UNIVERSIDAD TÉCNICA DE AMBATO

FACULTAD DE INGENIERÍA EN SISTEMAS, ELECTRÓNICA E INDUSTRIAL

CARRERA DE INGENIERÍA INDUSTRIAL EN PROCESOS DE AUTOMATIZACIÓN

Tema:

"FIABILIDAD Y VALIDEZ DE LAS EVALUACIONES POSTURALES DEL SISTEMA DE EVALUACIÓN ERGONÓMICO CON EL SENSOR KINECT V2"

Proyecto de Trabajo de Graduación Modalidad: Artículo Académico, presentado previo la obtención del título de Ingeniero Industrial en Procesos de Automatización.

SUBLÍNEA DE INVESTIGACIÓN: Sistema de Gestión de la Salud, Seguridad Ocupacional y Medio Ambiente.

AUTOR: Rafael Iván Santana Padilla

TUTOR: Ing. Christian Mariño, Mg.

Ambato – Ecuador

Marzo 2019

APROBACION DEL TUTOR

En mi calidad de tutor del Articulo Académico sobre el tema: "FIABILIDAD Y VALIDEZ DE LAS EVALUACIONES POSTURALES DEL SISTEMA DE EVALUACIÓN ERGONÓMICO CON EL SENSOR KINECT V2", del señor Santana Padilla Rafael Iván, estudiante de la Carrera de Ingeniería Industrial en Procesos de Automatización, de la Facultad de Ingeniería en Sistemas, Electrónica e Industrial, de la Universidad Técnica de Ambato, considero que el informe investigativo reúne los requisitos suficientes para que continúe con los tramites y consiguiente aprobación de conformidad con el numeral 7.2 de los Lineamientos Generales para la aplicación de Instructivos de las Modalidades de Titulación de las Facultades de la Universidad Técnica de Ambato.

Ambato Marzo, 2019

EL TUTOR

Ing. Mg. Christian Mariño

AUTORÍA

El presente Artículo Académico titulado: "FIABILIDAD Y VALIDEZ DE LAS EVALUACIONES POSTURALES DEL SISTEMA DE EVALUACIÓN ERGONÓMICO CON EL SENSOR KINECT V2", es absolutamente original, autentico y personal, en tal virtud, el contenido, efectos legales y académicos que se desprenden del mismo son de exclusiva responsabilidad del autor.

Ambato Marzo, 2019

Rafael Iván Santana Padilla

C.C.:1804438412

DERECHOS DE AUTOR

Autorizo a la Universidad Técnica de Ambato, que haga uso de este Trabajo de Titulación como un documento disponible para la lectura, consulta y procesos de investigación.

Cedo los derechos de mi Trabajo de Titulación, con fines de difusión pública, además autorizo su reproducción dentro de las regulaciones de la Universidad.

Ambato Marzo, 2019

Rafael Iván Santana Padilla

C.C.:1804438412

APROBACIÓN DE LA COMISIÓN CALIFICADORA

La Comisión Calificadora del presente trabajo conformada por los señores docentes Ing. Mg. Fernando Urrutia e Ing. Mg. Jessica López, reviso y aprobó el Informe Final del Artículo Académico titulado: "FIABILIDAD Y VALIDEZ DE LAS EVALUACIONES POSTURALES DEL SISTEMA DE EVALUACIÓN ERGONÓMICO CON EL SENSOR KINECT V2", presentado por el señor Rafael Iván Santana Padilla, de acuerdo al numeral 9.1 de los Lineamientos Generales para la aplicación de Instructivos de las Modalidades de Titulación de las Facultades de la Universidad Técnica de Ambato.

Ing. Elsa Pilar Urrutia Urrutia, Mg.

PRESIDENTA DEL TRIBUNAL

Ing. Fernando Urrutia, Mg.

DOCENTE CALIFICADOR

Ing. Jessica López, Mg.

DOCENTE CALIFICADOR

Reliability and Validity of Postural Evaluations with Kinect v2 Sensor Ergonomic Evaluation System

Christian Mariño[1(✉)], Rafael Santana[1], Javier Vargas[1], Luis Morales[1], and Lorena Cisneros[2]

[1] Facultad de Ingeniería en Sistemas Electrónica e Industrial, Universidad Técnica de Ambato, Ambato, Ecuador
{christianjmarino,rsantana8412,js.vargas, luisamorales}@uta.edu.ec

[2] Faculty of Business Administration, Bay Path University, Massachusetts, USA
lcisneros@baypath.edu

Abstract. Postural evaluations are becoming a priority in a world where occupational diseases derivatives from ergonomic situations are progressively common with serious consequences. This document proposes a semi-automatic ergonomic evaluation system with Kinect V2, which use the RULA method. It makes possible the discovery of conditions with postural risk and reduces errors in the estimating the evaluators' measurements due to lack of experience, expertise and handling of measurement instruments. Reducing the ergonomic evaluation time, compared to the direct postural evaluation method at a low cost. In a controlled environment, 30 participants with homogeneous characteristics are evaluated their postural work, using a direct method (goniometer) and a non-invasive (Kinect V2) method, to then compared the statistically results using the coefficient of correlation named Cohen's Kappa and vagueness type A. The final RULA scores issued by the direct method of postural evaluation and the proposed system are correlated. The uncertainty results established in the angular measurements on the arm, forearm, wrist, trunk and neck were respectively (±0.36°, ±0.22°, ±0.59°, ±0.27° and ±0.28°). A Cohen's Kappa correlation coefficient of 0.953 was obtained, which means an almost perfect correlation between the evaluations of both systems.

