FreeBody Visualiser
User Manual

v1.0

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Introduction

The standalone FreeBody Visualiser (FBV) presents musculoskeletal model data generated by the FreeBody software package[1, 4] using interactive, animated three-dimensional graphics. FreeBody outputs that can be viewed with FBV include the movement of bones and muscles, muscle activations and joint contact forces. Use FBV to:

- find errors in the model;
- quickly and effectively analyse the model;
- demonstrate the model to colleagues and / or the public.

This user manual contains detailed information about how to open and explore FreeBody 1.1 data using FBV.

Contents

1 Overview

The FreeBody Visualiser (FBV) is a desktop application for Windows XP and newer. (See Section 8 for details on an experimental mobile version.) An overview of the FBV interface can be seen in Fig. 1.

Figure 1: The FreeBody Visualiser interface. 1) Information about the currently loaded model and its corresponding study. 2) Main control panel includes toggles and settings for controlling the visualisation of various model features. 3) Animation control panel. 4) Visualisation of selected model features. 5) Interface for loading a new model.

A FreeBody 1.1 model can be quickly loaded and visualised with FBV (see Section 2). Primary interactions with the visualiser occur through basic mouse gestures (see Section 3). FBV provides a detailed control panel to finely tweak and control the visualisation of various model features (see Section 4) as well as manipulate animation (see Section 5).

2 Loading the Model

To visualise a model, FBV requires for the user to have previously run the FreeBody Lower Limb Model and the FreeBody Matlab Optimisation and Visualisation applications, as found in the FreeBody 1.1 software package.[4] Part of this process involves the creation of an XML parameter file for the model which contains details about the associated study and references to FreeBody simulation, analysis and optimisation output file locations on the user's file system. FBV locates these output files via the XML parameter file and visualises the model features described within.

Please refer to the FreeBody 1.1 User's Guide for details on how to set up a correct study XML parameter file.[3] A full example XML file, including a list of all attributes read by FBV, can be found in Section 6.2.

The following sections describe three alternative ways to load a FreeBody 1.1 model (its XML parameter file) in FBV: using the user interface (Section 2.1), using the command line (Section 2.2) and using drag&drop (Section 2.3).

2.1 Loading Model via User Interface

Upon launch, FBV presents the interface shown in Fig. 2 which can be used to enter the file path of the XML parameter file associated with the model to be visualised. An example file location could look as follows:

`C:\example\study_params.xml`

Figure 2: Model loading interface.

Enter the location of the XML parameter file and press *Load XML*. If successful, FBV will attempt to load all the model features it recognises. A log such as that seen in Fig. 3 is displayed to indicate if any features have failed to load. This may occur due to multiple reasons, and more informative error messages are shown when available. Please refer to Section 6 for an overview of potential problems and solutions.

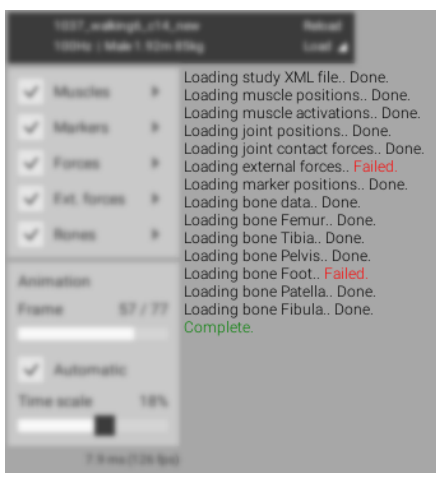

Figure 3: Model loading log.

Once a model has been successfully loaded and is visible, the control panel header (see Fig. 4) displays details such as the study name and subject details. It also has buttons to reload the model and toggle the interface for loading a new one.

Figure 4: Control panel header.

2.2 Loading Model via Command Line

To launch FBV from the command line (also known as the command prompt), type out the name of the FBV executable. To automatically load a model when launching from the command line, simply type out the path to the XML parameter file as the first argument after the name of the executable, e.g.:

```
FreeBodyVis.exe C:\example\STUDY_PARAMS.xml
```

FBV additionally supports the following FBV-specific arguments:

- `-fb-default-xml-path` argument should be path to XML parameter file that is used to automatically populate the loading UI in Section 2.1.

```
FreeBodyVis.exe –fb–default–xml–path C:\example\STUDY_PARAMS.xml
```

- `-fb-autoload-xml-path` argument should be path to XML parameter file that is automatically loaded on FBV launch.

```
FreeBodyVis.exe –fb–autoload–xml–path C:\example\STUDY_PARAMS.xml
```

Please refer to the Unity Standalone Player command line arguments list[12] for additional arguments that may be used when launching FBV from the command line.

2.3 Loading Model via Drag&Drop

To launch FBV and automatically load a model, drag the corresponding XML parameter file on top of the FBV executable (see Fig. 5).

