Virtual ergonomics in agriculture

Giuseppe Di Gironimo
IDEAinVR

Interactive Design and Ergonomics Applications in Virtual Reality

Giuseppe Di Gironimo
...methods and techniques that allow the design team to simulate human-product interaction when the product is still “immaterial”.

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Virtual Prototype

CAD model +

➢ Material, textures, shaders and lights

Collaboration with AnsaldoBreda

Collaboration with ESI Group
Virtual Prototype

CAD model +

- Material, textures, shaders and lights
- **Kinematic behaviors**
  - **Direct**
  - **Inverse**

Collaboration with Firema Trasporti
Virtual Prototype

CAD model +

- Material, textures, shaders and lights
- Kinematic behaviors
  - Direct
  - Inverse
- Dynamic behaviors
  - Rigid body

Collaboration with CIRA
Virtual Prototype

CAD model +

- Material, textures, shaders and lights
- Kinematic behaviors
  - Direct
  - Inverse
- Dynamic behaviors
  - Rigid body
  - Deformable body

Collaboration with Fraunhofer IGD
Collaboration with ESI – IC:IDO
Virtual Prototype

CAD model +

- Material, textures, shaders and lights
- Kinematic behaviors
  - Direct
  - Inverse
- Dynamic behaviors
  - Rigid body
  - Deformable body
- Sensitivity to collisions
  - Detection
  - Gliding
  - Avoiding

Collaboration with Firema
Virtual Prototype

CAD model +

- Material, textures, shaders and lights
- Kinematic behaviors
  - Direct
  - Inverse
- Dynamic behaviors
  - Rigid body
  - Deformable body
- Sensitivity to collisions
  - Detection
  - Gliding
  - Avoidance

Collaboration with PRISMA Lab – prof. Siciliano
...if compared with traditional design methods, engineering design using intuitive 3D interaction techniques in VR increases its contribution to...

• ...styling
• ...ergonomic performance
• ...product quality
• ...product lifecycle
• ...a product’s commercial competitiveness through product differentiation

Collaboration with Piaggio Aero Industries
**Main Goal:** build an integrated system that allows designers and engineers to visualize the new products and simulate their main performances

**Main Tasks:**

- Styling
- DMU and PMU correlation
- Ergonomics simulations
- Virtual Serviceability
- Digital Plant
- Marketing and Sales
CESMA-MARTE: Advanced Measures in VR

- Virtual Design Review
- Styling
- Concept Design
- Ergonomics
- Virtual Maintenance
- Virtual Manufacturing
- Virtual Training
- Post-processing of CAE data
- Virtual Marketing
- Cooperative Design
ErgoS - Advanced Measures on Ergonomics and Shapes

Integrated system for cinematic, dynamic, inertial and electromyography measurements on human body

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<thead>
<tr>
<th>Infared digital cameras</th>
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<td>Acquisition frequency at maximum resolution</td>
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<tr>
<td>Maximum acquisition frequency</td>
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<table>
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</tr>
<tr>
<td>Capacity for each sensor</td>
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</table>
**ErgoS - Advanced Measures on Ergonomics and Shapes**

Integrated system for cinematic, dynamic, inertial and electromyography measurements on human body

<p>| | |</p>
<table>
<thead>
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<tr>
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<tr>
<td><strong>Frequency</strong></td>
<td>Up to 4 KHz</td>
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<tr>
<td><strong>Frequency</strong></td>
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<td><strong>Data trasmission technology</strong></td>
<td>Bluetooth® Zig Bee</td>
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</table>
ErgoS - Advanced Measures on Ergonomics and Shapes

Internal project: Race Walking

Evaluation of the illegal Flight Phase
Critical review of projects (design review) certainly is one of the most crucial stages of product development with digital simulation tools.

The number of critical reviews of a product is proportional to the complexity of the project, because equally numerous and complex data coming from different simulation environments must be analyzed and critically evaluated.
Agenda

- Introduction and Aims
- International Standards for the design of tractor cabs
- Tractor’s virtual prototyping – Top-down approach
- Ergonomic analyses and optimization
  - Identification of critical driving tasks
  - Virtual simulations through digital human models
  - Definition of an Ergonomic Evaluation Index (EEI)
  - Test campaign
  - Ergonomic Improvement of tractor’s cab model
- Conclusions
The increasingly intensive use of agricultural tractors pushes users to require \textit{improvement of ergonomics} of driver cabs and usability of controls.

Several researches in literature have demonstrated that increasing comfort does not always require a very expensive and impressive change of the model. Even minor changes using \textit{re-design} within vehicles could improve comfort.

