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Thermal image processing system to monitor muscle warm-up in students prior to their sports activities

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Abstract

INTRODUCTION: Muscle warm-up plays a fundamental role before developing any physical activity because it allows the body to prepare to perform better in physical activity, being a process that is carried out through a series of moderate intensity exercises that result in an increase gradual reduction of muscle and body temperature, avoiding possible injuries or muscle pain. Therefore, muscle warm-up is an essential activity mainly in those sports where greater force is exerted on the legs, being the part of the body where injuries such as ankle sprains or knee injuries are commonly seen that lead to painful and uncomfortable injuries for students-athletes.
OBJECTIVES: Develop a thermal image processing system to monitor the muscle warm-up of students prior to their sports activities to evaluate the state of the muscle warm-up of the leg part and prevent damage or injuries, as well as the indication of requiring another additional muscle warm-up to determine a correct muscle warm-up.
METHODS: The proposed method involves the use of thermal images to monitor muscle warm-up before and after physical activity. In addition, the use of MATLAB software to analyze the images and compare the status of muscle warm-up.
RESULTS: Through the development of this proposed system, its operation was appreciated with an efficiency of 95.97% in monitoring the muscle warm-up of the students prior to their physical activities achieved through image processing.
CONCLUSION: It is concluded that the proposed system is effective in monitoring muscle warm-up and preventing injuries in student-athletes.

Keywords: muscle warm-up, thermal imaging, MATLAB, image processing.

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1. Introduction

The Physical Education course contributes to the comprehensive and harmonious formation of the student, as it allows the development of motor skills that contribute to the mental health of the student by dedicating many hours of intellectual work in the classroom (1).

Likewise, the practice of Physical Education or any other physical activity initially requires a previous muscular warm-up through a series of moderate-intensity physical exercises that cause a progressive increase in muscle and body temperature according to Ruiz Garrigós et al. (2020) (2), which allow acquiring an optimal state of psycho-physical and physiological disposition for a better performance on the development of physical activity (3). Muscle warm-up is an important process that must be developed beforehand to prepare the human body with ease of entry into physical exercise and thus avoid

possible contractures, injuries and muscle pulls that would limit the student to perform some physical activity temporarily or indefinitely (4), according to the severity of the injury they present during the development of the activity, this is detrimental to those students who aspire to be competitive athletes (5).

According to the World Health Organization (WHO), musculoskeletal disorders are the main cause of disability that has been occurring in recent years, with more than 160 diagnoses affecting muscles, bones and joints (6). On the other hand, the prevalence of musculoskeletal disorders occurs at any time of life and is a recurrent problem in students due to lack of knowledge. In 2018, it was the second leading cause of disability in the world with problems moving or walking, with an increase of 10% compared to previous years due to musculoskeletal disorder problems (7). This disorder is a health condition in student athletes, which can eliminate the opportunity to compete, in addition to affecting the physical performance of the student by suffering an injury that can be classified as acute, occurring suddenly, or chronic, when related to the excessive use of the injured part, depending on the continuous manifestation of the student when recovering from the injury (8). For this reason, it is important to warm up your muscles before physical or sports activities, even if it is in a short time, to activate the student's muscles respectively.

The muscular warm-up is a fundamental part of the student's training sessions, being considered as an essential activity for the various modalities of physical exercise, as injuries such as ankle sprains or knee injuries are commonly visualized, which apart from being painful and uncomfortable, directly affect the physical activities of the student (9). On the other hand, according to Pilco Toscano et al. (2021) (10) the student in a state of rest would maintain a body temperature around 37ºC and during some illnesses or physical activities can reach 40ºC or even 41ºC, based on this, some tests were carried out corresponding to a group of students from 12 to 16 years of age to practice a muscle warm-up for 11 minutes. At the end of the muscle warm-up, thermal tests were applied to the part of the students' muscles and values between 0.44°C and 1.66°C were obtained (11), determining the appropriate muscle temperature for sports activities, indicating that the muscle warm-up on the faces and necks of the students indicated a value of 1.65°C, while in the legs and feet of the students they indicated a value of 0.71°C (12), standard values managed by sports specialists during the practice of physical or sports activities for an adequate muscular warm-up for the student (13).

