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The Design of a Wireless Scoring System for Epee Fencing

Callum Laurenson [1], Jean-Michel Redouté[1]

[1] Department of Electrical and Computer Systems Engineering, Monash University, Clayton, Australia

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Abstract. This paper presents a method of registering hits in the sport of fencing, specifically for Epee, without the need for wires connecting the fencer to a central scoreboard. It outlines the problems associated with the development of such a system, including the lack of a common ground between devices. The paper focuses specifically be on the development of a prototype wireless scoring system for Epee fencing, compatible with existing equipment, which can be later adapted to operate with other weapons. The design and construction approaches taken to create a prototype solution are discussed. The use of high frequency signals, and exploitation of human body capacitive effects, and their usefulness in this context are explored. The success of the design in the trials is discussed, along with the limitations, which include latency and interface complexity. Finally, the paper analyses the strengths and weaknesses of the developed system, and recommends system improvements.

Keywords: fencing, wireless, scoring systems

1. Introduction

This paper outlines the results of the design, development and construction of a prototype wireless system for registering hits in the sport of Epee fencing.

The sport of fencing involves very fast movement, and has precise timing requirements. This makes the process of presiding (refereeing) very difficult. In order to aid the referee in scoring, a traditional electronic system is used, which connects fencers to a central score-box via wires extended from the roof. This scoring system works differently for each of the three weapons used in modern fencing.

The primary focus of this paper is on the development of a system for Epee. For this reason, a brief summary of the rules and scoring system operation is given, for this weapon only.

Epee is a stiff point weapon for which the whole body is target. Off-target hits to the floor or to the guard of the opponent do not stop the action of the bout.

The traditional wired Electric Epee hit detection system is comprised of a button located on the tip of the weapon, which when compressed completes a circuit within the blade. The scoring system detects this completed circuit and registers a hit. This initiates a timer which counts to a standard time limit. Once this time limit is reached, no further hits are registered. In addition to this, the button on the tip of the weapon has a conductive surface. If this surface comes into contact with the piste (the section of floor on which the bout occurs), or the guard, both of which are also conductive and connected to the scoring equipment, a second circuit is completed which prevents the hit from registering and halting the action.

Recently, wireless systems, which eliminate the need for a solid connection between the fencers and the score-box, and interface with the same basic structure, have been developed. However, these have the draw-backs of being too expensive for most clubs, or are simply unavailable. Existing systems typically also function for only one of the three modern fencing weapons. This leaves competitors from smaller clubs at a disadvantage when competing, using equipment that they are unfamiliar with. It also extends the already significant price barrier for individual entry into competitive fencing. In many countries, fencing struggles to attract attention and competitors. If it is to regain popularity, it must become more modern, and accessible to the public.

This study was carried out in an attempt to solve the problems associated with existing wireless systems, create a prototype wireless scoring system which reliably operates for Epee. This system was required to meet the following conditions:

1. Interface with existing scoring hardware and player equipment, without alteration.

2. Be robust and reliable.
3. Have portable units attached to fencers which are lightweight and compact.
4. Be at least as accurate with respect to timing and detection of hits as existing equipment.
5. Be significantly less expensive for both clubs and individuals than existing wireless systems.
6. Be safe for fencers to use.
7. Be able to run from standard battery power.

This paper will first outline the problems associated with producing a wireless scoring system for Epee. Next it will analyse and criticise existing solutions. Both the theory and the embodiment of the developed solution will then be described in detail. Finally, the success of the system in trials will be outlined, and future development opportunities will be suggested.

2. The Problem

2.1. The Common Ground Problem

Traditional electrical systems are able to distinguish between hits to target area and those to non-target areas. This is accomplished by applying a voltage at one side, and measuring the current flow through: current will flow when a hit is made and a circuit is completed. This method is effective, since there is a return path for the current through the wires attached to the fencer. A wireless system does not have these return paths available. This results in a lack of electrical commonality between the two fencers, and makes distinguishing on-target and off-target hits complex.

