DEVELOPMENT OF COMPUTER SIMULATION SOFTWARE "SWUMSUIT" TO ANALYZE MECHANICS OF HUMAN SWIMMING

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INTRODUCTION

Many studies have been carried out to date with respect to mechanics of human swimming. However, there are no simulation tool which can take into account of all fluid forces unsteadily acting on each part of the human body and can analyze mechanics of dynamic swimming motion. For this reason, the authors have already developed such a simulation program and proposed its idea as a simulation model "SWUM" (SWimming hUman Model)[1]. In this previous study, it has been clarified that the simulation model has sufficient capability to discuss quantitatively the mechanics of swimming, since the swimming speed of the simulation agrees well with the actual one in a simulation example of standard six beat front crawl.

The developed simulation program, however, was written in Fortran of thousands lines and there were no interface part. Therefore, the user must understand all source code and be trained in order to use it. For this reason, in this paper, the interface part of the simulation program is developed and integrated with Fortran main program as a simulation software. This software, named "Swumsuit" (SWimming hUman Model with Synthetic Use Interface Tools) is a Free Software based on GPL (GNU General Public License), runs on Windows and Linux, and open to the public at its website (http://www.swum.org/swumsuit/). Technical details, basic functions and a simulation example are presented.

METHODS

First, the outline of the simulation model SWUM [1] is shortly described. The present simulation model is designed to solve the six degree-of-freedom absolute motion of whole human body as one rigid body, using the inputs of human body geometry and relative body motion as joint angles. Therefore, swimming speed, roll, pitch and yaw motions, power efficiency, joint torques and so on are computed as output data. As the external forces acting on the whole human body, unsteady fluid force which includes buoyancy and gravitational force are taken into account. The unsteady fluid force, which consists of inertial force due to added mass of fluid, normal and tangential drag forces and buoyancy, is assumed to be computed from local position, velocity, acceleration, direction, angular velocity, and angular acceleration at each part of the human body at each time step.

The simulation software Swumsuit consists of main program as the analysis engine part written in Fortran and GUI (graphical user interface) part written in Tcl/Tk. Figure 1 shows the structure of Swumsuit. The analysis engine part which implements SWUM reads three input files, that is, data
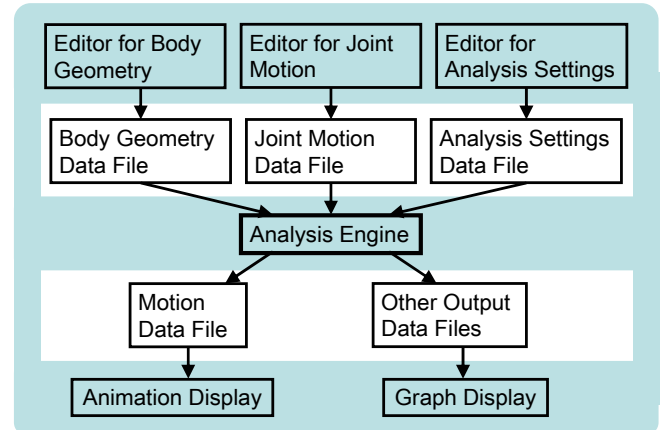

Figure 1: Structure of Swumsuit

files of body geometry, joint motion, and analysis settings. The parameters in these three files can be changed through three GUI editor parts. With respect to the output, a motion data file is produced to display animation of swimming motion. And many other data files are outputted, such as, swimming speed, time history of absolute position, consumed power, thrust, roll moment, joint torques at all joints, and so on. These data files are displayed by the graph display part.

In order to develop the software, the following tools are employed: Togl [2] for OpenGL animation BLT [3] for graph display part, freeWrap [4] for wrapping Tcl code and making an executable binary file), Visual Fortran compiler [5] for Windows, g77 Fortran compiler [6] for Linux, and SLATEC numerical calculation library [7] for numerical calculation in analysis engine part) .

RESULTS AND DISCUSSION

In this section, basic usage of Swumsuit is briefly described. Next, a simulation example is shown.