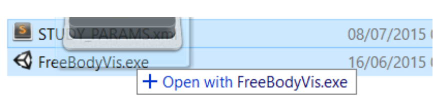

Figure 5: Dragging XML parameter file on top of FBV executable.

3 Control Basics

FBV is designed for use with mouse and keyboard.

1. **Click and drag** in the main window to orbit around and explore the loaded model features from multiple angles.

2. **Scroll** in the main window to zoom in or out.

3. **Click and drag** on the control panel header (see Fig. 4) to move the control panel around.

4. **Click** on various control panel interface elements (toggles, buttons and text boxes) to configure the visualisation.

5. **Press** the *LEFT* and *RIGHT* arrow keys to advance animation or control time dilation (see Section 5).

4 Controlling Visuals

FBV supports visualisation of the following FreeBody model features:

- The position and activation in time of all muscle parts.[1]
- The position in time of markers.[2]
- The position, direction and magnitude in time of joint contact forces.
- The position, direction and magnitude in time of external forces.
- The position and orientation in time of the major bones.[3]

FBV can be configured to completely enable or disable all visuals for a given feature using the toggles in the main control panel (see Fig. 6). However, each feature also has more fine-grained display options that can be accessed by clicking on that feature's label to open up an additional control panel. These detailed options are discussed in the following sections.

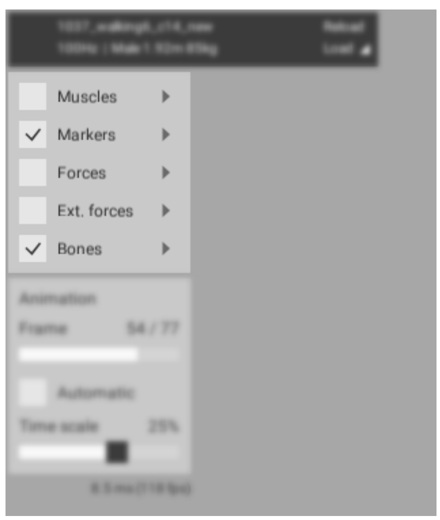

Figure 6: Visibility toggles for primary visualised model features.

[1]The muscle parts distinguished in the FreeBody Lower Limb Model are described in [8].

[2]Retro-reflective markers are used by the motion capture system to obtain the data input for FreeBody.

[3]The FreeBody Lower Limb Model outputs data for the *pelvis*, *femur*, *patella*, *fibula*, *tibia* and *foot* bone structures.

4.1 Muscle Visuals

The muscle visuals control panel (see Fig. 7) contains two primary configuration options:

1. **Display muscle activations** - turn *ON* to display muscles as lines that vary in weight (light to heavy) and color (black to red) according to a normalised activation value. Turn *OFF* to display all muscles as constant-weight lines that are color-coded according to muscle group (see Fig. 8).

2. **Display muscle parts** - toggle visibility of any individual muscle part *ON* or *OFF*.

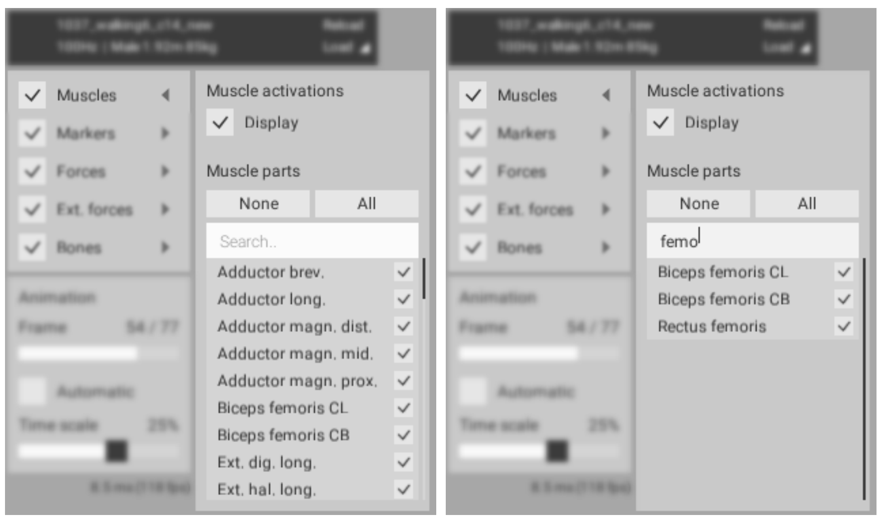

Figure 7: Control of muscle visuals includes the ability to toggle display of muscle activations and to search for and toggle the visibility of individual muscle parts.