This presentation illustrates a \textit{re-design approach} based on the use and the management of heterogeneous product information, advanced virtual prototyping tools and digital human models, for the re-design and the ergonomic optimization of an agricultural tractor’s driver cab.
International Standards for the design of tractor cabs

• **At the end of last century**, standards on agricultural tractor’s driver cab concerned only the seating accommodation dimensions, with particular reference to the distances among seat, pedals and steering wheel.

• **Nowadays**, due to the evolution of the design techniques, the scenario is changed and several rules and standards were studied and created to improve the quality of the tractors but especially to increase the driver’s safety.

• There are **62 ISO standards** specifically for agricultural tractors.

• The most important international organization for tractor’s standards is the **Organization for Economic Co-operation and Development (OECD)** which provides a common set of test procedures for tractors in three areas: *performance, driver’s safety*, and *noise measurement*. 
OECD rule N. 4 (“Testing of the strength of protective structures for agricultural and forestry tractors - static test”)

**Survival Cell dimensions**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>mm</th>
<th>Comment</th>
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</thead>
<tbody>
<tr>
<td>A1 A0</td>
<td>100</td>
<td>Minimum</td>
</tr>
<tr>
<td>B1 B0</td>
<td>100</td>
<td>Minimum</td>
</tr>
<tr>
<td>F1 F0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>F2 F0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>G1 G0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>G2 G0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>H1 H0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>H2 H0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>J1 J0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>J2 J0</td>
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<td>Minimum</td>
</tr>
<tr>
<td>E1 E0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>E2 E0</td>
<td>250</td>
<td>Minimum</td>
</tr>
<tr>
<td>D0 E0</td>
<td>300</td>
<td>Minimum</td>
</tr>
<tr>
<td>J0 E0</td>
<td>300</td>
<td>Minimum</td>
</tr>
<tr>
<td>A1 A2</td>
<td>500</td>
<td>Minimum</td>
</tr>
<tr>
<td>B1 B2</td>
<td>500</td>
<td>Minimum</td>
</tr>
<tr>
<td>C1 C2</td>
<td>500</td>
<td>Minimum</td>
</tr>
<tr>
<td>D1 D2</td>
<td>500</td>
<td>Minimum</td>
</tr>
<tr>
<td>I1 I2</td>
<td>500</td>
<td>Minimum</td>
</tr>
</tbody>
</table>
Case study

Real tractor
Tractor’s virtual prototyping – Top-down approach

Starting from manual measurement on the real model, photos, sketches and technical drawings, the layout of the CAD assembly prototype was realized.

Frontal and rear views of the tractor
Tractor’s virtual prototyping – Top-down approach

As the case study is composed by many elements, the structure of the assembly was defined starting from a **Top-Down approach** according to parameters that identify safety, ergonomic and comfort constraints.

Datum Planes used for the CAD modeling
Tractor’s virtual prototyping – Top-down approach

**Top-Down structure**

- **1 Platform**
  - Platform fender
  - Handle
  - Step ladder
  - Pages
  - Blinkers
  - Posterior lights
  - Parking lights

- **2 Cabin**
  - Frame
  - Lateral door
  - Cabin glasses
  - Seals
  - Door glasses
  - Anterior light

- **3 Engine Compartment**
  - E.C. Bodywork
  - E.C. Seals
  - Anterior grid
  - Anterior lights
  - Air Filter
  - Silencer
  - Engine
  - Logo
  - “Landini” Frieze
  - “14500” Frieze

- **4 Wheels**
  - Anterior Tyre
  - Tread
  - Posterior Tyre
  - Tread
  - Posterior rim
  - Anterior rim
  - Web and Hub

- **5 Dashboard**
  - Dashboard Shell
  - Steering Column Shell
  - Steering column
  - Control Panel
  - Red Lights
  - Green Lights
  - Blin leer
  - Tachometer
  - Fuel Level
  - Switches
  - Clutch Lever Handle
  - Manual accelerator

- **6 Seat**
  - Seat Bellows
  - Seat Lever
  - Backrest
  - Backrest Cushion
  - Armrests
  - Seat Sliding Lever
  - Slide lever handle
  - Window switch

- **7 Lifter**
  - Lifter Levers Shell
  - Lifter Levers
  - Lifter Lever
  - Lifter Lever Handle
  - Hydraulic Levers
  - Parking Brake
  - Parking Brake Handles
The extensive work to perform the CAD modeling through a top–down approach assures to perform automatic changes to the defined geometries, drastically reducing re-designing times.
Ergonomic Analyses

**Procedure for ergonomic optimization of the driver cab**

**Phases**

1. Identification of critical driving tasks, as regards to ergonomics

2. For each task:
   - Identification of critical situations as regards to: visibility, reachability, postural comfort

3. Changing of features parameters and updating of the 3D assembly structure

**Tools**

- Direct interviews
- Questionnaire
- Virtual simulations through digital human models
- CAD
Customers’ judgments on the real tractor have been collected in order to identify the most critical driving tasks perceived by the users as regards to usability.

