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ANTHROPOMETRY. COMPARATIVE ANALYSIS OF TECHNOLOGIES FOR THE CAPTURE OF ANTHROPOMETRIC DIMENSIONS

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ABSTRACT

This article is a review of the main aspects of anthropometry and various technologies for the capture of the anthropometric dimensions. Anthropometry is a scientific discipline that is closely related to Physical Ergonomics and develops in different fields of application. The science studies the dimensions of the human body, the knowledge and skills to perform measurements, as well as their statistical treatment.

In order to obtain anthropometric data for ergonomic ends, be it for actual or academic studies, it is necessary to have the appropriate tools for the realization of these types of measurements. There are various existing technologies and devices for capturing the anthropometric dimensions and anthropometry and although, historically, anthropometry has been one dimensional and manually registered using different instruments such as, stadiometer, anthropometer, anthropometric compass, measuring tape, anthropometric chair, among others, the development of technologies has enabled the creation of systems to capture anthropometric dimensions that do not require direct contact with the person being measured.

KEYWORDS: Anthropometry; Measurement technologies; Anthropometric dimensions; Analysis.

ANTROPOMETRÍA. ANÁLISIS COMPARATIVO DE LAS TECNOLOGÍAS PARA LA CAPTACIÓN DE LAS DIMENSIONES ANTROPOMÉTRICAS

RESUMEN

Este artículo constituye una revisión de los principales aspectos de la Antropometría y las distintas tecnologías para la captación de las dimensiones antropométricas. La antropometría es una disciplina científica que está estrechamente relacionada con la Ergonomía Física y se desarrolla en diferentes campos de aplicación. Es la ciencia que estudia

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las dimensiones del cuerpo humano, los conocimientos y técnicas para llevar a cabo las mediciones, así como su tratamiento estadístico.

Para obtener datos antropométricos con fines ergonómicos, ya sea para un estudio real o académico, es necesario contar con herramientas adecuadas para realizar este tipo de mediciones.

Son diversas las tecnologías o dispositivos existentes para la captación de las dimensiones antropométricas y aunque históricamente la antropometría ha sido unidimensional, registrada de forma manual, utilizando diferentes instrumentos tales como: estadiómetro, antropómetro, compás antropométrico, cinta métrica, silla antropométrica, entre otros; el desarrollo de las tecnologías ha permitido la creación de sistemas de captación de las dimensiones antropométricas que no requieren del contacto directo con la persona a medir.

PALABRAS CLAVES: Antropometría; tecnologías de medición; dimensiones antropométricas; análisis.

ANTROPOMETRIA. ANÁLISE COMPARATIVA DAS TECNOLOGIAS PARA A CAPTAÇÃO DAS DIMENSÕES ANTROPOMÉTRICAS

RESUMO

Este artigo é uma revisão dos principais aspectos da antropometria e as diferentes tecnologias para a captação das dimensões antropométricas. A antropometria é uma disciplina científica que está intimamente relacionado com a Ergonomia Física e se desenvolve em diferentes campos de aplicação. É a ciência que estuda as dimensões do corpo humano, os conhecimentos e as técnicas para realizar medições e seu tratamento estatístico. Para obter dados antropométricos para fins ergonômicos, tanto para o estudo real ou acadêmico, é necessário ter as ferramentas adequadas para realizar este tipo de medição.

Existem várias tecnologias ou dispositivos para capturar as dimensões antropométricas e embora historicamente a antropometria tem sido unidimensional, registrada manualmente, utilizando várias ferramentas, tais como: estadiômetro, antropômetro, bússola antropométrica, fita métrica, cadeira antropométrica, entre outros; o desenvolvimento das tecnologias tem permitido a criação de sistemas para capturar dimensões antropométricas que não requerem o contacto direto com a pessoa a ser medida.

PALAVRAS-CHAVE: Antropometria; Tecnologias de medição; Dimensões antropométricas; Análise.

