowski
Institute of Computer Science, Technical University of Lodz

September 15, 2006

Abstract. Existing collision detection methods usually need long pre-calculation stage or difficult, time-consuming real-time computation. Moreover its effectiveness steeps down while the complexity of the scene increases. So far seemingly promising solutions supported by potential fields do not introduce satisfactory functionality. This paper introduces method providing a new potential field construction which lets the camera reach objects without constraints and protect user from getting into their structure. Additionally proposed method comprises easy to bring through pre-calculation stage and becomes a scene-complexity independent solution.

Key words: collision detection, potential field, navigation

1. Introduction

Collision detection is a fundamental issue underlying objects simulation process. It is important especially in 3D games or VR applications devoted to various phenomena simulation when movement of the camera should be limited or behaviour of mutually moving objects is considered. The process of collision detection is theoretically very easy however the cost of calculations increases steeply with a scene complexity. The phenomena can be complicated not only by complexity of an individual object but by amount of independently moving objects to consider as well. Nevertheless the most common scenario in both games or VR application is one or a few moving objects in a static environment.

Collisions are usually resolved in two steps [10]. First step bases on a broad phase approach when algorithms cull away pairs of objects that can not possibly collide. This level makes use of various pre-calculated bounding volume hierarchies. Second step is called a narrow phase approach and applies accurate collision detection by means of real-time arithmetic calculations.

As complexity of the objects may vary (regular box vs. very irregular tree), arithmetic calculations costs make programmers simplify considered objects. There are two objects coexisting within a scene: one is displayed to the user and another, much simplified, is used for calculations. Many types of bounding boxes are used instead of originals while calculations. Considerable reduction in number of faces is rather unavoidable in real-time applications. Moreover users have already accustomed to simplifications, i.e.: nobody expects that thin branch of the tree can be an obstacle on his way whereas the tree trunk is always expected to block the user. This paper assumes that considering just simple convex and nonconvex objects do not reduce method generality, especially in case of explorative 3D environment.

Methods based on potential fields require pre-calculation stage however they considerably relieve calculation process. Potential fields assigned to the scene's objects become a source of potential field forces. These forces retrieved adequately to an actual camera position influence its consequent behaviour.

2. Related work

Construction of a potential filed already met in literature was considered mainly in robotics [3,6,9]. In such environments there is usually one goal and a few obstacles which should be passed by on the way to the predefined aim. Potential distribution is in conformity with a mathematical potential field theory. Goal object is placed in the minimum of a local potential field and the obstacles are situated in local fields' maximums. Finally algebraic superposition of the local fields is carried out. As a result global potential field distribution is formed and robot can follow the way from its initial position to a global potential field minimum (goal). Potential field construction methods are used analogically in a 3D environments where robot is replaced with a virtual camera. Nevertheless potential field characteristic, prevailing currently in literature, has many destructive drawbacks [1,2,7,8,12]. Local potential fields coming out of obstacles form unpredictable extremums which are situated in accidental places and they are blocking the camera on the way to the aim [4,5]. Forces coming out of potential field distribution do not let the camera approach obstacles and moreover do not protect camera from getting into the objects. Such potential field traps must be solved by additional correction algorithms [7,8,12].

On contrary to robotics' assumptions most of the applications require unconstrained camera movement with not predefined goal. Camera should neither get into the objects nor be blocked in accidental places. Collision detection should be precise enough to let the user reach each place in the scene not occupied by the objects. Such conditions can be fulfilled by forces coming out of newly constructed potential field distribution.

