PROBLEMY MECHATRONIKI
UZBROJENIE, LOTNICTWO, INŻYNIERIA BEZPIECZEŃSTWA

ISSN 2081-5891 **10, 3 (37), 2019, 91-102**

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

Implementation of a Realistic Damage Model in a Simulated Environment

Dominika KAZIOR, Damian BERESKA*, Witold ILEWICZ*

Silesian University of Technology,
Faculty of Automatic Control, Electronics and Computer Science
16 Akademicka Str., 44-100 Gliwice, Poland
**Corresponding author's e-mail address and ORCID*:
Damian.Bereska@polsl.pl; https://orcid.org/0000-0003-1110-8212
Witold.Ilewicz@polsl.pl; https://orcid.org/0000-0003-1951-0230

Received by the editorial staff on 31 March 2019
The reviewed and verified version was received on 13 September 2019

DOI 10.5604/01.3001.0013.4807

Abstract. Realism is an important aspect of the virtual shooting range, which increases the quality of the shooting training conducted there. An important element of realism is the modelling of damage arising during the impact of the projectile on the target. This article concerns damage modelling in computer simulation systems. Using the Unity environment, example simulations of damage caused by projectile impact on basic construction materials have been performed. The obtained solutions have been analysed, with the results compared with those of real experiments; conclusions pertaining to the optimal method of modelling destruction in simulation systems meant for visualisation at virtual shooting ranges have been drawn.

This work has been compiled from the paper presented during the 23rd International School of Computer Aided Design, Manufacturing and Operation, Pisz, Poland, May 13-17, 2019.

Keywords: virtual shooting range, modelling and computer simulation, computer animation, graphics engine, projectile, strike

1. INTRODUCTION

The subject literature broadly describes the analytical [1, 7] and numerical [2, 3, 4, 8, 9, 11] methods of analysing a projectile's interaction with the target at strike, supported with comparative experimental studies [e.g. 11] conducted on real objects. Finite element methods [6] are also applied, in particular. The questions pertaining to external ballistics are also broadly described (e.g. [10]). This way, it is possible to precisely determine the activity of the projectile, the effects of its interaction with the target, and the damage or deformation. A series of works in the field is dedicated to standard construction elements and materials such as concrete and brick walls [2, 3, 4, 5, 7] used to build buildings and other, common structures.

The aim of the simulation systems employed to virtual combat shooting ranges is slightly different, as they are geared towards the most faithful and credible reproduction of the visual effects of projectile strikes taking into consideration the real-time constraints, thus generating time and computing power limitations. As a result thereof, direct application of the numerical methods described in [1-11] is impracticable. Because of this, programming a useful simulation requires 3D graphic engines reflecting the approximate reality of the physical world, emphasising the best possible visual effect recreation. A virtual shooting range has been developed within the framework of Project DOB-BIO6/11/90/2014, "Virtual Simulator of Protective Measures of State Protection Service". The results presented in the article are a record of the initial attempts undertaken to achieve a realistic recreation of the look and reactions of a virtual shooting range. The target system uses a popular and well-documented graphics engine, 3D Unity, along with its Physics extension (library) [12]. Unity is an integrated programming environment for creating 2D and 3D video games and other materials such as visualisations or animations. The Unity environment can be used on the majority of computer platforms (MS Windows, Linux, etc.), and the applications created in it can be launched on personal computers, gaming consoles, and mobile devices. Employing it for creating the virtual shooting range's software seems natural, therefore it has been launched and tested.

The aim of the works described in the article is the initial development, implementation and testing of a realistic model of damage to basic construction elements caused by a projectile striking the structure in the Unity graphics environment, as well as to draw conclusions pertaining to the level of realism achieved by comparing the obtained results with sample experimental results taken from the subject literature or from the Internet.

The scope of the works entails modelling objects corresponding to real objects made of various materials in the Unity environment. The article describes the results for single and double brick walls, as well as a concrete airbrick.

The aim of the research is to adopt such simulation parameters that the effects of the simulation experiments are as close to their real-life counterparts as possible. For this aim, the Physics module, built into the Unity environment, has been used.

The Physics module operates on rigid-body objects. The objects' locations in the scene are determined using Taylor-series expansion, most commonly 2nd order (the values determined are location, velocity, and acceleration).

