

## ERGONOMIC AUTOMATIC CONTROLLED SYSTEM USED FOR INDUSTRIAL MANUAL OPERATIONS

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**Abstract.** *The objective of this paper is to create an ergonomic automatic controlled system based on several methodology used by companies which evaluate the worker movements during the takt. It involves the Project and Management area with planning, management and automation studies, with great importance to companies bringing continuous improvements due to quality increase, volume increase, costs reduction and standard routines creation. The system intention is to classify industrial operations as good, medium or bad work condition regarding ergonomics topic, in order to avoid health issues to the worker. Due to that, this study aims at worker position evaluation during factory routines instantaneously, in such a way that good ergonomic conditions and worker comfort are preserved and labor risk minimized. Therefore, an operator vestment prototype is developed with mechanical and electronic devices combined also using a sort of different sensors to acquire information like body/member position, and that indicate bad ergonomic situations in real time. There is a lack of ergonomic evaluation solutions, for industrial companies, even more automatic ones, which work with several manual operations but without continuous monitoring of working tasks. To validate this system, preliminary tests were conducted at the university, collecting the results and making improvements on the device in order to favor the operation and to avoid normal routine alteration. At the end, results are compared with the methodology and the efficiency of the system is noted. For next steps, this optimized system can be used in any manual industrial operation.*

**Keywords:** *Ergonomic index, manual work, industrial ergonomics, labor risk.*

### 1. INTRODUCTION

Slump times and continuous market competition make companies to redesign and optimize the production system in order to achieve better results through costs reduction. Recent works are explored regarding an expertise vision named by lean manufacturing, found under following papers: Jabbour et. al. (2013), Chiarini (2014), Alpenberg and Scarbrough (2016).

The authors Alpenberg and Scarbrough (2016) examined the daily work practices with lean production implementation at an organization and a pattern of practices used by managers in their daily work. An essential part of lean production is that participants are all involved in improvement activities.

The study of Jabbour et. al. (2013) is performed to verify the influence of Environmental Management on operational performance using the lean theory into 75 Brazilian automotive companies. A main result is the model tested revealed an adequate goodness of fit.

Another study investigates whether or not Lean Production tools can help in order to reduce the environmental impacts of production companies described by Chiarini (2014). Five companies were observed and measured before and after the implementation of some Lean tools: Value Stream Mapping (VSM), 5S, cellular manufacturing, Single Minute Exchange of Die (SMED) and Total Productive Maintenance (TPM).

However, as explain Duell et. al. (2006), to evaluate a workstation is needed to understand each involved operational task with the intention of having improvement directions. It is required to quantify the risks with focus on the individual.

In accordance to that, this study analysis the ergonomic condition during manual tasks execution. Due that, bibliography search is explored at chapter two to collect ergonomics information and to distinguish, latter on, a comfort and a danger working position. In beginning of chapter three is shown the angles range used for each body section and the times allowed per human position to avoid troubles health.

After that, this study presents a prototype human vestment to online signalize risks to the worker. It means that the worker can take a decision with the feedback warning, i.e. back to the safety condition as soon as possible. The prototype is focused on the arms, forearms, wrists, trunk and legs. Owing this, the devices are linked and parametrized with the script created into Arduino and LabVIEW program.

Additionally, at the end of this study is simulated a manual operation in order to test the prototype created. This study focused to develop this prototype with low investment due that has a lack of ergonomic aims special online system to avoid human health issues. Those ones available are usually expensive (Duarte, 2002).

## 2. ERGONOMICS

Ergonomics is the science of worker pose adaptation according mutual definition of Grandjean (1998), Iida (2005) and Abrahao (2009). There are some studies regarding ergonomics to ensure better conditions and to avoid health issues during tasks execution at work.

The intention is to improve the human tasks and the operational conditions through man-machine-environment combination analysis, according Grandjean (1998) and Iida (2005). It occurs at the beginning of work stations design, known as project phase, but may necessary to adapt some existing operations based on human condition limitations.

Generally, this evaluation goes on deepening gradually, as explain Abrahao (2009), until gets each work station level. A work station consists in one part of the company structure that acts one or more workers. The evaluation regards activities, postures and worker movements. According to the authors it is important to involve the operators in the evaluation process, noticing their opinion about the stations, their recommendations and possible solutions.

