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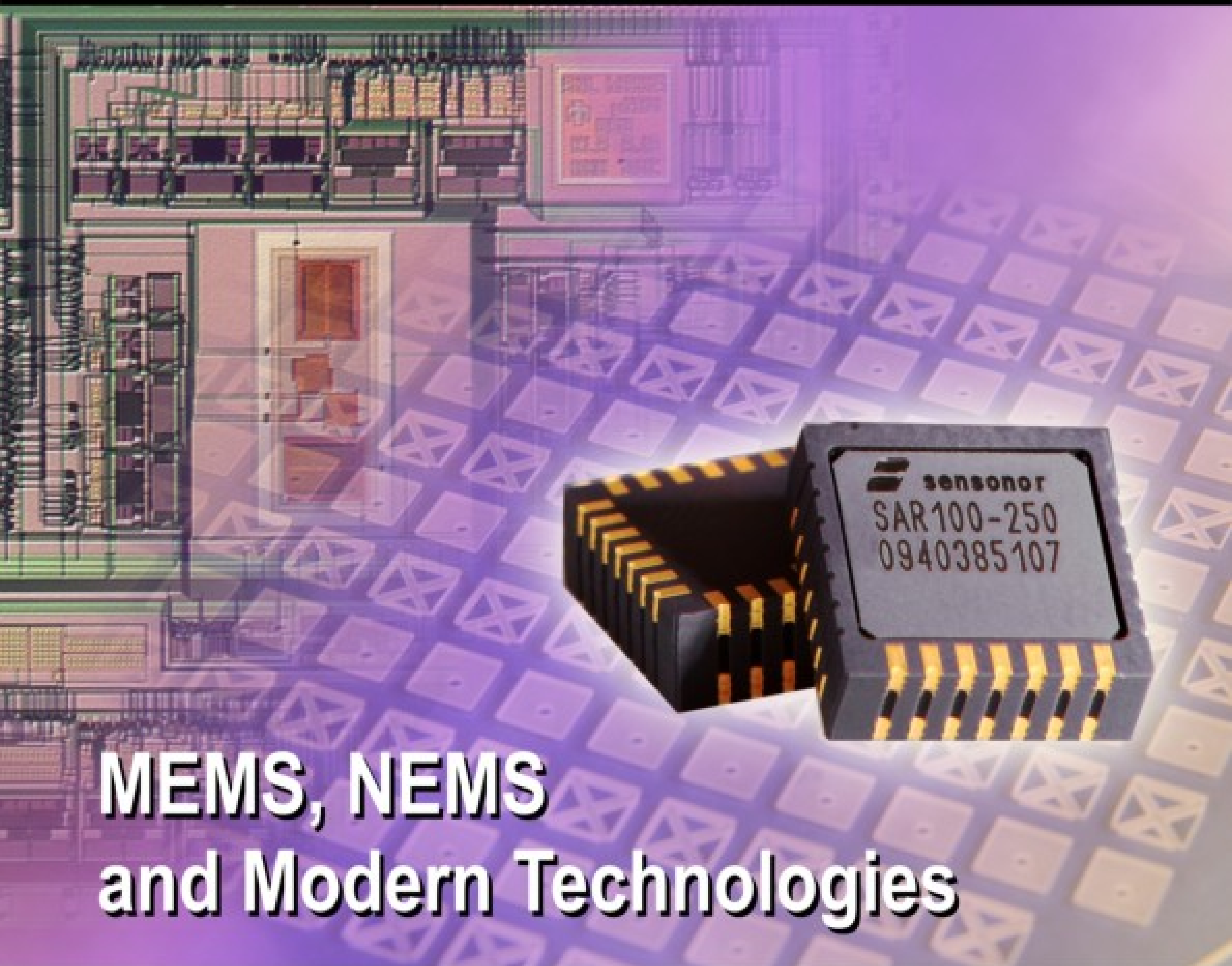

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Design and Implementation of an Embedded Digital Throwing System Based on MEMS Multiaxial Accelerometer