In the Physics module, the forces and force moments interacting with the rigid body are taken into consideration, determining the current velocity, location and orientation of the model in the subsequent discrete time points according to the value of the Δt time threshold. The Δt time threshold is a modifiable Unity parameter that may be changed according to the required precision and efficiency of the equipment used for simulation. The environment is able to detect moving object collision detection mechanics, allowing for the modelling of results of the impact with consideration of the forces applied to rigid bodies interacting with one another. The Physics allows simulating of bodies physical characteristics such as mass, friction forces, and flexibility, as well as modelling various collision types (elastic, non-elastic). The calculations may, of course, include the influence of gravity and other forces, such as the Coriolis force affecting the moving object trajectory.

The adopted method of resolving the above issue in the 3D Unity visual environment allows for the observation and analysis of the flight of a projectile in a virtual environment, as well as presenting damage close to that appearing in real world, without having to perform experiments with the use of real combat equipment and ammunition. The developed simulations model and visualise projectile trajectory and strikes on selected objects (a brick wall, a concrete airbrick).

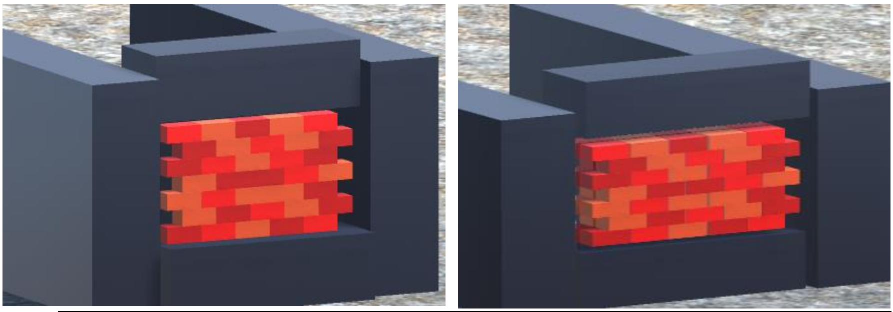
2. SCOPE OF THE RESEARCH

The article presents the results achieved for three of the many programmed scenes involving target objects and the projectile launcher. The projectile launcher has been modelled as an empty object placed in a determined location and orientation in relation to the object in the virtual world. The projectile launcher has a shooting script assigned to it. The targets are 2 brick wall models (single and double), as well as a concrete airbrick.

To program those models, standard bodies available in the Unity environment were used, with modelled physical attributes such as mass, the mechanical properties of the connections between the elements of the wall structure, considering friction and others assigned to the bodies.

Three scenes are used to present the test results:

- Scene 1: a virtual object – a single-layer brick wall; the wall model is made of bricks and tightening edges. Every brick is joined with the neighbouring ones using stiff joints simulating construction mortar, ensuring appropriate friction between the wall's elements. Each brick has been assigned a mass of 3.8 units, corresponding with a real-life mass of 3.8 kg (i.e. the standard mass of a single brick). The model considers the force of gravity as one pressing the wall against the ground. The tightening edges have been modelled as cuboids with a very high mass coefficient. They secure the wall against collapsing.
- Scene 2: a virtual object – a double-layer brick wall; modelled similarly to Scene 1, with an additional layer of bricks. The visualisation of Scenes 1 and 2 are presented in Fig. 1.



a) b)

Fig. 1. A virtual brick wall object; a) single-layer, b) double-layer

- Scene 3: a virtual object – a concrete airbrick model made up of seven cuboid-modelled parts, each connected with the neighbouring, appropriately-modelled joints imitating the force of friction. Every cuboid has been assigned a mass of 2 units (with the total corresponding to that of a real-life, 14 kg concrete airbrick). An image of the modelled object is presented in Fig. 2.

Fig. 2. Visualisation of the concrete block object

In addition, each scene has a modelled projectile launcher. The launcher model is an empty object with a script attached to it which launches projectiles with a determined velocity. The projectile has been modelled as a rigid body with a mass equal to that of a real projectile. The ability to change the projectile's mass and velocity has been implemented in the simulations, allowing for adapting the results to various weapon types. In the presented simulations, the projectile mass and velocity have been selected so as to correspond to the parameters of real ammunition.

3. RESULTS

A series of simulations were conducted in the prepared virtual scenes, with the parameters selected so as to make the results correspond to experiment results from a real-life shooting range as registered on video. The ammunition mass and velocity parameters were set to values corresponding to real-life ones from the recordings of experiments conducted at a shooting range. Sample results of the simulations are presented below.

3.1. Simulated strike effect on a single-layer brick wall

The scene features a wall made of a single layer of bricks. Shots using two kinds of ammunition were simulated: a Tactical Home Defence, with a mass of 28.35 g and an initial velocity of 413.4 m/s, as well as a Special Forces Short Magnum with a mass of 35.44 g and initial velocity of 442.8 m/s.