In anyhow, to improve the human operations, it should be investigated and reduced as much as possible the fatigue and the monotony, mainly by repetitive activities elimination. In fact, according Iida (2005) and Mondelo (2001), the work upgrading includes, also, better environment conditions regarding good conditions of temperatures, noises, vibrations, toxics gas and illuminations.

Another approach to achieve better ergonomic results is followed by five steps, from Iida (2009). The intention is to solve troubles due completely understanding in the real problem and the tasks needed. Generally, it involves the evaluation phase, diagnostic phase and, finally, the correction step.

### 2.1. Ergonomic Methods

The ergonomic analysis consists in an online worker observation or by video recording with a description about the body postures codes which is described under Bartnicka (2015). This code is defined in different conducts by degree ranges in accordance of the used method.

The ergonomic methods are described on several cases of study as Karhu (1977), Mcatamney (1993) and Hignett (2000), which are based on the body segments positions to indicate external codes for a particular category of workload. The authors advice to develop a methodology for ergonomic evaluation involving an online observation, videos recording of tasks execution and body postures measurements data acquisitions. Therefore, this section continuous following to explores some of these methods.

The method OWAS examines the whole body posture recording and analyzing the activities based on two parts, Karhu (1977). First step evaluates the work posture and the second classifies in a set of criteria to redesign the work procedures and places.

An ergonomic risks evaluation is developed by one-page checklist to features the assessment of legs, trunk and neck for repetitive tasks, Keyserling (1992). It is explored by persons with limited ergonomic training and by factors to assess postural risks on 335 jobs in four plants.

A national institute named by NIOSH (1981) first developed an equation to assist safety and health professionals to analysis lifting demands in the sagittal plane. This technique gradually evolves covering lifting index that can be used to identify hazardous lifting tasks explored by Waters (1993).

Another method found under Occhipinti (1998) is an originally recommended by NIOSH in the concise exposure index called by OCRA. It analysis the repetitive movements of the upper limb on the relationship between the daily number of actions performed by the upper limbs in repetitive tasks.

To identify the ergonomics hazards or risk factors can be use the PLIBEL method. In this sense, Kemmlert (2006) uses a checklist with questions for different body regions to highlight musculoskeletal risks in connection of workplace investigations.

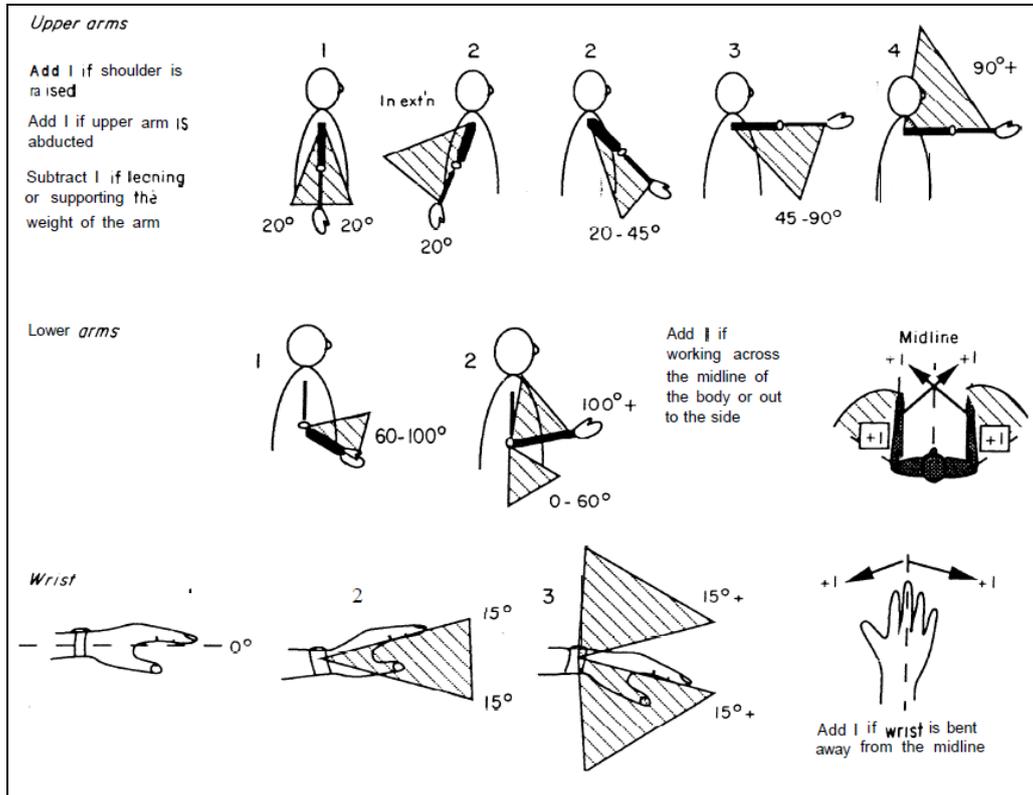
Also, Moore and Garg (1995) proposed a technique to assessment the jobs risk of upper extremity disorders based on knowledge and theory of the physiology, biomechanics and epidemiology. This methodology measures six task variables, involving the duration of exertion per cycle, efforts per minute, wrist posture, exertion speed, duration of tasks per day and exertion intensity.

