Design and Development of a Waterproof Garment Testing System

Jorge Yáñez*, José Fariña**, Juan J. Rodríguez-Andina** and Alejandro Marques de Magallanes*
* Partenon S.L., Redondela, Spain
** Institute of Applied Electronics, University of Vigo, Spain
jorge.yanez@partenon.net, jfarina@uvigo.es, jjrdguez@uvigo.es

***Abstract*—In the field of waterproof garments, there are commercial systems available that allow either fabrics or ready-to-wear garments to be tested, complying with existing testing standards. These standards and systems, however, do not account for some important effects, as for instance proper test ergonomics or the diagnosis of wrong sealing of seams, which are in fact very significant to the final quality of the product. This paper presents the design and development of a testing system that covers all aspects of waterproof garment testing. It is divided in a mechanical subsystem, consisting of a rain conditions emulator and a manikin that wears the clothes under test, and an electronic subsystem, consisting of sensors, an artificial vision environment and the associated elements in charge of all data acquisition, control and supervisory tasks. The system has been put into operation at the facilities of the company Partenon, in Spain.**

***Index Terms*—Waterproofness, Rain tower, Ready-to-wear garment**

I. Introduction

WATERPROOFNESS is an important requirement for some kinds of garments (as for instance those used by fire brigades) together with others like breathability, durability, mechanical resistance, thermal insulation, or fire resistance. Several studies [1] have shown that, in this context, the accuracy in the fulfillment of some of the usual tasks to be carried out by specialized workers, highly depends on certain factors like body core temperature that, in turn, are strongly influenced by the properties of the clothes they wear. Furthermore, they must be able to do their job regardless of the weather conditions, which again imposes strong requirements to garments. Therefore, the design and fabrication of high performance professional clothes is a very challenging task.

Although there are several commercial systems available that comply with the requirements of standards regarding waterproofness of fabrics, as the well-known Bundesmann [2], or, more important for the purposes of this work, whole ready-to-wear garments, they do not take into account (or at least not to enough extent) some effects which largely affect the quality of the final product:

1) Ergonomics. The location and structure of the joining (e.g., seams) and closing elements (e.g., zippers) influence the behavior of the garment under rainy conditions.

2) Motion. Obviously, the response of the garment if the wearer is moving will not be the same as if it is standing still.

3) Diagnosis. For the purposes of certification, it is enough to determine whether or not a given garment complies with standards, i.e., whether or not water enters the garment under the standardized conditions. However, in order for manufacturers to improve quality it is mandatory to detect not only defective pieces but also where the defect(s), as for instance a wrong sealed seam, are located.

The Spanish company Partenon is dedicated to the design, fabrication and commercialization of technical clothes. With an annual turnover of around €8 million, its main customers are the security forces and, especially, the police and fire brigades, having, for instance, a majority market share of Spanish police garments. Apart from Spain, it also has an important market share in other countries like Portugal, Italy or Germany.

Given the aforementioned limitations of currently available testing systems and standards, the development of a new system that takes into account all relevant aspects of waterproofness testing of ready-to-wear garments has been addressed by the company. The system is aimed at two main goals:

1) Waterproofness testing and diagnosis of new garments under severe rain conditions, that involves the location of the source of any hypothetical water entrance to the garment, as well as the determination of the paths through which water propagates once it has entered the garment.

2) Waterproofness testing of used garments, which will allow the garment's behavior to be determined for all its life-cycle. This implies the need for accelerated ageing experiments that emulate the deterioration suffered by a garment along its lifetime, which are outside the scope of this work.

The remainder of the paper is structured as follows. Standards and currently available testing systems for fabrics and ready-to-wear garments are briefly described in Section II. The proposed solution is presented in Section III. Finally, the conclusions of the work are summarized in Section IV.