Keywords: Ergonomic evaluation · Kinect V2 · Non-invasive · Uncertainty

1 Introduction

Being ergonomics a multidisciplinary science that embraces principles of biology, psychology, anatomy and physiology in order to adapt the work environment to the capabilities and postural limitations of workers [1, 2], its objective is to prevent the emergence of inflammatory and/or degenerative injuries to muscle, tendons, joints, tissues and nerves known as musculoskeletal disorders (MSDs) caused or aggravated by the work environment [3].

M. Botto-Tobar et al. (Eds.): TICEC 2018, AISC 884, pp. 86–99, 2019.
https://doi.org/10.1007/978-3-030-02828-2_7

The MSDs derived from work are the most common health problems in Europe [4], among the most common risk factors causing them are physical and biomechanical factors, organizational and psychosocial factors, and individual factors [5].

To evaluate the MSDs and the various components by which they occur, there are several methods of ergonomic evaluation of indirect type (based on observation), direct, self-reports [6] and semiautomatic [7]. Indirect assessment methods use data collected through photos, videos and surveys by a professional who observes the activity to be evaluated [8], but they have the disadvantage of variability in the data, it depends on the experience and expertise of the evaluator (this is subjectivity) [9], on the other hand, has advantages economic and requires simple tools [10].

Direct evaluation methods are those that provide the most accurate data [11, 12], but are not frequently used because it requires equipment such as exoskeletons and electromagnetic sensor systems that are expensive and not applicable in the workplace because those are invasive [13].

Self-reports collect data from workers' journals, interviews, questionnaires and web questionnaires. These methods are relatively inexpensive, applicable to many populations and easy to use. The problem is that workers' perceptions of risk exposure are vague and unreliable [14, 15].

Semi-automatic evaluation methods use 3D sensors and high-tech software are increasingly being developed for these methods and there are more options on the market [16, 17]. The advantages of these systems are accuracy of measurement, reduced evaluation time, non-invasive [18], multiple applicability, simple user interface and practical reporting [19].

There are several methods of indirect postural evaluation. For upper extremities assessment, Rapid Upper Limb Assessment (RULA) is commonly used, a method where the postures of the body segments are observed and graded, increasing the score as the postures are more deviated from the neutral position of the person, allowing the evaluation of the postures adopted, the repetitiveness of movements and the force applied in the static activity [20].

In practice, joint angles are estimated through video or captured images of people, so the implementation of low-cost 3D sensors results in the semi-automation of observation methods [7, 16, 21].

When validating new semi-automatic postural evaluation systems, several studies used goniometry as an established, proven and accurate method. In addition, statistical methods are used in which the means of validated methods are related to the system to be evaluated. The statistical methods used are the coefficient correlation called Cohen's Kappa and the coefficient correlation called intraclass [7, 22].

This study is focused on validating the data delivered by the semi-automatic system called Ergonomic Evaluation System with the use of the Kinect V2 sensor (SEEK V2) [23], which is applied in the postural evaluation of the manual cutting activity in materials for shoe manufacturing. The ergonomic postural method programmed in the proposed system is RULA.

Within the industry at national level footwear manufacturing is the fastest growing, for this reason this research is conducted in this sector based on an existing agreement, so the results will be applied later to the same industry.

The concordance of the results issued by the SEEK V2 system evaluations and the direct evaluations applied with the RULA method are studied. The latter measures were carried out with a direct evaluation. Assumptions are defined, H0: SEEK V2 RULA final scores do not match the final scores made with direct measurement. H1: SEEK V2 RULA final scores are consistent with the final scores made with direct measurement. In addition, the measurement uncertainty of the SEEK V2 is calculated taking as a standard the angular measurements taken with the direct method.

2 Materials and Methods

2.1 Type of Research

The current study is experimental in nature as it is carried out under controlled conditions of sensor data capture and measurement with the direct method; on a previously selected population. A correlation study is also performed between both methods of postural evaluation which calculated an uncertainty type A in the measurements.

2.2 Subjects of Study

The type of sampling is convenient because a homogeneous group was sought for the validation of the proposed system, otherwise there could be biases in the statistical analysis.

The participants studied are 30 university students, of which 26 are male and 4 are female, 3 are left-handed and 27 are right-handed. Under the following demographic characteristics, they are all mestizo, in an age range of 20 to 32 years, in a height range of 1.51 to 1.81 meters and with an average body mass index of 23.91 kg/m^2. All participants gave their written consent to participate in this study. We excluded participants with musculoskeletal problems so as not to generate biases in statistical analysis.

2.3 Environmental Conditions

The laboratory experiment was conducted on a single day in the morning in a large room so that all participants would be subjected to the same temperature and light conditions during the evaluation exercise.