3. Potential field construction

Movement of the camera, representing user's point of view, within a static three dimensional environment can be constrained to predefined limits that do not reduce method's utility. The altitude of the camera (the shortest distance between camera position and the ground) achieved while the movement can be described as an ordinary height (h_c), minimum height (h_{min}) and maximum height (h_{max}). These are adequately:

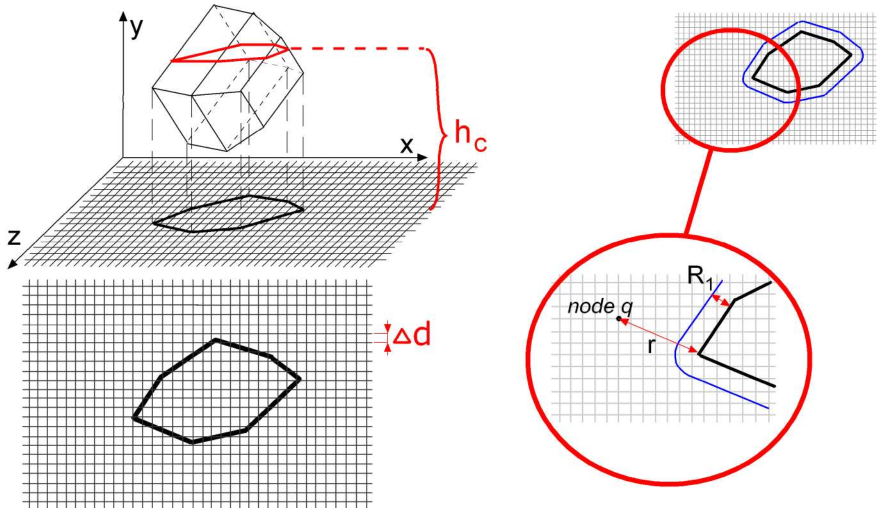

Fig. 1. Construction of an object's contour and definition of the object's vicinity (R_1).

level achieved while walking mode (h_c), level achieved while squatting (h_{min}) and level achieved while jumping (h_{max}). Such assumption cause that only objects which parts are placed lower then actual camera height (h_c, h_{max} or h_{min}) can collide with the camera. Limitations generated for h_c, h_{min} and h_{max} can differ and depend on objects' structure.

As a first stage collision contour is made by an orthogonal XZ[1] projection of the object's faces whose at least one vertex' vertical (Y) co-ordinate is lower then h_c (fig. 1). Analogically two additional contours for h_{min} and h_{max} are introduced. Their usage is connected with a changeable camera altitude and is explained in the next section. Contour obtained on the ground surface reflects the barrier that can not be exceeded by the camera. Contours would be also used as a reference shape for potential field calculation. Potential values discretely defined for each node of a square mesh depend on a distance between the node and the contour. Density and size of the mesh is predefined and reflects size and complexity of the scene. This paper demonstrates a simple convex object however proposed method can be flexibly adjusted to more complex objects by increasing the density of a mesh the contour is projected on (fig. 1). In such a case Δd determines the minimum thickness of the part of the object that should be considered in collisions detection.

Considering constant height of the camera movement, potential values within a con-

[1] XZ projection is an orthogonal projection on XZ plane (plane of the ground)

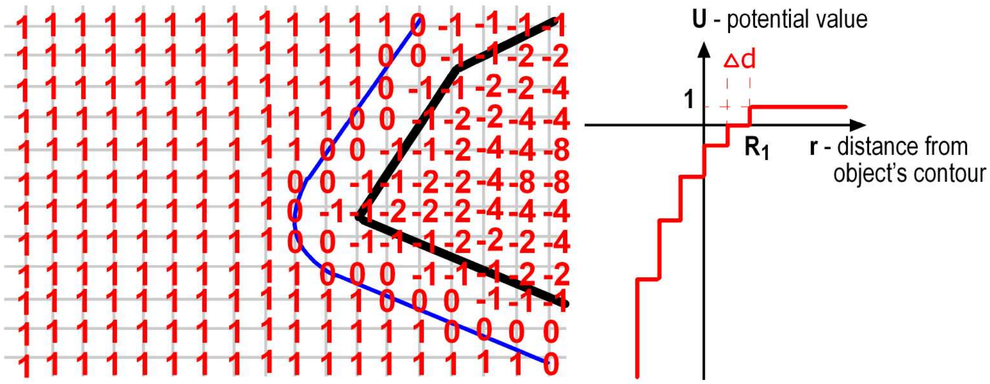

Fig. 2. An exemplary contour and its potential field distribution.