<table>
<thead>
<tr>
<th>Non-dangerous devices - ND</th>
<th>Dangerous Devices - DD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Seat suspension handle</td>
<td>1. Primary clutch pedal</td>
</tr>
<tr>
<td>2. Lumbar adjustment knob</td>
<td>2. Gear lever</td>
</tr>
<tr>
<td>4. Seat height lever</td>
<td>4. Parking brake lever</td>
</tr>
<tr>
<td>5. Seat tilt lever</td>
<td>5. Power take-off lever</td>
</tr>
<tr>
<td>7. Accelerator pedal</td>
<td>7. Power take-off motion lever</td>
</tr>
<tr>
<td>8. Ignition key</td>
<td>8. Lift lever 1</td>
</tr>
<tr>
<td>9. Light switch</td>
<td>9. Lift lever 2</td>
</tr>
<tr>
<td>10. Directional light switch</td>
<td>10. Lift locking lever</td>
</tr>
<tr>
<td>11. Differential gear lock pedal</td>
<td>11. Services levers</td>
</tr>
</tbody>
</table>

Some devices in the driver cab correspond to potentially dangerous actions.

“Non-dangerous Devices - ND” → weight ($H_n=1$)

“Dangerous Devices - DD” → weight ($H_d=1.5$)
Customers’ judgments on the real tractor have been collected in order to identify the most critical driving tasks perceived by the users as regards to usability

**Questionnaire:**

- **10 skilled tractor drivers** of different percentiles [5th – 95th]
- They were asked to assign a score, from 1 to 5, to evaluate the usability of the devices.

  1: very easy to use; 2: easy to use; 3: little difficult to use; 4: difficult to use; 5: very difficult to use

- The score assigned to each device was then amplified with the corresponding weight.

- The **critical range** is between

  3 (for a Non-dangerous device little difficult to use)
  7.5 (for a Dangerous Device very difficult to use)
Phase 1: Identification of critical driving tasks

Customers’ judgments on the real tractor have been collected in order to identify the most critical driving tasks perceived by the users as regards to usability.

### Critical devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Mean Score</th>
<th>Weighted Mean Score (WMS)</th>
<th>Normalized WMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Power take-off lever</td>
<td>5</td>
<td>7.50</td>
<td>1</td>
</tr>
<tr>
<td>2. Parking brake lever</td>
<td>4.5</td>
<td>6.75</td>
<td>0.9</td>
</tr>
<tr>
<td>3. Services levers</td>
<td>2.5</td>
<td>3.75</td>
<td>0.5</td>
</tr>
</tbody>
</table>

✓ The results of the survey highlighted that only three devices are critical because present a Weighted Mean Score (WMS) between 3 and 7.5.
✓ The survey allowed to highlight, in a qualitative way, what are the control devices in the cabin that skilled drivers perceive as “difficult to use”
In order to improve the usability of the critical control devices, we need to understand why those devices are perceived as “DIFFICULT TO USE”.

Usability

Objective characteristics

- Visibility
- Reachability
- Postural comfort

Subjective characteristics
Phase 2: Virtual simulations through digital human models

**Visibility analyses**

- The three tasks were simulated in virtual environment.
- The software allows to see the simulation of a task with the eyes of the manikin, highlighting the field of view of both eyes

✓ All tests returned positive results
✓ The dissatisfaction of the real drivers with the use of critical devices cannot be adduced to the lack of visibility
Phase 2: Virtual simulations through digital human models

Reachability analyses

- Once the manikin has been opportunely constrained inside the driver cab, using the inverse kinematic algorithm it was possible to verify the reachability of the critical devices, also computing a reach envelope surface.

- Even if in order to reach the devices, the driver has to incline the trunk and to extend the hands, the reachability is satisfied.

