3D Laser Models for the Ergonomic Assessment of the Working Environment

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Abstract The article presents an analysis of the applicability of 3D laser model technology in the ergonomic assessment of the working environment. The results show that in the case of 3D technology, it is especially useful to describe the changes in the working environment and the ways of performing work activities (deviations from the regulations regarding activities specified by the employer). The article also presents algorithms for the use of 3D laser models in many workplaces where one cannot plan the work tasks in detail, since they are flexible and often their course is changed. This applies to work such as that of warehouse workers, maintenance staff or mining work.

Keywords Ergonomic assessment · Human-Systems integration · Systems engineering

1 Introduction

Presently, there is an observable tendency towards computer visualization of an increasing number of aspects of the working environment, relating to not only the spatial parameters of the environment and its facilities, but also the real time visualization of the course of the whole production process including the body position of the worker during subsequent stages of production. The digitalization of various areas of a company, or the creation of a comprehensive network of digital models, methods and tools, which form a cohesive system, gives the opportunity to

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manage data in a comprehensive way, however, it requires the collection of massive amounts of data, such as spatial parameters, as well as programming methods enabling pattern recognition.

Given the growing demand for rapid recognition of hazardous states and the simultaneous documentation of these events for their later or remote analysis, 3D recording has become an indispensable tool in process excellence, which has a kind of side effect of increasing the ergonomic quality of work [1]. The use of 3D imaging methods can be found in the following areas of human activity: security features involving the identification of unique individual characteristics [2, 3], rendering body shapes for medical and rehabilitation purposes [4], reverse engineering [5], surveying, architecture [6], archeology [7], and for the purposes of forensic science, agriculture and forestry [8]. However, its relative applicability in ergonomic engineering to date has been limited to anthropometric measurements [9, 10] and the field of reverse engineering. On the other hand, there has been much development in the simulation capabilities of 3D technology [11], which allows to present reality in a simulated setting, to create simulations and evaluate them based on the simulated virtual reality.

The use of 3D scanning in ergonomics has become particularly important in the search for opportunities to increase the ergonomic quality of work for complex anthropotechnical systems [12], while reducing the time needed for their implementation.

2 Frames of 3D Scanning Technology

Telemetric and advanced scanning methods have significantly facilitated the transfer of the observed reality into virtual reality. This is also the case in 3D laser scanning, which calculates the distance between the measured object and the unit (scanner) emitting and receiving the laser pulses reflected from the object, while determining the spatial coordinates (X, Y, Z) describing the position of the device in space as well as the direction of the laser beam at the time of sending the pulse. Operating on a “point cloud” allows for realistic visuals, a precise measurement of the space transferred to virtual reality as well as a foundation for advanced spatial modeling and reverse engineering [13].

3D laser scanning has many applications, however it is particularly useful in the design of a system taking into consideration an already existing, specified space which imposes certain conditions. Traditional methods, involving the measurement of points of actual dimensions of a select few features (e.g., distance between buildings), are suited for small and simple subjects. Employing these methods for a reconstruction of such a large subject, with multiple installations of a complicated course, irregular shape, with inaccessible spaces, e.g. located high above the floor, is practically impossible and unprofitable, because its measurement and transfer to a CAD program would take a massive amount of time, even with the involvement of a large group of people. In such cases, the ideal solution is to use terrestrial laser scanning technology.

To enhance documentation during 3D scanning, in addition to point clouds, a so-called bubble view is generated. The point cloud, which is assigned RGB colors based on taken photographs and data such as reflectance intensity and thermal scans, allows to recognize phenomena of a varied nature, which could not previously be examined due to their transience. It should be noted that during measurement a laser scanner is able to collect a huge amount of data in a relatively short period of time (up to one million points per second), which means that it will reflect the spatial characteristics of events that are short-term, but static for at least a few minutes (time of scanning depends on the assumed density and precision of scanning).

A major advantage of 3D scanning is its non-contact feature, which enables the measurement of objects without having to set up special platforms, scaffolding or other entries around them, which would not be possible with conventional methods due to the lack of access [14]. Scanners also work independently of a light source—the laser beam itself is light, so measurements can be performed in poorly-lit areas as well as during the night. This provides the ability to perform 24-h measurements [15].