QEC is another method from Li and Buckle (1999) based on investigation of the user's needs. It consists in a practical tool for the assessment of physical exposure to risks for work-related musculoskeletal disorders.

An ergonomic assessment tool named as REBA uses a systematic process to evaluate the whole body postural and risks associated with job tasks. For this, a single page worksheet is used by Hignett and Mcatamney (2000) to reevaluate each body section.

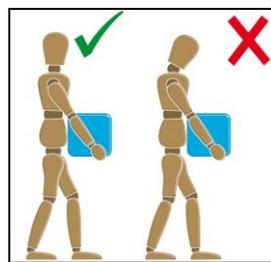
As assessment technique for postural loading named by LUBA includes the hand, arm, neck and back evaluation and the corresponding maximum holding times in static posture, Kee and Karwowski (2001). Twenty male subjects participated in the experiment designed to measure perceived joint discomforts.

Another method is called by RULA which categorizes the body postures and expended forces, which is explored under Mcatamney (1993). This tool requires no special equipment providing a quick assessment of the body sections. Figure 1 shows the ranges for some body parts by way of upper arm, lower arm and wrist. These movements ranges were assessed and scored on the basis findings from studies carried out by Tichauer (1966), Iaffin (1973), Hagberg (1981) and Schuldt (1987).



**Figure 1. The postures scores for body part group: the upper arm, lower arm and wrist twist, from Mcatamney (1993).**

Also, is created a manual handling operations guidance on HEALTH (2016) in order to help manage, control and reduce the injury risks from manual tasks execution. The main aim is to prevent injury on any part of the body, mainly the back area. Figure 2 presents an advisement of this guidance that reduces the injury risks direct to the neck.



**Figure 2. Team handling, from book HEALTH (2016)**

A study performed on the book Health (2002) the upper limb disorder guidance area in order to create a checklist hazards in the workplace. The label “upper limb disorder” is used to refer a range of medical conditions which can be caused or made worse by work.

Another observation method came by Ketola (2001) which contains 127 work cycles observation at a food-processing plant and a paper mill. At this time, six risk factors were included: repetitive hand use, hand force use, pinch grip, non-neutral wrist posture, elevation of upper arm and local mechanical pressure.

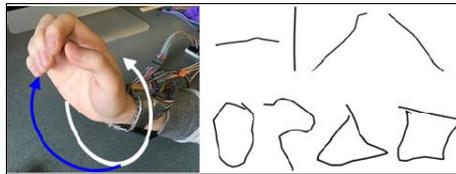
A tool is created by Monnington (2003) with manual assessment health and safety for inspectors in order to guide prioritization and intervention on main risk factors. It is named by Manual Handling Assessment Charts (MAC) with the intention to identify manual handling high risks due assessment most common risk factors in lifting and lowering, carrying and team handling operations.

In anyhow, David (2005) grouped examples of ergonomic methods and classified them according what is evaluated as posture, load, movement, vibration and others (mechanical compression, glove use, environmental condition, visual demands, etc). These techniques can be reach by several studies also.

In another situation is developed by Ray and Teizer (2012) an automated approach for posture estimation using a range camera and defining tasks risks. This study consists on the analysis of overhead work, squat or sit to lift load, bend to lift load and crawl, and each one is verified the angles working, height, with a logic script behind.

As the same reason for ergonomic analysis, Herzog (2015) created a systematic approach to the workplace designed in ophthalmology department for strain and stress using OWAS analysis to accuse bad ergonomics position.

One case study found under Gong (2016) explores a new input modality suited on the wrist as a joystick to perform on-handed movements on smartwatches. The prototype performance and the results are demonstrate on the figure 3.