Common use cases:

- Investigate a specific muscle part -
  1. Hide all muscle parts by selecting *NONE*.
  2. Search for muscle part by name.
  3. View muscle part by toggling it *ON*.
  4. Turn muscle activations *OFF* to observe position in time. Turn muscle activations *ON* to observe position and activation in time.

Figure 8: Color code for all lower-limb muscle parts.

4.2 Marker Visuals

The marker visuals control panel (see Fig. 9) contains two options:

1. **Marker type** - toggle between displaying either the dynamic or virtual static markers. The positions of virtual static markers are corrected for the inaccuracies present in the measured dynamic markers.

2. **Marker display size** - scale the spheres representing markers to a comfortable size.

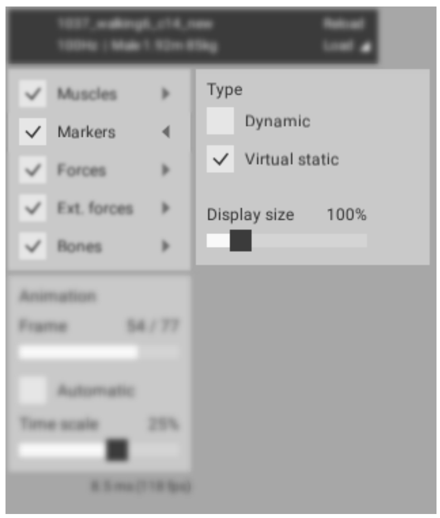

Figure 9

4.3 Force Visuals

The joint contact force visuals control panel (see Fig. 10) contains an option to scale the arrows representing forces to a comfortable size.

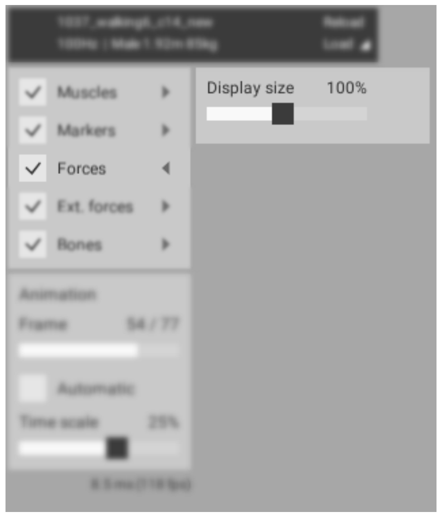

Figure 10

4.4 External Force Visuals

The external forces visuals are controlled in an identical manner to joint contact forces. Refer to Section 4.3.

4.5 Bone Visuals

The bone visuals control panel (see Fig. 11) contains two primary options:

1. **Display ghost frames** - turn *ON* to display translucent bones at the middle and extremities of the animation cycle.

2. **Display individual bones** - toggle visibility of any individual bone *ON* or *OFF*.

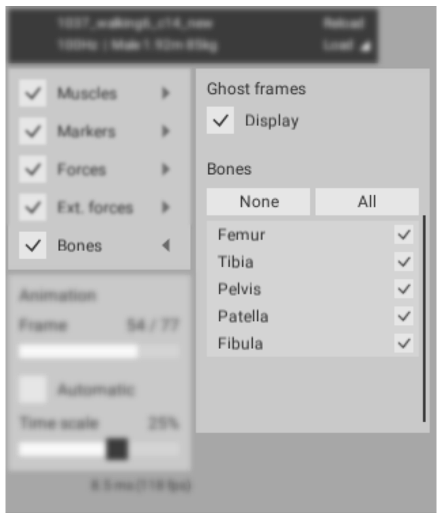

Figure 11

5 Controlling Animation

FreeBody models capture the motion of the human subject. To express position varying in time, the model outputs discretise time into a sequence of frames, each of a fixed duration. Each frame contains information about the state of all dynamic anatomy for its corresponding moment in time. FBV can play back the state, one frame at a time, in rapid succession to create an animation that approximates the original movement. Linear interpolation is performed between frames to achieve smoother animation at higher frame rates. FBV displays the current frame and total frame count in the animation control panel (see Fig. 12).

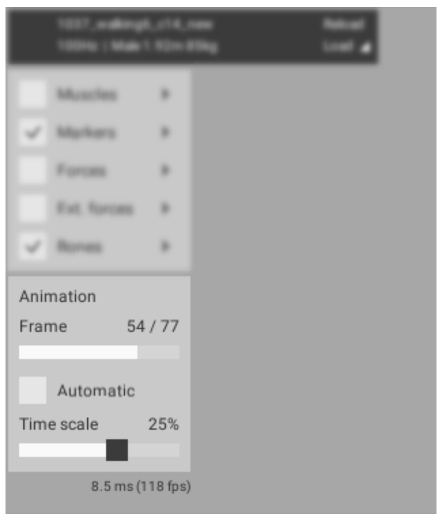

Figure 12: Animation control panel.