2.4 Study Environment

The laboratory study consisted of a folding cutting table that should be in the center of the room isolated from unnecessary objects, in an area of 2 m^2. A cutting mold located in the center of the table was used. The evaluators along with the direct measurement tools and logs are kept away while the participant's data is being captured by the sensor within a set time.

To evaluate a left-handed or right-handed participant, the Kinect must be positioned diagonally to their dominant hand due to the limited capture area of the sensor. For this study the Kinect has been positioned in the same places previously marked on the floor of the room for data capture of left-handed or right-handed participants (see Fig. 1).

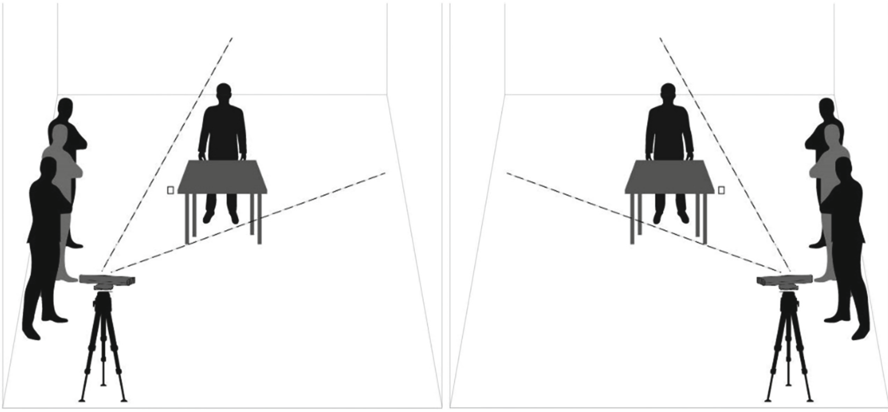

Fig. 1. Position of the sensor in the workspace.

2.5 Evaluation Procedure with SEEK V2

The SEEK V2 [20] is a system developed by the authors in previous investigations in which the programming, sensor capture method and the results found are shown. To capture the data through the Kinect, the depth camera is used as the main sensor. For this reason, the system obtains the angles in different positions using mathematical methods such as Euler angles and processing through the rotation matrix [21].

The Kinect is positioned at a height of 1.25 m and a distance of 1.5 m on the right (or left) diagonal of the cutting table. In order to facilitate evaluations in industry and other fields of study the SEEK V2 has the ability to evaluate in a range of 1 to 1.5 m in height and in a range of 1 to 2 m in lateral distance. In this study, the sensor was placed at the optimum system development distances for validation purposes.

There should be no objects or other people crossing between the Kinect and the person being tested. The processing of the sensors with respect to the evaluation system is an internal architecture where each participant generates information that the software processes through a programming for calculation of angles and points for each end evaluated (see Fig. 2).

Previous studies have found that Kinect's detection points are severely out of phase or cannot be located because clothing does not show the joints. The system proposed in this work can find the joints in people with clothing because it detects a limb and in the smaller segment where the skin is shown a point of union is located and takes it as a reference to locate a point of intersection. The correct functioning of this has been validated in an adjacent study.

The evaluations with the SEEK V2 were carried out offline, in a controlled environment where data was recorded with the sensor and after the execution was analyzed with the developed system. The objective is to obtain data a main study thrown by the direct

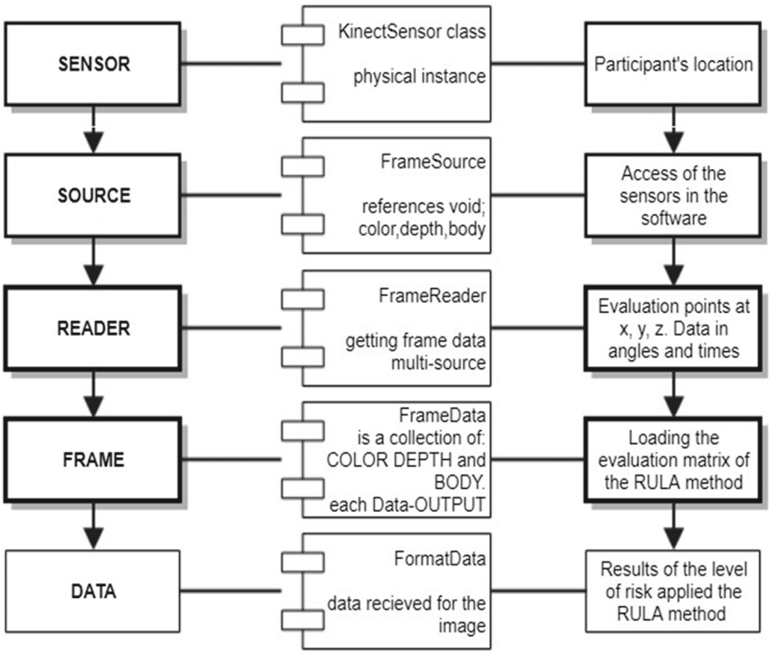

Fig. 2. Sensor processing with evaluation system.

method which allows us to compare with the obtained within the system once already evaluated.

2.6 Angular Measurement Procedure with the Direct Method

The angular values of flexion and abduction measured in the parts of the body (head, trunk, arms and forearm) taken with a goniometer are based on the RULA methodology [5, 24]. It should be indicated that the participants will carry out a task of marking the contour of a mold to simulate the manual cutting activity.