**Figure 3. Left: wrist whirling using a prototype. Right: example gestures drawn, from Gong (2016)**

Another method explored by Sanchez (2005) is named as ABATech which is based in some analysis criteria. According the author, the activities have to avoid any stress factors that could be harmful to health, both during the planning phase as well as for existing workplaces, due 11 characteristics. The result will indicated by traffic light from bad to good workstation condition.

1. Work height
2. Neck muscles stress
3. Above shoulder work
4. Trunk mobility
5. Arms mobility
6. Arms and shoulders stress
7. Wrists stress
8. Fingers stress
9. Knee joints mobility
10. Distribution of standing, walking, sitting
11. Loads handling

### 3. ERGONOMIC VESTMENT PROTOTYPE

This section approaches the human vestment prototype developed to online warn the user about the alert and dangers positions during the tasks execution. Below is described the script, the used devices for angles control and a simulation. In additional, is explored the angles and times correlated under Figures 4 up to 8.

#### 3.1. Angles and times correlation

Several ergonomic methods are considered according chapter two exploration. Due that, the following figures have been created in order to correlate the angles with operation time divided per body section. It is considered the time that the user can work in such angle and the colors accuse the risk for health conditions as low for green, medium for yellow and high for red. As explained before, under David (2005) studies, most musculoskeletal disorders are assessed on upper regions of the body such as the back, neck, shoulder, arms and wrists.

Figure 4 presents the correlation between the arm and the time used to execute the user tasks. As shown, there is a range of 0° up to 40° considered as safety zone. The user can use 10% of operation time working with 40 up to 90° and continuous in security, but it turns a yellow or attention health condition if it is used more than 10% and became a red station or dangers position if pass 50% in this position. In anyhow, if the user rotate the arm more than 90° is already an attention situation at beginning and a red one if it is used more than 5%.

Next figure awards the forearm. It is similar to the figure 4, but it has a difference at the safety range which is considered from 0 up to 60°.

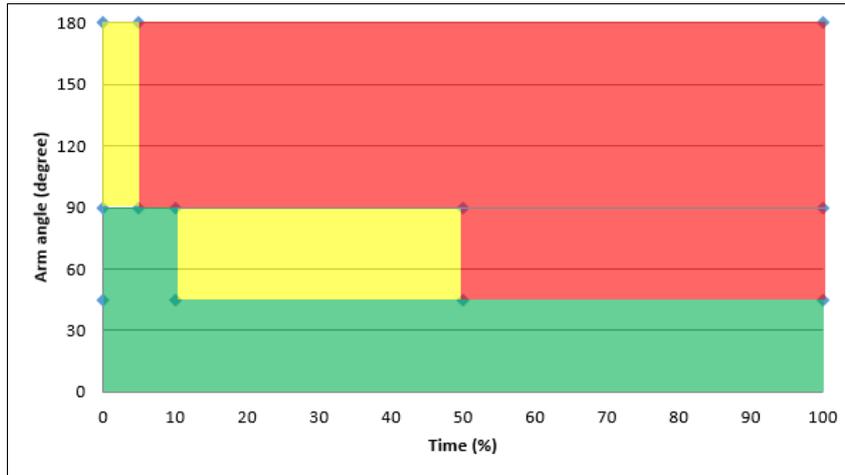


Figure 4. Arm correlation

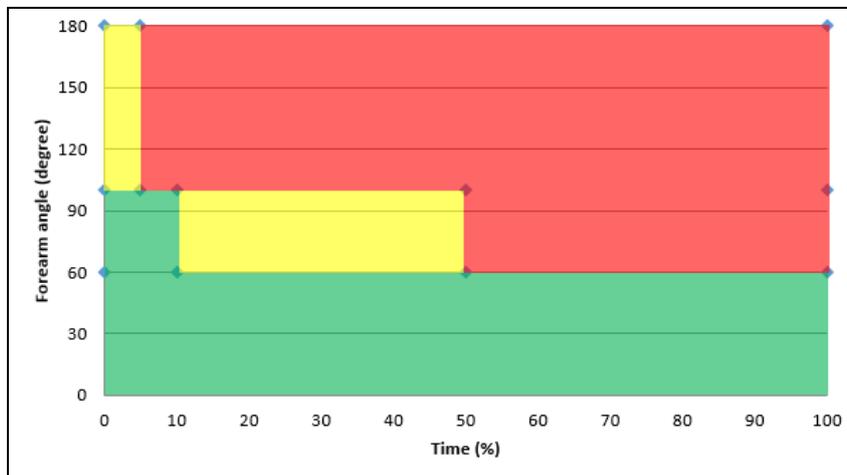


Figure 5. Forearm correlation

The representation of wrist and legs are very similar, as figures 6 and 7. It starts with the angle range 0 up to 15° in green until 40% of operation time and yellow until 70%. Above this range is already considered as alert condition until 10% of time and dangers in time is spent more than that. An important observation is that the angle legs are the sum of thigh and calf. Therefore, the greater means these links are being approach each other.

