Testing the Micro Climate in Sports Shoes by a New Manikins Measurement System

Wei Zhao*, Pengcheng Yuan and Linghua Kong
Laboratory of Internet of Things, College of Mechanical and Automotive Engineering, Fu Jian University of Technology, Fuzhou, Fujian, 350118, China

*Corresponding author email: zhaowei@fjut.edu.cn

Abstract. To measure the temperature and humidity of micro climate in the shoes is a necessary step to design and manufacture new kind of ones. The temperature and humidity in moving human foot are important factors of the shoes’ thermal-humidity comfort. A new moving manikins test system for measuring temperature and humidity in sports shoes is introduced. Experiments and calculated results by the traditional method and by the moving manikins method shows that the new moving manikins test system can measure the temperature and humidity of sports shoes correctly, repeatably and normatively.

1. Introduction
A suitable micro climate between the shoes and foot guarantee the comfortability and healthiness. To test the changing temperature and humidity, which are important factors in the micro climate, is a necessary procedure for the design and manufacture of footwear[1-6]. The test methods used to be carried out by measuring the human’s walking or motionless foot with their shoes[1]. The changing trends and interrelations of the factors, such as temperature, humidity, airflow rate, thermal resistance, wet resistance, etc, were researched[1-3]. Recently, New test methods applying the foot model or manikins to simulate the measurement have been developed[2-9]. The new methods have better feasibility and normative, however, they can not measure the moving foot and shoes’ temperature and humidity.

A moving-manikins test system developed by FuJian University of Technology are introduced, which aims to measure the micro climate in footware. The comparative experiments based on the new test system and on the old method have been carried out, the results of which show that the moving-manikins test system can substitute for old test methods.
2. A Moving-manikins Test System

As shown in Figure 1(a), the moving manikins test system are included in a chamber, in which the temperature, humidity and wind speed can be regulated by a PLC control sub-system to simulate nature environment. The temperature can be regulated from -5°C to 50°C with accuracy about ±0.1°C; humidity regulated from 10% to 100%, with accuracy about ±2%; wind speed regulated from 0 m/s to 4 m/s, with accuracy about ±0.2 m/s. Under the chamber, there are a set of actuators driven by step motors and mechanics sub-system, which provide two freedom motion to the bottom of manikins. In the chamber there is a translation mechanism above the manikins to provide one freedom motion. The three freedom manikins are designed to simulate gait of human beings[8,9].

As shown in Figure 1(b), in the surface of manikins’ fake-foot, there are six temperature and humidity sensors with accuracy of temperature about ±0.1°C, humidity accuracy about ±2%. On the surface of the fake-foot, there are eight capillary-like tubes driven by peristaltic pump with memmert to simulate the foot’s perspiration. In the fake-foot, there are several heating resistors controlled by PLC subsystem to simulate the foot’s temperature. At the bottom of fake-foot, there are six pressure sensors. In the shin bone of manikins, there are a set of spring-damper-like sub-system, which can be adjusted to simulate the pressure in manikins.

3. Measuring the Temperature and Humidity

3.1. Test Methods

The human being test method (Referred to as old method) and the manikins test method (Referred to as new method) are independently carried out to compare the similarities and differences. Five sports shoes of same brand are chosen to be tested. Both the five people and the manikins are tested without socks.

3.1.1. The human being test method. The instruments of old test system includes an infrared thermal imager, a treadmill, a humidity sensing data recording instrument.

The test is carried out in an air conditioned room, where temperature is adjusted to 25±0.5°C, humidity 70%±2°C. Five male students with almost same weight and same foot size are chosen as subjects. The experiments are carried out in two stage, the motionless test and walking test. In the motionless stage, the foot and shoes’ temperature and humidity are measured every three minutes. In the walking stage, measurements are carried out every minutes.

In each test stage, the test results of five subjects are averaged as one result, which is used to compare with that of the new test methods.

3.1.2. The human being test method. The new test method is carried out in manikins test system, as shown in Fig.1. Humidity and temperature in chamber are also regulated as 70±2% and 25±0.5°C.
temperature of manikins’ fake foot is regulated from 36.1°C to 37.5°C according to test status, which simulate the temperature of human foot. The flow rate of peristaltic pump is adjusted from 0.9 ml/min to 5.5 ml/min, according to the test status. The tempo of actuators is also regulated according to the old method.

3.2. Results and Evaluation

![Figure 2. Temperature measured by two methods in motionless status.](image1)

As shown in Figure 2, the curve marked as Temp1 Human Motionless is the records of average value of five test subjects. They sat in an air conditioned room, were tested about every five minutes. Their shoes’ temperature is 29.5°C at 30 minute and reach the stable state firstly. From 30 minute to 60 minute, the temperature of sports shoes keeps 29.5±0.2°C. The Temp2 curve is the record of Manikins Motionless. It reaches 30.2°C at 20 minute, and reaches the peak value of 30.7°C at 5 minute later. Then it reduces to 30.3±0.1°C from then on. The curve of Temp2 shows an overshoot phenomenon, the reason of that may be the inertia of manikins test system, which is a mechatronic system. Though the temperature of manikins is just set as 36.1°C, its shoe’s stable temperature is higher than that of human foot shoes’ temperature. The reason may be that the temperature of motionless human foot in a 25±0.5°C room is actually lower than 36.1°C, which is incorrectly supposed to be a normal value of human body.