According to physical education teachers, the muscle warm-up ends when it is certain that the student is ready to perform the physical activity or sports in the best way (14), indicating that the steps for the muscle warm-up should include a smooth and progressive movement to intersperse the muscle stretches through an active warm-up when carried out through non-specific physical exercises (jogging, jogging stretching and coordination) for the preparation of the various functional systems of the body and the most important muscle groups of the body (15), applied prior to each session of physical activity or sports.

The objective of this research work is to perform a thermal image processing system to monitor the muscle warm-up in students prior to their sports activities, in order to evaluate the muscle warm-up of the students to prevent muscle damage or injuries and indicate if another additional muscle warm-up is required, by comparing the muscle temperature before and after to determine if a correct warm-up was performed. For the development of this system, the FLIR ONE Pro thermal camera was used for the images taken in real time and, through the image processing developed in MATLAB, the thermography technique will be integrated to determine the temperature of different areas of the body, specifically in the legs, at a distance without physical contact between the system and the student.

In section II, a literature review of some research papers that present the topic of interest will be carried out. In section III, the methodology will present the development of image processing for the monitoring of the student's muscle warm-up. In section IV, the results of the tests of the image processing system will be presented. In section V, the discussion of the system will be presented by highlighting the importance of its operation. Finally, in section VI, the conclusion and recommendation of the system will be presented.

2. Literature review

The muscle warm-up is based on a series of simple physical exercises that are performed gently and progressively prior to each physical activity or sport, likewise, it plays a fundamental role that gives tone to the muscles to prepare them for a more intense subsequent effort, improving the dynamics of the muscles and the range of motion so that the probability of injuring the muscles is lower. For this reason, systems should be used that allow the muscle temperature values of each student or athlete to be more accurate and indicate whether an additional warm-up should be carried out to avoid injury problems. For example, according to Carissimo et al. (2023)(16), the researchers mention that the muscular warm-up of professional athletes should be carried out continuously, carried out by coaches who apply orderly previous evaluations for the good development of the sports activity by the athletes, likewise, they indicate that there are no patterns or rules that are suitable for the muscular warm-up for a series of steps, but that the coach must adapt based on his knowledge and ability to direct the athletes in the best way to perform the muscle warm-up correctly, being a problem that has been growing constantly due to lack of knowledge about the appropriate muscle temperature so that the athlete feels able to compete or develop physical activity without avoiding injuries. All this is often driven by unreliable warm-ups

that make athletes see themselves in a negative scenario when they miss competitions, therefore, they decided to develop an automated system for evaluating muscle temperature during training in sports scenarios. The methodology applied by the researchers is based on the development of a system that allows the automatic measurement of muscle temperature in the development of coordination skills based on the use of IMU sensors integrated in wearable devices, for this, the researchers define a sequential order, starting with the provision of information about the athlete's rest time. It then continues with the development of physical activity until it is exhausted, ending with the information of the time in which the athlete performed the physical activity. As a result, they presented an 81.02% efficiency in the monitoring of muscle temperature applied to athletes during the development of their activities, concluding that their developed system performs the monitoring in a reduced time, approximating the values that indicate the athlete's warm-up.

