VIRTUAL SPORTS TRAINING SYSTEM USING KINECT V2 SENSOR

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The advancement of new technologies in Virtual Reality (VR) allows us to build virtual sports training systems. These systems generally imply videos or computer animations for training demonstrations. VR sports training systems can be used at any time and location. This way, the user can play the sport even at night regardless of weather conditions and can also train or compete alongside other remote users. The virtual sports training system can be used also to help patients suffering from stroke or paraplegia, and can be used in medical rehabilitation. Microsoft Kinect V2 sensor with its great features, like face and body tracking, body gesture, and others, extends the use of virtual reality in different kinds of applications. In this paper, we used the Kinect v2 sensor to design and build a real-time VR sports training system. The system displays in a 3D avatar, simple and complex exercises, captures and records the trainee movements in real-time, highlighting wrong movements and helping the trainee to correct his actions.

Keywords: Virtual reality, Kinect V2 sensor, Training system, Unreal engine

1. Introduction

Virtual reality is an innovation which permits a user to collaborate with a PC reproduced environment, whether that environment is a recreation of this present reality or a fictional universe. Most of the present virtual reality environments are essentially visual encounters, showed either on a PC screen or through unique or stereoscopic showcases, yet a few reproductions incorporate extra tactile data, for example, sound through speakers or earphones [1].

Virtual reality uses advanced technologies, including PCs and different interactive media peripherals, to create a simulated environment that clients imagine as similar to real world objects and events. With the guide of

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extraordinarily planned transducers and sensors, users can work with images, moving and controlling virtual objects, and performing different activities in a manner that brings on a sentiment of genuine vicinity in the reproduced environment [2]. One of the cardinal elements of virtual reality is the procurement of the feeling of a real vicinity and control over the re-enacted environment. This element is accomplished to a more noteworthy or lesser degree in the different uses of virtual reality, contingent also on the objectives of the specific application and the expenses alongside the specialized intricacy its engineers are ready to accept. [3].

Virtual reality is simulated in a 3-D image that can be investigated conjecturally at a PC, generally by controlling keys or the mouse so that the substance of the picture moves in some bearing or zooms in or out. More modern endeavours include such methodologies as wrap-around showcase screens, real rooms enlarged with wearable PCs, and haptic devices that let the user feel the presentation pictures.

The use of Virtual Reality technology for developing tools for rehabilitation has attracted significant interest in the physical therapy arena [4]. Sports training and rehabilitation have recently achieved a major enthusiasm for our life, so many researchers attempt to build interactive software applications, assisting the users with learning how to do the right sports rehabilitation movements or various training.

The paper is composed as follows. In section 2, a brief presentation of human motion capturing and tracking systems. Section 3 presents human motion tracking using Kinect sensor features. Section 4 describes the related researches on motion tracking based on Kinect sensor. Section 5 clarifies our proposed approach for building sports training system based on Kinect v2. Section 6, demonstrates the implementation of the proposed system. Section 7 describes our exploratory results and finally, section 8 contains the conclusions.

2. Human motion capturing and tracking systems

Virtual reality is not characterized or restricted by any technological methodology or equipment setup. The making of a VR client experience can be accomplished utilizing mixes of a wide assortment of interaction gadgets and sensory presentation frameworks and the design of content presented in a computer-generated graphic world. Progressive advances have happened in the fields of VR and intelligent computerized innovation technology and has bolstered innovative work that has focused on essential societal-level medicinal services challenges in ways that were unrealistic in the past [4].

Sports training systems are based on human motion capturing and tracking. The subject of human motion capturing and tracking received a considerable attention over the last decades. There is a wide range of applications that use human motion tracking while the industry provides constantly newer movement tracking systems, which have a great accuracy and high performance. Human motion tracking is receiving increased attention from computer vision researchers. This interest is motivated by a wide spectrum of applications, such as therapists, athletic performance analysis, military applications, video games, video conferencing, validation of computer vision and robotics [5].

Motion capture system research started from a long time. A survey of vision-based technologies can be found in [6] [7]. At the beginning of the 21th century, given the rapid growth in new technology, new methods have been developed. The most modern systems extract the shape or the graph of the performer from the background. All joints orientations or joint angles are computed by implementing them in a mathematical formula that can be used for analysis and comparison.