The simulated Tactical Home Defence strike did not cause significant damage to the wall (Fig. 3). The projectile moved one brick without knocking it out of the wall. The wall's structure has been altered. As a result of continued shooting in the same spot, the projectiles can pass through the obstacle.

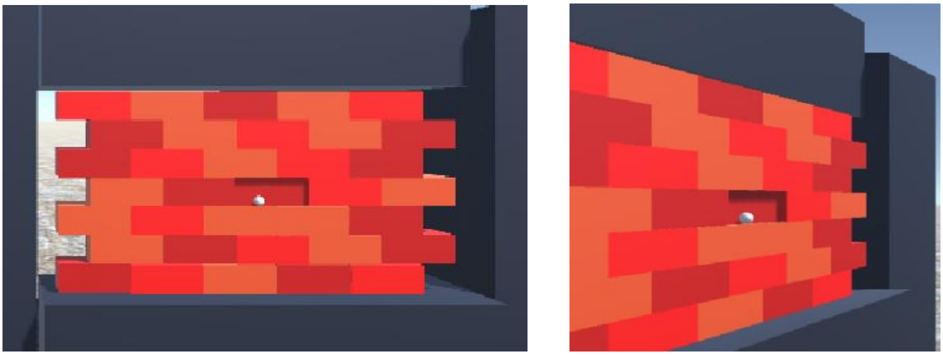


Fig. 3. The virtual brick wall object after a simulated Tactical Home Defence shot; front and lateral view

Fig. 4. A real-life object after being struck by a single Tactical Home Defence missile

The projectile moved one brick without knocking it out of the wall. The wall's structure has been altered. As a result of continued shooting in the same spot, the projectiles can pass through the obstacle.

A similar effect can be observed in Fig. 4, showing a real-life wall after being hit by such a projectile. Cracks appeared on the wall. The wall was not destroyed.

In the next simulation, the Special Forces Short Magnum projectile knocked a single brick out of the wall (Fig. 5), creating a hole. The rest of the wall did not sustain significant damage. After being struck, the brick fell to the ground due to gravity. The strike results are presented in Fig. 5.

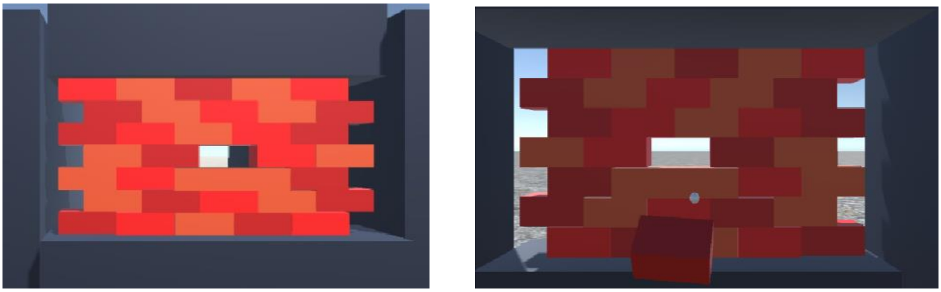


Fig. 5. A virtual brick wall after being hit with a single Special Forces Short Magnum projectile, front and rear view

The simulated shot led to similar results showed for the real-life object. The results of striking a real-life wall are shown in Fig. 6. In the real-life experiment, the projectile left a hole, knocking out a brick fragment and breaking through to the other side.

Fig. 6. A real brick wall after being hit by a projectile

3.2. Simulation of the effect of striking a double-layer brick wall

In the scene: a double-layer brick wall. Shots using two kinds of ammunition were simulated: a Tactical Home Defence, with a mass of 28.35 g and an initial velocity of 413.4 m/s, as well as a Special Forces Short Magnum with a mass of 35.44 g and initial velocity of 442.8 m/s.

The effect of a single simulated Tactical Home Defence ammunition strike is shown in Fig. 7. The projectile does not perforate the wall, merely violating its structure. There are visible cracks and displaced elements. The next shots may perforate it. Comparing this result with that of a shot against a single-layer wall the double-layer wall is weakened, but there are no elements knocked out.