THE CAPTURE OF THE ANTHROPOMETRIC DIMENSIONS

1. INTRODUCTION

The knowledge of human beings' psycho-physiological and anthropometric capabilities is necessary for carrying out ergonomic studies that enable the evaluation and design of different work spaces that adhere to people's characteristics. Anthropometry for ergonomic purposes aims to offer anthropometric data that will serve as a base to size objects that will adjust to the true characteristics of end users (Gómez, 2005). It is a scientific discipline closely related to Physical Ergonomics and developed in different fields of application. Generally, a worker must adapt to "what there is," mainly because a great deal of furniture is imported or not designed to be used by Cuban workers. The majority of labor tasks nowadays require the worker to maintain a fixed position for long periods of time. If a poorly designed workplace (one that does not correspond to the anthropometric needs of the end user) is added to that fact, it may drive the user to adopt uncomfortable postures and make undue efforts leading to discomfort, ailments and affectations in workers' health.

Pursuant to the above, different research developed in the Cuban backdrop between 2009 and 2012 was consulted. Said research consisted of ergonomic evaluation of work places at different Cuban companies, such as Durero Caribe S.A., joint venture of the gaphic sector, Medsol, belonging to the Biopharmaceutical and Pharmaceutical Group (BioCubaFarma), Mathisa, a state-owned company for the manufacturing of sanitary and hygiene supplies, Suchel Camacho S.A., a joint venture of the hygiene sector, among others. The results of this research made it possible to establish that there are problems in Cuba with regards to health, productivity, efficiency and efficacy associated to poorly designed workplaces (Carmona, 2009; Díaz, 2009; Lubián, 2011; Gallardo, 2011; Barrabí, 2012; Martínez, 2012).

A total of 84 workplaces were evaluated using ergonomic evaluation tools, such as Individual Risk Evaluation (ERIN in Spanish), Rapid Entire Body Assessment (REBA) and Rapid Upper Limb Assessment (RULA). A total of 319 workers were surveyed using the Muscular-Skeletal Symptoms Questionnaire. The results of these evaluations showed 65% of workplaces are high risk, needing changes in the short term and 35% require design changes. The applied survey showed the existence of muscular-skeletal symptoms, where 92% of workers surveyed expressed feeling pain in some part of the body, as well as a high exposure to risk factors for Muscular-Skeletal Disorders (MSD).

This paper presents the theoretical substantiation of the main aspects of anthropometry, anthropometric studies and a critical comparative analysis of the different technologies to capture anthropometric dimensions, such as some studies made with each one of the devices developed.

2. ANTHROPOMETRY AND ANTHROPOMETRIC STUDIES

The term *Anthropometry* refers to the study of the measurement of the human body in terms of the dimension of the bones, muscle and adipose (fat) tissue. The word anthropometry is derived from the Greek antropo, which means human being and the Greek metron, which means measure. The field of anthropometry covers a variety of measurements of the human body. Weight, stature (height when standing), reclined length, skin pleats, circumference (head, waist, etc.), length of extremities and widths (shoulders, wrist, etc.) are examples of anthropometric measurements (Pate, Oria y Pillsburry, 2012; Vicente, 2015; Norton y Tim, 2012).

Pursuant to the definition above, it can be noted that anthropometry studies all body measurements (Geraldo, 2015).

Anthropometry is a quantitative, systematic representation of the individual for the purpose of understanding his physical variation. Anthropometry is used in the design of clothing and equipment, for example, through anthropometric techniques in order to establish human dimensions (Nada, Zuhair y Nawal, 2014).

According to Arellano (2009), anthropometry is the science for the determination and application the human body's measurements, both in repose and in movement. These measurements are determined by the length of the bones and muscles and the shape of the joints. Anthropometry for ergonomic ends looks to offer anthropometric data that can be used as a basis to measure objects that adjust to the true characteristics of the end-users (Gómez, 2005; Narváez, 2013).

All authors consulted coincide in the stance that anthropometry is the discipline that studies the dynamic and static dimensions of the human body, the procedures and techniques to carry out measurements and statistical analysis. Anthropometry techniques offer data that will serve in the design of objects taking into account the characteristics of the end users, thus complying with the ergonomic principle of adapting production means to workers.

When the workplace does not adjust to anthropometry of the worker, unnecessary effort is generated, as well as limitation of the blood flow, fatigue in certain muscles and different pain. Also, productivity is reduced, error probability increases, quality decreases and the number or work related accidents goes up (Alonso, 2006; Vázquez, 2013; Narváez, 2013).