Human motion tracking methods used devices that permit the tracking of many motions like waving, standing, sitting, walking, running and even facial movements. There are wide methods used for capturing human motion in the virtual environment which utilized optical motion capture systems [8], inertial systems [9], acoustic systems [10] other systems used to combine multiple sensor types [11]. Motion capture systems are used to capture human motions on computers with the aim of translating these motions to animated or simulated characters [12].

Nowadays, almost all capture and track systems require specific hardware and software, the cost of which are expensive. In addition, these systems need long times and complicated steps to install [13].

3. Human motion tracking using Kinect

New advancements in the research field includes the Xbox Kinect system, developed by Microsoft, which may motivate users to do more sports movement through games and interactivity, emulating this way the daily exercise recommendations [9].

Microsoft Company produced and realized a Kinect V2 technology in September 2010. This new Kinect sensor with a dual-camera allowed for three-dimensional body tracking without the need for multiple cameras or a meticulous marker setup for the users. The unique functionality of the Kinect sensor, coupled with a fast and uncomplicated setup, an easy development framework, and access to a lot of online learning resources made a huge impact on the research community. Microsoft Kinect V2 sensor with its Software Development Kit (SDK) is a considerable advancement of technology from older versions [14], an improved motion-sensing device that provides to the users a facility to interact with computers and game consoles through many ways like gestures or spoken commands. This technology allowed many researchers and companies to develop, beyond the original scope of gaming, many real-time applications in various fields like healthcare, sport training, facial emotion detection, airport security, law enforcement, three-dimensional reconstruction, motion recognition, and even more, like sign language recognition, robotic control, voice and gesture recognition, as well as 3D reconstruction, wonderful for the 3D printing [15] [16] [17].

Kinect sensor allows us to extract the location and body position of a person, without requiring additional computer vision techniques. It will become easier to acquire data, and we can easily extend it to other environments as well. The sensor is not bound to specific lighting conditions. Even when the lighting conditions are continuously changing or when there is no light at all, the infrared technology ensures that we can always track people [18].

One of the most important Kinect features is tracking. For body tracking, Kinect can track a total of 25 skeletal joints instead of 20 joints for the older version. The new joints that were added are hand tips, thumbs, and shoulder center. The 25 joints improved the understanding of the soft connective tissue and body positioning, so we can get more anatomically correct positions for crisp interactions, more accurate avatars, and avatars that are more lifelike. This improvement for the body tracking feature opened many prospective applications.

4. Related researches on motion tracking based on Kinect sensor

Until now, many authors in the literature focused on a specific field and limited environments for the Kinect's applicability. Lately, the research has extended to analysis of dance performance and golf aids or to online combative technique showing stages and enhanced physical recovery, proving that there are still a wide range of unsearched areas of applicability and other uses cases to be found and researched using this new innovative sensor.

Clark, et al. [19], have conducted a study about the validity of Kinect's postural control. They did a comparison for twenty various subjects performing three unique and distinct movements between skeleton tracking data acquired from Kinect's sensor and skeletal tracking with an established kinematic assessment tool using 3D camera-based motion analysis. The experimental results of their study show the capability of the Kinect to provide valid anatomical displacement data, compared to the 3D camera-based motion analysis system. They conclude that the Kinect sensor is therefore an effective, reliable and marker-less alternative to a lot of elaborate marker-bound 3D camera-based systems for conducting potential anatomical positioning analysis.

Chang, et al., [20], presented another comparable research about the feasibility of Kinect. The comparison was done between the use of Kinect against an expert multi-camera setup, to prove the performance and the capability for rehabilitation purposes in clinical and home environments. Their outcomes assess Kinect as an effective option compared to some other costlier and prohibitive systems. While they mentioned that the restriction to one camera angle puts certain limitations on the Kinect sensor, it fares remarkably well in most experiments and movement comparisons.

Another approach was presented by Shotton, et al [21], as one of the significant research teams and software developers behind Kinect skeletal tracking ability and specifically funded by Microsoft for their contributions to Kinect's technology. They used a Kinect for skeleton recognition to show the Kinect reliability, they described a new approach to rapidly and precisely forecast 3D positions of body joints from a Kinect's single depth image without using temporal information.

From the above three studies, the Kinect can be considered a potential innovation that can provide precise joint information to prescient modelling purposes compared to other costlier and extensive systems.

Other researches focused on the applicability of the Kinect sensor equipment on aspects of detection ability and also on comparing and analyzing various kinds of movement patterns.

