Using a web-based query engine and immersive virtual reality to select and view 3D anthropometry in vehicle operator workstation design

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Abstract
This paper presents the development and testing of a tool for designing vehicle operator workstations using 3D anthropometry. The tool consists of two major modules: 1) a web-based engine to query a large database of human anthropometry for selecting human operators representative of a specified user population, and 2) an immersive Virtual Reality (VR) software application used to view the selected anthropometry in relation to vehicle CAD designs. This tool allows a designer to view and interact with fully immersive 3D representations of vehicle operator enclosures and controls from typical CAD models along with digital human models selected from the anthropometry database. This environment allows visualization to aid in the trade-off decisions that come between ergonomic and functional (i.e. structural, electrical, etc.) design. The environment makes use of a web-based interface for the querying of a large anthropometric dataset with over 4500 participants. A designer is presented with a rich set of features to build, store, and manage queries using attributes such as height, weight, reach, gender, and occupation to locate pertinent subsets of subjects for a specific vehicle design. A list of subjects obtained from the query engine can then be sent to a VR environment for viewing with vehicle CAD data. This linkage makes the selecting and viewing of subjects seamless. A detailed description of the design problem being addressed, software development, and sample test cases are presented to demonstrate the intuitive nature and ease of use of the environment.

Keywords
Virtual Reality Applications Center, 3D anthropometry, CAD models, datasets, computer workstations, database systems, ergonomics, mathematical models, query languages, structural design, three dimensional, virtual reality

Disciplines
Computer-Aided Engineering and Design | Mechanical Engineering

Comments
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This paper presents the development and testing of a tool for designing vehicle operator workstations using 3D anthropometry. The tool consists of two major modules: 1) a web-based engine to query a large database of human anthropometry for selecting human operators representative of a specified user population, and 2) an immersive Virtual Reality (VR) software application used to view the selected anthropometry in relation to vehicle CAD designs. This tool allows a designer to view and interact with fully immersive 3D representations of vehicle operator enclosures and controls from typical CAD models along with digital human models selected from the anthropometry database. This environment allows visualization to aid in the trade-off decisions that come between ergonomic and functional (i.e. structural, electrical, etc.) design. The environment makes use of a web-based interface for the querying of a large anthropometric dataset with over 4500 participants. A designer is presented with a rich set of features to build, store, and manage queries using attributes such as height, weight, reach, gender, and occupation to locate pertinent subsets of subjects for a specific vehicle design. A list of subjects obtained from the query engine can then be sent to a VR environment for viewing with vehicle CAD data. This linkage makes the selecting and viewing of subjects seamless. A detailed description of the design problem being addressed, software development, and sample test cases are presented to demonstrate the intuitive nature and ease of use of the environment.

I. Introduction

The design of vehicle operator workstations is a complex task involving integration of many different engineering disciplines. Of particular interest are the myriad of issues dealing with comfort, ease of use of operator controls, and accommodation of physical diversity within the user population.

One of the greatest challenges in designing vehicles for a world-wide population of users is accommodating the physical diversity of that population. Traditionally, this has been attempted through the use of univariate anthropometric distance measurements, which are commonly compiled into tables of summary statistics for a population. These methods, however, do not capture the diversity of body structure and form within the population. The recent completion of the Civilian American and European Surface Anthropometry Resource (CAESAR) and other similar studies has provided the design community with a rich set of demographic and three dimensional...
anthropometric data. This has made it possible to base design decisions on the suitability of the design for a specific population of individuals, rather than a generalized statistical case (e.g., the 95th percentile male).

Immersive Virtual Reality (VR) provides an excellent means of visualizing and interacting with human anthropometry data. An immersive 3D environment allows complex relationships among workstation geometry and anthropometry data to become readily apparent, thus shaping ergonomic design choices early in the design cycle. This technology allows important characteristics and relationships that would otherwise go unnoticed, to be explored early in a design process.

This paper presents the development and testing of an environment for operator workstation using 3D anthropometry. The environment consists of two modules: 1) A web-based engine to query a large database of human anthropometry data and 2) an immersive VR software application to view selected data with CAD models.

II. Background

A. Human Anthropometry

Human anthropometry is the information resulting from the study of measurements of the human body. Quantities such as length, breadth, width, girth, height and mass values recorded for a measured population are considered traditional anthropometric data. Collection involves subjects to be positioned in various postures (e.g., sitting and standing) with measurements taken using anthropometers, calipers and steel tape measures.