tour and its vicinity can be assigned to zero [11]. However assuming camera height changeability value of the potential (U_{col}) for each node (q_{ij}) of the mesh is calculated according to equation 1.

$$U_{col}(q_{i,j}) = \begin{cases} 1 & \text{if } r>R_1 \\ 1 - max\left\{1, antie\left[(1-\frac{r}{R})\cdot antie(\frac{R}{\Delta d})\right]^{1.5}\right\} & \text{if } r\leq R_1 \end{cases} \tag{1}$$

where

r is a distance between contour and node q_{ij},

R is a radius of object's bounding sphere,

R_1 is a predefined vicinity of the contour that provides descent distance between the camera and the object. It compensates divergences between real space occupied by the object and its orthogonal reproduction,

$antie(x)$ is an integer part of x,

Δd is a minimum acceptable object's thickness.

Exemplary potential field distribution is presented in figure 2.

Potential field is a source of forces calculated for each node q_{ij} according to equation 2.

$$\begin{aligned} &\vec{F}(q_{i,j}) = < F_x(q_{i,j}), F_y(q_{i,j}), F_z(q_{i,j}) > \\ &F_x(q_{i,j}) = [U(q_{i-1,j+1}) - U(q_{i-1,j-1}) + U(q_{i,j+1}) - U(q_{i,j-1}) + U(q_{i+1,j+1}) - U(q_{i+1,j-1})] \\ &F_y(q_{i,j}) = U(q_{i,j}) \\ &F_z(q_{i,j}) = [U(q_{i+1,j-1}) - U(q_{i-1,j-1}) + U(q_{i+1,j}) - U(q_{i-1,j}) + U(q_{i+1,j+1}) - U(q_{i-1,j+1})] \end{aligned} \tag{2}$$

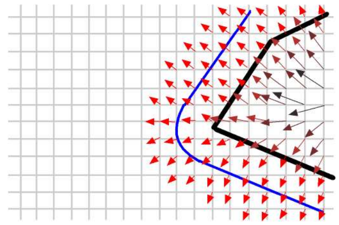

Fig. 3. Potential field forces distribution for an exemplary object's contour.

where i,j are mesh nodes' indexes.

Forces' distribution for an exemplary object is presented in figure 3.

Forces calculated for each node of the mesh can be taken into consideration while camera movement. However the mean force ($\vec{F}_{med}$) for an actual camera position ($\vec{pos}$) should be interpolated as a mean of 16 neighbouring, discretely defined, potential field forces (equation 3).

$$\vec{F}_{med}(\vec{pos}) = \sum_{s=i-1,t=j-1}^{s=i+2,t=j+2} \left[\vec{F}_{XZ}(q_{s,t}) \cdot exp^{-distance(\vec{pos};q_{s,t})}\right] \tag{3}$$

where $distance(\vec{pos}, q_{st})$ is a distance between actual camera position ($\vec{pos}$) and a node of the mesh (q_{st}).

Camera is steered by input devices. Applying input devices generates vector $\vec{K}$ concurrent with a direction of camera movement ($\vec{dir}$). As a result position of the camera ($\vec{pos}$) is modified by vector $\vec{K}$ (figure 4).

Camera steered by input devices can freely navigate throughout the scene until it reaches potential field in the objects' neighbourhood. In this area potential field forces would contradict camera tendencies to approach objects' contour. Modification of the camera position influenced by potential field forces is calculated in accordance with equation 4.

$$\vec{pos'} = \vec{pos} \oplus \left(\vec{dir} \cdot \alpha_1\right) \oplus \left(\vec{F}_{med}(\vec{pos}) \cdot \alpha_2\right) \tag{4}$$

where α_1 and α_2 are scalar coefficients modifying proportions between influence of input devices and collision forces and $\oplus$ is a vector sum. Due to α_1 and α_2 strength of collision forces can be easily modified. When $\vec{K}$ vector and potential field forces are normalised experiments shows that doubling α_2 in comparison with α_1 ($\alpha_2 = 2 * \alpha_1$) provides sufficient collision detection. Camera can approach the object but forces protect it from getting into the object. Different proportions between coefficients let design solutions that elastically make use of potential field properties.