II. Current Solutions

The current European standards related to textiles and water tests have been analyzed as the first step in the definition of the specifications of the target system. Two of them describe methods to test the waterproofness of either fabrics or whole ready-to-wear garments and have been used to define the general design guidelines of the system:

1) EN14360 [3], which describes a method to emulate a vertical rain, like the one produced in a cloudburst.

2) EN468 [4], which describes a method to emulate a horizontal rain, like the one produced when there is a combination of wind and rain. This second method is also useful to determine the waterproofness of motorcycle clothing or for other similar applications.

There are also several commercial testing systems available. The first commercial system that created a standardized artificial rain in order to test waterproofness was the Bundesmann shower test [2]. The main limitation of this system, shown in Fig. 1, is that it is only intended to test fabric waterproofness. More recent systems that allow garments to be tested are EMPA [5] and Gore-Tex [6] rain towers. The development of the EMPA rain tower was the basis for the creation of the EN14360 standard [3]. From the point of view of a garment manufacturer like Partenon, the limitation of both systems is that they are mainly intended to final product quality control and not to determine the sources of hypothetical waterproofness problems.

Fig. 1. Bundesmann shower system.

III. Proposed Solution

The block diagram of the proposed system is shown in Fig. 2, where the following subsystems can be identified:

1) Rain conditions emulator, which emulates rain conditions occurring in a real bad weather situation. These conditions must be characterized in order to achieve both similarity to actual rain conditions and repeatability from experiment to experiment.

2) Garment wearer, which can be configured to wear the garments under test in the same way a real wearer would do and must allow sensors to be placed in specific positions. In addition, as explained below, it must be capable of containing the associated electronic equipment for signal conditioning, data acquisition and communications. The garment wearer has to exhibit high resilience to the environmental conditions of the tests. It must allow sensors to be easily replaced and the internal electronic equipment to be accessed without compromising watertightness. Finally, it must allow garments to be put on and off easily.

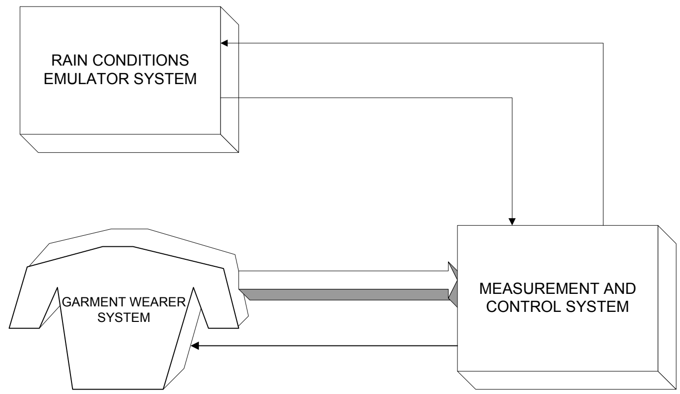

Fig. 2. Block diagram of the proposed testing system.

3) Measurement and control, which includes the following functional blocks:

- Waterproofness measurement system, consisting of three sets of sensors, used to detect water presence as well as to measure humidity and temperature, and the corresponding conditioning and data acquisition circuitry.
- Vision system, consisting of a set of video cameras and the associated hardware needed to digitally record the test images, which are fundamental information for the diagnosis process.
- Control system, whose main function is to coordinate the execution of the test. It includes the necessary set of control sensors and actuators (flow switches, inductive proximity sensors, electrovalves, contactors, etc.). It must also include elements to ensure test safety.
- Interface and test registry system, whose main functions are to set up test parameters and conditions, to program the test and to display its results. It must also act as interface between the whole testing system and the user. The main features that this system must have are high storage capacity, easy access to test results and easy and intuitive interface
- Communication system, which is in charge of the communications among all elements of the testing system.

A. Rain conditions emulator

A protective garment used by specialized workers can be exposed to many different conditions, which imply the accomplishment of different requirements. The developed rain tower is capable of emulating the most usual rain conditions that occur in practice. Both vertical and horizontal rain can be artificially generated.