By default, FBV launches with *Automatic* time progression enabled, i.e. any loaded model is automatically animated. To stop or start automatic animation, press the *Automatic* toggle.

To make it easier to analyse motion, FBV's animation features time dilation. Using the *Time scale* slider, speed up, slow down, stop or completely reverse the animation.

5.1 Keyboard Animation Control

Use the *LEFT* and *RIGHT* arrow keys to control animation using your keyboard. The arrow keys have two modes of operation that depend on the state of the *Automatic* time progression toggle.

- **Automatic ON** - *LEFT* and *RIGHT* arrow keys control the *Time scale* slider.
- **Automatic OFF** - *LEFT* and *RIGHT* arrow keys control the current frame of animation.

6 Troubleshooting

6.1 Poor Performance

The numbers below the animation control panel (see Fig. 12) indicate the current performance of the FBV program itself, specifically the speed at which FBV is drawing the model features. The first number indicates how long it took to draw a single frame (in milliseconds - the lower, the better); the second number indicates the corresponding frame rate (in frames per second - the higher, the better). Note that *frame* in this context refers to the image drawn to your computer screen, **not** the *frame* of the FreeBody model animation. Generally values over `60fps` are preferred. If you are seeing a lower frames per second value, you are recommended to:

1. turn off visualisation of features that you are not interested in,
2. use less detailed (i.e. decimated) 3D bone models,
3. reduce the size of the FBV window (see Section 7), and / or
4. use FBV on a more powerful PC.

6.2 Failure to Load Model

FreeBody 1.1 defines a schema for the study XML parameter file.[3] FBV may fail to load and display the model if:

- the XML file, when provided as in Section 2, is missing, or
- the XML file is present but is missing certain elements and / or attributes.

The XML elements and attributes parsed and used by FBV are listed below:

- `study_level_parameters`
  - `study_name`
  - `responsible_person`
  - `output_directory_path_for_visualisation`
  - `output_directory_path_for_optimisation`
- `universal_physical_parameters`
  - `frames_per_second`
  - `radius_per_marker_metres`
- `subject`
  - `subject_sex`
  - `subject_height_metres`
  - `subject_mass_kg`
  - `subject_anatomy_dataset_path`
  - `subject_anatomy_dataset_file_name`
- `dynamic_trial_parameters`
  - `start_frame_number`
  - `end_frame_number`

An example XML parameter file can be found on the following page. Please note that this file does not strictly adhere to the full original FreeBody 1.1 XML parameter file schema[3]; instead, it demonstrates use of the subset of elements and attributes parsed by FBV. The name of the file is arbitrary.

study_params.xml

```xml
<?xml version="1.0" encoding="utf-8"?>
<study_level_parameters
 study_name="1037_walking6_c14_new"
 responsible_person="Ziyun Ding (z.ding@imperial.ac.uk)"
 output_directory_path_for_visualisation=
 "C:\example\1037_C14\walking6\Outputs\Muscle_geometry"
 output_directory_path_for_optimisation=
 "C:\example\1037_C14\walking6\Outputs\Optimisation">

  <universal_physical_parameters
   frames_per_second="100"
   radius_per_marker_metres="0.007"/>

  <subject
   subject_sex="Male"
   subject_height_metres="1.92"
   subject_mass_kg="85"
   subject_anatomy_dataset_path="C:\example\Anatomy_dataset"
   subject_anatomy_dataset_file_name="Zhan303_C14_dataset.xml">

    <dynamic_trial_parameters
     start_frame_number="1"
     end_frame_number="77" />

  </subject>

</study_level_parameters>
```

6.3 Missing Files

To visualise a FreeBody model, FBV has to load files output by the FreeBody Lower Limb Model and the FreeBody Matlab Optimisation and Visualisation applications, as found in the FreeBody 1.1 software package.[4] If some or all of the files are missing, FBV will indicate so in the log (see Section 2.1).

If a file is missing, FBV skips loading the corresponding feature. If one or multiple features of the model fail(s) to load, ensure that all the files that fall under that feature in the list in Section 6.3.1 are present and formatted per the FreeBody spec.[2]

The file paths in the list in Section 6.3.1 use the following abbreviations that refer to paths obtained from the XML parameter file attributes (see Section 6.2):

- `VIS` = value of `output_directory_path_for_visualisation`.
- `OPT` = value of `output_directory_path_for_optimisation`.
- `STUDY` = value of `study_name`.
- `AN_PATH` = value of `subject_anatomy_dataset_path`.
- `AN_PREFIX` = value of `subject_anatomy_dataset_file_name`, with the suffix trimmed; e.g. if the value is `Zhan303_C01_dataset.xml`, `AN_PREFIX` = `Zhan303_C01`.