There are two types of body dimensions: structural and functional. Structural dimensions are made up of the head, trunk and extremities in sitting or standing position. Functional or dynamic dimensions are those which involve movement made by the body in a specific activity (Yáñez, 2009b). This means that, in static anthropometry, body measurements are taken by placing the person in a fixed position and measuring between specific anatomical points. Whereas in dynamics, measurements of the human body in movement are taken.

Most used, relevant dimensions of the human body for the purpose of design have been recommended by authors such as, Alonso (2006), Panero (2009) and ISO (2010), among others. Anthropometric dimensions vary in individuals of different ethnicities, time periods, age, gender, etc. (Alonso, 2006). It is necessary to take the population who will be using the workplace into account in the design of said workplace.

In an article by Amanda, Nogués y Pinilla (2008), reference is made to anthropometric studies in Cuba from a historical perspective. The paper alleges that the first anthropometric study made in Cuba was done by the French doctor Henri Dumont (1824-1878), who between 1865 and 1866, made 27 measurements of 7 persons, 4 of whom where male and 3 female. All came from the same place and were of the black race.

Diverse anthropometric studies have been made in Cuba, the majority of which have been oriented toward nutrition, sports, infancy growth and development and school furniture design for primary schools. Studies oriented toward workplace design have been scarcer.

The bibliography consulted evidenced the scarcity of anthropometric data in Latin America (Goméz, 2005; Franco, 2005; Oliveira, 2011). There are some scientific studies in countries such as Mexico, Colombia, Chile and Venezuela offered by (Ávila and Prado, 1999) in their book "*Dimensiones Antropométricas de la población Latinoamericana*," where Cuba was also included. In both editions of the book, the same study made by Dr. Antonio Martínez Fuentes of the University of Havana was referenced. In this study, 34 anthropometric dimensions were measured from a sample of 583 female Cuban workers from the sectors of agriculture, industry and commerce. It would be wrong to use this study for the purpose of design because the sample chosen represents 0.1% of the existing population, according to the National Office of Statistics and Information (ONEI in Spanish). In the sectors used in the study (ONEI, 2012), more than 35 years have passed since the study, which didn't include the all the required dimensions for the evaluation and design of workplaces, according to ISO (2010), i.e., height of the eyes when standing, height of the eyes when sitting, minimum range of arm, among others. It's important to highlight that the studies published by Ávila and Prado have been the most encompassing of Latin America. In Europe and North America, studies have also been made in countries such as, Germany, Spain, Italy, England and the United States, among others.

The majority of anthropometric studies consulted, such as those published by Vicente et al. (2011); Rojas (2013); Alacid, Muyor y Lopéz (2011); K. Chhagan (2012); Gonzalez et al. (2012); Betancourt y Manuel (2011); Guerra y Oriendo (2013); Marinho, Del Vecchio, y Franchini (2011); Lera et al. (2014) and Gerando (2015), carried out in Cuba as well as in the rest of the world, refer to the science of sports and nutrition. Other studies are oriented toward the world of fashion, design and evaluation of school furniture in public schools, among others.

3. TECHNOLOGIES TO CAPTURE ANTHROPOMETRIC DIMENSIONS

Existing technologies to capture anthropometric dimensions are diverse, as are those to obtain anthropometric data. The latter can be acquired in diverse formats: one-dimensional (1D), two-dimensional (2D) and three-dimensional (3D). 1D data include heights, lengths and perimeters of body segments. 2D data consist of silhouettes or body sections, outlines formed by curves or points (x, y). 3D anthropometry is made up of cloud points with coordinates (x, y, z) which represent body surface. An example is 3D body scans formed by cloud points which usually contain between 20,000 and 300,000 points. The acquisition, treatment and analysis of data considerably increase in complexity from 1D data to 3D (Vicente, 2015).

Anthropometric measuring methods can be direct or indirect (Alonso, 2006). The direct method is based on obtaining anthropometric dimension directly from the person from the anthropometric points, making use of equipment and instruments such as those previously mentioned. These tools and equipment as scarce in our country. The estimated cost of acquiring a module of this equipment is $2,668 Médicos-Nutricionales, 2013), which is an aquisition disadvantage for Cuba.