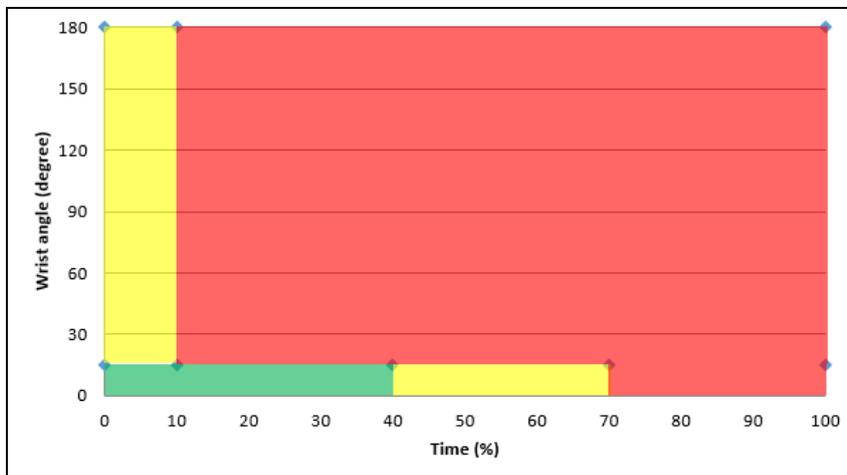
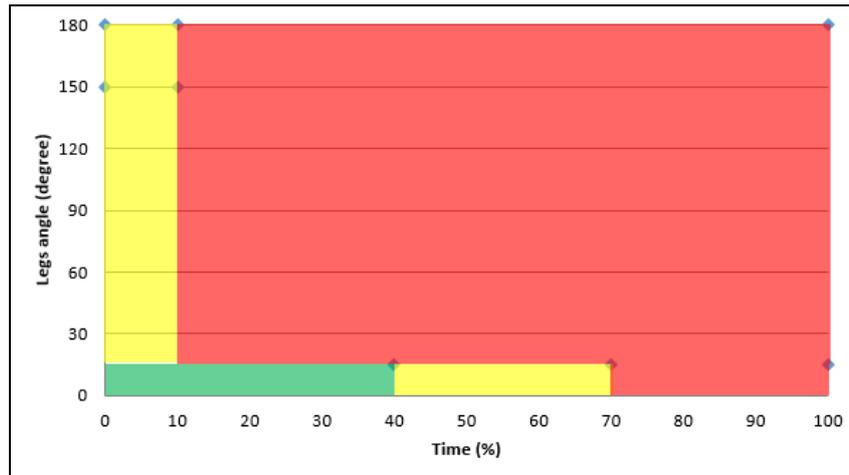
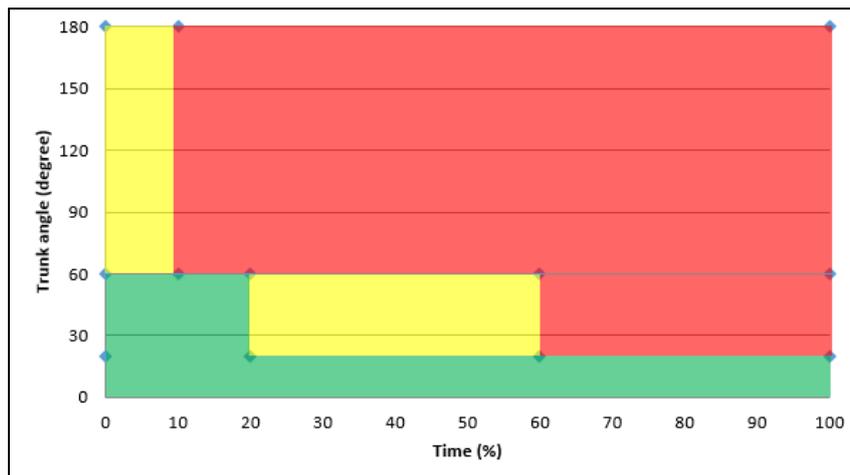


Figure 6. Wrist correlation



**Figure 7. Legs correlation**

The trunk and time correlation have a safety zone 0 up to 20°. After that, the user can rotate the trunk until 60° using 20% of the time to continuous under security condition, 60% modify to yellow and above turns dangers ergonomics condition. Above of 60° rotation is already considered as alert and dangers conditions, as it is expressed by the figure 8.