According to Gutiérrez-García et al. (2021) (17), the researchers mention that the muscular warm-up of athletes prior to a competition is important for the activation and preparation of the body, likewise, they indicate that performing a correct muscle warm-up procedure favors them to improve the performance of the athlete and reduce the chances of injuries or fractures during the development of the activity, but to date, there have been problems regarding constant injuries of athletes who do not perform the correct warm-up steps, starting with high-intensity exercises or doing it through a short period that make their capacity look bad through the long development of the activity, therefore, they decided to develop a system of analysis of pre-competitive muscle warm-ups in professional soccer players through movements. The methodology applied by the researchers is based on carrying out an evaluation of the pre-competitive warm-ups of professional footballers by relating it to their performance through the development of competitive activity, allowing the maximum performance time of the athlete to be taken into account to compare it with the effect of their muscle warm-up and establish warm-up protocols at the time they rest from their football match. To do this, they used a GPS to visualize a heat map and compare the values using an Arduino card with respect to the times of the pre-competitive warm-ups. As a result, they presented a 78.39% efficiency in the analysis of the pre-competitive muscle warm-ups of the athletes during the development of their activities, concluding that their developed system performs a punctual analysis on the muscle warm-up for the prevention of sports injuries in competition.

Based on Ismail et al. (2010) (18), the researchers mention that muscle warm-up is an important component in the physical activity of the athlete as it is beneficial in sports such as soccer for dribbling and snatching the ball, which require a maximum performance of athletes due to the speed they must apply to excel in this physical sport, therefore, coaches play a primary role in the development of the athlete by applying a warm-up protocol that can be used in the physical activity of the athlete. To reduce the rate of muscle injuries, being the static warm-up that has been researched by specialists and indicating that it does not perform a beneficial warm-up for the athlete, therefore, they decided to develop an automatic system for identifying muscle warm-up protocols based on the speed performance of the athletes. The methodology applied by the researchers is based on identifying the effects of the muscle warm-up protocol on the player's performance, for this reason, they studied a group of players to perform a test session over several days by comparing the form of muscle warm-up in an estimated time of 15 minutes of static warm-up when applying a resting stretch to the limit and 10 minutes of dynamic warm-up by applying repetitive and directed movements, controlled by a Raspberry Pi controller accompanied by a timer to count the warm-up. As a result, they presented an 83.46% efficiency in the identification of muscle warm-up protocols based on the athlete's speed performance, concluding that their developed system makes a comparison in the best way to determine that both warm-ups cause a decrease in the athlete's performance.

Lin & Song (2020) (19), the researchers mention that muscle warm-up plays a fundamental role during the training and competitions of professional athletes, including the improvement in the increase in muscle activity, the improvement in the agility and dexterity of the professional athlete, as well as the ability to perform a better potential during the physical activity developed, mainly reducing muscle viscosity for a better dynamic traction of the body that beneficially reduces injuries or tears during the development of physical activity, in view of this, many coaches put into practice a warm-up with static traction that has been causing a lot of expectation due to the little positive impact it generates in professional athletes, therefore, they decided to develop an evaluation system of muscle warm-up protocols based on the performance of professional athletes. The methodology applied by the researchers is based on carrying out a verification on the muscle warm-up methods commonly applied by coaches, applied in a group of professional athletes who are divided into warm-up groups with static and dynamic traction, using temperature sensors for the final validation of each muscle warm-up, accompanied by an Arduino Nano board to control the temperature of the professional athletes for 10 minutes. For each warm-up with static and dynamic traction, all of this was experienced in one day for the beneficial verification of each technique applied by the trainers. As a result, they presented a 90.44% efficiency in the verification of the muscle warm-up methods commonly applied by coaches in athletes, concluding that the warm-up with dynamic traction is more advantageous for professional athletes with respect to the precise movements that allow them to perform physical activity in the best way.