2.2. The Coupling Problem

The wires which connect to the Epee button are very close, both to each other, and to the supporting metallic structure. They remain this close as they travel together for approximately 90 cm [1]. This is not a problem when dealing with constant voltages, however, any attempt to send an AC signal down these wires will result in severe coupling issues.

2.3. The Inductance Problem

Since the wires which are glued to the blade are very thin and very long, they develop an inductance. Depending on the method of sensing used, this may result in signal attenuation.

3. Existing Solutions

3.1. Equipment Based Solutions

Many existing methods of sensing designed for wireless epee involve major changes in the primary equipment to be used by the fencer. This could include the clothing, or the weapon design. Following is a discussion of some of these methods.

Marciano [2] has discussed the use of a pressure sensitive fabric which is worn over target area. As it utilises physical sensors, this system has the advantage of avoiding the transmission of an electrical signal without common ground. However, it does involve an extensive change in the equipment needed by the fencer. Not only that, the clothing which contains the pressure sensor is likely to be very expensive, and possibly bulky. Also, it does not distinguish between a hit made by the opponent to your target area, and a hit against yourself (for example when drawing the elbow back). This would also significantly change the nature of the sport, since in general lighter hits are considered to be more skilful, but these might not set off a pressure based system. This method is therefore not well suited to fencing.

Some sensing methods have been proposed that involve the use of conductive soled shoes to complete a sensing circuit [3]. These methods share a common problem: If a competitor jumps and leaves the ground, the sensing system will no longer operate correctly. This situation is not unlikely, and would probably encourage fencers to favour movements which involve leaving the ground (for example the flunge). This method was used with some acclaim in a final year project completed at Auburn University in 2007 [4].

An alternative method, considered by Weske et al. [5], is to replace the conductors used in the existing electronic weapons with fibre optics. Target could be distinguished based on colour differences. While this solution has the potential to be effective, it does involve significant changes and hence is unlikely to be accepted by the fencing community, at least in the short term.

3.2. Electronics Based Solutions

An alternative method to adjusting the primary equipment used by the fencer, and the method preferred in this paper, is in altering the electronics of the sensing system, to overcome the limitations inherent in the weapon design. Following is a discussion of some of the solutions proposed.

The oldest paper on this topic suggested the transmission of a pulse through the weapon. This pulse was detected on the opponent's guard, or on the floor [6]. Although this was not discussed, presumably this system is designed to work by employing the capacitance formed between the system and ground, and relying on the conductivity of this capacitance when exposed to the high frequency edge of each pulse. The disadvantages of this system include the fact that it necessitates the connection of the system to the piste (which may be time consuming). In addition, this system is likely to be susceptible to noise and interference, particularly since pulses generated by one fencer could quite easily feed back into their own system.

Many recent methods involve the generation of a high frequency signal, which is sensed on the ground, and by the opponent. One notable design in this area is that of Lindsay [7]. This system is also presumed to work by employing the capacitance between the systems and ground. However, instead of utilising the edges of pulses as a source of high frequency, this system uses a continuous frequency generator. This method is superior since it allows the use of different frequencies for each fencer, allowing the system to distinguish between hits to the opponent and hits to oneself. It also allows a greater level of noise immunity. However, like Delcayre in [6], this system requires wiring to an electric piste.

Another method suggests the generation and sensing of signals using voltage controller oscillators and phase locked loops [8]. This method is promising since it makes use of existing technology which can be found in integrated circuitry. This will decrease cost and also the size footprint of a final product. However, it suffers from the same limitation as other systems: It requires separate sensors to be connected to the piste. Additionally, as outlined in the article, the combination of phase locked loops and voltage controlled oscillators is unreliable since the oscillator frequency varies greatly based on a large number of factors. Until technology improves, this will not be an acceptable solution.

All of the discussed solutions above require a strong capacitive path to ground. This can be created on the system with a metal plate. However, a better path can be obtained by making use of a contact with the human body, and using the body's natural capacitive behaviour.