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Abstract: This paper presents a novel embedded digital throwing system for synchronously sensing the throwing force of shot-put athletes in real time. The three axes integrated accelerometer, as a crucial device in the force sensing system, can acquire the kinetics data along three orthogonal directions with reasonably high accuracy. The digital shot with almost the same size and weight as the standard shot for open female has been designed, fabricated and implemented. The mechanical structure, signal processing system, and human-machine interface are illuminated in detail. In this manner, the force sensing system serves as a powerful tool for coaches and sports scientists to make scientific researches on professional throwing techniques. It also provides an intuitive and reliable guidance for the throwing athletes to improve their skills. *Copyright © 2010 IFSA.*

Keywords: Digital-shot, Shot-put, MEMS accelerometer, Information acquisition, Throwing motion

1. Introduction

Nowadays with the rapid development of scientific and technological research in the field of sports, the improvement of athletes' professional skills depend more on the level of related science and technology. Emphases on the shot-put athlete training have gradually shifted from the personal experiences of the coaches to the precise analysis of the biomechanical information obtained from the athlete in motion with auxiliary equipment [1].

The human body was simplified as a multibody system consisted of fifteen rigid components. Theoretical analysis and comprehensive experiments are conducted by many scholars to investigate the throwing behaviors [2-11]. The javelin throwing process of the athlete was photographed by high-speed photograph in [2]. Motion human modeling as a potent method has been used gradually. In [3], the raw EMG data was extracted from the various muscles of limbs. Comparison was implemented to display the differences of muscular activation for the upper extremity in heavy weighted shot put and discus throwing. In [4], the shot slanting throwing movement was derived by non-linear curve fitting, momentum balance equation, multiple regression analysis and fuzzy synthesized logic. Hubbard *et al.* [5] considered that when the shot was released above a horizontal plane, optimal release conditions can be calculated if the dependence of release velocity on other variables was known. In [6], the kinematic parameters related to pitching mechanics and resultant kinetics on the throwing arm elbow and shoulder joints were derived. In [7], time-frequency analysis of the EMG signal and the biomechanical measurements of the lifting technique were combined to identify the excessive muscular response.

As human body is a complex gigantic system, many factors must be considered together for well analyzing the behavior of skilled shot-putter. The above solutions try to construct the whole human body model or partial body model by some traditional technique or pure mathematics means. But as the insufficiency of the information acquiring methods, especially the lack of kinetics data, the error cannot be completely avoided. The goal of this research is to develop a throwing multi-dimensional force sensing system to overcome the shortcoming of former instruments and recognize the correctness of athletes' action.

2. Sensor of the Digital-Shot

As the most crucial portion of the digital-shot, the quality of the force sensor has direct influence upon the performance of the system. In the previous work, a strain gauge sensor for male shot-putter was designed and fabricated. However, the force sensor could not endure severe violent collisions felling to the ground. In the second generation of digital-shot, many actual problems have been addressed. By amending some faults of the first generation of digital-shot, the compact three axes acceleration sensor have been investigated and developed as shown in Fig. 1. In this scenario, the analog PCB, the elastomer, the compensatory mass, and the sensor were mounted together to reduce vibration. Although it has obvious improvement compared with the former one, the inherent defects of the sensor made of alloy steel material still remain.

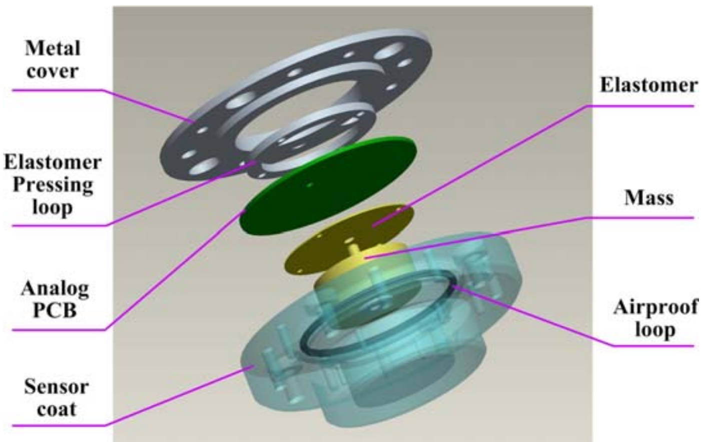


Fig. 1. Exploded view of the three axes acceleration sensor of the second generation digital-shot.