Anthropometric data had been traditionally used as a research and development tool in the military population with some surveys even known to be conducted and used during the civil war. For example, the United States Army Air Forces conducted studies as early as 1942 with the resulting data used in human engineering. To date, the 1991 Army Anthropometric Survey (ANSUR) is one of the most frequently used data sets of 240 measures for 1,224 men and 2,208 women. Additional data surveys were made in 1972 and 1977 to acquire newer information to assist in engineering design decisions.

It was not until recently that the benefits of using human anthropometry were seen in civilian engineering design. According to the Society of Automotive Engineers (SAE) the use of anthropometric data on civilian populations spans many industries and countries, and can be a reliable tool in decision making in many areas. One such example is the Prototype Anthropometric Database Project that is being developed in the School of Architecture and Planning at the University at Buffalo. This project focuses on developing an anthropometry database of wheelchair users to facilitate the development of ergonomic modeling software. Other examples are usage for the assessment of health, nutrition and social well-being, utilization for body-fat distribution and obesity analysis, and for apparel fitting. Most of these examples use the data to make inferences about the size and weight of a population subset. This is different than when used for engineering design, where the data must be incorporated with the product or process in which it will interact. Thus, new methods must be devised to view these interactions and interact with them.

In the design of operator workstations it is critical to accommodate for a large physical diversity among users. Traditionally decisions made concerning the operator controls were based on one-dimensional anthropometric data sets that describe anatomical distance measures using a “percentile” approach. Percentiles indicate the position of a value in relation to its sample group. For example, the height of a 95th percentile female is the height at which 95% of the females in the sample group are equal to or shorter. Digital human modeling tools such as Jack, SAFEWORK Pro, Ramsis and DI-Guy use these traditional approaches in ergonomic design. However, these percentile approaches can introduce considerable design inaccuracies. They tend to be specific to the sampled population and only relevant in the single dimension varied. Robinette and McConville demonstrated that these percentiles are not additive and that representing multiple body dimensions using percentiles leads to gross design inaccuracies.

In 2001 an extensive human anthropometry study was completed named the Civilian American and European Surface Anthropometry Resource (CAESAR) project. CAESAR provided the design community with comprehensive data, including full-body 3-D surface scans from approximately 4500 civilians across North America (United States, Canada) and Europe (Italy, Netherlands) in the age range of 18-65. This project was a joint venture of the U.S. Air Force’s Computerized Anthropometric Research and Design (CARD) Laboratory funded by the Department of Defense and the SAE.

The CAESAR data consists of the following:
1. Demographic data
2. Full-body 3D scans in three different postures
3. 3D coordinates for 73 different landmarks in each posture (“landmark” data)
4. Univariate measures:
   a. 40 “traditional distance measures” such as circumference and skinfold thickness

2 American Institute of Aeronautics and Astronautics
The CAESAR study is regarded as one of the largest and most comprehensive anthropometric studies currently available. Although the anthropometric design environment presented in this paper is not limited to a specific dataset, the CAESAR survey has been used for development and testing.

B. Preparation of CAESAR Data

An efficient manner to store and manage the CAESAR study is through a relational database. Oracle\textsuperscript{19}, Microsoft’s SQL Server\textsuperscript{20}, IBM’s DB2\textsuperscript{21}, MySQL\textsuperscript{22}, and PostgreSQL\textsuperscript{23} are software packages capable of storing and managing the CAESAR data. MySQL was selected for this project due to its flexibility in usage, low setup and maintenance costs, speed of operation and cross-platform compatibility. With appropriate query statements, a designer can retrieve the information of desired test subjects in real-time. However, to do this directly in MySQL simple query language (SQL) must be used. While relatively simple, SQL use does require training. Thus, a simple, intuitive front-end interface with the capability to dynamically build query statements was needed. As MySQL integrates easily with web-based applications, it was determined to use a dynamic web page for access to the CAESAR data. This type of interface allows instant accessibility to any location requiring only a computer and Internet connection.