6.3.1 Files Used by FBV

The following is a list of all files used by FBV to display the model, sorted by model feature. All abbreviations (capitalised) are explained in the previous section.

- **Muscles**:
  - `VIS/STUDY_muscle_path`$\{i\}$`.csv` - position of each muscle's origin and insertion points, per frame. Note that this path refers to multiple files, where the $\{i\}$ is replaced by $\{i \in \mathbb{Z} \mid 0 \leq i < 163\}$, and 163 is the number of distinct muscle elements.
  - `OPT/STUDY_force_gcs.csv` - actual activation of each muscle, per frame.
  - `OPT/STUDY_force_ub.csv` - maximum activation of each muscle, per frame.
- **Joint contact forces**:
  - `VIS/STUDY_rot_centres_gcs.csv` - positions of ankle, knee and hip joints.
  - `VIS/STUDY_tf_contact_gcs.csv` - positions of lateral and medial tibiofemoral joints.
  - `OPT/STUDY_force_gcs.csv` - magnitudes and directions of joint contact forces. (note same file as for muscle activations)
- **External forces**:
  - `VIS/STUDY_external_forces.csv` - positions, magnitudes and directions of ground reaction forces.
- **Markers**:
  - `VIS/STUDY_dynamic_marker.csv` - positions of dynamic markers.
  - `VIS/STUDY_virtual_static_marker.csv` - positions of virtual static markers.
- **Bones**:
  - `VIS/STUDY_anatomy_model_origin.csv` - default position offset for each bone in model.
  - `VIS/STUDY_anatomy_model_orientation.csv` - default rotation offset for each bone in model.

- VIS/STUDY_origins.csv - position of each bone in model for each frame.
- OPT/STUDY_lcs_quaternion.csv - rotation of each bone in model for each frame.
- (optional) AN_PATH/AN_PREFIX_bones/AN_PREFIX_Foot.stl
- (optional) AN_PATH/AN_PREFIX_bones/AN_PREFIX_Tibia.stl
- (optional) AN_PATH/AN_PREFIX_bones/AN_PREFIX_Fibula.stl
- (optional) AN_PATH/AN_PREFIX_bones/AN_PREFIX_Patella.stl
- (optional) AN_PATH/AN_PREFIX_bones/AN_PREFIX_Femur.stl
- (optional) AN_PATH/AN_PREFIX_bones/AN_PREFIX_Pelvis.stl

7 Configuration Options

1. **Configure default window size** - press and hold down the *ALT* key while launching FBV to configure window, graphics and input settings (see Fig. 13).

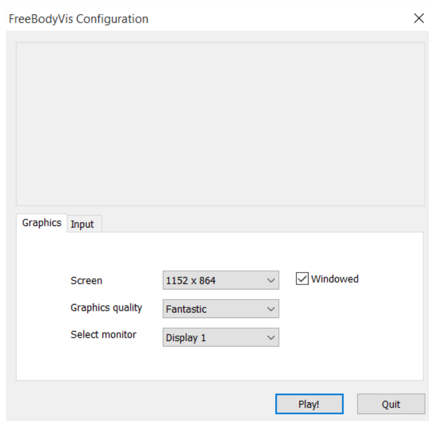

Figure 13: Configuration before launch.

8 FreeBody Visualiser Mobile

The experimental FreeBody Visualiser Mobile (FBVM) is FBV for mobile devices (see Fig. 14). FBVM has most of the capabilities of FBV, with some additional features and benefits:

- view FreeBody models on the go with no need for a powerful workstation;
- view FreeBody models in interactive three-dimensional space;
- load FreeBody models from a single file with no need for manual configuration.

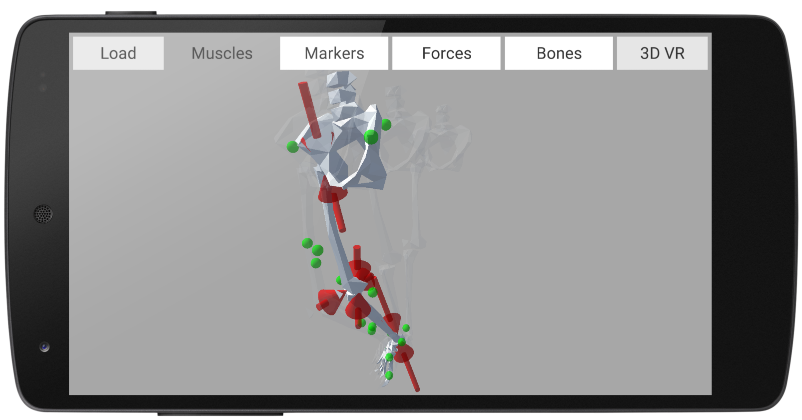

Figure 14: FreeBody Visualiser Mobile.