4. System Design

4.1. Theoretical Sensing Approach

The chosen system design operates through the use of a high frequency oscillating electrical signal, to be passed down to the tip of the weapon. The ground plane of the system will be coupled with the fencers body. The use of high frequencies reduces the impedance of the capacitance of the human body, essentially allowing the equipment on each fencer to obtain an approximate path to ground. Hits will be sensed electrically in multiple locations on the equipment. Electrical sensors comprise of:

(1) An attenuation sensor for the electrical sensor sent to the tip of the weapon, to identify when a direct connection with ground is formed.

(2) A sensor on the guard of each weapon which will register any voltage asserted with the same frequency as the opponent's blade, caused by contact between the blade tip and the guard.

This approach has several weaknesses. The impedance of the fencer's body, and thus the signal strength, will vary greatly between each fencer, the level of sweatiness, the type of clothing worn, and the fencers shoes. This necessitated the use of dynamic system calibration. Additionally, the system is adversely affected by the coupling and inductance problems mentioned in section 2.

Figure 1 shows the sensing process to be followed to determine whether or not a valid hit to target area has occurred.

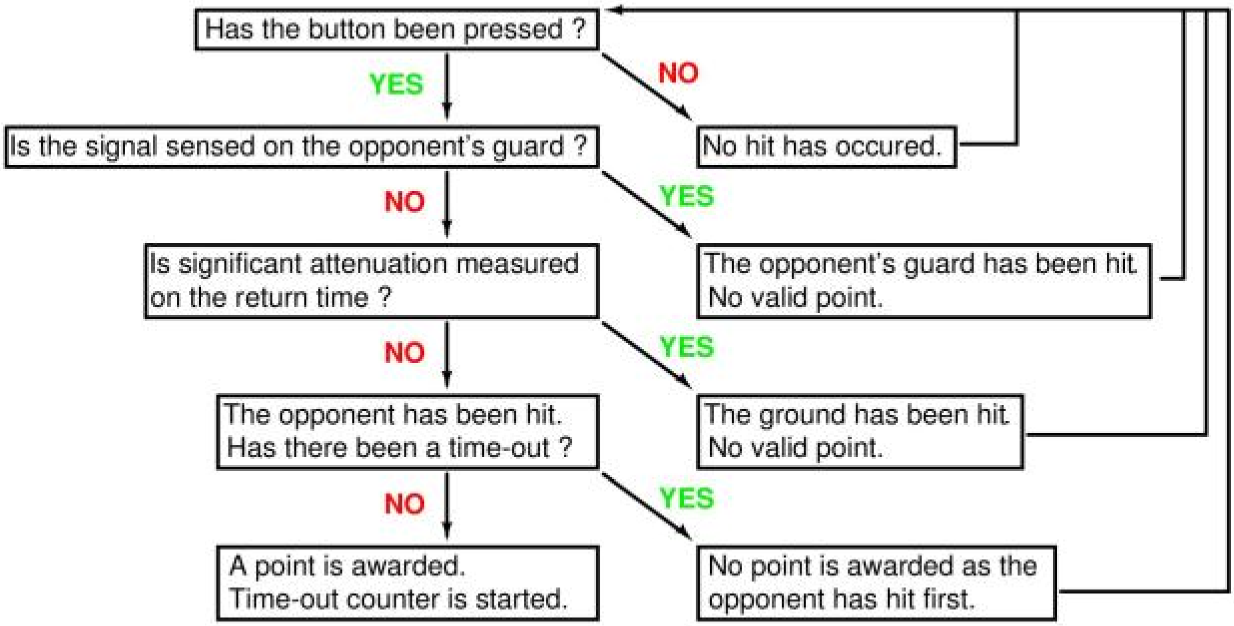

Figure 1: The sensing process.

4.2. Sensing Frequency Selection

Selecting a frequency on which the sensor system should operate involved a process of balancing the problems mentioned in section 2.