Bo, et al., [15], presented a methodology by connecting Kinect's skeletal tracking and internal sensors (accelerometers, gyro-meters) to enhance the accuracy and quality of self-physical treatment and rehabilitation. They are utilizing the combination of both systems to balance out sometimes the significant estimation errors of the inertial sensors. These sensors, comprised of accelerometers and gyro-meters, are appended to a patient's knee and ankle, yet require constant re-calibration. Subsequently, the authors want to utilize Kinect's simple setup and joint tracking capabilities for calibration reference of these sensors, by including 3-D joint angle calculations in the initial setup and initialization process. Their experimental results show that the combination of internal sensors (accelerometers, gyro-meters) with external motion capturing hardware (Kinect) yields easier and more reliable initialization procedures and better visualization capabilities

Zhang, L. et al. [22], also presented another exploration to enhance and improve Kinect's practicality for golf swing analysis. They built an automated system utilizing the Kinect sensor that can segment golf swing recordings and classify them based on an exclusively modified scoring system. For analyzing and classification, they utilized the extracted positional data and applyied a Support Vector. They classified the positions in four various classes based on classification dataset. The results demonstrate that their methodology is accurate in extracting and classifying test swings accordingly, with an average exactness of 84%.

Yao-Jen Chang, Shu-Fang Chen, and Jun-Da Huang [23] presented a system based on Kinect for physical rehabilitation, by studies done on a pilot for young adults with motor disabilities.

5. Our proposed approach for building sports training system based on Kinect v2 sensor

Athletes are always searching for additional equipments or systems to assist them to perform in their sport. Pierre Beauchamp, Ph.D., and Jocelyn Faubert, Ph.D.[24], in their paper asked, "How do we create effective simulations for training purposes?". The answer was by using virtual reality. In virtual reality, users will move their heads, eyes, and limbs to explore multisensory 3-D integration whenever they will act with objects [25]. Sports organizations and researchers have explored the potential of virtual reality environments except for baseball batting caves [26] and table tennis [27].

The system presented by them outline a training technology for enhancing perceptual-cognitive skills of athletes achieved through training with a 3D "cave" environment [24].

Our approach aims to record and display on the screen the sequences of several sport exercises performed by a professional sportsman and captured using Kinect V2 sensor, and then represented by a 3D avatar. The trainee person tries to imitate these exercises; the system records the imitative actions performed by the trainee and makes a comparison between them. A real-time correction is shown on the screen through messages and body parts highlights, assisting the trainee to correct his movements. Thus, the trainee can self-learn the sequence of exercises by following the real-time visual feedback. Toward the end of the considerable number of movements, a synopsis of his execution and a general aggregate score will be shown on the screen. In this methodology, we used the information of the body skeleton (joint pivots, positions, and angles between joints) which were gathered to make the comparison. Fig. 1 shows the flowchart for the proposed system.

Unreal Engine 4 (UE4) software supports Kinect V2 sensor with all its 25 joints and it is an extremely powerful graphics engine for building and developing games or other graphical applications, starting from 2D mobile games to full 3D immersive applications. Unreal Engine 4 provides all that we needed to begin building our project, so we used it to deliver a prototype very fast.

We have chosen UE4 engine also because of its great scripting language: Blueprint - a visual scripting tool that hastens a lot the development process and helps focusing just on the actual functionality and quick results. The Blueprint system represents components (functions, variables, events etc.) as nodes that can be related (connected) with other components through virtual wires (Fig. 2).