According to Zhou et al. (2016) (20), the researchers mention that the studies of muscle warming is a fundamental issue that has been taking center stage in

recent years, this is due to the little knowledge about the functioning of muscles during sports activities and their effects that these can have on the professional athlete, therefore, knowing and applying efficient methods will allow the muscles to prepare for the development of the sports activity with little probability. Likewise, the researchers also mention that currently the control over muscle warm-up is limited in sports laboratories, therefore, they decided to develop a portable monitoring system based on muscle warm-up during sports activities. The methodology applied by the researchers is based on monitoring muscle warm-up using a pressure sensor located on the leg of the professional athlete, being a sensor that is based on a detection matrix with precise characteristics for the comfort of athletes in the lower part of their quadriceps, recording their activity in each second when walking. When exercising and relaxing, they also take into account the repetitions of each process carried out to relate it to the quality of the training, taken from a group of 6 people evaluated during a specific time. As a result, they presented a 91.77% efficiency in the monitoring of muscle warm-up applied to a group of professional athletes, concluding that their work is a novel system that allows evaluating the professional athlete in a new scenario to monitor the muscle warm-up that professional athletes in movement are developing.

3. Methodology

The methodology is based on the development of a system that allows monitoring the muscle warm-up of students prior to their sports activities, in such a way that image processing techniques are applied to evaluate the muscle warm-up of students and prevent muscle damage or injuries that may affect the development of their physical activities. Taking these characteristics into account, a block diagram is developed to describe the internal management of the system, as shown in Figure 1.

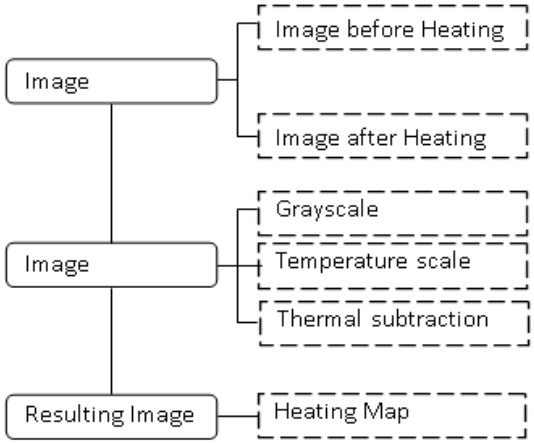


Figure 1. System block diagram

According to figure 1, the representation of the internal operability of the system is detailed through a group of steps that allow monitoring the muscle warm-up in students prior to their sports activities, each step is performed in the order specified as shown below.

3.1. Thermal Camera

At this stage, a portable thermal camera is incorporated in order to acquire the image of the students before performing the muscle warm-up and after performing the muscle warm-up to later analyze it and ensure the prevention of muscle damage in the part of the student's leg, therefore, the FLIR ONE Pro device is used that captures thermal images of objects with a sensitivity that detects temperature differences without the need for any physical contact, as can be seen in figure 2, having both lenses that allow capturing RGB images and thermal images, in addition to having its own application for the visualization and configuration of thermal images, and a Type-C connector for the functionality of any mobile device.

Figure 2. Thermal Camera

This device is a thermal imaging camera that allows you to connect directly to your smartphone, designed for professional use to detect problems and get work done in less time. Initially it was developed due to the various problems of identification of faults in industrial equipment for the facilitation of the damaged point, likewise, it has been a device that has had improvements in its characteristics, such as the improvement of thermal images by easily recognizing the details of the focus where there is temperature variation, being constantly used by the health sector to determine the body temperature of patients in a specific area of their body, as well as in various investigations.

Table I shows the characteristics of the thermal camera (21).

Table 1. Characteristics of thermal camera

FLIR ONE Pro	
IR Sensor	160 x 120 Sensor
Temperature	-20 °C 400 °C
Accuracy	+/-3°C
Connector	Type-C
Weight	35.99 g