Leading advantages of using manual instruments:

- Enables measuring all anthropometric dimensions.
- The reading of measurements is direct.

Leading disadvantages of using manual instruments:

- Requires trained personnel for taking measurements.
- Measurements are taken one at a time for each one of the subjects.
- Measuring time, recording and processing of information are extensive.

With the passing of time, the development of technologies has enabled the creation of systems that capture the anthropometric dimensions without the need to interact with the person directly (indirect method). Digital 3D anthropometry emerged to reduce the time of acquisition per subject. The scanning is reduced to a few seconds and software processing can provide anthropometrical dimensions automatically, this way enabling obtaining of data at any time necessary (Vicente, 2015).

3D scanners can be full body or of a certain part of the body, such as feet or head. There are diverse types, such as structured light technology manufactured by the French company Telmat Industrie (SYMCAD) or developed by the company Textile Clothing and Technology Corporation (TC^2). Laser projection scanners emerge as an alternative which, albeit more expensive, the resulting 3D precision is much greater. These are used in most anthropometric studies in Spain. As an example of these scanners, we have those by Cyberware (USA) and Human Solutions (Germany) (Vicente, 2015).

Some devices use in indirect measurement technology, their fundamental characteristics, operation principles and applications are mentioned below:

a) Infrared thermography machine *(Arellano, 2009)*

This is basically a thermal imaging camera within the wavelength bands of 8 to 12 μm. The camera operates according to the principle of scanning the object to be measured, which is shown through a two-dimensional reflecting scanner.

The horizontal scanner carries out detection in lines of 300 pixels each, with a frequency sample of 135 Hz (to the left and to the right) and operates as a resonant oscillator moved by a continuous current engine. The vertical scanner configures the complete image from the diverse lines. 200 lines are captured, the image repetition sequence being 1.25 Hz. It can also work with 100 or with 50 lines.

b) SYMCAD *(Arellano, 2009; Vicente, 2015)*

The SYMCAD does not use harmful radiations. The data capture device is fixed (there are no moving pieces), giving reliable results and it is easy to maintain. It's patented 3D acquisition technology is based on the technique of projection of bands with natural light. It extracts peculiar delimited measurements by markers arranged on anatomic points which it automatically detects and identifies, as well as calculates adequate anthropometric measurements according to ISO-7250 e ISO 8559 regulations (perimeter, height, length…) or specific ones.

c) Body Scanner

The 3D Body Scanner is made up of four columns, each one including two CCD cameras and one category 1 harmless laser for sight. The units are fixed to the floor. Only 8 seconds are necessary to explore the entire human body. For that, the client must take off his clothes and remain standing at a natural posture (Investor's Business, 2014).

The system detects the human body surface and reproduces a three-dimensional representation on the computer.

Up to this point, the main instruments suggested by Arellano (2009) that do not require physical contact with the user have been described. Other authors, such as Annichini et al. (2013), Overton (2013), Polviven (2012), Zwane, Moses and Lawrence (2010), Giachetti et al. (2015) and Bing-ru et al. (2010) conducted research with the use of 3D Body Scanner technology. However, in our country, due to financial issues, it is not possible to acquire this costly technology (Rodríguez, 2011).

Since 3D scanner first appeared, a number of anthropometric studies have been conducted (Vicente, 2015). Anthropometric studies with 3D scanners in several countries can be cited, countries such as USA (Size USA), France (Anthropometric study of the French population), Germany (Size Germany), Spain (Anthropometric study of the female population in Spain), among others (Magros, 2012; Rodriguez, 2010.

An anthropometric study conducted in Mexico began in 2010 with an initial sample of 16,000 people in the 14 most important cities of the country. 3D Body Scanner technology was used and at an initial estimated cost of 500,000 USD (Quezada, 2010). At the end of the study, 17,364 people of both genders were measured (Ruvalcaba, 2012). Measurements were taken of persons from 16 to 66 years of age. The sample represents 0.023% of the Mexican population in this age range and their objectives were toward the clothing manufacturing sector, according to the anatomic characteristics of consumers (Cherem, 2012).

Leading advantages of using a), b) y c) previously explained:

- Only very few seconds are necessary to explore the entire human body.
- Enables taking a great number of measurements in a short time.
- Human manipulation is minimum.
- Precision and reliability of results.