In order to transcend the native limitation of traditional force/acceleration sensor, the MEMS accelerometer is selected as the crucial element in the third generation digital shot. Fig. 2 displays the prototype PCB based on the ADXL78 (Analog Devices Inc) that can simultaneously measure acceleration information along three orthogonal directions. As it is one kind of sensor with single axis, to detect 3-dimensional signals during athletes' throwing process, the information acquisition circuits which comprise three single axial sensors are designed to satisfy the special structure as rectangular Cartesian coordinate system.

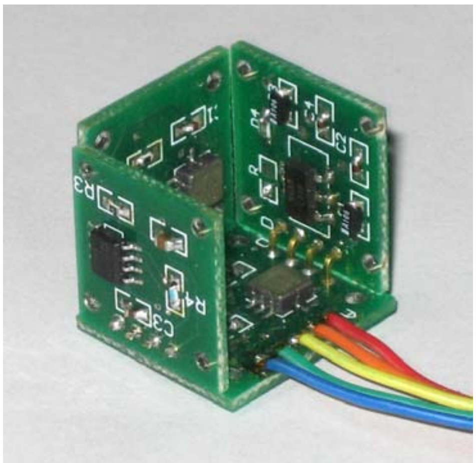


Fig. 2. Force sensing PCB based on MEMS accelerometers.

The ADXL78 is the surface micro-machined MEMS element. Both of the dynamic acceleration (i.e. vibration) and the static acceleration (i.e. gravity) can be recorded with high performance. The accelerometer is temperature stable and accurate over the automotive temperature range, with a self-test feature that fully exercises all the mechanical and electrical elements of the sensor with a digital signal applied to a single pin [12]. The size of the spatial sensing PCB is 20 *mm* by 20 *mm* by 18 *mm*.

Fig. 3 is a simplified view of the sensor elements which include several differential capacitor unit cells. Each cell is composed of fixed plates attached to the substrate and movable plates attached to the frame. Tiny displacement of the movable plate alters the differential capacitance that is measured by on-chip circuitry [12]. Fig. 4 shows the results of static calibration of the sensor by means of putting the sensor in different angles with respect to the direction of gravity that it can sense a series of acceleration changes, in which the maximal value is the one (1) gravitational acceleration. Then the output of the sensor is recorded with the form of different voltage values. Excellent linearity can be found from the picture.

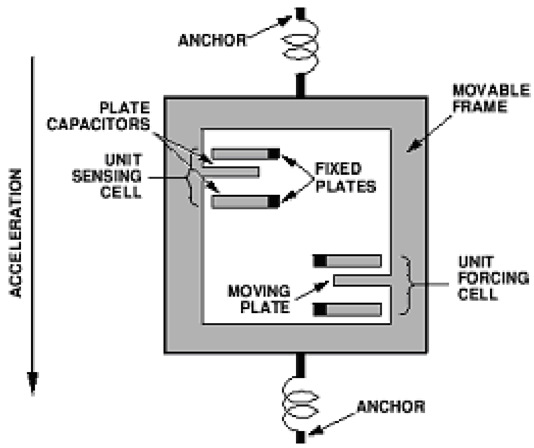


Fig. 3. Simplified view of sensor under acceleration (courtesy of *Analog Devices, Inc.*).