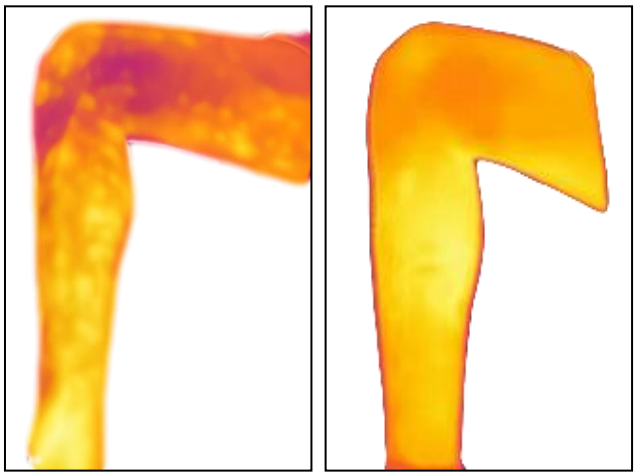
3.2. Image Processing

In this stage, it begins with the acquisition of images by the thermal camera to incorporate it into the system by means of a code in MATLAB, placing the image of the student before and after the muscle warm-up at a distance of approximately 30 cm from the position of the thermal camera, as can be seen in Figure 3 orienting the camera to focus on the student's leg and can be viewed through the computer monitor when the thermal camera receives the corresponding images.

Figure 3. The student's leg

The images indicated follow a specific order, as indicated in Figure 1, performing an image processing to represent them through a heat map and to observe the muscle warm-up in the leg area. The programming in MATLAB is based on reading an image in imgN.jpg format from a specific time and storing them in a folder, indicating that, initially, there is a specific time for the user to capture the images before and after the muscle warm-up for their corresponding processing, as can be seen in Figure 4.

```
CLC
clear all
close all
%Read an image
I = imread ('imgBefore.jpg');
figure
imshow (I)
%Read an image
J = imread ('imgAfter.jpg');
figure
imshow (J)
```



(a) (b)

Figure 4. (a) Thermal Image before Heating. (b) Thermal Image after Heating|

After reading the before and after images of the muscle warm-up in the MATLAB software acquired by the thermal camera, the first step of the image processing follows, which is the conversion to grayscale for the little use of resources during the process, changing the intensity of each color in values of 0 and 1 by applying the following formula that performs the conversion to grayscale (RGB2GRAY) by means of the MATLAB software, as shown in Figure 5, specified below:

```
CLC
clear all
close all
%Read an image
I = imread ('imgBefore.jpg');
figure
imshow(I)
%Read an image
J = imread ('imgAfter.jpg');
figure
imshow (J)
% Declare variable for grayscale
P = rgb2gray (I);
% Show image
Figure
imshow (P);
% Declare variable for grayscale
T = rgb2gray (J);
```

```
% Show image
Figure
imshow (T);
```

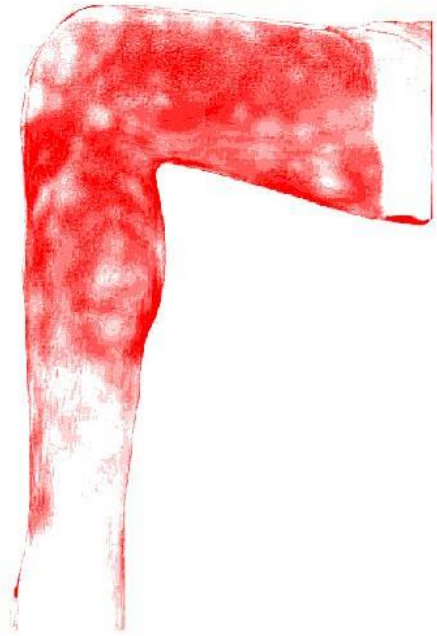


Figure 5. (a) Grayscale Image before Heating. (b) Grayscale Image after Heating

This grayscale conversion procedure is fundamental for this system because it provides us with values ranging from 0-255, facilitating image processing and filter applications. Then follows the second step of image processing, which is the conversion of grayscale images to temperature scale, which basically consists of the conversion of pixels to temperature ranges, in order to identify the pixels with the highest temperature, for this, the following formula is applied through the MATLAB software specified below (21).