FBVM is designed to be intuitive and simple to use, with fewer configuration options but all the power of FBV. FBVM is a mobile application for smartphones and tablets running an Android OS. FBVM is classified as experimental because it has received only limited testing and uses a novel package format for distribution and loading of FreeBody data.

8.1 Overview

An overview of the FBVM interface can be seen in Fig. 15.

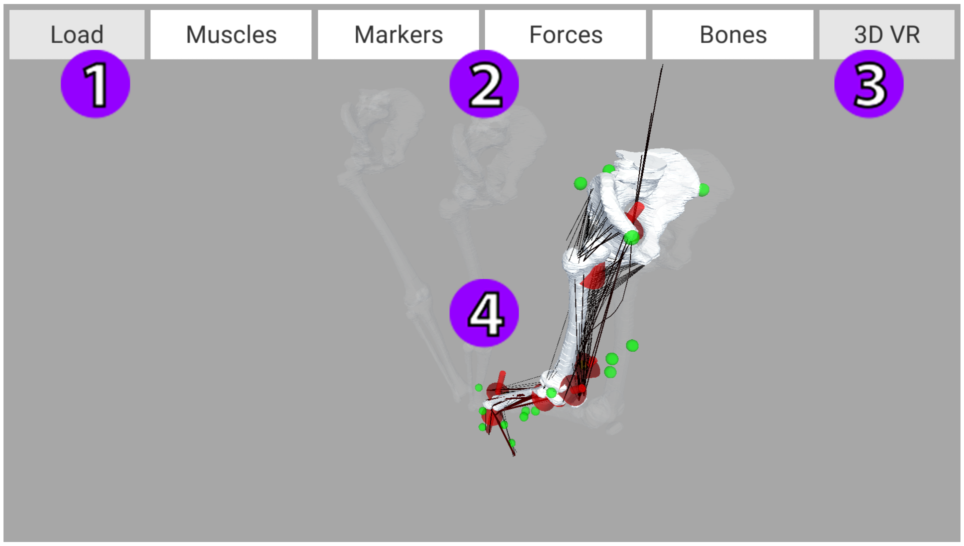

Figure 15: The FreeBody Visualiser Mobile interface. 1) Button to load a new model. 2) Toggles for visualisation of major model features. 3) Button to enter three-dimensional virtual reality mode. 4) Visualisation of selected model features.

A FreeBody 1.1 model needs to be converted to a FreeBody model package for distribution and viewing with FBVM (see Section 8.2). The model can be explored using motion gestures (see Section 8.3). FBVM provides minimal configuration options for tweaking the visualisation (see Section 8.4), but supports viewing the model in interactive three-dimensional virtual reality (see Section 8.5).

8.2 Loading the Model

Operating systems (OSs) on mobile devices typically provide the user with only limited access to the underlying file system. Furthermore, different mobile OSs or even different versions of the same OS may use different file system layouts and abstractions. It is because of this that using the desktop FBV method for loading FreeBody 1.1 models (see Section 2) is neither practical nor desirable. Instead, this document proposes a new method to store, distribute and load FreeBody models that is used by FBVM.

8.2.1 FreeBody Model Package

To greatly simplify distribution and loading on mobile devices, all FreeBody files are consolidated into a single directory, here referred to as a FreeBody *model package*. A model package is an entirely self-contained directory that contains all the files of a single FreeBody model. The directory is compressed to become a .ZIP file archive, which offers two benefits:

1. FreeBody model packages can be distributed as a single file, and
2. the compressed file, by definition, is of a smaller size.

The layout of the model package can be seen below. The package contains a standard FreeBody 1.1 XML parameter file, which must be named `parameters.xml`, at its root path. The one primary requirement for the XML parameter file unique to this model package format is that **all file paths must be relative and contained within the package**. A relative path in this context is a file path with its root as the root of the model package directory (i.e. the location of the `parameters.xml` file). The name of the model package .ZIP archive is arbitrary.

Model package layout

```
study_name.zip
| parameters.xml
| <... files>
```

An example XML parameter file that conforms to this relative path requirement for a FreeBody model package can be found on the following page (compare to a standard XML parameter file in Section 6.2). Note the relative path values for the attributes

- `output_directory_path_for_visualisation`,
- `output_directory_path_for_optimisation`, and
- `subject_anatomy_dataset_path`.