3 Application of 3D Scanning Technology in Safety Engineering and Ergonomics

Laser scanning can be applied in many fields related to safety, where, in view of the massive amount of data and complexity of spaces, it replaces traditional measurement methods. Thanks to laser scanning, it's possible to analyze at-risk industrial facilities with the aim of early hazard detection and conducting in-depth analyses of deformation, strain, changes in position, which can be a source of information on whether to undertake modernization actions. Examples include:

- measurement and analysis of tank deformation or of other facilities at risk for an uncontrolled release of energy;
- measurement and analysis of changes in the shape of lift shafts in mines and mine workings;
- measurement of strain and deflection of steel and reinforced concrete, e.g. tent hall construction, monitoring roof sagging under snow load; monitoring and analysis of building deflection under wind, thermal loads or deformation due to the influence of natural or artificial sources of energy (requires the additional use of a thermal imaging camera to color the point cloud with colors corresponding to temperature);
- comparison of the model created from the point cloud with its theoretical counterpart, also in terms of dynamics and critical states;

- post-disaster analysis, which is particularly important when rescue work or restoration of communication routes will obscure information important to determine the causes and circumstances of the event;
- measurement of the spatial position (geometry) of components of mechanical devices in different states, e.g. vertical and horizontal alignment of devices; monitoring the straightness of crane subgrades;

This can be extremely important in case of design for safety especially in reboost design or design focused on process safety [16]. In addition to the typical uses of 3D scanners in safety engineering, the possibility of modeling the environment responsible for the ergonomics of work or daily life should also be mentioned, in particular:

- the width and height of passageways (travel distances) in work spaces; the distance between devices and workstations—e.g. for the future imaging of phenomena such as noise propagation;
- the distance between racks and stacks of materials, in order to check whether they are suitable for the means of transport and the ability to manipulate them and for the safe handling and piling by employees; angle of material piling in order to determine the possibility of safe passage around the heap or stockpile (in the case of traditional surveying methods there is a risk of burying the employee performing the measurement);
- distances which must be overcome by an employee between workstations or at one station, the slope of the surface on which an employee moves, and features of the terrain that must be overcome (the data can be used to calculate energy expenditures, the possibility of manual handling of materials based on e.g. the slope of the floor, as well as the optimization of work processes);
- site planning taking into account the needs of people with reduced mobility—e.g. by creating alternative barrier-free routes in an urban environment, these scans may also be used by a city's government to determine the areas in which these measures would have the greatest impact on the quality of life of residents with disabilities;
- the surface area of the workplace, the whole space, which can be compared with the existing regulations related to the amount of space per employee, the ratio of window surface area to floor surface area related to the use of daylight for lighting workplaces;

The application of any solution other than 3D scanning will require the use of additional software to identify and classify the specified areas, which in the case of significant variability of processes cannot be performed manually. Some of the applications of 3D method will be also found by complex reengineering of human machines subsystems [17], with the exceptions made in next chapter.

4 Application of 3D Scanning Technology in Ergonomic Assessment

Ergonomic assessment is one of the key phases in the redesign of work organization and work stations. It occurs both during the first and the last phases of the design process and determines the success of the entire procedure since the obtained degree of change is what determines the ergonomic quality of a solution, and thus the long-term user satisfaction. The table presents assessment criteria of workstations, along with areas for the possible application of 3D technology.

It should be noted that the reproduction of moving objects is made difficult because of the coverage area and in most cases it will be ineffective. The propositions presented in Table 1 are related to the use of 3D technology, taking into account currently used devices, however their application requires the development of an operating algorithm, the validity of which seems to be the biggest in the event of a clear superiority of mapping with the use of point clouds in comparison to other methods of recording reality. Examples of such situations are presented in Table 2.

Table 1 Example of ergonomic assessment phases and alternative methods

Ergonomic assessment phase	Traditional method	3D application example
Work area formation assessment	Measurement of individual technical environment parameters, e.g. countertop height and acromial process	Establishing distance ranges between points demarcating areas of impact (grip, reach) and work zones (levers, devices)—however, there still are no capabilities to map anthropometric features in the case of human movement
Communication system suitability assessment	Measurement of individual spatial parameters, eye tracking	Establishing angles of signaling devices (screens) in relation to the position of the head and shoulder girdle—determines the neutral zone during performance of work (which will be difficult in the case of movement of the operator)
Work posture assessment	Observational and classification methods—OWAS, RULA, REBA	Determining the body segments critical for body position and their mutual relationship as well as an evaluation based on objective criteria
Biomechanical load assessment	Biomechanical models based on selected individual characteristics (height, arm length) e.g. Delmia, 3DSSPP	Full spatial mapping of the human body together with the determination of the center of gravity of body segments during static positions

(continued)

Table 1 (continued)