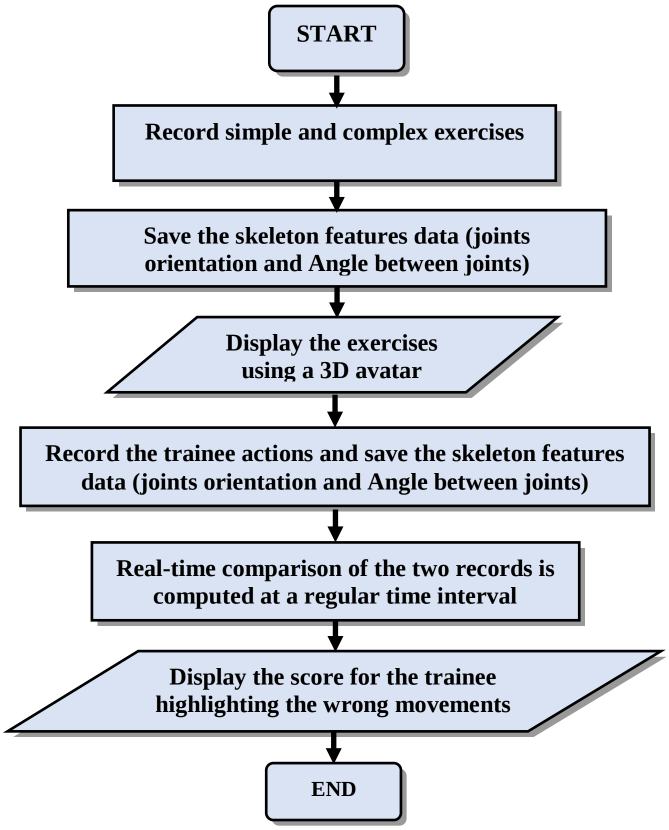


Fig. 1. Flowchart for the proposed approach

Also, UE4 has support for Kinect V2 SDK through several middleware plugins. One of them, Kinect 4 Unreal (sometimes abbreviated to K4U) permits Unreal Engine 4 developers to use the Blueprint visual scripting system to access the full functionality of Kinect 2 for Windows as seamlessly and as easily as possible. The key outline goal of K4U is to engage artists and designers by exposing everything through Blueprint so that the development group has the ability to focus their exertion on developing their project without a graphics programmer expert. Presenting more than 30 original nodes, all with broad documentation and pre-assembled Avateering systems, K4U exposes all that the Kinect has to offer to UE4 developers. The plugin primarily interfaces through a component-based system where, once activated through the plugin menu, any Blueprint can have the Kinect Interface Component added to it. The Kinect Interface Component gives developers access to a wide number of Blueprint nodes, each granting them access to some aspect of the Kinect functionality [28].

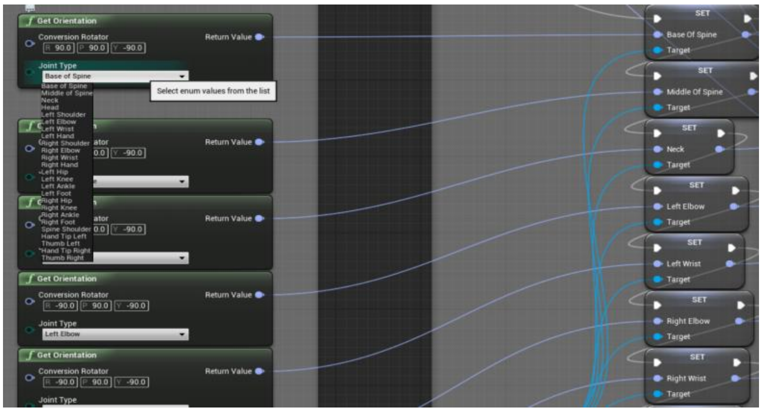


Fig. 2. Kinect 4 Unreal plugin Blueprint example.

6. Implementation of the proposed system

The proposed system contains two main stages:

A. Recording Stage

We used the features and facilities of UE4, along with the K4U plugin and the Blueprint scripting to create and build an interactive interface to record simple and complex exercises and we saved the skeleton motion data (joint orientation and angles between joints) for each exercise. Each saved file can then be displayed in a 3D avatar character when the trainee selects the exercise from the menu. All the motion data is collected using the blueprints offered by the K4U plugin and saved in a special structure as binary data on disk. We can have unlimited records, but currently the menu for playing the records is limited to several entries. The recording captures for each frame all the 25 joints and combines them to create a skeletal animation to be displayed in real-time on the screen. Fig. 3 shows a 3D skinned avatar alongside his joint structure, represented, in UE4, as a simple tree list.

B. Comparison Stage

After the trainee selects the desired exercise, the system will first start a counter for the trainee to be able to prepare. After the countdown has finished, the recorded exercise will start to play so the trainee will have to imitate the record. Both the record and the trainee are represented on the screen using 3D avatars, one playing the training record to imitate and the other one with the real-time captured motions of the trainee. The system will capture the trainee movement data similar to the recording stage and will run real-time comparison algorithms.