$$\text{Map} = \left(\frac{(\text{Pixel}_{\text{Image}} - \text{From}_{\text{Low}}) * (\text{To}_{High} - \text{To}_{\text{Low}})}{(\text{From}_{\text{High}} - \text{From}_{\text{Low}})}\right) + \text{To}_{\text{Low}} \quad (1)$$

Where and are the grayscale that vary from 0 to 255, and y represent From_Low From_High To_Low To_High the temperature range from 15°C to 40°C to which we will convert the image. On the other hand, maximum and minimum ranges are defined with the following programming by means of the MATLAB software specified below:

$$\text{Map} = \left(\frac{(\text{Pixel}_{\text{Image}} - 0) * (40 - 15)}{(255 - 0)}\right) + 15 \quad (2)$$

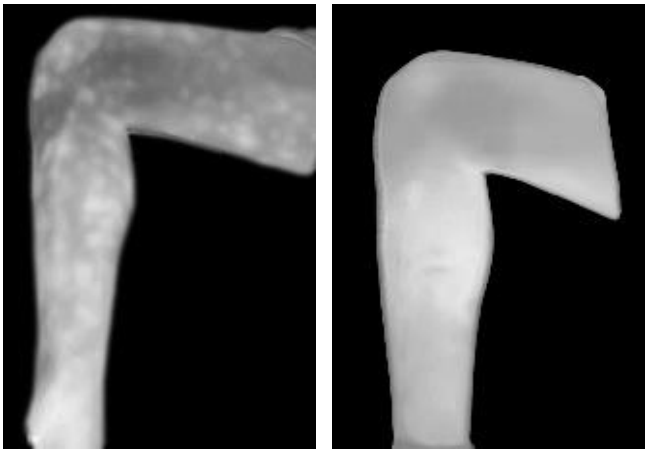
```
%Declare the image size
[n o] = size (P);
%Firs Loop
for (i =1: n)
%Second Loop
for (j=1:o)
a = P (i, j);
%Declare variable
out = ((double(a) - 0) * (40 - 15) / (255 - 0)) + 15;
mapa_de_calor (i, j) =out;
End
End
%Declare the image size
[n o] = size (T);
%Firs Loop
for (i =1: n)
%Second Loop
for (j=1:o)
b = T (i, j);
%Declare variable
out2 = ((double(b) - 0) * (40 - 15) / (255 - 0)) + 15;
mapa_de_calor (i, j) =out2;
End
End
```

According to the specified schedule, first the size of the images is declared in order to perform a complete sweep of both images, then two loops have to be applied to take all the pixels of the images as a reference. Likewise, a new variable is declared for the application of the mathematical formula specified above about the heat map, achieving the conversion of both grayscale images to temperature scale.

After converting both grayscale images to temperature scale, we continue with the third step of image processing, which is the difference between both thermal images in temperature scale, in order to obtain the areas of the leg where there is a temperature variation to determine the appropriate warm-up process where thermal imaging predominates after muscle warm-up. To do this, the following formula is applied using the MATLAB software specified below:

$$\text{Subtraction} = (\text{imgAfter} - \text{imgBefore}) \quad (3)$$

From the subtraction proposed in the previous formula, the result is generated that will turn the image into a warm-up map of the student, as can be seen in figure 6, where the area with the highest temperature is visualized as there is greater movement in the warm-up process, likewise, this warm-up map allows the coach to identify the parts that have had a greater movement by specifying it by means of a more red color. intense. Finally, this image allows us to identify if the student has performed an adequate muscle warm-up in the part of the quadriceps, calves and soleus muscles.



(a) (b)

Figure 6. Heating map

4. Results

The development of this image processing system fulfills the objective of monitoring the muscle warm-up of students prior to their sports activities by comparing the muscle temperature before and after the warm-up by using the thermal camera with a 160 x 120 sensor for any device. With this, the treatment of the images is carried out and the decision is made to prevent muscle damage or injury by indicating if another additional muscle warm-up is required.