The vertical rain is similar to the one caused by a cloudburst, i.e., coarse droplets falling perpendicularly to the ground are produced. This part of the system has been designed based on the EN14360 standard. As depicted in Fig. 3, it consists of the following elements:

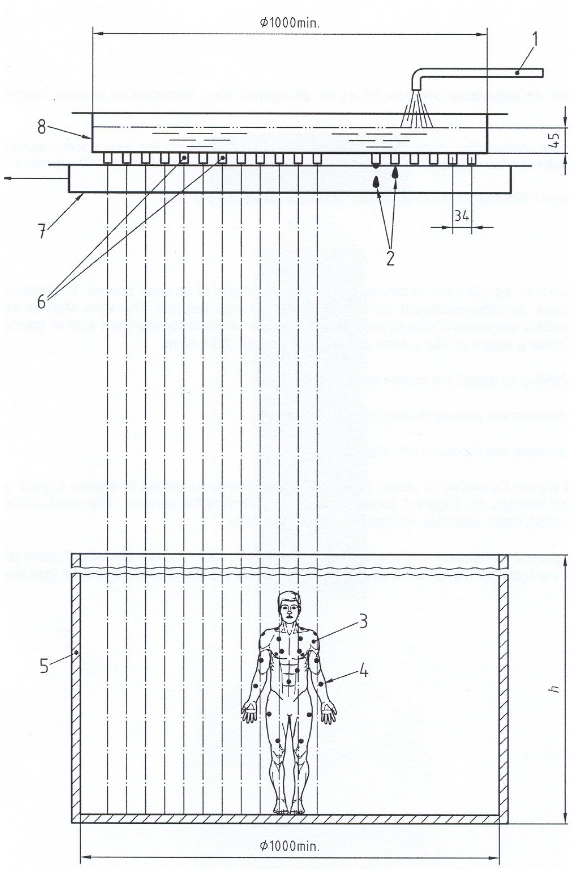

Fig. 3. Vertical rain tower structure, as specified in EN14360.

1) Water pipeline (#1). The water used to generate the rain must have a mineral content as low as possible, to prevent the droplet nozzles to be obstructed. In addition, its temperature must be controlled to avoid condensation in the garment wearer, which could cause a false indication of water entering the garment during the tests.

2) Nozzles (#6) and water tank (#8). Nozzles allow droplets of predefined size to be repetitively generated. They are regularly distributed at the bottom part of the water tank. The practical implementation of the water tank and a detailed view of the nozzles that allow standardized droplets (#2) to be obtained are shown in Fig. 4.

3) Rain enabling / disabling system (#7). A key issue in the practical implementation of the test is that rain must fall over the garments not only at the right time but also in a homogeneous way. The proposed system incorporates a retractile structure formed by three plates, located in the bottom part of Fig. 5, whose mission is to prevent the rain from falling over the garment wearer until it is homogeneously generated. It must be noted that, at the beginning of the test, when the tank starts to be filled up with water, it would not produce homogenous rain. An induction machine is used to fold and unfold the plates. A flow switch, located in the brim through which the excess of water is eliminated, is used to indicate the moment at which rain can be released, reaching the suitable steady state in terms of intensity and droplet size.

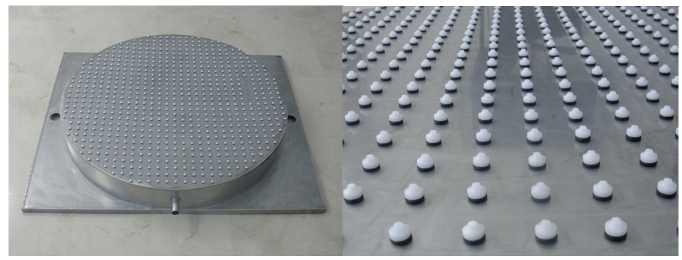

Fig. 4. Water tank (left) and detailed view of the nozzles (right).