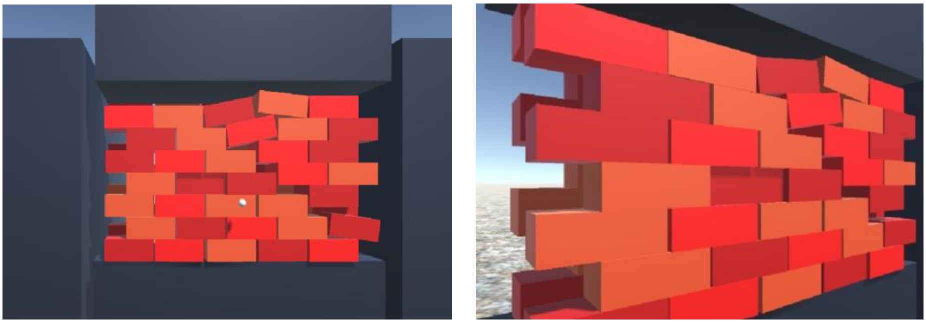


Fig. 7. The effect of a simulated Tactical Home Defence projectile strike against a double brick wall; frontal and slightly lateral view

The effect of a single simulated Special Forces Short Magnum ammunition strike is shown in Fig. 8. Once again, the projectile does not pass through the wall, but the structure violation is greater.

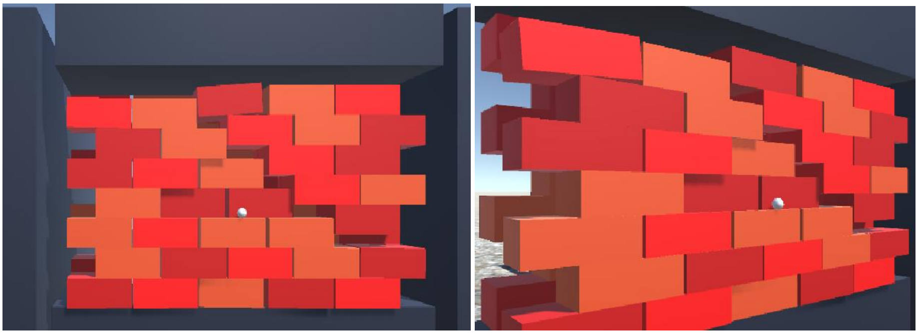


Fig. 8. The effect of a simulated Special Forces Short Magnum strike on a double-layer wall; frontal and slightly lateral view

The effect of the strike is slightly stronger than with Tactical Home Defence due to the projectile's greater kinetic energy; the result, however, is similar.

3.3. Simulation of the effect of striking a concrete block

The scene shows the sample simulated results of striking a concrete airbrick with a single Special Forces Short Magnum shot, with the ammunition's parameters being: 35.44 g mass, 442.8 m/s initial velocity.

As a result of the interaction with the impact force, the joints between the walls crack, and the block's upper part cracks into pieces. The corresponding simulation results are shown in Fig. 9.

To compare the effect of a simulated strike with real-life results, Fig. 10 shows the real-life effects of striking a concrete airbrick. The experiment from Fig. 10 uses real Special Forces Short Magnum Ammunition with the parameters as described above.

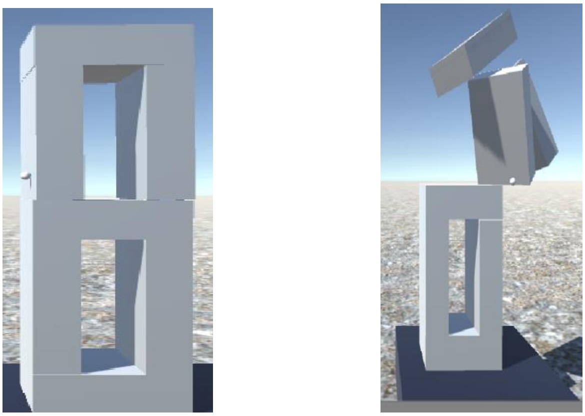


Fig. 9. The effect of a simulated Special Forces Short Magnum strike against a concrete block; view before and after the strike

Fig. 10. The effect of a real Special Forces Short Magnum strike, front and lateral view

Comparing the results of the simulation (Fig. 8) with the video (Fig. 9) taken during the real-life experiment leads to the conclusion that the virtual object behaves in a manner similar to that of the real-life object. As a result of the strike, the concrete block's walls cracked and fell down. The projectile did not pass through the block. The results are not identical to those of the real-life experiment due to the approximations adopted for the simulation. It assumes that each of the concrete block's walls is a rigid body through which the projectile will not pass. In reality, the projectile did pass through the wall.

4. CONCLUSIONS

Virtual combat shooting ranges are an increasingly common tool used for shooting training. They have a series of advantages, including the ability to implement virtually any training scenario in a relatively safe manner, at a relatively low cost. Such a shooting range perfectly complements field training. Shooting ranges of this type are also used for advanced training of the state's special forces. Realism is an important aspect of a virtual shooting range, raising the quality of the training taking place with its use and teaching the shooter proper sensibility regarding shots fired using various types of firearms against certain objects. An important element of this realism is modelling the damage caused by a projectile's strike against structure-type targets (buildings, walls, etc.). The article presents the results of using the Unity programming environment for modelling and visualising the effects of strikes against construction elements. Example simulations of damage caused by projectile strikes against walls made of basic construction materials have been programmed and conducted. The preliminary results obtained have proven to correspond to those of real-life experiments, as observed in the pictures and videos.