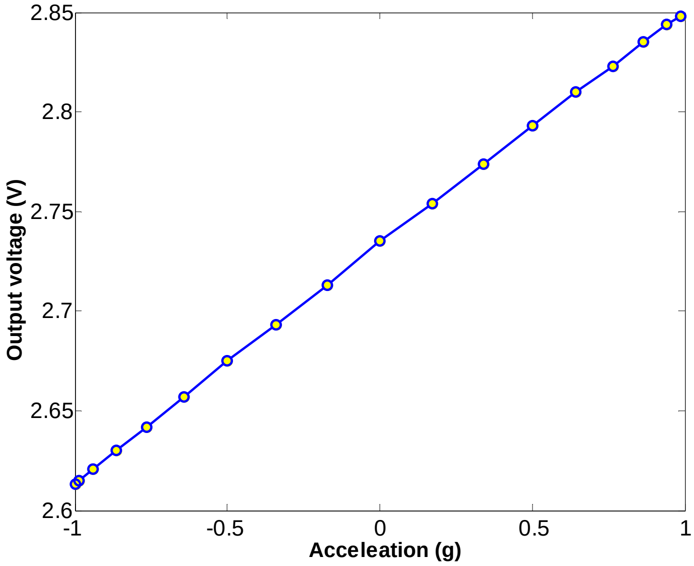
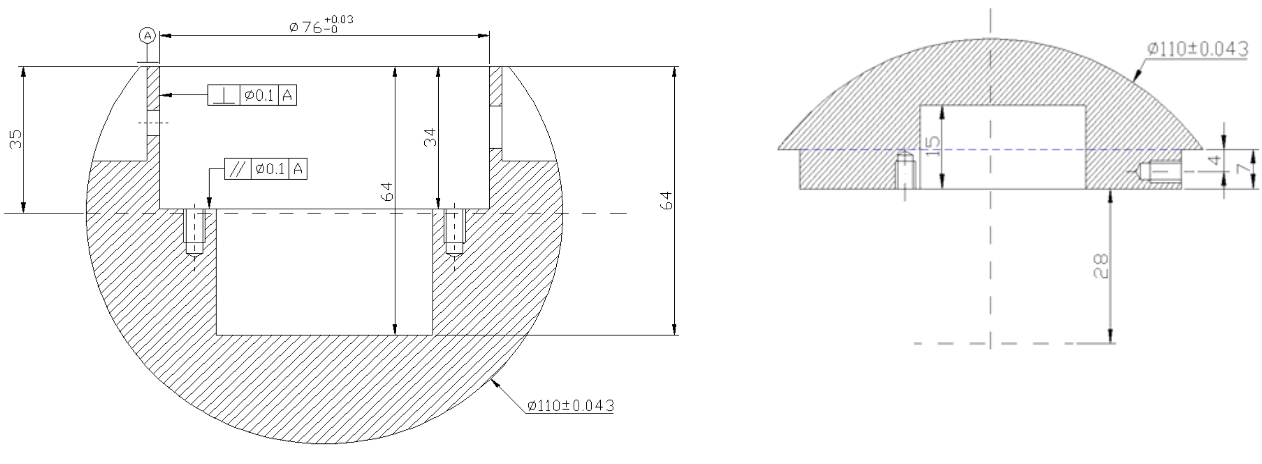


Fig. 4. Static calibration of the shot-put sensor.

3. Fabrication of the Mechanical System

The mechanical structure of the digital shot mainly includes the upper shell and the lower shell (as shown in Figs. 5-6). The upper shell, connected with the lower one via four screw joints, is manufactured to install and fix the supplying power. Besides of the tri-dimensional accelerometer circuits, the analog-digital conversion and storing circuits are installed in the body of the lower shell, which is attached with the power lamp and its switch, the sampling lamp and its switch, and the synchronizing module etc.



(a) (b)

Fig. 5. The dimension of the mechanical structure of the shot-put system; (a) lower shell, (b) upper shell.

Fig. 6. Installation of the overall digital shot.

4. The Signal Processing System

After the system is supplied with power, the 51 kernel of C8051F320 first initializes peripheral equipment (see Fig. 7). If the system is in working status, it begins to wait for the user triggering the detect switch or receiving the data transmit command sent by computer. Once the command is received, the processor controls the AD transducer to detect the acceleration information from sensor bridge output. The data detected is saved to flash memory via GPIO interface. When we need to analyze the data, the shot is combined to computer with a USB cable, the computer controls 51 kernel to allow the data stored in Flash memory to flow into computer via USB interface.