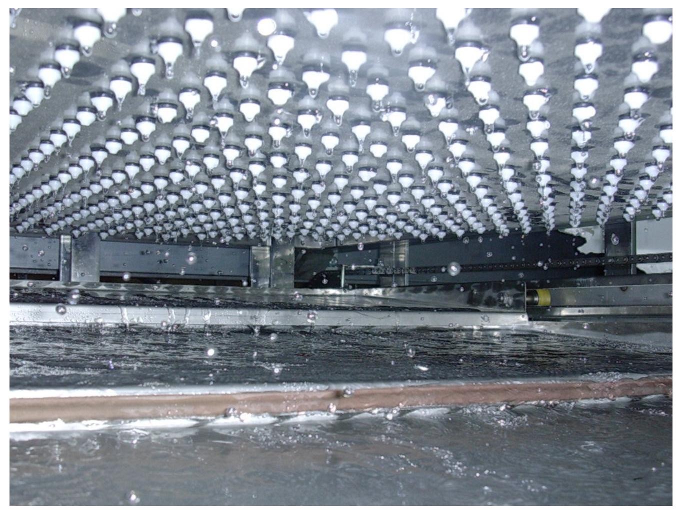

Fig. 5. Detail of the rain enabling / disabling system.

4) Rain room (#5).

5) Garment wearer (manikin, #3) with integrated sensors (#4). These elements are not part of the rain generator, and are described in following sections.

Fig. 6 shows a general view of the whole vertical rain generator, located in the upper part of the rain room.

The horizontal rain generator has been designed based in part on the EN468 standard (Fig. 7). In this case, the garment wearer must rotate in order to be completely affected by the rain, and therefore must be placed on a rotary element, labeled as a) in Fig. 7. The developed horizontal rain generator emulates weather conditions rougher than the ones described in the standard, because of the strong quality requirements of Partenon’s products. Due to this fact, means are provided to control:

1) The pressure at which the nozzles in the horizontal generator eject water.

2) The rotation speed.

Fig. 6. Rain room and vertical rain generator.

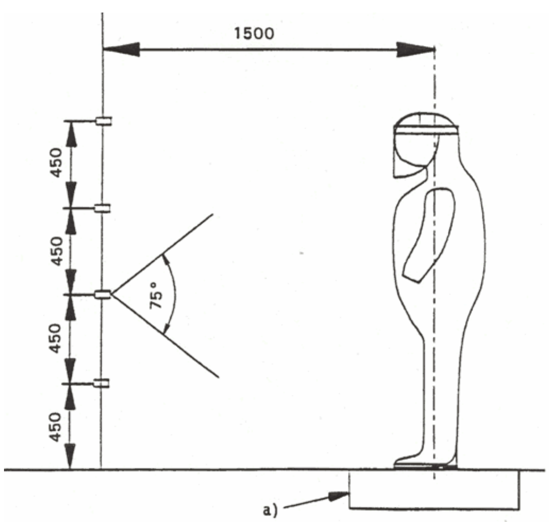

Fig. 7. Horizontal rain system, as specified in EN468.

B. Garment wearer

A semi-transparent fiberglass manikin was built to serve as garment wearer due to the following reasons:

1) Its shape is similar enough to that of a human being as to guarantee realistic tests to be carried out.

2) Its mechanical resistance is good enough for the intended working conditions.

3) Its ease of mechanization simplifies, for instance, the integration of the embedded sensors.

4) It eases the detection of its own hypothetical lacks of waterproofness (produced, for example, due to a bad sealing of the integrated water presence and humidity sensors).

Waterproofness testing requires a large number of sensors to be used. On the other hand, as stated in the previous section, the manikin must rotate during some of the tests to be performed. Due to this, at the design phase it has been decided to place the waterproofness measurement system inside the manikin. This imposes strong mechanical limitations to connectivity due to the rotating nature of the structure. To overcome them, a wireless link is used to communicate the measurement system with the interface and test registry system. A stainless steel skeleton was built in order to hold the measurement system and the wireless transmitter. Fig. 8 shows how the skeleton and the manikin are integrated.