The following standardized verbal instructions are given to the participants on how to perform the manual cutting simulation activity, such as: seeking comfort to perform the task, emphasizing the edge of the cutting mold, and remaining immobile when listening to the evaluator's signal. When the most repetitive posture is determined, the participant must remain completely immobile, while measurements are taken using the anthropometric measurement points as a basis (see Fig. 3).

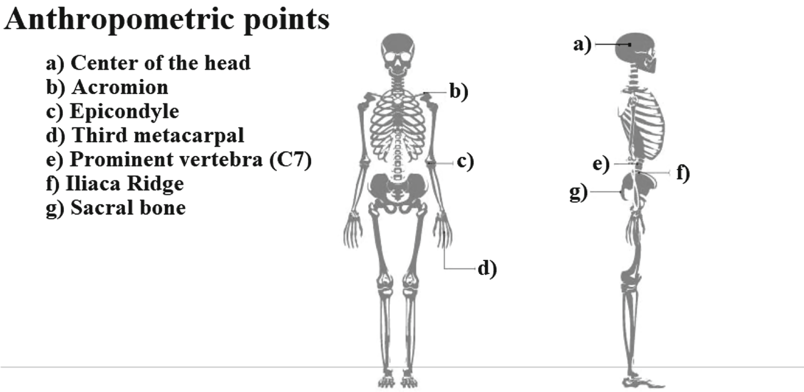

Fig. 3. Anthropometric measuring points.

The direct evaluation of the angles is done by experienced evaluators. The instruments used consist of the universal goniometer for angular joint measurements, a metric tape to define reference axes in the body and a plumb line to define the neutral position.

Arm: The angle formed by the end to the axis of the trunk shall be measured (see Fig. 4a).

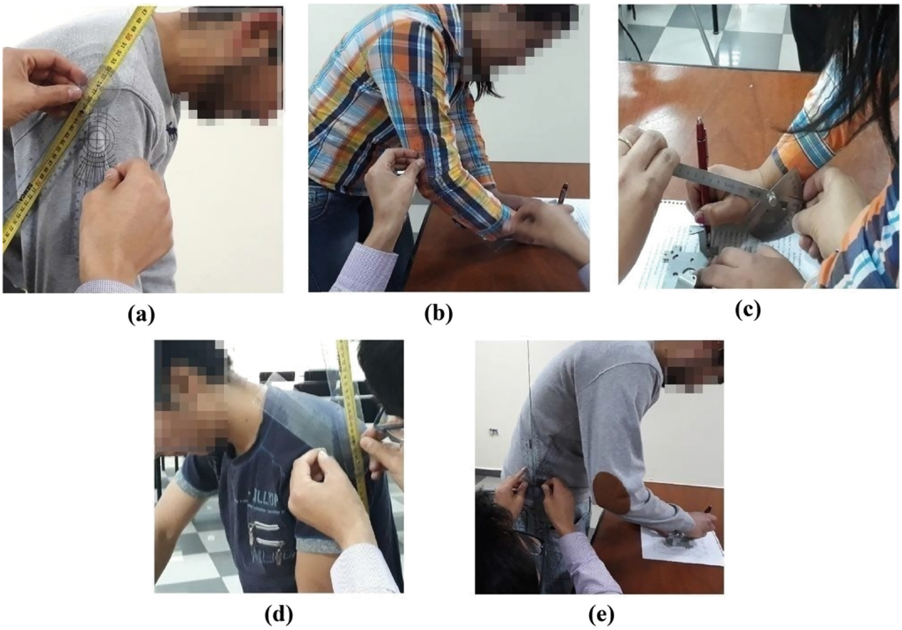

Fig. 4. Sample data collection from participants.

Forearm: The angle formed by the axis of the limb and the axis of the arm shall be measured (see Fig. 4b).
Wrist: The angle of flexion or extension is measured from the neutral position (see Fig. 4c).
Neck: The angle formed by the axis line of the head and trunk shall be measured (see Fig. 4d).
Trunk: The angle formed by the trunk and a vertical plane is measured (see Fig. 4e).

Participants were asked to wear clothes that fit their body, so methods will not be affected by the type of clothing used. Figure 3 shows the measurements taken using the direct method. Being the system able to evaluate a participant's exact points with or without appropriate work clothing.

2.7 Procedure for Statistical Analysis of Results

The absolute error is calculated from the measurements taken on the parts of the body evaluated such as the arm, forearm, wrist, neck and trunk of each participant. The direct method is considered as the standard measurement because it is the proven and validated method and the SEEK V2 is considered as an approximate value because it is the method whose uncertainty is to be estimated.

To calculate the expanded measurement uncertainty of the SEEK V2 with 95% confidence, the absolute error results (1) previously found for each joint evaluated are used. In addition, the typical uncertainty type A evaluation is used; the procedure outlined in the GUM guide is followed for the evaluation of measurement data [25].

$$\left|X_{Direct\,Method} - X_{SEEK\,V2}\right| = Absolute\,Error \tag{1}$$

It was applied the method of Bland-Atlman plots [26] of the measurement differences between the angles emitted by the SEEK V2 and those taken using the direct method of each part of the body evaluated are made using spreadsheets.