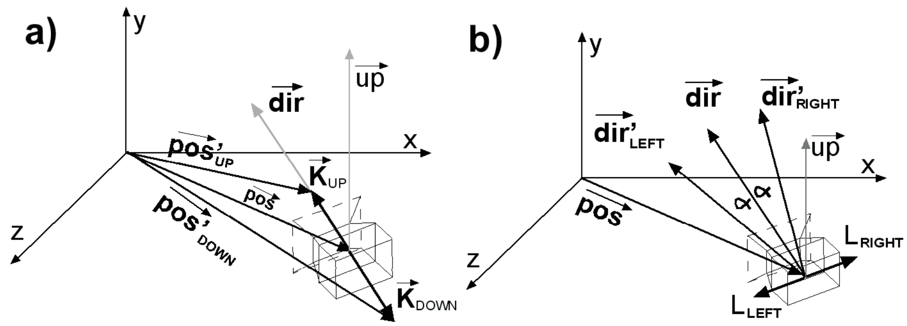

Fig. 4. Modification of the camera position by input devices. a) position of the camera modified by pressing keyboard UP or DOWN arrows; b) direction of the camera modified by pressing keyboard LEFT or RIGHT arrows;

4. Management of a camera altitude

In order to manage the camera more accurately three independent potential field distributions are made - separately for objects' faces whose vertexes do not exceed h_{max}, h_c, and h_{min}. In case of camera's height modification potential field distributions should be interpolated. However assuming that time devoted to camera's walking is dominating in comparison with time devoted to quatting or jumping, potential field distribution for h_c was chosen as a prevailing one. Transition between key modes is considerably short in comparison with a time the camera spend at key heights (h_{max}, h_c, and h_{min}). That is why it can be assumed that camera is being switched between different modes and as a result potential field distributions influencing camera movement can be also switched and do not have to be interpolated. Camera situated at a key altitude has assigned adequately chosen potential filed distribution and is moving under influence of prevailing potential field forces.

In case of situation where "quatting" camera was moved under the object which should arise a collision at a normal height (h_c) camera is falling under strong influence of repulsing forces. As a result camera is transitioned towards the place where forces do not influence the camera. This is a border of the contour generated for normal camera height. However rapid change of the camera height should not result in rapid camera push off. Influence is initially diminished and is being raised up along the time. This causes gradual and acceptable camera movement from repulsive potential filed area towards its neutral distribution (outside the contour of the object).

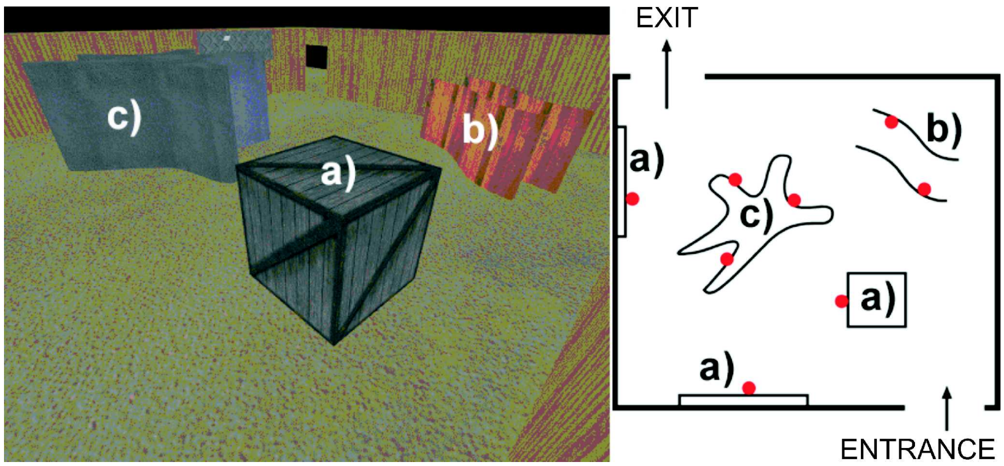

Fig. 5. A 3D static environment used for the tests. The scene has comprised three groups of objects: a) simple convex objects, b) object with interior, c) simple nonconvex object.