This image processing system acquired the thermal images through a homogeneous protocol, as it required thermal images captured with the same characteristics for subsequent treatment, likewise, when testing its operability on a group of students, an accuracy in its tests was demonstrated with an efficiency of 95.97% in the monitoring of the muscle warm-up on the students prior to their physical activities. An adequate efficiency is achieved through the image processing techniques that are carried out in programming.

With the operation of the system, the information about the condition in which the student is after having performed the muscle warm-up is detailed by analyzing both parts of the legs, visualizing through a warm-up map the parts in which there is a temperature variation, determining that those reddish areas are in optimal conditions unlike the other remaining parts of the leg. This would indicate that the student should repeat the muscle warm-up process again to be in optimal condition.

The results show that the monitoring of muscle warm-up obtained from the image processing system presents a detailed analysis of the areas of the leg in which the temperature is higher, when compared with other systems that do not detail their results, likewise, its operability requires a basic electronic device accompanied by a correct programming in the MATLAB software that analyzes the part of the leg through the processing techniques specified throughout the methodology to show a correct muscle warm-up.

According to Table II, the main characteristics of the thermal image processing system to monitor the muscle warm-up in students prior to their sports activities are appreciated, where the important parts of the system are detailed, being beneficial for the prevention of muscle damage or injuries in students by performing a complete analysis of the leg part. generating greater confidence about a correct muscle warm-up before performing a physical activity.

Table II details the characteristics of the system

Table 2. System characteristics

System evaluation	
Distance	30 cm
Software	MATLAB
Temperature Range	15 °C – 40 °C
Body analysis	Quadriceps, Calf and soleus muscles
Resting Time	0
Efficiency	95,97%

The implementation of this image processing system is a fundamental tool for students or professional athletes who need to avoid muscle injuries that can affect their sports career, likewise, this system is not expensive to develop and presents an efficient monitoring of muscle warm-up as it is accessible to anyone, since the software and parameters specified in table II must be considered of the system and demonstrate the correct functioning to determine an adequate muscle warm-up.

5. Discussion

The Muscle warm-up has been a topic discussed by many researchers regarding the time and order in which this activity should be performed, this interest is mainly due to the constant cases of injuries suffered by many students or athletes in the development of a physical or sports activity, presenting temporary injuries that keep them away from all physical activity for a specific time, as well as the definitive retirement of his professional career as an athlete after suffering a chronic injury.

This thermal image processing system to monitor muscle warm-up is fundamental for the evaluation of the student's muscle temperature by applying a novel methodology that differentiates it from the research works, for example, the research work developed by Carissimo et al. (2023) (22), where the researchers proposed to perform an automated system of muscle temperature evaluation during training in sports scenarios. Achieving as a result an efficiency of 81.02% in the monitoring of muscle temperature applied to athletes during the development of their activities, but this system works particularly with an

IMU sensor to analyze the movement of the athlete in an unspecified time during the evaluation of the activity, likewise, the instruction provided to the athletes is not clear, They simply order him to develop any activity with a high pace, which can hurt some of the athlete's muscles by forcing the movements by not telling him that they should start from a low intensity and work their way up slowly.

We also have the work developed by Gutiérrez García et al. (2021) (23), where the researchers proposed to carry out a system of analysis of pre-competitive muscle warm-ups in professional footballers through movements. Reaching as a result an efficiency of 78.39% in the analysis of the pre-competitive muscle warm-ups of the athletes during the development of their activities, but this system during its implementation does not manage to clearly differentiate the heat map that the players represent in the development of the game, this limits the analysis of the required muscle warm-up based on the time in which the player is in physical activity, On the other hand, the warm-up protocols established in the physical break do not specify the time needed for the players to be able to perform another muscle warm-up due to the lack of information regarding the heat map.