C. Virtual Reality

Scientific visualization and Virtual Reality (VR) are increasingly becoming key tools in complex design processes. Interpreting three-dimensional representations instead of numbers and text enormously increases the understanding of complex data\textsuperscript{24-27}. VR technology enables designers to enter a 3D environment and interact with real size digital models of their designs. Additional capabilities such as 3D navigation, stereo viewing, and position tracking allow VR to further become a more intuitive, “natural” design tool. VR allows much better understanding of a design by removing the keyboard and mouse and allowing interaction with virtual models as if they were in a designer’s hands. An engineer can focus on the physics and form of a design rather than trying to understand a programming language or a myriad of graphical drop-down menus from a complex software product.

VR tools for anthropometric design are not prevalent in the current software market. Although ergonomic solutions such as Jack\textsuperscript{28} provide a certain degree of compatibility with a VR environment, the percentile approach they use allow inaccuracies in the design. This issue was addressed by Cerney\textsuperscript{29}, who studied the use of univariate and multivariate data in the design of advanced operator workstations. A part of the research involved the development of a tool to examine the landmark and scan data from the CAESAR study in an immersive VR setting. This work showed how multiple characteristics of human anthropometry greatly enhance the design of a complex product. However, this tool lacked the flexibility of querying for subjects in real-time with a direct linkage to the visual environment. These capabilities will provide a designer with the flexibility to not only search for test subjects in the CAESAR database but also virtually determine if the designed controls in the operator workstation are sufficient for a wide range of users and associated requirements.

III. Anthropometric Design Environment

A. VJ Anthro Software Module

As stated earlier, CAESAR data includes anatomical landmarks and full-body surface scans for each subject who participated in the study. Therefore, a designer is able to examine issues relative to any individual or subset of individuals from the entire subject population, as dictated by the needs of the particular design. The end result is design decisions based on actual human anthropometry rather than composite statistical representations\textsuperscript{28}.

The VJ Anthro software module was implemented with two primary development tools: 1) VR Juggler\textsuperscript{29} and 2) SGI OpenGL Performer\textsuperscript{30}. VR Juggler is an open source VR application development framework from the Virtual Reality Applications Center (VRAC) at Iowa State University. VR Juggler abstracts all interface aspects of a VR application, including display surfaces, object tracking, selection, navigation, graphics rendering, and graphical user interfaces from the computer hardware. This allows the resulting application to be portable between computer platforms and VR systems. SGI OpenGL Performer is a programming interface for performance-oriented 3D graphics applications and is used within VJ Anthro to manage the many aspects of the virtual scene graph.

The data for the VJ Anthro software module consists of both CAESAR data and CAD models. The landmark data for each subject and posture is stored as a list of landmark names and vertices in a separate text file. This landmark data is read into the application as needed, with each landmark point being represented in the virtual environment by a small, colored, geometric primitive. Surface scan data is stored in the OpenFlight (FLT) file
format after being decimated and translated from the original file format. The OpenFlight format was chosen for its ability to retain both vertex color and normal information and because of its prevalence in the visualization simulation industry. Once these files have been made available outside of the application they can be loaded and viewed on demand from within the virtual environment.

In addition to displaying the anthropometric data and CAD models, the VJ Anthro application also assists the designer in discerning posture information and in distinguishing between individual subjects through the use of "LineMen". These LineMen resemble stick figures, but are formed by connecting surface locations (as defined by specific landmarks) rather than joint centers. As such, they represent the extents of their respective subjects, and can be used both to visualize posture information and to highlight particular subjects within the visible population.

CAD geometry can be loaded into the application from one or many files using any of the file formats supported by Performer (e.g., OBJ, STL, 3DS, FLT). An XML-based configuration file is used to specify the models to be loaded and the geometry file(s) associated with them. If multiple CAD models are available, they can be defined as separate “model groups” within the configuration file and viewed independently within the virtual environment at the user’s discretion.

Interaction with the VJ Anthro application was accomplished through addition of a wireless wand, although any input device such as a pinch glove or data glove would function. When combined with a wireless position and orientation tracker, the wand allows the user to access the application menus and to navigate within the virtual environment. The text-based menus contain display options for both the anthropometric data and the CAD models, and can be repositioned or hidden as desired. Buttons on the wand are used to select and activate the desired menu options. Navigation becomes active when the menus are hidden, providing the user with the ability to move freely about the virtual environment simply by pressing a button and pointing the wand in the desired direction of travel. Movement within the environment can also be accomplished by tracking the user’s head position and updating the displays accordingly. This encourages a more natural means of inspecting the virtual objects and data within the environment by enabling the user to look around, under, over, and between the models and data being shown.