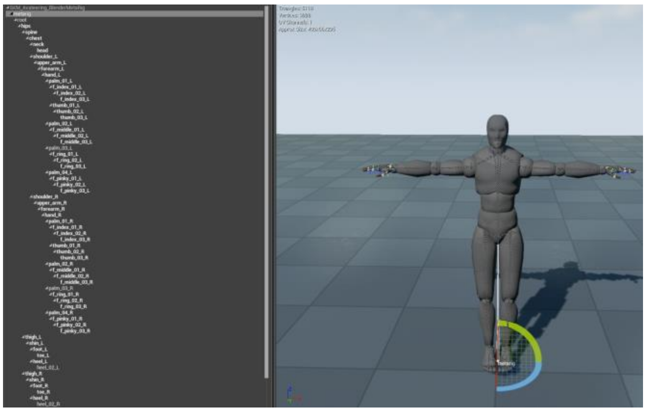


Fig. 3. Skinned avatar with joint list in UE4

We experimented with two different comparison algorithms: simple joint orientation and angles between joints providing real-time feedback side by side.

The simple joint orientation algorithm captures each joint orientation at a given time and compares the orientation values for each of the 25 joints returning the total matching percentage. We implemented this function programmatically and then we exposed some Blueprints functions to be able to easy interact with them. We experimented with the algorithm and then considered a final threshold of a 20-degree angle in order to have relevant results. The comparison result is computed each second in time, based on the maximum result from every frame comparison set computed in that second.

The angles between joints algorithm are implemented as described in [29] directly in the UE4 Blueprint system using multiple custom defined functions. The algorithm proposes to define vectors that join two joint points and then compute the angle between sets of two vectors. This way, we can capture and compare movements using a more natural approach (for example we would rather compare the angle between the arm and the forearm or the shoulder and the arm, than just comparing just the elbow joint or the shoulder joint orientation). This algorithm proved to be much more stable and precise so we managed to lower the threshold experimentally to about 12-degrees. As with the other algorithm, we computed the result at a second interval, based on the maximum result from every frame comparison set computed in that second. For both algorithms, we considered a movement matched if it was within the defined threshold. The movements results are highlighted as seen in Fig. 4, considering the result for each body part.

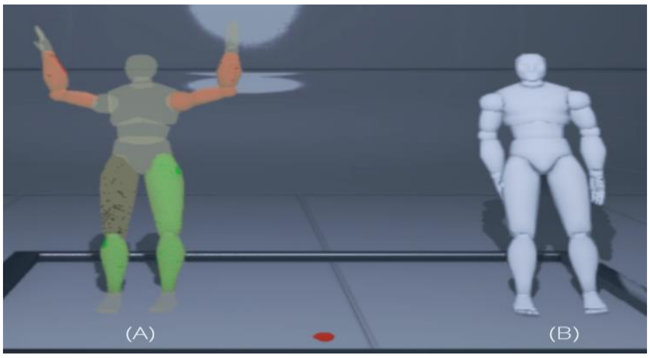


Fig. 4. Real-time movement highlight feedback. (A) – Trainee Real-Time Movement
(B) – Trainer Record

In order to achieve this result, using Autodesk Maya, we created the avatar from multiple separated parts, skinned to the same skeletal rig (Fig. 5) and using UE4 import tool we bounded each individual part to the same skeleton animation.

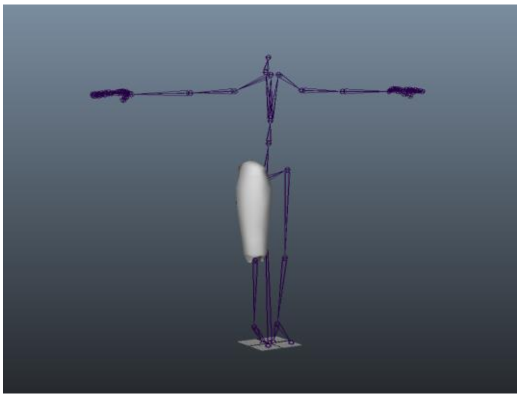


Fig. 5. Rigged body part mesh in Maya

7. Experimental results

To assess the proposed system, we experimented it by using several types of exercises. We started with some simple stretch movements and then continued with some more complex exercises. Each recorded exercise was imitated by two types of trainees, one with sports background (U1) and another one, a common person (U2). The system highlights the performance in real-time, providing color feedback for each movement and computing a general score for each presented algorithm: A1-joint orientation and A2-angle between joints (Fig. 6). Wrong movements are represented using red color and the green color represents a good or perfect imitated movements. The general score represents the percentage of the matched movements and it will help the trainees to track their improvements. It starts at 100% and keeps decreasing with every mistake. Currently there is no history functionality able to record past performances and list them in the graphical interface.