For the calculation of Cohen's Kappa concordance coefficient, the SPSS Software Version 23.0 (IBM Corporation, Chicago, IL, USA) is applied; the RULA final scores are considered as categories (see Table 1), exposed in the generated reports by the SEEK V2 and the scores reported by the direct method of postural evaluation, to interpret the degree of agreement the Landis and Koch [27] scale is used.

Table 1. Final scores RULA

Final score	Level of performance
1 o 2	Acceptable risk activity can be maintained
3 o 4	More study needed; changes in activity may occur
5 o 6	Redesign and more homework research coming soon
7	Urgent intervention in the activity

3 Results

The angular values taken from the neck, trunk, arm, forearm, wrist, and neck joints using the direct method and the reports issued by the SEEK V2 which is shown in Table 2.

Table 2. Angular values of the participants in each joint measured with direct method.

Participant number	Trunk (°)		Neck(°)		Arm (°)		Forearm (°)		Wrist(°)	
	S	D	S	D	S	D	S	D	S	D
1	8	8	21	20	11	11	70	69	42	43
2	38	38	29	29	52	52	40	39	50	52
3	31	31	54	54	25	25	58	57	14	15
4	27	26	40	40	48	50	65	64	23	28
5	19	18	37	37	14	14	39	40	33	36
6	13	13	30	30	24	24	27	26	39	46
7	23	23	41	40	34	34	38	38	15	18
8	11	10	39	40	14	14	48	46	52	57
9	44	44	29	28	67	66	66	66	16	17
10	30	30	40	41	44	44	48	48	25	26
11	43	44	29	30	51	52	62	61	23	26
12	28	30	50	50	52	52	63	64	26	25
13	46	46	29	27	46	44	66	66	14	16
14	13	15	34	34	24	24	62	63	12	12
15	8	6	82	84	13	14	42	42	26	27
16	30	30	68	70	64	63	61	60	13	13
17	28	30	55	55	21	22	80	80	24	24
18	49	48	18	18	49	50	70	70	6	8
19	41	39	58	58	54	54	69	70	22	23
20	33	33	55	53	58	58	65	66	1	1
21	52	51	36	36	40	40	96	94	20	21
22	31	31	62	61	38	38	74	74	22	23
23	28	28	58	57	30	30	61	61	25	26
24	58	58	44	44	62	60	92	92	7	8
25	62	62	26	28	92	96	88	88	5	5
26	42	42	16	15	72	74	55	55	27	28
27	46	45	26	26	74	73	59	59	8	9
28	30	30	44	44	24	26	64	64	35	35
29	35	34	30	30	38	40	54	54	1	0
30	22	22	38	40	26	26	65	65	17	20

*S: Angle taken by the SEEK V2.
*D: Angle taken with the direct method.

In the Bland-Altman plots with Average Mean Differences (AMD) and 95% Limits of Agreements (LOA), the joint measurements acquired by the SEEK V2 and by the direct postural evaluation method for all parts of the body evaluated (see Fig. 5).