B. Database Query Interface Module

The first step in creating an appropriate front-end to query the CAESAR data was to provide designers with a simple yet powerful software interface. A web-based application was decided upon to meet this need. This offers several distinct advantages:

1. **Platform Independence** - With care in the interface construction, users will be able to access the engine from any computer running any operating system. All that is required is a web-browser and an Internet connection. In addition, installation of additional software on a user’s machine is not necessary.

2. **Intuitive Interface** - Web-based controls such as buttons and drop-down menus are easy to navigate and learn as shown in the widespread adoption of the Internet. Most design professionals are familiar with these controls, thus training time is significantly reduced or eliminated altogether.

3. **Centralized Storage and Retrieval** – Using the Internet allows data to be stored in one centralized location. Thus, any changes to the interface codes or data can be made once and are instantly propagated to all users of the system.

The query engine was built on a server running the Apache	extsuperscript{31} web server with PHP	extsuperscript{32} (HyperText PreProcessor) and the MySQL relational database server. The four functions of the query interface are: 1) building a query, 2) committing a query, 3) storage of query history, and 4) output options for an executed query.

1. **Building a Query**

This section walks a designer through the steps to properly construct a query. Each step in the construction is clearly shown through graphical dividers and text. A user is notified at the current step if all previous steps have not been completed. Figure 1 shows the input screen used to build a query.

While the interface is very intuitive and simple to use, complex queries can be constructed. A truly relational query using SQL “join” statements can be built which searches on multiple fields from multiple database tables at once as well as simple queries searching on a single field from a single table. The query interface abstracts this step so any user simply searches on whatever fields they wish from the appropriate tables. The application keeps track of all needed fields and tables. It performs the “bookkeeping” to build the SQL statement on-the-fly, perform the query, and return the result. Each segment of a SQL statement is broken down. These are:

- **Database to search**
- **Tables from which to search**
- **Fields in which to search**
• Fields to return
• Boolean operators for search fields
• Boolean values for search fields

The input for each of these segments is obtained from the user through the web-based interface. At each step the software dynamically updates the choices in the interface controls. Once obtained and checked for errors, the SQL statement is constructed. Once the construction is complete, a user may test it to view the results. This ensures that the query is built properly and is capturing the designer’s intent. All settings of the query are available for changing to tune the resultant output. Once a designer is satisfied they may name and commit the query which places it in a saved state for future use.

2. Committed Query
   This section of the interface allows management of all saved queries for each user. Each query is listed with its full property values. A designer may run or delete any query in the list.

3. Query History
   This section of the interface displays the recent queries that have been executed. A designer is able to view and run all past queries, regardless of whether they still exist in the committed query list.

4. Query Output Options
   This section of the interface allows the results from any query to be output to a comma-delimited file or to be sent to the VJ Anthro module. Users from any location may query data and then immediately provide it for viewing in the VR environment. A sample result window with available output options is shown in Figure 2. Item (i) in the figure shows the option to send the results to VJ Anthro, item (ii) to export to a comma-delimited file and item (iii) is a column heading, which can be clicked to sort all results by the selected column.

All web pages of the query interface are constructed with CAESAR data and user inputs on the fly via PHP programs. This setup allows any database in MySQL (or other relational database with minor programming changes) to function with this interface. This offers scalability for future growth of CAESAR or any other human anthropometry study.

Figure 1 - Difference between ‘search by fields’ and ‘return fields’
C. Communication between Database Query Interface and VJ Anthro

The database query interface is able to communicate with VJ Anthro via omniORB, a high-performance implementation of the Common Object Request Broker Architecture (CORBA) specifications. This communication pathway has four software components: 1) the web-based query interface, 2) an omniORB client application, 3) an omniNames server, and 4) an omniORB server code contained within the VJ Anthro application. The purpose of this pathway is to allow subjects identified in the query interface to be loaded into VJ Anthro.

Once a set of subjects has been identified within the database query interface and the user has requested that it be sent to the VJ Anthro design environment, a message file containing a list of the appropriate subject numbers is written to disk by the web-based query. The omniORB client application constantly monitors this message file for changes. If detected, the file contents are read and composed into a message string. The omniORB client then connects to the omniNames server and transmits the message string to the omniORB server code inside VJ Anthro. The message string is immediately parsed and input causing the selected data to be loaded into the virtual environment.