5. Tests

To proof effectiveness of the method adequate tests were performed. Three types of objects were taken into consideration: simple convex objects, simple nonconvex object and object with interior (fig. 5).

The goal of the test was to gain evidence that navigation within a scene comprising selected objects let the user move freely among obstacles. Users should be able to approach the objects not entering their structure.

At the beginning of the test users were situated next to the entrance (fig. 5). The task was to visit the places marked with red dots and leave the scene through exit. The order and the time were not taken into consideration but just users' experience collected by means of questionnaire was reported.

In the form people were asked to write personal details like: gender, age, occupation and 3D navigation experience. They were also asked to answer the most important question whether they had any problems while approaching the objects during scene exploration and whether they have experienced entering the structure of the objects.

Twenty six person took part in the test, five women and twenty one men. They were between 22 and 29, and most of them were 4th and 5th year students of the computer science faculty. In spite of their occupation 6 participants declared themselves as experienced users, 6 as beginners and the rest as medium experienced users.

The test revealed that all the participants could approach the objects without any problems, and nobody had faced problem of penetrating objects' structure. The results of the test have proved that the proposed method works in a expected manner, meeting people acceptance, protecting user from entering objects' structure and letting them navigate within a scene without disturbances.

6. Conclusions

So far potential filed theory was mainly utilized in robotics. There were also few attempts to make use of its advantages in three dimensional scene navigation. Unfortunately clear mathematical potential field calculation approach arises many trapping situations. This article has shown that proposed potential field distributions and described potential field superposition algorithms can be a very useful tool. In this paper potential fields were used for collisions detection process which was perceived as a time consuming and calculation costful task. Proposed method has appeared to be not only easy to use but easily adjustable to scene complexity as well. The effectiveness of the method was approved by adequate tests.

References

2000
[1] Beckhaus S., Ritter F., Strothotte T.: CubicalPath - Dynamic Potential Fields for Guided Exploration in Virtual Environments. Eighth Pacific Conference on Computer Graphics and Applications, PG'00, IEEE

2002
[2] Beckhaus S.: Dynamic Potential Fields for Guided Exploration in Virtual Environments. PhD thesis, Otto-von-Gueicke-Universitat Magdeburg

2004
[3] Dulba I.: Metody i algorytmy planowania ruchu robotw mobilnych i manipulacyjnych. Akademicka Oficyna Wydawnicza Exit

1986
[4] Khatib O.: Real-time obstacle avoidance for manipulators and mobile robots. International Journal of Mobile Research, vol. 5(1): 90-99

1995
[5] Khatib M., Chatila R.: An Extended Potential Field Approach for Mobile Robot Sensor-based Motions. Intl. Conf. on Intelligent Autonomous Systems IAS'4

1991
[6] Latombe J. C.: Robot Motion Planning. Kluwer Academic Publishers

2001
[7] Li T. Y., Chou H. C.: Improving Navigation Efficiency with Artificial Force Fields. Proceedings of 14th IPPR Conference on Computer Vision, Graphics and Image Processing, Taiwan

2004
[8] Li T. Y., Hsu S. W.: An Intelligent 3D User Interface Adapting to User Control Behaviours. Proceedings of the 9th International Conference on Intelligent User Interface, 184-190, Madeira, Funchal, Portugalia

2000
[9] Murphy R. R.: Introduction to AI Robotics. MIT Press

2002
[10] Watt A., Policarpo F.: 3D Games. Real-time Rendering and Software Technology. Addison-Wesley **2005**
[11] Wojciechowski A.: Wspomaganie dynamiki procesu nawigacji w eksploracyjnym rodowisku wirtualnym. PhD Thesis, Technical University of Lodz **1998**
[12] Xiao D., Hubbold R.: Navigation Guided by Artificial Force Fields. Proceedings of CHI'98, Los Angeles, USA