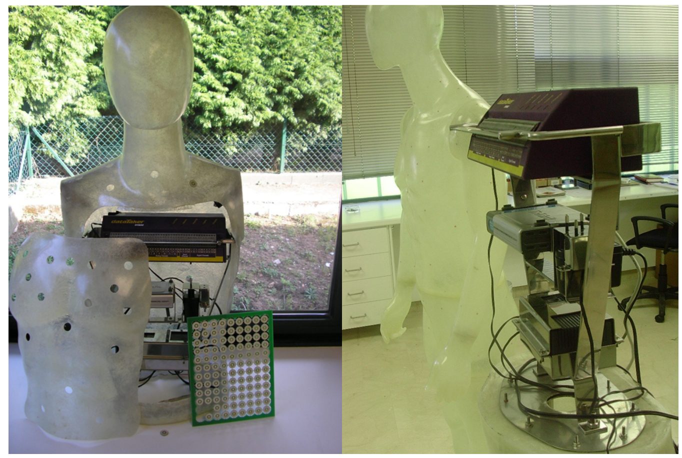

Fig. 8. Integration of the measurement system in the garment wearer.

C. Measurement and control system

Fig. 9 shows the block diagram of the developed measurement and control system. There is a central computer, in which the user interface and the test registry are implemented. An application has been developed in NI's LabView in which the following options are available:

1) User-controlled operation. In this mode, it is possible to check the behavior of all elements in the system and to execute step-by-step tests in which the sequence of actions to be performed is indicated in real time by the operator.

2) Selection and specification of conditions for automated tests. It is possible to specify parameters like vertical or horizontal rain, rotation speed or duration of the test. Test conditions can be saved to allow normalized experiments to be carried out. This is useful, for instance, in the certification of garments.

3) Automated test execution. In this mode, the application controls the execution of the sequence of tasks a predefined test consists of.

4) Test registry and report. The state of the sensors integrated in the manikin is obtained, and all significant events (start of rain, detection of water inside the garment, etc.) are flagged. At the end of the test, a report is generated including its most significant results.

The waterproof measurement system located in the manikin is based on three kinds of sensors:

1) Water presence sensors. The detection of the presence of water inside the garment is based on a resistance measurement between the two concentric electrodes that form a sensor (Fig. 10), specifically developed for this application. The number of sensors determines the resolution that can be achieved, which