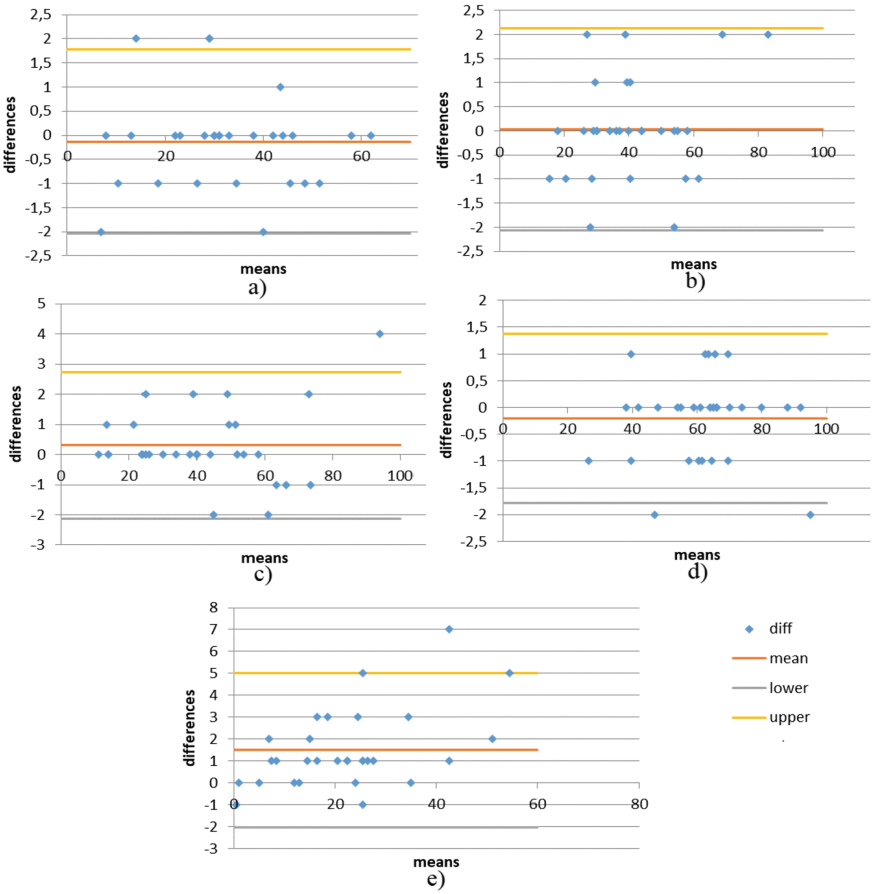

Fig. 5. Bland Altman plots (a) comparison of angles between SEEK V2 and direct method on the trunk, (b) comparison of angles between SEEK V2 and direct method on the neck, (c) comparison of angles between SEEK V2 and direct method on the arm, (d) comparison of angles between SEEK V2 and direct method on the forearm, (e) comparison of angles between SEEK V2 and direct method on the wrist.

Bland-Altman diagrams revealed agreement in the AMD between the direct methods and SEEK V2 on the trunk (−0.13°, LOA −1.77 to 2.04; see Fig. 5a), neck (0.33°, LOA −2.06 to 2.12; see Fig. 5b), arm (0.30°, LOA −2.12 to 2.72; see Fig. 5c), forearm (−0.20°, LOA −1.78 to 1.38; see Fig. 5d) and wrist (1.50°, LOA −2.02 to 5.02; see Fig. 5e). It is observed that the LOA is small in all parts of the body, which implies that there is not much variation between the measurements produced by both methods. AMDs are close to zero, which means that similar results are produced in the angular measurements between the two methods. The variability of the data is consistent with the fact that no measured value exceeds the limits of agreement in the neck, only 1 measured value exceeds the upper limit in the arm and wrist, 2 measured values exceed the upper limit in the forearm and trunk. The data found are found on the trunk (6° to 62°), neck (15° to 84°), arm (11° to 96°), forearm (26° to 96°) and wrist (0° to 57°) (see Table 2).

Table 3 shows the data of average, maximum variation and uncertainty ($\bar{X}$, S, ± U), which has the SEEK V2 with respect to the measurements taken with the direct method for each part of the body of the participants.

Table 3. Comparative statistical results of angular measurements.

	Average $\bar{X}$(°)	Maximum variation M(°)	Expanded uncertainty U(°)
Arm	0.76	4	0.36
Forearm	0.53	2	0.22
Wrist	1.63	7	0.59
Trunk	0.60	2	0.27
Neck	0.70	2	0.28

The results of the angular measurements of the different parts of the body are: arm ($\bar{X} = 0.76°$, $M = 4°$, U = ±0.36°), forearm ($\bar{X} = 0.53°$, $M = 2°$, U= ±0.22°), wrist ($\bar{X} = 1.63°$, $M = 7°$, U= ±0.59°), trunk ($\bar{X} = 0.60°$, $M = 2°$, U= ± 0.27°) and neck ($\bar{X} = 0.70°$, $M = 2°$, U= ±0.28°) (see Table 3). It is appreciated that the wrist is the joint with the greatest variation in the data compared between the methods of postural evaluation, this is due to the fact that it is the most difficult joint to detect for the Kinect and complex to measure with the direct method because of the movements required by the task with which the data is corroborated, that is, it is the point of measurement of the lowest reliability that the system gives, followed by the arm, although with greater confidence. The other joints have a much smaller variation in results, which is believed to be due to their shapes and sizes, which makes them easy to detect for the sensor and to measure for the evaluators.

In Fig. 6 it shows the number of participants who obtained final RULA scores of 4 to 7 (see Table 1), comparing the SEEK V2 with the direct measurement method.

For the direct postural evaluation method and for the SEEK V2, five participants obtained a RULA final score of 4, both methods found 5 participants in a RULA final score of 5, the direct method found 13 participants in a RULA final score of 6, while the SEEK V2 method found 7 participants in a RULA final score of 7, while the SEEK V2 method found 8 participants in a RULA final score of 7.

The final RULA scores in the direct and SEEK V2 methods are similar in both evaluations, the existing variations are 1 point (see Fig. 6) and are due to the wide ranges that are considered in the ergonomic method applied.

Cohen's Kappa concordance coefficient with an alpha of 5% gives a result of 0.953, according to the Landis and Koch scale [26] there is a very good degree of agreement between the final RULA scores of the direct ergonomic evaluation method and those issued by the SEEK V2.

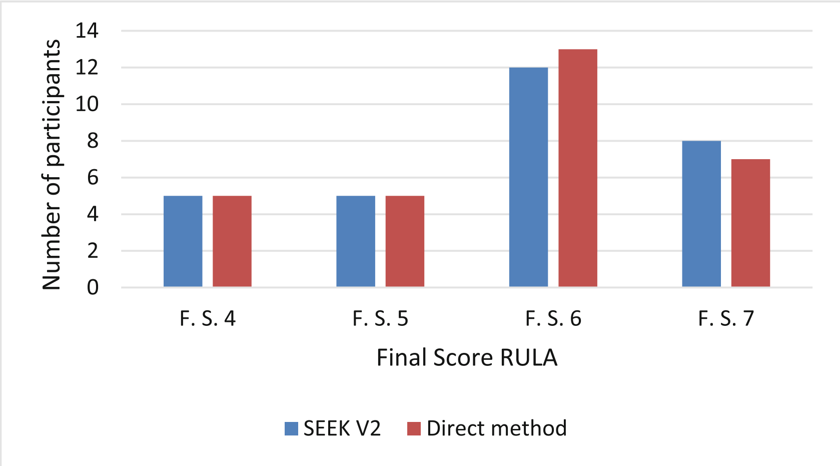

Fig. 6. Final RULA Direct Method vs SEEK V2 RULA Scores.