**Figure 8. Trunk correlation**

### 3.2. Prototype parametrization and simulation

After this information of range and time designed for each body section, it is developed a vestment prototype system to map these information and to online accuse the unsafety positions. This system is described below which is designed to not disturb normal tasks execution.

Owning this situation, the prototype is divided by two subsystems, which send the data to one central controller linked in a computer for data acquisition. This computer has the script created to react according different ranges of movement and light up indicators in a user interface. One subsystem takes care about arm, forearm and wrist, which is designed to measure the angular variations and overhead positions. The second regards the legs and the trunk positions.

Both subsystems are shown in the schematic of Figure 9 awarding the devices connected accordingly. The sign is sent wirelessly to the central microcontroller, as explained which is connected in a computer, to collect the results. The devices instrumented are following numerated items of figure 9:

- 1) Microcontroller Arduino Nano;
- 2) Transmissor 433 MHz;
- 3) 9V battery;
- 4) Accelerometer MPU-6050 linked to the arm or leg;
- 5) Accelerometer MPU-6050 linked to the forearm or calf;
- 6) Flex sensor 2.2 inches linked to the wrist or Potentiometer linked to the trunk.

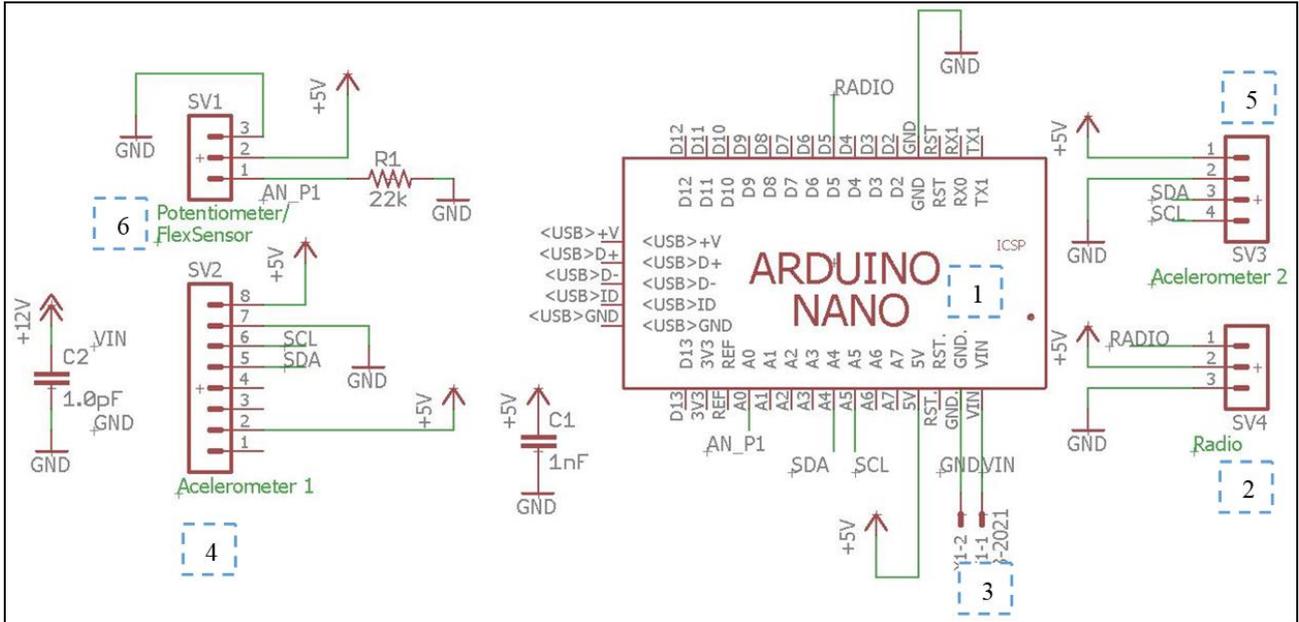


Figure 9. Schematic for body data acquisition

The second subsystem showed uses the same structure as the schematic, but with a difference that instead of a flex sensor a potentiometer is used, so the resistor R1 has to be removed of the circuit. The subsystem in this case aims to accuse the knee joints mobility and trunk angle, for that counting with two accelerometers for the leg and calf and the potentiometer is linked to a device to capture the trunk movement analyzing the variation over the potentiometer axis turning. The measure of the angle between the leg and the calf by using the accelerometer in each of this parts of the inferior member and making a mathematical operation to reach the angle between them.