Note also that paths are defined with forward-slashes (/) instead of backslashes (\) to better conform to the major mobile OS (derived from Unix) conventions.

parameters.xml

```xml
<?xml version="1.0" encoding="utf-8"?>
<study_level_parameters
  study_name="1037_walking6_c14_new"
  responsible_person="Ziyun Ding (z.ding@imperial.ac.uk)"
  output_directory_path_for_visualisation=
  "./Outputs/Muscle_geometry"
  output_directory_path_for_optimisation=
  "./Outputs/Optimisation">

  <universal_physical_parameters
    frames_per_second="100"
    radius_per_marker_metres="0.007"/>

  <subject
    subject_sex="Male"
    subject_height_metres="1.92"
    subject_mass_kg="85"
    subject_anatomy_dataset_path="./Anatomy_dataset"
    subject_anatomy_dataset_file_name="Zhan303_C14_dataset.xml">

    <dynamic_trial_parameters
      start_frame_number="1"
      end_frame_number="77" />

  </subject>

</study_level_parameters>
```

The corresponding file structure of the model package can be seen below.

Example model package layout

```
C14_walking6.zip
| parameters.xml
--Anatomy_dataset
  | Zhan303_C14_dataset.xml
  --Zhan303_C14_bones
    | <... files>
--Outputs
  --Muscle_geometry
    | <... files>
  --Optimisation
    | <... files>
```

8.2.2 Loading the Model Package

Once a FreeBody model package has been created, it is straightforward to open and visualise it in FBVM. Download the model package on the mobile device through e-mail, online file storage, or any other means. Tap the *Load* button (see Fig. 15 item 1) and choose the model package using the system file picker (see Fig. 16).

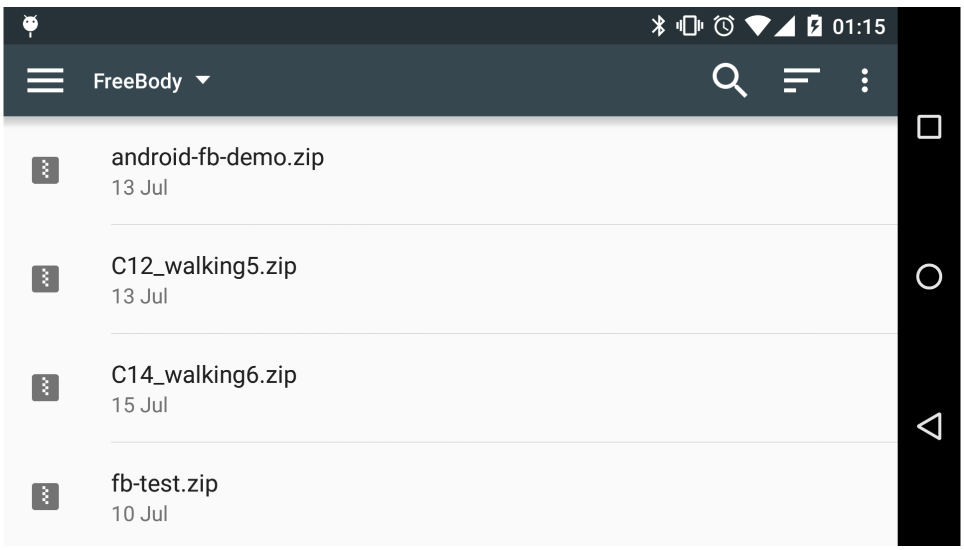

Figure 16: Android system file picker.

The FreeBody model package is automatically loaded after a brief period of time. See Section 8.6 for troubleshooting tips if the model package fails to load.

8.3 Control Basics

FBVM uses two simple input methods:

1. **Move, rotate and tilt** the physical mobile device to explore the visualised model from any direction.

2. **Tap** on the buttons and toggles at the top of the screen to trigger their associated actions.

8.4 Controlling Visuals

Use the toggles at the top of the screen to turn *ON* and *OFF* visualisation of major model features in FBVM, including *Muscles*, *Markers*, *Forces* and *Bones*. For example, FBVM can be seen with *Muscles* and *Forces* turned *OFF* in Fig. 17.