We also have the work developed by Ismail et al. (2019) (24), where the researchers proposed to make an automatic system for identifying muscle warm-up protocols based on the speed performance of athletes. Reaching as a result an efficiency of 83.46% in the identification of muscle warm-up protocols based on the athlete's speed performance, but this system presents inaccurate results regarding the measurement time due to lack of control over the system, likewise, it presents limitations regarding the counting of movements of the players' muscle warm-up due to lack of technological equipment that can efficiently identify the difference in movements static and dynamic, limiting the research by determining that static warm-up presents disadvantages for the speed performance of professional athletes.

We also have the work developed by Lin et al. (2020) (25), where the researchers proposed to make an evaluation system of muscle warm-up protocols based on the performance of professional athletes. Reaching as a result an efficiency of 90.44% in the verification of the muscle warm-up methods commonly applied by coaches in athletes, but this system when performing a warm-up evaluation with static and dynamic traction, performs tests in a short time on the movements in the group of athletes, this does not allow to correctly differentiate the advantages of each muscle warm-up, Likewise, it uses an Arduino nano that has a limitation in its memory for a greater capacity of athletes who plan to evaluate later, reducing the work of the system by little its capacity.

We also have the work developed by Zhou et al. (2019) (26), where the researchers proposed to perform a portable monitoring system based on muscle warm-up during sports activities. Achieving as a result an efficiency of 91.77% in the monitoring of the muscle warm-up applied to a group of professional athletes, but this system is based on a muscle temperature monitoring through a pressure sensor that can be fragile if the sport applied by the athlete is usually physical contact, likewise, It can be uncomfortable for other athletes who decide to use it during the development of physical activity and when constantly adjusted it can generate an erroneous monitoring that would make it difficult for the coach to know the values of the athlete's muscle temperature. A comparison will then be made in Table III of this system (a) with our proposed system (b).

Table III details the comparisons of the two systems.

	a	b
System	Semi-automatic	Automatic
Acquisition of information	Pressure sensor	Thermal camera
Patient's condition	Physical activity	Physical activity
Software	Arduino IDE	MATLAB
Body part analyzed	Leg	Leg
Accuracy	91,77%	95,97%

Table 3. Comparison of system

6. Conclusion and recommendations

It is concluded that this image processing system facilitates the monitoring of the muscle warm-up of the students prior to their sports activities in an effective way in a certain time for the demonstration of the areas of both legs that have the highest temperature, likewise, it allows to analyze the student and suggest if necessary to repeat the muscle warm-up process again if the system does not detect a correct warm-up.

It is concluded that this image processing system performs its entire procedure automatically, from the acquisition of both images to the treatment of the same, in the same way, the high efficiency in its results shows that it is a step forward compared to existing research systems, making it a safe and reliable system for monitoring muscle temperature in students prior to their activities.

It is concluded that this research system presents an easy handling so that coaches or students can use it without any difficulty, likewise, this system captured the images at the precise moment in which the student finishes his first warm-up to ensure the correct analysis since the body can cool down and would make it difficult to monitor the areas with the highest temperature as the specific values are not detailed.

It is concluded that this image processing system is based on the analysis of thermal images for the monitoring of areas of the leg in which a muscle warm-up should be performed, resulting in valuable information for the athlete

to have a decrease in the probability of injury or pain once the muscle warm-up is finished by improving the elasticity of the muscles in the determined area of the body.

It is concluded that this image processing system allows detecting areas with temperature variation through a new approach by analyzing the body part through programming in the MATLAB software, likewise, it does so without contact with the student for greater security by established protocols that adjust to the size of the leg by means of the thermal camera. No limitations of use and with reliable results.

As a future work, an algorithm could be added to the proposed system that allows detecting muscle injuries that may occur during muscle warm-ups, indicating the area and magnitude of the injury that would affect the sports development of students, making it a more complete system in professional athletes without losing safety and efficiency.

It is recommended that the thermal camera has an adequate focus so that the system can analyze it correctly without image problems, respecting the characteristics specified in the previous table for a good analysis in the results without errors or complications.

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