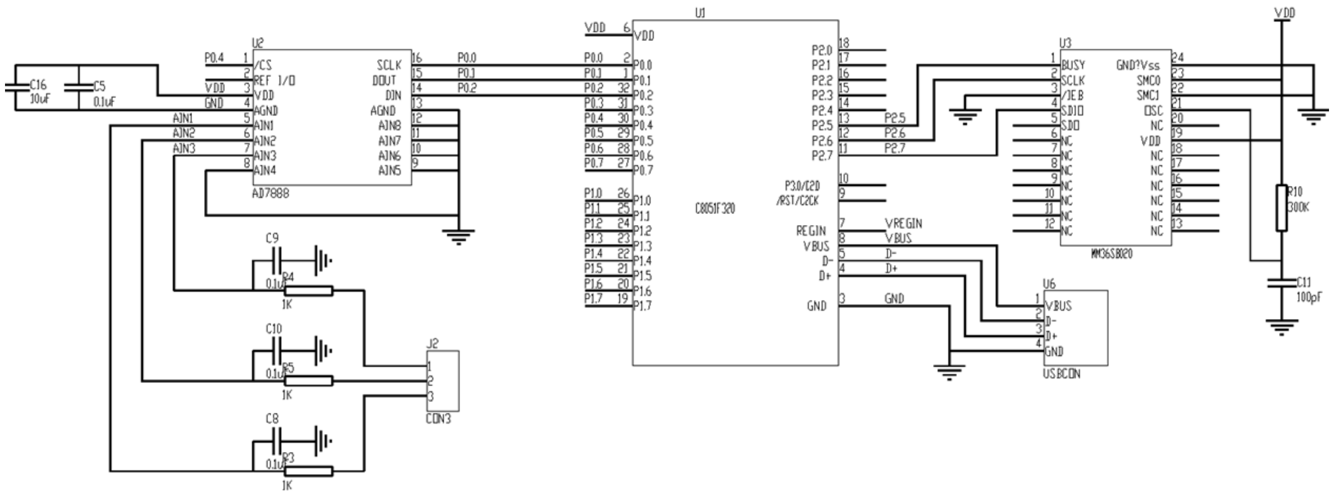


Fig. 7. The schematic diagram for signal processing circuit.

5. Human-Computer Interface

From the viewpoint of biomechanics information acquisition, human motion represents as a kind of complicated mechanical behavior, whose feature parameters are generalized as nonlinear, time-varied and unrepeatable. To model the human motion and construct the athletes coaching system, kinetics parameter is extraordinarily important.

A graphics based user interface (GUI) is developed to display and operate the kinetics curves acquired in real time from a series of motion when throwing the digital-shot device. To have a user friendly communication between the human operator and machine, the measured data in the upper PC with text format, date reading and display programs are written in Visual C++ considering its advantage of powerful digital I/O interface functions and multithreading feature.

Fig. 8 shows a typical series of acceleration signals by the developed GUI. In addition to data processing, it also includes functions such as data erasing and storing etc. The black, yellow and red curves represent the accelerations along X, Y and Z directions respectively, while the write curve is the sum of them.