These devices are mounted together, over a printed circuit board as the layout shown in the Figure 10. The objective of having a board is to reduce the electrical connections using wires and by this way improving the signal quality and decrease the bad contact occurrence.

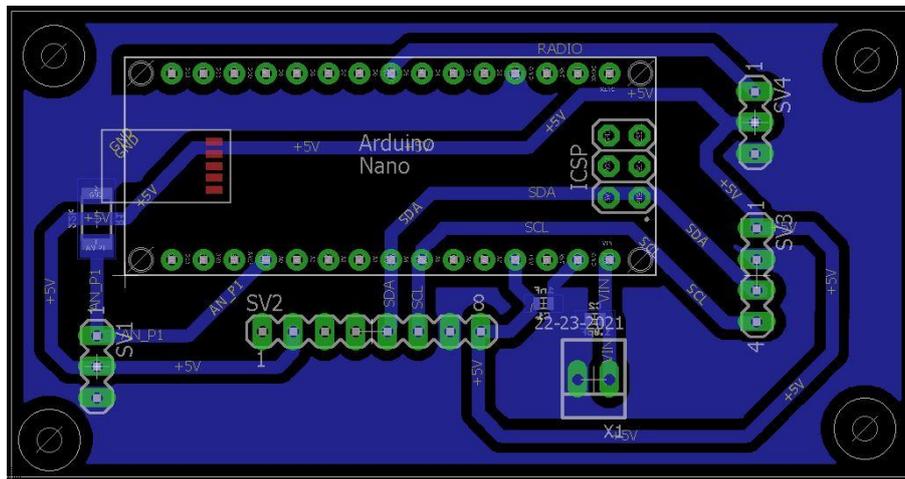


Figure 10. PCB Layout – module of data acquisition

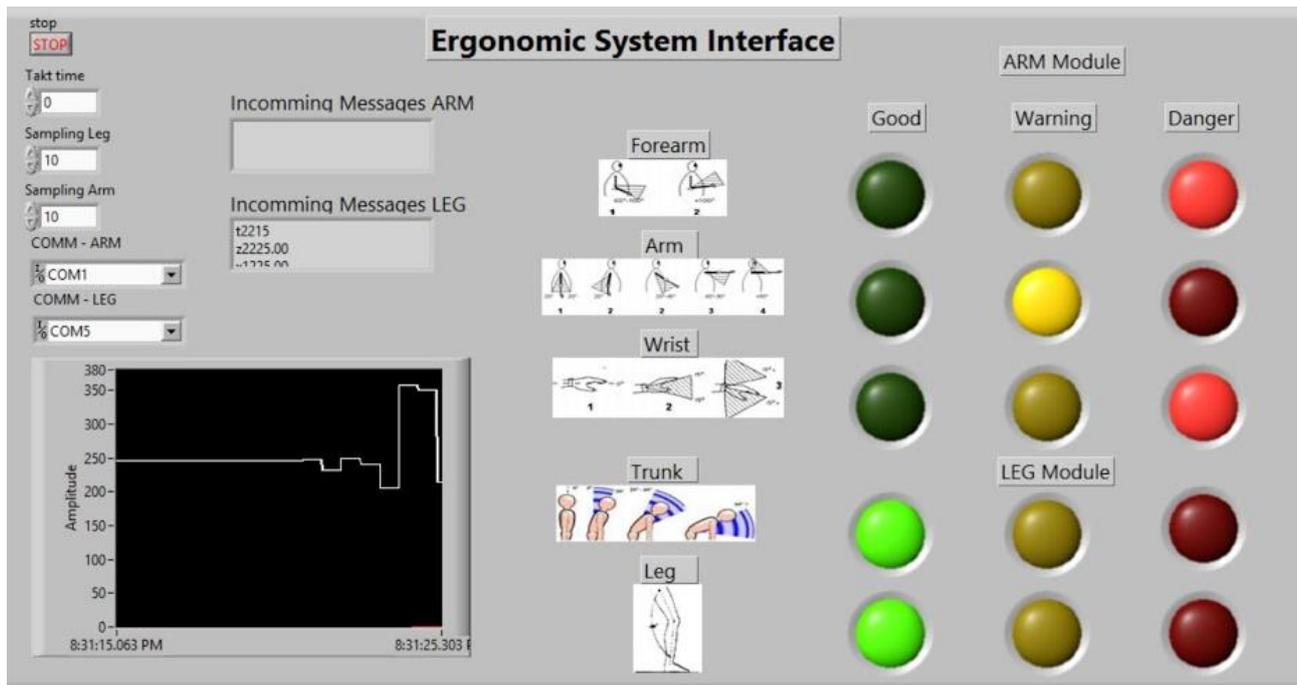
According Cuarelli (2013), there are several potentiometers models with this rotation angle. Owing the study characteristic, it is used one that has a linear variance of 10 kΩ, connected in a voltage of 5 VCC, linked in maximum rotation of 260°. This device is connected at a microcontroller analog input. As explanation of da Costa (2007), due the 10 bits resolution from analog input, the device has about a range of 1024 values. Therefore, the calibration is linked for minimum parameter of 0V to the value 0000 bits and for the maximum of 5V to the value 1023 bits.