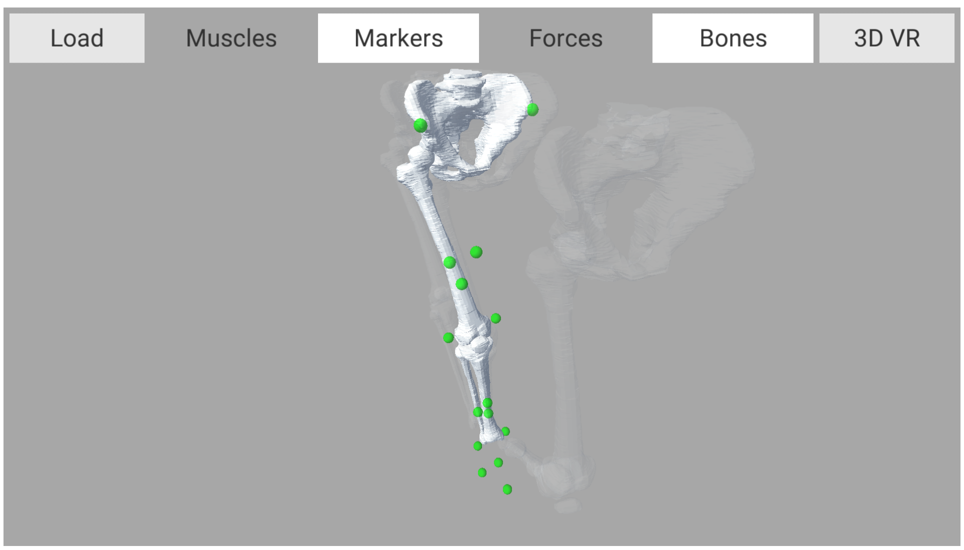

Figure 17: FreeBody model in FBVM with *Muscles* and *Forces* turned *OFF*.

8.5 3D Virtual Reality Mode

Use the *3D VR* button at the top right of the screen to enter a view that supports three-dimensional (3D) virtual reality (VR). This is accomplished by displaying the FreeBody model in stereoscopic 3D (see Fig. 18) and coupling the mobile device with a stereoscopic viewer / headset. The stereoscopic view and viewer enable the user to perceive depth in virtual space, while the motion and orientation sensors on the mobile device match the direction of view into the virtual space to the direction that the user is facing. This creates an immersive, intuitive environment to explore the model with full depth perception.

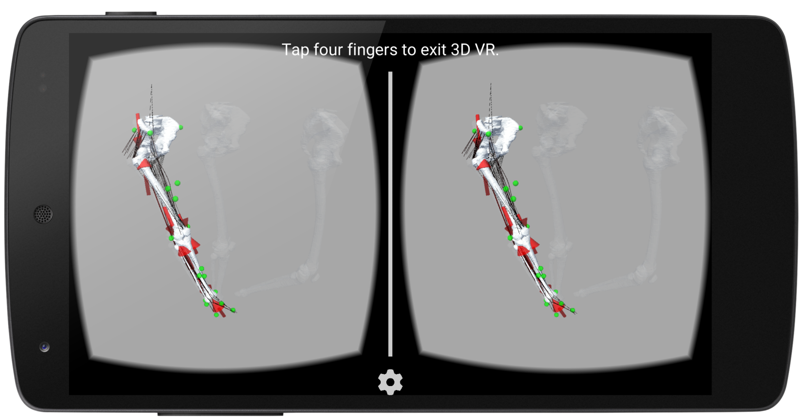

Figure 18: FreeBody model in stereoscopic 3D.

As of the time of writing, there is a large number of affordable stereoscopic viewers on the market, including open hardware designs that can be used to manufacture your own. FBVM was developed with a Google Cardboard headset[5] costing under £10, but there are many alternatives.[6, 7, 9, 10, 11]

Use a four-finger tap gesture to exit the 3D VR mode.

8.6 Troubleshooting

8.6.1 Poor Performance

A mobile device is more resource-constrained, both in terms of computing and graphical power, than a desktop workstation. FBVM therefore may, on certain devices and with certain models, struggle to present the FreeBody model with smooth animation. If FBVM is stuttering or reacting slowly, you are recommended to:

1. turn off visualisation of features that you are not interested in,
2. use less detailed (i.e. decimated) 3D bone models,
3. not use 3D VR mode, and / or
4. use FBVM on a more powerful mobile device.

8.6.2 Failure to Load Model

FBVM may fail to load a FreeBody model package if:

- the package is not a .ZIP package,
- the package does not contain a `parameters.xml` file in its root path,
- the `parameters.xml` file is not a valid FreeBody XML parameter file,
- the `parameters.xml` file path attributes are not relative paths, or
- the package does not contain the needed files at the relative paths.

Please refer to Sections 8.2 and 6.2 for details on setting up a correct FreeBody model package and XML parameter file. Refer to Section 6.3 for a list of files that FBVM needs to find in the package and load to properly visualise a model.

9 Glossary

Common terms used throughout this document:

- **model** - a set of files conforming to the FreeBody data structure, including input and output files of the FreeBody Lower Limb Model and the FreeBody Matlab Optimisation and Visualisation applications and (optionally) 3D bone model files, *for a single study.* In FreeBody 1.1, the locations of these files are declared in an XML parameter file.

- **study** - a process that generated the input files for a single FreeBody model. In FreeBody 1.1, relevant details of a study are described in an XML parameter file.

- **XML** - a general and widely used ‘Extensible Markup Language.‘ In the context of FreeBody 1.1 and FBV, this is the format used by the parameter file for each study / model.

- **model package** - a custom schema for a self-contained .ZIP file archive that contains a valid FreeBody model XML parameter file and all associated files needed for visualisation.

- **ZIP** - a widely used file format for an archive file which may contain one or more files and / or folders. In the context of FBVM, this is the format used by the self-contained model package.

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