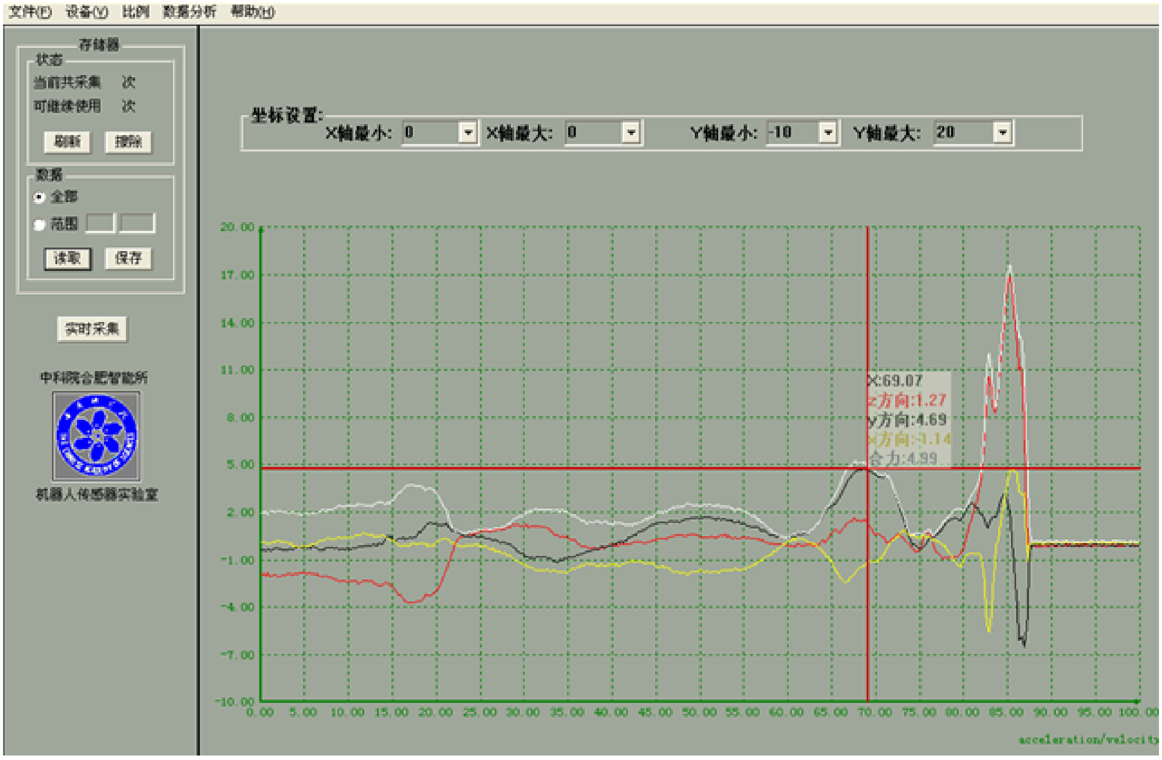


Fig. 8. User interface of the data sampling and processing system.

6. Experiment and Analysis

The major function of this work is to find out the technical merit and inaccuracy in the process of shot throwing given the data obtained by the digital shot system. This is undertaken by analyzing the motion behavior and features of athletes based on the knowledge of sports biomechanics. Analysis of the kinetics curves is the key to realize the evaluation of accomplished motion patterns. It should be noticed that in field training and throwing process, the human body is located in the geodetic coordinate system, while the digital-shot records and outputs tri-dimensional signals in the calibration coordinate system (as shown in Fig. 9). Besides, when the athletes grip the device, the relative position between palm and shot will affect the pose of calibration coordinate system. To reduce the uncertainty of the measurement, the fingerprints are engraved on the surface of the digital-shot to constrain the gripping position.

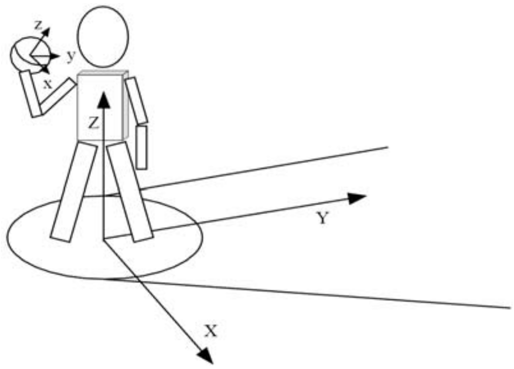


Fig. 9. Geodetic coordinate system and shot-put coordinate system.