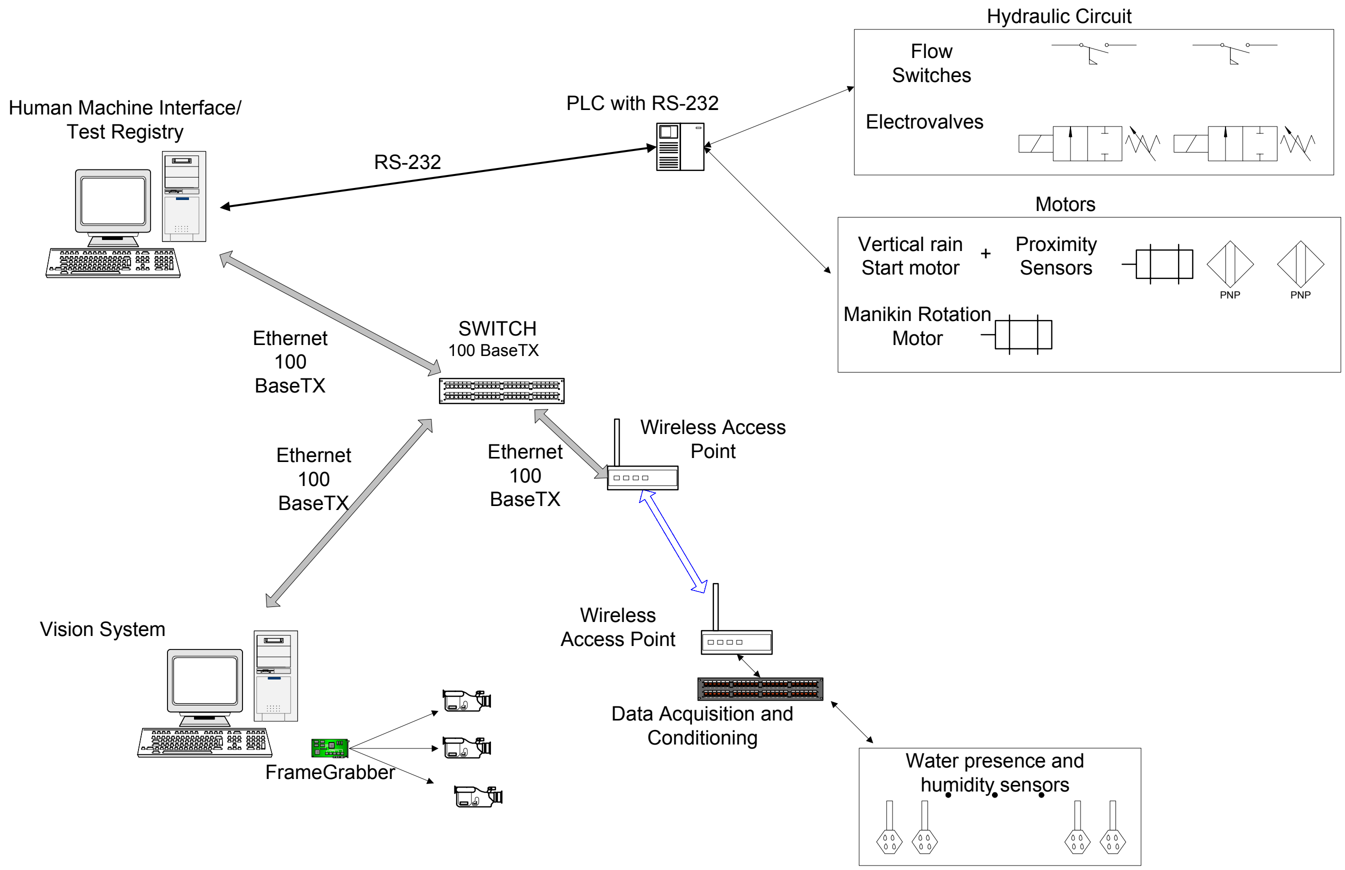

Fig. 8. Measurement and control system.

in turn influences the quality of the tests. In this case, 90 sensors have been distributed all along the manikin surface (some of them can be identified as dark circular shapes in Fig. 8) instead of the 20 specified in standards.

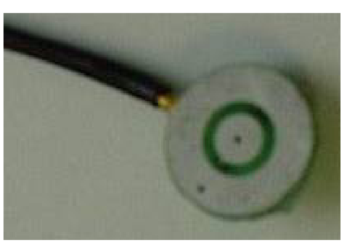

Fig. 10. Water presence sensor.

2) Humidity sensors. These sensors are also located in the manikin surface. They are aimed at detecting the occurrence of steam condensation and, therefore, characterizing as accurately as possible the conditions under which the tests are performed. For this purpose, HU1015NA sensors from GE Thermometrics [7] have been chosen because of their ability to be used in dew condensation conditions and of their integrated conditioning circuitry.

3) Temperature sensors. These sensors are located both inside and outside the manikin. They provide an indication about the existence of possible conditions for condensation. This information is used in a water temperature control loop, to avoid condensation. The data acquisition system's integrated temperature sensor is used to determine the manikin inner temperature. For outer temperature, LM35-based sensors [8] are used.