Ergonomic assessment phase	Traditional method	3D application example
Multi-faceted assessment of task groups—team performance	Subjective methods—questionnaires, spaghetti plots, evaluation of selected spatial parameters—e.g. passageway width	Spatial modeling of the movement of objects and people, but because laser scanners mapping human movement, e.g. Velodyne, are a fairly small group of solutions, modeling will take place through the use of dual technology introducing a virtual simulation of movement to the static environment mapped by laser scanning, which will detect collisions and mismatch of the real environment to the intended actions; Virtual verification of existing facilities in terms of group behavior during the evacuation of people and property

Table 2 Areas of application of 3D laser scanning technology and the conditions for its application in ergonomic engineering

Action	Application	Remarks
Spatial record along with detailed mapping of participating facilities	Archiving immediately following accidents (work, transportation or other event), for which the complexity of analysis or consequences of findings exclude a simplified analysis	A record using point clouds in a universal format should give various specialists access to the data necessary for the simulation of the event, which would limit the time needed for data collection and at the same time reduce the downtime resulting from the event (e.g. road accident)
Preparation for modeling the material work environment	Preparation of spatial maps for the modeling of phenomena such as noise, radiation	Visualization of the work environment allows to determine what real objects constitute hazards—e.g. noise at a certain frequency or radiation, the point analysis of which allows to present a spatial analysis of a particular phenomenon, however, technology alone could not capture these phenomena without the use of other measurement tools (e.g. noise phenomenon)

(continued)

Table 2 (continued)

Action	Application	Remarks
Supporting mapping of loads leading to WRMSDs	Analysis of static positions and the ability to map body position during work, particularly in the case of difficult access to the studied workstation (no view of the position in the frontal and sagittal planes)	Positions adopted by the employee while working, along with a depiction of coordinates for each point of reference, independent of the available space and the place of performing scanning (in the case of an ordinary photograph it is not possible to determine the spatial relationships between a human and the work environment—Fig. 1.)

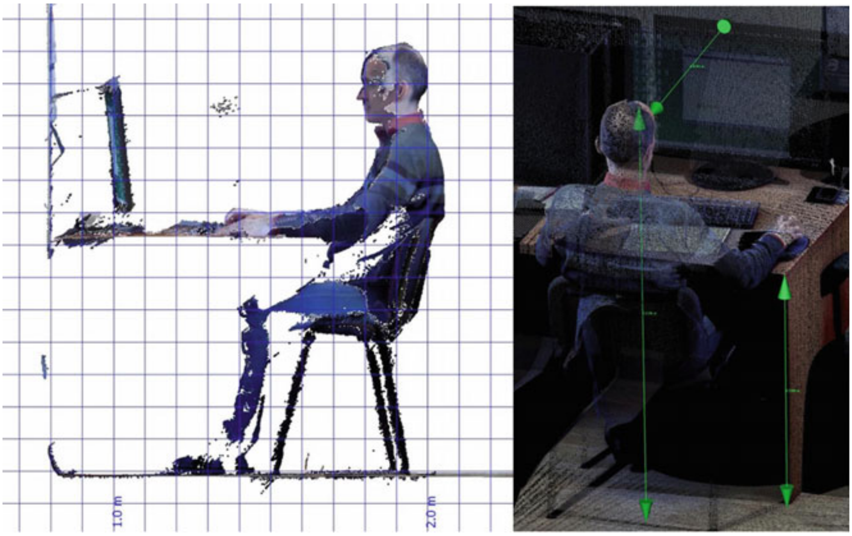

Fig. 1 Example of point cloud for workplace assessment

Due to the rather static image obtained during 3D scanning, along with the high cost of the method, its use is limited to application in documentation, however, it is anticipated that the growing number of lawsuits arising from the loss of health at work will force employers to increase focus on the quality of working conditions, while documenting efforts in this regard. A significant limitation of the method used in dynamic environments is time—e.g. for one workstation this time (for the scanner Z+F IMAGER 5010C) is approx. 3 min 20 s (point density—every 6.3 mm by 10 m), not including photos. Taking pictures takes an additional 3–10 min depending on how long the scanner will collect and grayscale images and whether the photos should be prepared using an additional source of light. For faster scans, which last approximately 1 min less, the lower accuracy and point density may not give sufficient information for analysis.

5 Conclusion

Increasingly advanced means of communication allow to obtain information about the characteristics of reality and to represent it spatially in a computer in a way hitherto unknown. This has brought about a need for increasingly complex computational techniques, which will enable the interpretation of the observed reality. Ergonomic design methods based on an assessment of the current situation, will have to absorb much more data, which in the future may allow to obtain solutions with a much higher level of ergonomic quality. For this purpose, operational methods supporting design decisions will have to be used.

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