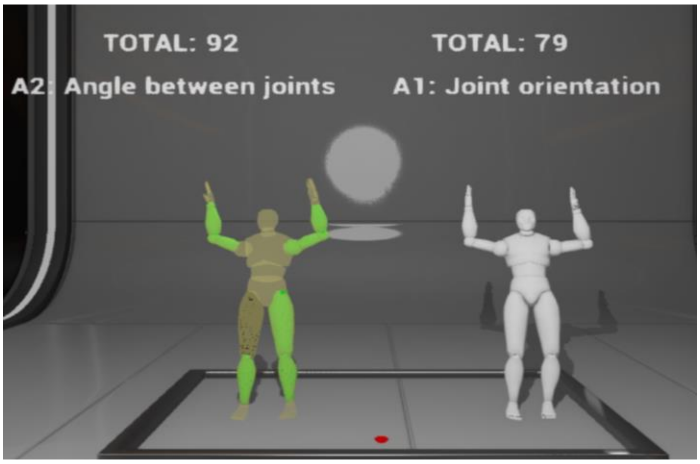
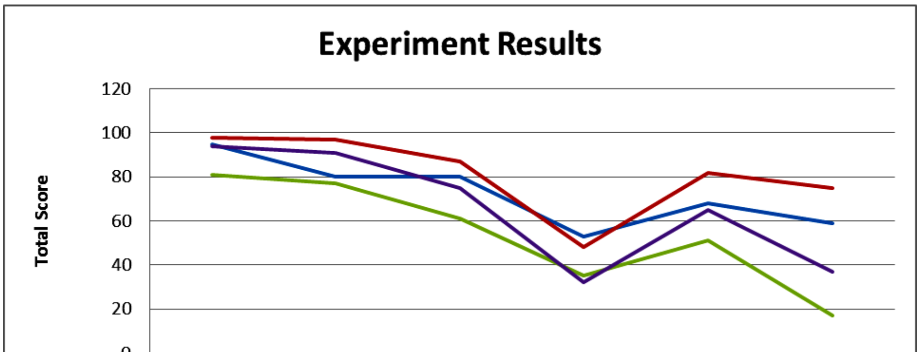


Fig. 6. Imitation of a model with computed total score and movement highlighting

The experimental results are presented below in Fig. 7.



	Arm Stretches	Lateral Stretch	Squats	Pushup	Arm circles	Cross-body bicycle
U1 : A1	95	80	80	53	68	59
U1 : A2	98	97	87	48	82	75
U2 : A1	81	77	61	35	51	17
U2 : A2	94	91	75	32	65	37

Fig. 7. Experimental results

We notice that the score is decreasing proportionally with the increasing complexity of the exercises. This is somehow expected because the more complex is an exercise the harder is to imitate it, even for an experienced trainee. Still, there are a couple of remarks, resulted from this experiment, to take into account regarding the system.

First of all, even if it has greatly improved since the last version, the capture from the Kinect V2 sensor is not perfect, so smoothing should be manually applied to the captured values to lower the noise.

The countdown function was a very good addition. The system also shows the first movement of the training during this countdown, so the trainee has time to prepare and get in the correct position for the training.

The synchronization threshold, comparing the movement each second (so it can cover up to 60 frames differences) is also very important as the user can perceive and follow usually just one movement in one second.

Regarding the comparison algorithms, we can see from the experimental results that the A2 – angle between joints algorithm is more stable and has better results.

8. Conclusions

In this paper, we proposed an advanced virtual sports training system using the new Kinect V2 sensor and we implemented and presented a working prototype with promising experimental results in using the sensor for sports training. For building our system, we described a novel and simple approach by using the Unreal Engine 4 graphics engine alongside the Kinect 4 Unreal plugin. The experiment results show that the system can further be improved, but it validates the proposed approach for a 3D virtual reality sports training application that can be used easily at home and removes the need for a personal instructor each time.

Our sports training system is currently built for static physical training, in a closed environment, but can also be extended to other kinds of sports in a very simple and flexible way, and then just record any kind of sports exercise by an expert sportsman and save it in the system so that a trainee can simply select which sports he wants and enjoys the training course.

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