Data are acquired by means of a commercial system, a DT800 [9] with 24 input channels. In order to measure data coming from more than 100 sensors, an auxiliary acquisition and multiplexing board has been designed and implemented. In addition, this circuit allows the excitation signals for the resistive water presence sensors to be generated.

The control of the actuations over the system is performed with a PLC, which can operate in manual mode, executing operator commands received from a panel or the central computer, or in automatic mode, executing an automated test sequence received from the central computer.

The vision system includes three JAI CV-S3300 analog color video cameras [10], which provide 752x582 pixel resolution and 25 frames/s allowing all the experiment's viewing angles to be covered. Two Bandit-II CV frame grabber cards [11], each one capable of supporting two cameras, are used to record the evolution of the tests in real time. Recordings provide important information, which complements that obtained from sensors. On one hand, they allow the initial conditions of the tests (e.g., the position of the garment on the manikin) to be normalized. On the other hand, they allow the points through which water has entered the garment to be identified, when several of them are close enough to the sensors that flagged the defect. Finally, if some constructive elements or others related to the wearing of the garment, as the existence of bends that guide the water, cause a waterproofness failure, this fact can be noticed with the help of the sequences of images.

The communications between the central computer and the remaining elements of the system have the following characteristics:

1) The waterproofness measurement system provides the data coming from the water presence, humidity and temperature sensors through an Ethernet 54 Mbps wireless channel.

2) The vision system provides the images obtained during the execution of the tests through an Ethernet 100 Mbps channel.

3) The control system PLC receives the test configuration parameters (e.g., the states of electrovalves) and returns the test state variables (e.g., the state of the inductive proximity switches) through an RS-232 channel.

IV. Conclusion

The main issues related to waterproof testing of technical ready-to-wear garments have been identified and discussed. Given the practical limitations of currently existing systems and standards, a new testing system has been designed and implemented. Its mechanical structure, as well as the measurement, control and supervisory subsystems, have been described.

The proposed system is capable of emulating weather conditions rougher than those specified in current European standards, which is a need given the quality requirements of the garments to be tested. In addition to an improvement of waterproofness, the developed system allows also other properties, like durability, to be indirectly enhanced.

A very important and differentiating characteristic of the system is that it has been designed aiming not only at certification but also at diagnosis of defective behaviors. This is a fundamental step for the quality improvement of the garments produced by Partenon, the Spanish company in whose facilities the system has been installed.

Some practical aspects of the system are still under development, the most important being:

1) The integration of the results provided by the artificial vision system in test reports.

2) The development of accelerated ageing experiments that emulate the deterioration suffered by a garment along its lifetime, in order for tests of the garment's life-cycle behavior to be implemented.

Acknowledgment

This work has been supported in part by Xunta de Galicia, under research project PGIDIT04DPI086E.

References

[1] C. N. Nelson, N. W. Henry (eds.), *Performance of Protective Clothing: Issues and Priorities for the 21st Century*, 2000.

[2] European Norm EN29865 (ISO 9865:1991), *Textiles – Determination of water repellency of fabrics by the Bundesmann rain-shower test*.

[3] European Norm EN14360, *Protective clothing against foul weather - Test method for the rain tightness of a ready made garment - Impact from above with high energy droplets*.

[4] European Norm EN468, *Protective clothing - Protection against liquid chemicals - Test method: Determination of resistance to penetration by spray (Spray Test)*.

[5] EMPA rain tower, http://www.empa.ch

[6] Gore-Tex rain tower, http://www.gore-tex.co.uk/ published/gfe_navnode /gb.lab.machines.rain.html

[7] http://www.thermometrics.com/assets/images/hu10.pdf

[8] http://www.national.com/pf/LM/LM35.html.

[9] http://www.datataker.com/products/dt800.html

[10] http://www.jai.com/camera/products_info.asp/id=190& sprog=dk

[11] http://www.coreco.com