Leading disadvantages of using a), b) y c) previously explained:

- Persons must travel to the place where the cabin is installed.
- Need to train personnel for use.
- Expensive equipment.

d) Measuring with a photograph

This technique doesn't require physical contact with the person either. It's based mainly on projective geometry which establishes a mathematical model of a photo camera in the form: m = PM, where m is the image of the object, M is the object to be measured and P is the projection matrix. To take the measurements, it is necessary to have a pattern of reference (Yáñez, 2009a).

Projective geometry is an alternative in the design and development of software to take anthropometric measurements in a simple way through a photo camera (Yáñez, 2009a). The physical presence of a person ceases to be necessary to the process of measurement and can be carried out at any time and place by just sending a file containing the photos to be processed.

Leading advantages of using photography:

- Physical presence of the person ceases to be necessary for the measuring process. It can be done at any moment and place by simply sending a file containing photographs to be processed.
- Precision and reliability of results.

Leading disadvantages of using photography:

- A scope of reference is necessary for each photograph.
- Adequate lighting that remains constant at all times is essential.
- The camera must be placed at the same location during the entire study

e) Kinect (measurement with images and movement)

Kinect, which was originally named "Birth Project," is a device created by Alex Kipman and developed by Microsoft for its videoconsole Xbox 360 (Magros, 2012; Samaniego, 2012).

This device was announced for the first time in June 2009 at the Electronic Entertainment Expo 2009 as a new generation of home entertainment. Movements can be controlled with the use of the camera, as well as player action and game menus (Magros, 2012).

The Kinect device has two cameras, RGB and NIR, and an infrared light source which enables the NIR camera to obtain data, including in the absence of light (Magros, 2012). Meanwhile, the RGB camera is in charge of obtaining information about color from everything that is situated within its field of vision. The short-range infrared camera is in charge of obtaining information pertaining to depth. The two exterior lenses correspond to the infrared information while the lens in the middle corresponds to the color camera (Magros, 2012).

There are different computer drivers for the use of the Kinect. Among these is Kinect for Windows SDK, OpenNI, OpenKinect or Libfreenect (Magros, 2012; Velardo y Dugelay, 2011; Lee et al., 2015; Clarkson et al., 2014).

Kinect SDK is able to detect the position of up to six people but it is only able to register the skeleton of two of them (the closest two), obtaining the structure containing 20 points detected. In order to be able to identify postures and positions that are partially hidden, Kinect has 200 common postures filled in hidden spaces (Magros, 2012).

This device has been applied in:

- Videogames for XBOX 360
- Assistant for vehicle matching
- Development of orthopedic prostheses
- Viewing in operating rooms
- Treatment of cerebral paralysis
- Weight control
- Geographic studies
- Robot control by means of body commands

It is an interactive tool that is currently being used to acquire anthropometric data. This sensor belongs to a class of devices known as depth cameras. Comparing many traditional systems that capture movement, the Kinect does not require the reference points on the people to be measured to be marked previously. This substantially reduces data collection time but also reduces accuracy. The cost of acquisition of this tool is approximately 150 dollars (Espitia, Sanchez y Uribe, 2014; Robison y Parkinson, 2013; Samaniego, 2012).

In spite of being a tool which is still under development for the capture of anthropometric data, some studies have been conducted as those published by Velardo and Dugelay (2011); Lee et al. (2015) an Clarkson et al. (2014), wherein this technology is compared to traditional methods.

Leading advantages of using this technology:

- Does not require user reference points to be marked .
- Reasonably priced sensor.
- Ease in the preparation of different environments.
- Connects to a computer.

Leading disadvantages:

- The user must carry out a series of tasks that are commanded by the study maker.
- The computer to be connected to the device must have a specific driver to be able to use the Kinect.
- Kinect software does not allow tracking of skeleton when using more than one sensor at the same time.

f) Android application for anthropometric measurement from mobiles

Android is an operating system originally thought of for mobile phones but subsequently being used on tablets and other devices such as appliances, television sets or watches. What makes it different is that it is based on Linux, an operating system nucleus that has no cost is open and on a multiplatform (Vicente, 2015).