4 Discussion

In the literature consulted Manghisi et al. [7] presented a semiautomatic RULA evaluation system with Kinect v2 and validated it by obtaining an almost perfect Kappa (0.84) agreement between the system and an expert RULA evaluator. Additionally, it presented a lower Kappa statistical agreement (0.34) when it compared to commercial software based on Kinect v1, for 30 non-ergonomic positions. These postures were static and with the frontal sensor to the person, the results found are consistent with this article in which the Kappa coefficient (0.953) also has an almost perfect concordance between the proposed system and the evaluations made by the direct method. The difference with the present article, is the participants in this study perform diverse and complex movements because they had to perform a thorough task of tracking the mold in which the position of the wrist was difficult to detect for the Kinect and visually.

The angular measurements obtained from the evaluated joints of the body show an expanded uncertainty of less than 0.5° except for the wrist which is 0.59° the highest variation found. It is believed that this is due to the distance to which the Kinect should be placed. It is difficult to determine the small movements that the wrist makes, this distance is inevitable to evaluate all the necessary body parts. This agrees with the evaluation of the human body carried out by Alabbasi et al. [12] where it shows the Kinect V2 is robust in capturing complex movements, but it is not perfect, as the complexity of the movement increases the sensor capture errors increase too.

According to the RULA method and the different methods of ergonomic evaluation based on joint measurements, a measurement of precision is not needed, but a measurement that allows to determine between the ranges given by the method in whole angular values and to qualify the joint in one or another risk score.

A future solution to achieve more precise result in the wrist studies would be to implement a second Kinect, it should be exclusive for this articulation, this is a valid option because the sensor is only used to acquire angular data which is process by programming the SEEK V2.

During the taking of direct joint measures, the wrist was the most complicated joint to evaluate, for example: in Table 2 the data of participant number 6 is shown who obtained values of 39° with the system and 46° with the direct method on the wrist. This variation of 7°, influences by the distance exist from the Kinect to the person. Furthermore, it should be considered the perception of evaluators [28] also plays an important role to have greater uncertainty in this articulation and not only due to sensor accuracy problems.

As shown in Table 3, the remaining arm, forearm, trunk and neck joints are more reliable in terms of angular measurements, this could be since when the participant uses movements to perform the activity, the sensor is diagonally easy to grasp all these joints.

It is believed that the measurements have a strong reliability because the results of the Bland-Altman diagrams revealed an AMD agreement closer to 0 in all cases, besides the LOA values do not have an important amplitude, which provides confidence in the results obtained.

The proposed system has the advantage of evaluating with the sensor on the side of the person and with suitable garments as shown in Fig. 3, which is believed to be the main contribution of the project, as the RULA method mentions, the best evaluation plane is the sagittal [5] because it is where all the necessary articular measures are captured. SEEK V2 presents a viable contribution and alternative for the industry. As stated, it is intended to carry out future studies in footwear companies of the region under real working conditions.

5 Conclusions

The semiautomatic system developed of ergonomic evaluation with Kinect V2, demonstrates to be a non-invasive method which allows the worker to carry out their activities in a natural way making the data more real and reliable. Furthermore, it's allowing the discovery of the ergonomic risk associated with the postures in a precision task, thus decreasing the estimation errors of measurements taken by the evaluators with a direct measurement. As well, it considerably reduces the time in the development of an ergonomic evaluation.

The reliability of the SEEK V2 is evidenced by the angular values of the upper extremities emitted by the system, contrasted with those taken with the direct postural evaluation method, obtaining results of expanded uncertainty of 0.36° for the arm, 0.22° for the forearm, 0.59° for the wrist, 0.27° for the trunk and 0.28° for the neck. The wrist is the joint that shows the greatest variation but does not affect the results of the RULA method. On the other hand, the forearm shows more accurate results.

The correlation between the evaluations RULA of the SEEK V2 and performed with the direct method, provides a Cohen Kappa correlation coefficient of 0.953, which shows under controlled conditions that the RULA final scores of the SEEK V2 are in perfect agreement with a direct evaluation.

In the future research, it is suggested to apply the system in real working conditions to enhance it with the use of a new sensor centered on the wrist joint.

Acknowledgments. The authors would like to thanks to the Technical University of Ambato (UTA) for financing the project ‘‘System of Evaluation of Postural Risk Using Kinect 2.0 in the activity of Cutting of the Production of Footwear for the CALTU Ambato”, for the support to develop this work.