✓ All tests returned positive results
✓ The dissatisfaction of the real drivers with the use of critical devices cannot be adduced to the lack of reachability
Phase 2: Virtual simulations through digital human models

Postural analyses

Ergonomics’ Evaluation Index” (EEI index)

EEI = (P + R) / 2

*P index: Postural Score Analysis tool*

*R index: Rapid Upper Limb Assessment analysis tool*
Phase 2: Virtual simulations through digital human models

*Postural analyses*

The evaluation of P index needs the preventive knowledge of:

- the angles that have to be examined ("*favorite angles*"),
- their comfort range.
Phase 2: Virtual simulations through digital human models

Postural analyses

2\textsuperscript{nd} Test campaign

3 skilled drivers (5\textsuperscript{th}, 50\textsuperscript{th}, 95\textsuperscript{th})

AIMS:

a) to determine the segments and \textit{the favorite angles} of the drivers that are most involved during the activation of the critical devices

This aim was reached through a visual observation of photos and videos captured during the tests. As result we individuated: the full spine, the left arm and the right arm, and the relative adjacent joints angles, for a total of \textbf{9 favorite angles}. 
Phase 2: Virtual simulations through digital human models

Postural analyses

2nd Test campaign

3 skilled drivers (5th, 50th, 95th)

AIMS:

b) to qualitatively evaluate the comfort range of the favorite angles in order to implement them in the Human Posture Analysis module of Delmia.

We obtained this aim asking the drivers to:
Assume a driving posture; Move only one joint at a time along all the possible ranges, leaving all other joints locked. Stop the motion when an uncomfortable angle is reached. In this way we could qualitatively measure with manual tools the comfort range of the favorite angles (φi) related to a tractor driving posture.
Phase 2: Virtual simulations through digital human models

Postural analyses

Running the Postural Score Analysis tool, the P index can be obtained through the following formula

$$ P = \frac{1}{100} \times \frac{\sum_{i=1}^{n}[100-p(\phi_i)]}{n} $$

“n” is the number of favorite angles taken into account (n=9 in our case); “p(\phi_i)” is the score related to the favorite angle \( \phi_i \). It can range between 0 (worst) to 100 (best).

P ranges between 0 (optimal posture) to 1 (critical posture).
Phase 2: Virtual simulations through digital human models

Postural analyses

**EEI index evaluation**

<table>
<thead>
<tr>
<th></th>
<th>P index</th>
<th>R index</th>
<th>EEI</th>
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<tbody>
<tr>
<td>Power take-off lever</td>
<td>0.81</td>
<td>0.86</td>
<td>0.83</td>
</tr>
<tr>
<td>Parking brake lever</td>
<td>0.65</td>
<td>0.86</td>
<td>0.75</td>
</tr>
<tr>
<td>Services levers</td>
<td>0.35</td>
<td>0.43</td>
<td>0.39</td>
</tr>
</tbody>
</table>

- The EEI score can range between 0 (optimal posture) and 1 (critical posture).
- EEI less than 0.5 can be considered acceptable.
Phase 2: Virtual simulations through digital human models

Postural analyses

The results of the virtual simulation confirm the qualitative results obtained from the experimental test conducted with real drivers.

The dissatisfaction of the real drivers with the use of critical devices can be completely adduced to the non-comfortable postures that they have to assume to reach the devices.
In order to decrease the flexion value of the driver spine, the height from the floor of both the devices was incremented.

At first we adjusted the flexion angle of the spine until the obtaining of EEI scores lower than 0.5. Then, with the reach envelope surface activated, he have lifted the devices until they were inside the reach envelope surface.
Phase 3: Ergonomic Improvement of tractor’s cab model

Checking of visibility performance

Using the field of view of the manikin’s eyes, we have checked that visibility didn’t perform worst after the repositioning of the devices.

Before change

After change
### Phase 3: Ergonomic Improvement of tractor’s cab model

<table>
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<tr>
<th></th>
<th>Before change</th>
<th>After change</th>
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<tr>
<td></td>
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<td>R index</td>
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<td>Power take-off lever</td>
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</tr>
</tbody>
</table>

After the design modifications, the values of the ergonomic indexes were improved, and the EEI values became acceptable (lower than 0.5)
VR can give advantages....

...before

✓ This research has illustrated the tools and the methodological approach adopted for the redesign and the ergonomic optimization of an agricultural tractor’s driver cab.

✓ The research has illustrated how to realize an experimental test with real persons in order to obtain the database for the driving posture of an agricultural tractor.

...after

✓ Virtual training of operators
... un detto cinese molto diffuso nella comunità della RV!

“Tell me and I’ll forget
show me and I’ll remember
involve me and I’ll learn”