![Figure 3. Temperature measured by two methods in walking status.](image2)

As shown in Figure 3, the curve marked as Temp2 Human Walking is the average value measured from five spots shoes walking at a speed of 4 kilometer/hour. These values are measured about every one minute. The Temp2 Human Walking shows the shoes’ temperature takes 10 minutes to reach 32.2°C, and it keeps stable temperature from then on. The Temp1 Manikins curve shows that the temperature of the shoe on the “walking” manikins’ fake foot also takes 10 minutes to reach 32.2°C. After an overshoot, the temperature curve decades to 32.4°C, which is a stable value. The Temp1 Manikins curve shows when the manikins’ temperature is regulated as 37.2°C, while the Temp3 Manikins curve is the result when it is set as 36.5°C. The Temp1 Manikins curve shows the same trend, but reach the stable temperature valve at 5 minutes later and lower value at 31.3°C.

From the Figure 2 and Figure 3, there are two important conclusions. The manikins test system always show a overshoot phenomenon, the reason of which may be the inertia of mechatronic system. Another phenomenon is that, not like manikins, the human foot seems can “control” their temperature more optimal: it changes slowly when in a quiescent condition, while it changes faster when in a spots condition.
As shown in Figure 4, in motionless status the humidity values of human shoes are measured every 5 minutes. Its curve takes 20 minutes to reach 86.5±2%, as is a stable value. While the corresponding value of manikins take almost 40 minutes to reach stable value 88.1±2%.

As shown in Figure 5, in walking status the humidity value of human shoes just takes 15 minutes to reaches the stable value 92.2±2%, while corresponding values of manikins take more than 10 minutes. The curve marked as humidity1 Manikins moving are measured as flow rate of the peristaltic pump is adjusted to 2.8 ml/min, while the curve of humidity1 Manikins moving adjusted to 2.2 ml/min. Not like in Figure 2 and Figure 3, the test results shown in Figure 2 and Figure 3 have no overshoot phenomenons. There are perhaps two reasons: one is the test accuracy, the humidity can only measure with an accuracy ±2%; the other is that the subsystem of capillary-like tubes and the peristaltic pump is a complex hydrodynamics process, which can not be considered as a linear system.

From the above figures, it seems that the measured curves of manikins test system is not just the same as that measured by the old method. Nevertheless, the manikins’ test curves are much more normative and reproducible than that of the old method.

As shown in Table 1, when the measured values above are applied to calculate the temperature resistance and wet resistance, it shows that the temperature resistance and wet resistance of shoes on the five walking foot have too much difference. For example, the test subject3’s temperature resistance is 0.314m²K/W, much higher than test subject1’s 0.241m²K/W. While the temperature resistance value calculated from walking manikins’ shoe is 0.288±0.05 m²K/W, a rather steady value. The wet resistance in table 1 also shows a remarkable individual difference, while the wet resistance of walking manikins’ shoes is 175±5 m²Pa/W, which shows a steady value again. It can be concluded that the old method is not suitable for testing temperature and humidity.

| Test subject | Thermal resistance (m²K/W) | Wet resistance (m²Pa/W) |
|--------------|----------------------------|------------------------|
| 1            | 0.241                      | 157                    |
| 2            | 0.294                      | 210                    |
| 3            | 0.314                      | 165                    |
| 4            | 0.276                      | 200                    |
| 5            | 0.262                      | 180                    |

4. Conclusions
Recently, many researchers have developed new test methods for measuring thermal-humidity comfort. A moving-manikins test system is firstly introduced to test thermal-humidity comfort. Experiments by the traditional method and by manikins method are carried out with purpose of comparing their repetitiveness and normalization. Based on measured values, such as the temperature and humidity, it
shows that the moving-manikins test system can perform the measurement of thermal-humidity comfort with better normative and repetitive. Though this new test system can effectively test thermal-humidity comfort of sports shoes, it still has a lot of work to do. Understanding biomechanics of a moving foot with footwear and controlling the manikins system with intelligent algorithm, for examples, are expected to improve the moving-manikins test system.

References

[1] Wang X and Yuan J J et al 2015 Testing on Thermal-humidity Comfort of Sports Shoes’ Micro-climate Environment in Wearing Condition China Leather vol 44(10) p 110-115
[2] Chen D Z 2016 Research on Test Method of Thermal-wet Comfort for Sport Shoes Leather Science and Engineering vol 25(03) p55-58
[3] Man X D and Yan X N 2014 Investigation on the hot and damp comfortability of human feet in socks and shoes Journal of Xi’an Polytechnic University vol 28(04) p 402-405+412
[4] Xu Y Q and Chen L et al 2018 Exploration of Measuring Water Vapor Permeability and Water Vapor Absorption of Shoes Leather Science and Engineering vol 28(02) p68-71
[5] Fan Y J 2018 Study on the measurement device for thermal comfort of socks Zhejiang Sci-Tech University
[6] Zhang Y W 2017 Research on the foot pressure, temperature and humidity system based on customization and sensing technology. DONGHUA University
[7] Hong C Y, Zhang Y F, Zhang M X, et al. 2016 Application of FBG sensors for geotechnical health monitoring, a review of sensor design, implementation methods and packaging techniques. Sensors and Actuators A: Physical, , 244: 184-197.
[8] Hu J and Wang D M et al 2016 A Multi-segment Foot Model for Gait Simulation Based on Automatic Dynamic Analysis of Mechanical Systems Journal of Biomedical Engineering vol 33(06) p 1060-1066
[9] Zhang Y and Jiang K N et al 2019 Development of Dynamic Ankle Prosthesis (review) Chinese Journal of Rehabilitation Theory and Practice vol 25(12) p 1389-1394