The accelerometers work in the same way for the arm and the leg subsystems. They are initially calibrated to a known position as zero mark. After that, the member positioning can change the angles in each axis for every

accelerometers, being need to receive this generated data and process it, according to each criteria observed. For the first analysis, each sensor is being monitored due the movement direction of major impact about the criteria observed.

In addition, in this study the subsystems microcontrollers and the central receiver are Arduino boards (2016). To program the Arduino boards is used a USB cable connected to a computer using an IDE available on the device. With the central board connected to the computer the data received on it wirelessly through the 433 MHz modules are now transferred to the computer and other actions can be taken with this data available.

Led are used, illuminated by green, red and yellow colors in order to warn the user about alerts and dangers ergonomic conditions due the work angles. Figure 11 presents the interface for user warning. The sign is displayed on the monitor.



**Figure 11. User interface**

Finally, it is simulated a manual routine tasks at an university using the vestment prototype presented. The activity consists, basically, to maintain the organization of photocopy area and to operate the copy machine, by an internal office. The tasks considered on the simulation are composed, basically, in the movement of books and papers from one area to another. The scenario is composed by one intern without any special equipment to handle the materials.

The complete monitored hardware system was fixed on the user. It was defined a time to move 5 books from the workbench to the copy machine, being possible to evaluate the ergonomic vestment developed. The led yellow and the red had turned on, which was accused high risks to execute such tasks. It is related, specific, in the moment of papers grip once the trunk screw more than 60° during 40% of total operation time.

In anyhow, the improvement actions from ergonomic evaluation should start in those tasks, which contain critical ergonomics problems, analyzing the height numbers of mistakes, accidents, ills, absenteeism and turnover, as explained by Iida (2005). It is analyzed the posture and effort required in tasks execution, detailing the mainly sinews and muscles pains caused by tensions.

#### 4. FINAL REMARKS AND NEXT STEPS

With the explanation of existing ergonomic methods, presented on the second section, is noted an easier work evaluation due the determinate values. With explanation, is created the figures 4 up to 8 showed under third section, which presents safety and unsafety work positions. It was included a time for each evaluated section body, related to the angles ranges. Therefore, the industrial application can consider the cycle time about the operation to be analyzed.

For the future, it is recommended to allowed the system in order to modify the data presented under figures 4 up to 8. Therefore, the user can input the times referred to each angle, according the experience of such work.

This paper presented an own modeling posture feedback system developed as prototype. It is divided by subsystems in order to fix in the user body sections. It is mapped the legs, arms, forearms, trunk and wrists.

To validate this system, an office work is simulated using this developed prototype, accusing the alert and dangers positions though led yellow and red turning on. This project demonstrates to attend the expectative, as the results were

send in a real time and it accuses the bad ergonomic condition to the user makes an important decision, e.g. coming back to a safety position. It was eliminated transmission cables during the development, due noted interferences during the parametrizations and simulations.

In anyhow, the hard work that affects the muscles must be transferred to the sensitive and attention organs, adapting the worker, Gardjean (1998). For this, the validation of workstation must has to take care about improvements on the conditions of manual operation. Then, another recommendation from this study is to improve the station evaluated, defining a plan to change the work height, or even to invest in new equipment to help this manual task simulated.

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