References

1. Geraldo AP (2015) Ergonomía y Antropometría Aplicada con Criterios Ergonómicos en Puestos de Trabajo en un Grupo de Trabajadoras del Subsector de Autopartes en Bogotá, D.C. Colombia. Rev Repub 135–150
2. Jesús M, Rojo F, Canga A, Ferrer AP, José P, Quintana MF (2000) Manual Básico de Prevención de Riesgos Laborales: Higiene industrial. Seguridad y Ergonomía. Imprenta Firma, S. A., Mieres
3. Cursoforum S.L.U: Riesgos Ergonómicos y Medidas Preventivas en las Empresas Lideradas por Jóvenes Empresarios., Madrid
4. Agencia Europea para la Seguridad y la Salud en el Trabajo: Introducción a los trastornos musculoesqueléticos de origen laboral - Salud y seguridad en el trabajo - EU-OSHA,https://osha.europa.eu/es/tools-and-publications/publications/factsheets/71/view
5. Asensio-Cuesta S, Bastante-Ceca J, Diego-Más JA (2012) Evaluación Ergonómica de los Puestos de Trabajo. Paraninfo, SA, Madrid
6. David GC (2005) Ergonomic methods for assessing exposure to risk factors for work-related musculoskeletal disorders. Occup Med (Chic. Ill) 55:190–199
7. Manghisi VM, Uva AE, Fiorentino M, Bevilacqua V, Trotta GF, Monno G (2017) Real time RULA assessment using Kinect v2 sensor. Appl Ergon 65:481–491
8. Lite AS, García García M, Ángel M, Del Campo M (2007) Métodos de evaluación y herramientas aplicadas al diseño y optimización ergonómica de puestos de trabajo
9. Dockrell S, O’Grady E, Bennett K, Mullarkey C, Mc Connell R, Ruddy R, Twomey S, Flannery C (2012) An investigation of the reliability of Rapid Upper Limb Assessment (RULA) as a method of assessment of children’s computing posture. Appl Ergon 43:632–636
10. Rodríguez-Ruíz Y, Guevara-Velasco C (2010) Empleo de los Métodos ERIN y RULA en la Evaluación Ergonómica de Estaciones de Trabajo. Ing Ind 32:19–27
11. Garrido-Castro JL (2014) Diferencias en el análisis cinemático 2D/3D de los parámetros utilizados para la evaluación del pedaleo en el ciclismo. XXXVII Congr. LA Soc. Ibérica Biomecánica Y Biomater. pp 3–4
12. Alabbasi H, Gradinaru A, Moldoveanu F, Moldoveanu A (2015) Human motion tracking & evaluation using Kinect V2 sensor. In: 2015 E-Health and Bioengineering Conference (EHB). IEEE, pp 1–4
13. FLores-Bazán, R.: Análisis de la relación entre ergonomía, calidad de vida y eficiencia de la producción en la industria maquiladora de Tamaulipas. México, DF. In: ANFECA (2012)
14. Teschke K, Trask C, Johnson P, Chow Y, Village J, Koehoorn M (2009) Measuring posture for epidemiology: Comparing inclinometry, observations and self-reports. Ergonomics 52:1067–1078

15. María V. Posturas de Trabajo: Evaluación del Riesgo, http://www.insht.es/MusculoEsqueleticos/Contenidos/Formacion divulgacion/material didactico/Posturas trabajo.pdf
16. Plantard P, Auvinet E, Pierres A-S, Multon F (2015) Pose estimation with a kinect for ergonomic studies: evaluation of the accuracy using a Virtual Mannequin. Sensors 15:1785–1803
17. Greene RL, Azari DP, Hu YH, Radwin RG (2017) Visualizing stressful aspects of repetitive motion tasks and opportunities for ergonomic improvements using computer vision. Appl Ergon 65:461–472
18. Spielholz P, Silverstein B, Morgan M, Checkoway H, Kaufman J (2001) Comparison of self-report, video observation and direct measurement methods for upper extremity musculoskeletal disorder physical risk factors. Ergonomics 44:588–613
19. Clark RA, Pua Y-H, Fortin K, Ritchie C, Webster KE, Denehy L, Bryant AL (2012) Validity of the Microsoft Kinect for assessment of postural control. Gait Posture. 36:372–377
20. McAtamney L, Nigel Corlett E (1993) RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon 24:91–99
21. Dutta T (2012) Evaluation of the Kinect™ sensor for 3-D kinematic measurement in the workplace. Appl Ergon 43:645–649
22. Alba-Martín R (2016) Fiabilidad y validez de las mediciones en hombro y codo: análisis de una aplicación de Android y un goniómetro. Rehabilitacion 50:71–74
23. Marino C, Vargas J, Aldas C, Morales L, Toasa R (2018) Non-invasive monitoring environment: Toward solutions for assessing postures at work. In: 2018 13th Iberian conference on information systems and technologies (CISTI). IEEE, pp 1–4
24. Diego-Más JA. Evaluación postural mediante el método RULA. https://www.ergonautas.upv.es/metodos/rula/rula-ayuda.php
25. Hipp J, Hill C, Hall M (2007) Evaluación de datos de medición Guía para la Expresión de la Incertidumbre de Medida
26. Martin Bland J, Altman D (1986) Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 327:307–310
27. Landis JR, Koch GG (1977) The measurement of observer agreement for categorical data. Biometrics 33:159
28. Escamilla Esquivel A (2000) Metrología y sus aplicaciones. Larousse - Grupo Editorial Patria