This android application for mobiles consists of taking two photographs, one of the front and a profile. The person will have to place himself as the silhouettes on the phone screen indicate. The application then extracts the outline of the person for each photograph using image treatment techniques. The Smartphone was the chosen means both for image capturing and subsequent treatment in order to obtain necessary data for 3D reconstruction, as well as the necessary anthropometric measurements (Vicente, 2015).

Once the 3D model is reconstructed by means of own libraries developed at the Biomedical Institute of Valencia (BIV), the necessary anthropometric measurements are calculated. These will serve for both clothing manufacturing and a future virtual dressing room or future applications to be developed (Vicente, 2015).

Comparisons were made with 18 dimensions obtained with the new application and a 3D Scanner. There were smaller and larger differences, for example, in the height at the half-way point of the neck, the error does not reach 1% (1.46mm difference). However, in the length of the front thigh the error is over 35% (86.8 mm difference). The author of this application affirms that the algorithm for the calculation of the anthropometric dimensions can improve, since the available version at the time of the project was the first version (Vicente, 2015).

Because it is a recent project, there are still no possible advantages and disadvantages available.

Table 1 shows a summary of the critical-comparative analysis of the main characteristics of technologies that have been used for measuring or capturing anthropometric dimensions.

TABLE 1. MAIN CHARACTERISTICS OF ANTHROPOMETRIC MEASURING DEVICES

DEVICES	MEASURING METHOD	PRECISION*	DIMENSIONS	TIME	COST ($)
Manual Instruments	Direct	Little precision	All anthropometric dimensions	45 - 60 minutes per subject	Set of equipment 2.668 usd
(Lasers) Thermograph Infrared SYMCAD BodyScanner	Indirect	Precise	Possible to capture more than 200 dimensions	8 - 10 seconds per subject	Max.: 35.000 usd
Measuring with Photograph	Indirect	Precise	Not possible to capture all anthropometric dimensions (circumference and perimeter)	1 – 2 minutes per subject	89 – 1,363 usd (depending on model and make)
Kinect	Indirect	Little precision	All anthropometric dimensions (depending on software programming)	1 – 2 minutes per subject	150 – 250 usd
Android application for anthropometric measurement from mobiles (first version)	Indirect	Little precision (recent application, studies for improvement are being conducted)	Possible to capture more than 200 dimensions	1 – 2 minutes per subject	Based on Linux, an operating system nucleus that has no cost is free and on a multiplatform

Source: Own preparation

(* Refers to results achieved in the different tests conducted with these devices).

From the analysis depicted on table one it is deemed that of the techniques used, the manual measurement from instruments is the only one that has direct contact with the subject of measurement. It can be highlighted that measuring time is less. The author considers that in the measurement with photograph technique, although it is not possible to capture circumference and perimeter, it is possible to capture the necessary dimensions for the anthropometric design of a workplaces. Additionally, from the analysis to date, this is the method that offers the greatest possibilities for this research in Cuba given the cost, possible precision to be achieved, as ascertained by studies with this technology, and the fact that it is not necessary to transport the objects to be studied.

4. CONCLUSIONS

The analysis conducted of the different aspects of anthropometry and anthropometric studies in Cuba and the rest of the world helped evidence the need for anthropometric dimensions in the Cuban population, mainly the current labor force, which presents affectations in health fundamentally related to the poor design of workplaces.

The Cuban anthropometric studies conducted are fundamentally directed toward the science of sport, nutrition and infant growth and development. These studies contribute a methodological value to the doctoral research based on the design of a model for the anthropometric study and evaluation and design of a workplaces, as well as a software tool that will increase the efficiency and efficacy in the practical application of the model. It also contributes toward perfecting the provision of the anthropometry laboratory for the subject of Ergonomics in pre-graduate graduate and masters courses.

For the realization of anthropometric studies, we use manual instruments, infrared thermography, SYMCAD, BodyScanner, measuring with photograph, Kinect and Android application for anthropometric measurement from mobiles. In the critical-comparative analysis of these techniques, taking into account the anthropometric dimensions that enable capturing, the cost of acquisition, training of personnel that will take measurements, precision, measurement time and the need to transport the subjects to be studied, it is considered that the technology for capturing anthropometric data that offers the greatest possibilities at this time for this research in Cuba, is measuring from photograph.

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