Higher frequencies reduce the impedance of the capacitive path to ground formed by the human body, and hence increase the system sensitivity. However, these same higher frequencies result in an increase in the coupling between lines on the blade, and also an increase in the impedance of the blade itself.

A study by Vaillancourt et al. [9] provides information about power loss in the human body for different frequencies. According to this study, power loss within the human body is at a minimum within the range of approximately 1 MHz to 20 MHz. Since a lower power loss within the body means greater signal transmission through the body, this provides an indication of the frequency range within which the system should operate.

In order to minimise the problems caused by inductance and coupling, the minimum possible frequencies which will still maximise human conductivity should be chosen. Frequencies of close to 1 MHz should therefore be used in the developed system. Using an integrated resonator is more efficient in terms of cost, and footprint, than designing a resonator. Integrated resonators also typically have narrower frequency ranges. For this reason, two frequencies for which there are commonly available integrated resonators were selected; 2MHz and 3.58MHz.

4.3. Wireless Communication Method

Several different methods of wireless communication were considered for the purposes of constructing this system. The simplest and most effective method was decided to be one which used an existing protocol, since the communication requirements of this system are common with many other applications.

Wi-fi and Bluetooth were both initially considered. These protocols are well established, which is valuable, since the system could be used to communicate with other compatible devices (such as the iPhone). An additional advantage is both operate on the worldwide ISM band of 2.4GHz. However, they are not cheap to implement, and are not designed for low power applications. This could result in excessively short battery life. The benefits of these protocols, such as high data rates, or high compatibility, are unlikely to benefit a wireless fencing system, which has very low data rate requirements, and is likely to primarily interface with scoring equipment only.

Wireless fencing systems have been implemented using RFID tags [8]. These have the advantage of relatively simple interfaces, and a small form factor. In addition, they are designed for low power. However, it has been noted that RFID introduces significant delays into the communication process. If RFID were used, this could result in an introduction of significant lag into the scoring system. Until the technology of

RFID improves, this is unlikely to be an effective solution.

Many other, less well known proprietary technologies exist for wireless communication. These are generally less complex and cheaper than the above protocols, and are often associated with particular wireless modules, and are designed for use in small devices such as remote controls. As such, these communication protocols are quite suitable for use in a wireless fencing system. The CC2511F32 microcontroller from Texas Instruments, a product which relies on one of the proprietary protocols mentioned above, was selected as the most appropriate low power and low cost solution.

5. Prototype Construction

5.1. Electronic Prototypes

The prototype designed consisted of a scoring display, which was designed to remain stationary, and two portable components for sensing, to be carried by the fencer.

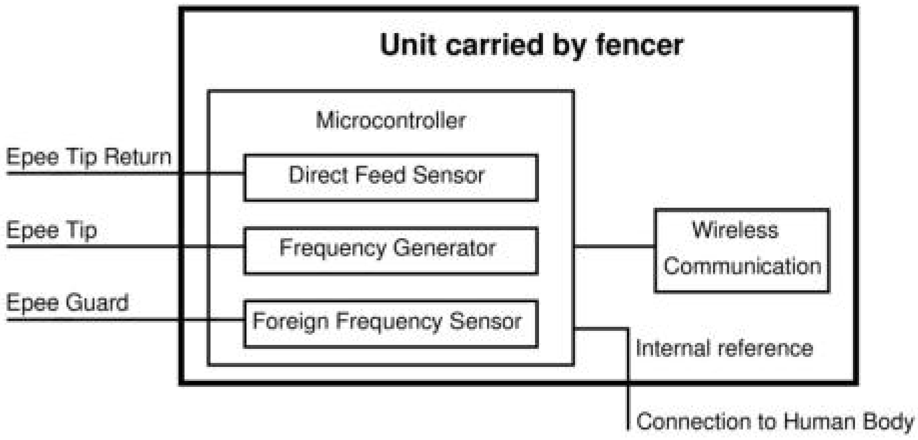

Figure 2: The simplified system using a microcontroller for sensing.