A representative shot-throwing behavior with the glide technology is performed and corresponding acceleration curves form three orthogonal directions X, Y and Z respectively is shown in Fig. 10. By observing the character of the curves, available features can be abstracted which can be used to analysis the correctness of the technical movement.

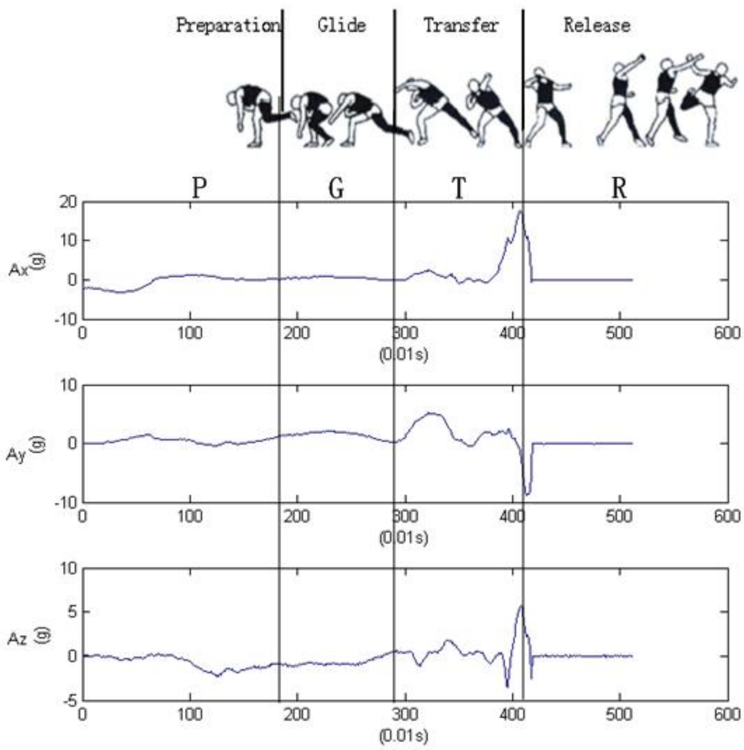


Fig. 10. The four phases of glide technology and acceleration curves from three orthogonal directions.

The general throwing process can be divided into four phrases, namely preparation (*P*), glide (*G*), transfer (*T*), and release (*R*), respectively. The straight line with no vibration after the upmost peak in phase *R* expresses that the shot is flying in the air. In phase *T*, maximal forces are applied on the shot-put sensor. To reach the optimal parameters of shot-put throwing with the technique of back gliding, i.e. maximum acceleration in ideal release angle, the athlete moves into power position when the front foot touches down and the athlete has both feet in contact with the throwing circle in preparation for the delivery of the throw. As the action of arm stretching, acceleration from Z-dimension begins to decrease, while the other two directional accelerations increase a little. *Az* increases rapidly and reaches its peak value suddenly because of the rotation from side to front and at the instant of right hand leaving right shoulder comes to the maximum. The objective of this type of professional movement is to achieve an ideal release angle and maximum release velocity. Besides, the effective application for the power of supporting legs is also essential technical factor. The best force and motion sequence under constraining of human body geometry to reach the perfect status is the issue that can be regarded as an optimization problem.

7. Conclusion

In this paper, an embedded digital-shot for acquiring the throwing force information of skilled shot-putter in real time is presented. Being a crucial device, the three axes accelerometer, developed based on MEMS technology, can acquire the kinetics data along three orthogonal directions with a decoupled manner.

For the future work, the integrated athlete coaching system comprised by a digital shot, a six axis force measuring plate, an EMG signal remote measuring device and high-speed camera based vision system will be developed. The six-axis force measuring plate is used to measure the ground reaction force. Two high-speed video cameras are used to capture the 3D motion images. The EMG recorder combined with motion video and force measurement will allow a quantitative examination of the internal and external factors governing human motions, particularly for effective sampling of the electric signals from human upper limbs such as biceps and triceps. Then multi-target and multi-parameter athlete biomechanics information can be acquired via data fusion.

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- Sensor instrumentation;
- Virtual instruments;
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