IV. Test Cases

Two test cases are presented below to demonstrate the capabilities of the developed environment.

1. Test Case 1:

This query was constructed to locate subjects with elbows high off the seat and wide shoulders. This query is used to examine the location of armrests with relation to operator controls. If not ergonomically correct, stress on the shoulder and back muscles can occur after prolonged periods of time. The exact query components are left elbow height $\geq 337.69$ mm, right elbow height $\geq 329.23$ mm, and shoulder breadth Bidebtoid $\geq 550.31$mm. The return fields chosen were the Subject Number, left and right seated elbow heights and the shoulder breadth. Screenshots of the query building page and the results page are shown in Figures 3 and 4. Figure 3 depicts the process of how the query is built. The 'Test Query' button returns the results in a pop-up window as shown in figure 4. This query resulted in 23 subjects returned.
The resulting output was then sent to the VJ Anthro module for visualization. The resultant visual representations are shown in Figures 5 and 6. Figure 5 contains a vehicle seat with most landmark types visible for all subjects. A single LineMan is also visible. This representation makes it easy to see where important points such as elbows and knees are in relation to the controls and seat. Figure 6 has the same tractor seat, but in order to reduce clutter and focus on points of interest, the only landmark types visible are for the elbow, shoulder and head (seilion). A single LineMan is once again displayed. With this environment a designer is able to quickly toggle between actual subject data and view it exactly as it interfaces with a CAD model. There is no abstraction as in the case of software using...
the percentile approach. A designer can truly see what subjects “fit” into their designs and where adjustments need to be made. The representations shown in Figures 5 and 6 may be rotated, panned, or zoomed or altered with various visual options (e.g., linemen, subsets of selected subjects, etc.). It is also possible to display the full 3D body scan for each subject. This will show the actual subject’s physical attributes (face, hair, width of arms, etc.). This is another layer of detail to view the cabin design with real subject data. These representations make it easy to see that for most of the selected subjects, the current seat design does not interfere with most elbow locations. It also provides information as to how the seat arms, if adjustable, need to change for users with the queried physical attributes.

This test case was performed in real-time in the design environment. In a matter of seconds the query is created and the subjects are viewed in immersive VR. Complete information about several physical characteristics are instantly available in 3D for viewing and manipulation. This examination without this environment could take days to weeks to complete and might still miss critical relationships for the selected subjects.

![Image](image_url)

**Figure 5** – Results from Test Case 1 in VJ Anthro with all landmarks and a single LineMan
2. **Test Case 2:**
   
   This query was constructed to examine the relationship large girth has with eye location. The exact query components were maximum hip circumference $\leq 911$ mm and $\geq 1225$ mm, infraorbitale height, sitting left $\leq 770$ mm and $\geq 728$ mm. This query would therefore return subjects with large and small girths and various eye positions so that comparisons could be made between subjects. This query resulted in 22 subjects returned. The resultant output, after sent to VJ Anthro, is shown in figures 7 and 8. Figure 7 depicts a vehicle seat with knee, elbow, shoulder, and head landmarks visible for each subject. The LineMan selected was for a subject with one of the largest girths returned. Of interest here is the fore/aft position of the head (sellion) points and the relation to girth. Figure 10 shows the representation with the addition of another LineMan, this one with a small girth. Figures 7 and 8 show that the large girth subject’s landmarks are very close to various parts of the CAD model. Figure 8 shows how a small girth has room in the seat and thus a larger range of motion.

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**Figure 6** – Results from Test Case 1 in VJ Anthro with selected landmarks (elbow, shoulder and head) and a single LineMan
Figure 7 – Results from Test Case 2 in VJ Anthro with all landmarks and a single LineMan

Figure 8 – Results from Test Case 2 in VJ Anthro with landmarks and two LineMen
V. Summary and Conclusions

In this paper, an environment to allow human anthropometry to be incorporated into a complex design process has been presented. This environment allows a designer to easily search a large human anthropometry dataset and in real-time visualize the results in a fully immersive VR application. A designer is able to study multiple human physical characteristics at the same time and explore complex ergonomic and human factor issues that might otherwise go unnoticed. The test cases presented highlight the easy to use, yet powerful query interface as well as the integration of query results with CAD models.

References