Figure 3: The completed prototype, including the portable units and scoreboard, in a box

When designing the physical circuitry, it is important to consider various factors, including the minimisation of interference, and ensuring reasonable resilience to knocks.

The initial prototype was constructed on breadboard. This demonstrated the viability of the theoretical approach. However, it was neither compact, resilient nor interference immune enough to be used in the actual system. It also required the extra integration of the wireless communication systems.

The next iteration for the prototype consisted of a PCB, which allowed a far smaller footprint, and superior performance with regards to durability and resilience to interference.

The general physical design of the portable prototype is represented in Figure 2. As can be seen from this figure, each of the inputs is passed through to a microcontroller, which runs the required calculations, before sending the result to the central scoreboard. The prototype central scoreboard consisted of a wireless module and microcontroller, to receive and interpret the data sent, and a display device comprising LEDs and a buzzer.

The appearance of the completed prototypes, of both the portable units and the scoring box, are shown in Figures 3 and 4. The internal circuitry of one of the portable units is shown in Figure 5, and the scoreboard in Figure 6.

Figure 4: The portable unit of the prototype, with pen for size comparison.

Figure 5: Inside view, the portable unit of the prototype.

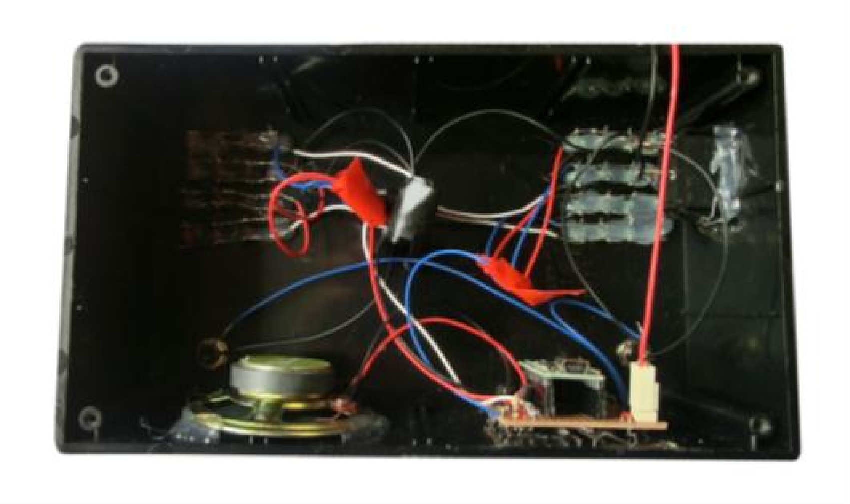

Figure 6: Inside view, the scoreboard component of the prototype.

6. Solution Effectiveness

The system was trialled in the Monash University Fencing Club. By allowing regular fencers to use the system, faults were discovered that could otherwise have remained undetected. It is not only technical issues or bugs that can be uncovered; user interface improvements can also originate from this kind of testing.

During the testing, the system was found to be fully operational. Hits were reliably detected and target areas were differentiated. Unfortunately, no metal piste was available upon which to test the attenuation sensors. However, proof of concept was achieved outside of the fencing environment.

The results of this testing also indicated that the final system suffered a number of shortfalls. The calibration procedures that were required in order for the system to operate correctly were deemed to be too lengthy. A slight latency of approximately 80ms was also noticeable between hits and detection. However, this did not result in missed hits or timing errors, since it was not associated with the sensing circuitry. In addition to these issues, it was noted that the prototype suffered from a number of minor interface issues, such as confusing light signals, and buttons which were too easily knocked.

The reliability of the wireless link was also tested, in various locations and at various distances. The intent was to determine the likelihood of accidental signal drop-out during a bout. The range of the wireless communication of the system was found to be over 80 meters, line of sight. However, through walls the communication distance reduced significantly. This is not considered to be a major problem, since during a fencing bout, there should be an unobstructed line from the central scoreboard and each of the fencers. The presence of interfering signals also reduced the maximum range. However, in testing, the system always worked when communication was line of sight, and the distance was less than 20 meters.