The selected method of modelling and visualising the damage caused by a strike in the Unity 3D graphics environment together with the Physics module has proven successful, therefore its implementation and further refinement are planned.

FUNDING

The work has been financed by the Polish National Research and Development Centre within the scope of Project DOB-BIO6/11/90/2014 "Virtual Simulator of Protective Measures of State Protection Service".

REFERENCES

[1] Bresciani L.M., Andrea Manes, Marco Giglio. 2018. "An analytical model for ballistic impacts against ceramic tiles". *Ceramics International* 44 (17) : 21249-21261.

[2] Shao Ruizhe, Chengqing Wu, Zhongxian Liu, Yu Su. 2019. "Experimental and numerical investigations of penetration resistance of ultra-high strength conctrete protected with ceramic balls subjected to projectile impact". *Ceramics International* 45 (6) : 7961-7975.

[3] Xu Xiangzhao, Tianbao Ma, Jianguo Ning. 2019. „Failure mechanism of reinforced conctrete subjected to projectile impact loading". *Engineering Failure Analysis* 96 : 468-483.

[4] Hu Feng, Hao Wu, Qin Fang, J.C. Liu. 2018. „Impact resistance of concrete targets pre-damaged by explosively formed projectile (EFP) against rigid projectile”. *International Journal of Impact Engineering* 122 : 251-264.

[5] Sauer Christoph, Andreas Heine, Werner Riedel. 2019. “Comprehensive study of projectile impact on lightweight adobe masonry”. *International Journal of Impact Engineering* 125 : 56-62.

[6] Ihran Baris, Joško Ožbolt, Daniela Ruta. 2015. “3D finite element simulations of high velocity projectile impact”. *International Journal of Solids and Structures* 72 : 38-49.

[7] Li Piani Tiziano, Jaap Weerheijm, Lambertus J. Sluys. 2018. “Ballistic model for the prediction of penetration depth and residual velocity in adobe: A new interpretation of the ballistic resistance of earthen masonry”. *Defence Technology* 14 : 607-611.

[8] Niezgoda Tadeusz, Krzysztof Kosiuczenko, Wiesław Barnat, Robert Panowicz. 2011. “Symulacja numeryczna przebijania odłamkiem osłony balistycznej wykonanej z kompozytu”. *Modelowanie Inżynierskie* 11 (42) : 295-302.

[9] Wiśniewski Adam, Dawid Pacek. 2012. “Walidacja modelu numerycznego pocisku 9 mm Parabellum”. *Mechanik* 2 : 138-140.

[10] Baranowski Leszek, Marek Kojdecki. 2007. „Zagadnienie odwrotne balistyki zewnętrznej i algorytm wyznaczania parametrów modeli ruchu pocisków artyleryjskich”. *Biuletyn Wojskowej Akademii Technicznej* 56 (4) : 167-186.

[11] Flis Leszek, Marek Sperski. 2011. „Badania odporności balistycznej pancerzy ze stali 10GHMBA na ostrzał pociskami 12,7 mm”. *Zeszyty Naukowe Akademii Marynarki Wojennej* 52 (3) : 27-42.

[12] https://unity3d.com/unity (2019)

Implementacja realistycznego modelu zniszczeń w środowisku symulacyjnym

Dominika KAZIOR, Damian BERESKA, Witold ILEWICZ

Politechnika Śląska, ul. Akademicka 16, 44-100 Gliwice

Streszczenie. Artykuł dotyczy modelowania zniszczeń w komputerowych systemach symulacyjnych. Przy zastosowaniu środowiska Unity zaprogramowano oraz przeprowadzono przykładowe symulacje zniszczeń na skutek trafienia pociskiem podstawowych materiałów budowlanych. Otrzymane rozwiązania przeanalizowano, wyniki porównano z efektami rzeczywistych eksperymentów oraz wyciągnięto wnioski dotyczące sposobu optymalnego modelowania zniszczeń w systemach symulacyjnych przeznaczonych do wizualizacji na wirtualnych strzelnicach.

Słowa kluczowe: strzelnica wirtualna, modelowanie i symulacje komputerowe, animacje komputerowe, silnik graficzny, pocisk, uderzenie