A scoring system which constantly requires batteries to be changed is likely to be expensive, and is unlikely to gain acceptance into the fencing community. Because of this, battery life is an important consideration. The portable units were designed to accept two AAA batteries. Based on the power draw of the circuitry, and standard AAA battery life, the system should last approximately 40 hours of continuous fencing, as shown in Table 1. The scoreboard takes 4 AA batteries, and has a conservatively estimated battery life of approximately 11 hours of continuous fencing, as shown in Table 2. Both of these figures are considered to be sufficient.

Low cost was considered to be a priority in the design of this system. Therefore, when gauging the effectiveness of the solution it is important to consider the project budget. While it is difficult to estimate manufacturing expense of a product in its prototype stages, the value of the components used in constructing the prototype can give an indication. The total cost of producing the prototype system, not including labour, was approximately $150. This includes the shirts used to construct the body contact. A full breakdown of costs is shown in Table 3. This is significantly cheaper than any existing systems.

Table 1: Calculation of battery life of the prototype portable module

Component in Portable Unit	Maximum Current Draw (mA)	AAA battery life (1200mAh)
Wireless Module	30	
Microcontroller	0.37	
Complete Unit:	**30.37**	**39.5 hours**

Table 2: Calculation of battery life of the prototype scoreboard

Component in scoreboard	Quantity	Current Draw Per Unit (mA)	Total Current Draw (mA)	AA battery life (2400mAh)
Wireless Module	1	30	30	
Microcontroller	1	0.37	0.37	
LED	34	5	170	
Piezo Buzzer	1	25	25	
Complete Unit:	**1**		**225.37**	**10.5 hours**

Table 3: Analysis and breakdown of overall component costs.

Component	Cost
Wireless Modules	$60.00
Shirts and Fabric	$34.00
Plastic Cases	$15.50
LEDs	$7.28
PCBs	$5.00
Microcontrollers	$4.72
Battery Cases	$4.60
Switches	$3.90
Miscellaneous Electronic Components	$16.24
Total:	**$151.24**

7. Conclusions and recommendations

This project has succeeded in its objectives. The final design has been accepted by fencers as a viable alternative to the wired system, and has been used at the Monash University Fencing Club. It has also created some interest commercially. The system is sufficiently accurate in its determination of points and its distinguishing of timing. It is also sufficiently portable and lightweight to be used in situations where the existing system cannot be. The system has a sufficient battery life, which will allow it to be used consistently in clubs. It also has a significantly lower cost that existing systems. However, it has not met the needs of the fencing community perfectly. Following are some recommendations and improvements from which the designed system might benefit.

The system as designed requires calibration at every start-up. While the calibration routine is not excessively long, it might still be advantageous to have a system which could skip this step. It might be possible to develop a way of testing previous calibration data for relevance. In this way, calibration could be skipped on start-up, and instead the system could be calibrated only when required.

It might also be possible to change the calibration routine to reduce the complexity of the procedure on system start-up. Calibration could be performed when fencers test guards at the start of the bout. This could improve the usability of the system.

In the case of signal interference, it is possible that some wireless information will be lost. Currently, data is not time-stamped, so there is no way of knowing how many transmissions have been missed in the event of data loss. Correlating data between microcontrollers is limited to the analysis of the order of arrival, which depends on the transmission schedule. This leads to high response time, since the scoreboard must wait to ensure data has not been missed before it decides whether to award a hit. Time-stamping data could avoid this problem and hence reduce the system response time.

There are some advantages of using a system based on high frequency that have not been utilised in this design. Since the signal couples between all lines on the device, it is possible to determine whether or not weapons are connected correctly. When an Epee is not connected, the level of coupling between the signal wire and the return wire would be greatly reduced. A traditional wired system, which requires physical connection between lines since it uses primarily DC, would not be capable of detecting this.

Finally, aspects of the user interface should be improved. The display is currently unintuitive, and some of the buttons on the portable units can be accidentally pressed.

8. Acknowledgements

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