Startup window

Figure 2 shows the screenshot of startup window. In Swumsuit, a data set which includes all input and output files is located in
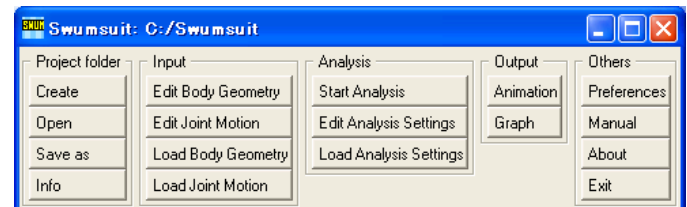

Figure 2: Startup window

a "project folder". All the parts shown in Figure 1 can be easily invoked from this window.

Editing body geometry
Figure 3 shows the screenshot of editing body geometry. In SWUM, human body is modeled as a series of 21 body segments which are represented by truncated elliptic cones. In the left window, the user can specify the size of each body segment, that is, length, width and depth, as well as the density. And the user can check the resultant body geometry at the right window.
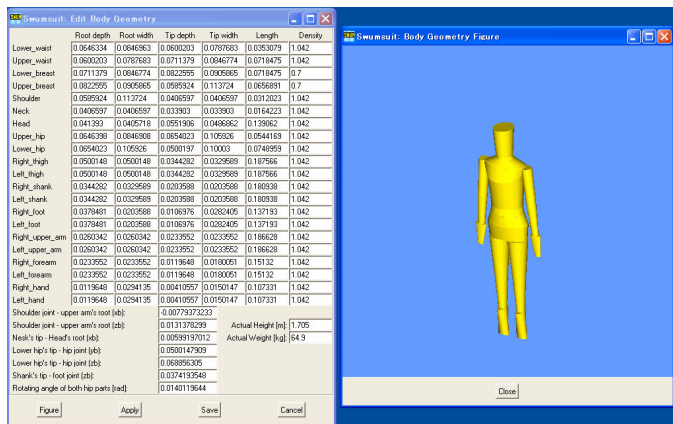

Figure 3: Editing body geometry

Editing joint motion
Figure 4 shows the screenshot of editing joint motion. In SWUM, joint motion is represented as rotations of body segments about body (relative) coordinate. In the upper left window, the user can create a new rotation and change the order of the rotation. In the lower left window, the user can set rotation angle at each time frame. Figure 4 is the case of standard six beat front crawl and one stroke cycle is divided into 18 time frames. The user can check the rotation angle at the graph in the lower left window and the right window which displays an animation.
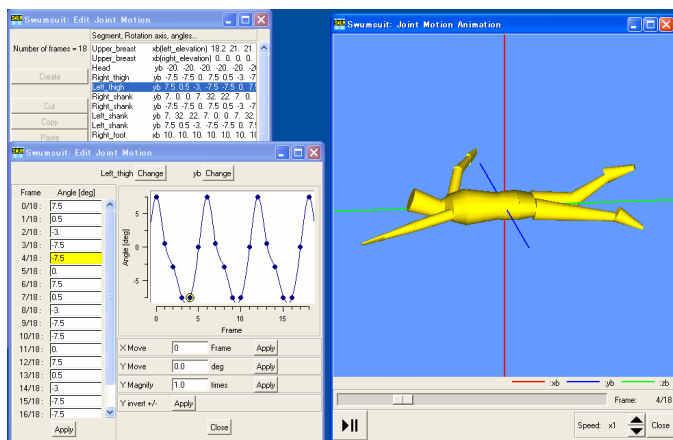

Figure 4: Editing joint motion

Simulation example and its output
The case of standard six beat front crawl is calculated. The calculation time depends on number of cycle to be calculated and number of time step in one cycle. In the case of 5 for number of cycle and 72 for number of time step, the calculation time is about 3 minutes with a Pentium 1 GHz PC. The simulation results and their outputs are shown in Figure 5. The upper left window shows history of swimming speed averaged in each cycle. The lower left window shows variation of thrust due to the fluid force during one cycle. From these graphs, the user can easily obtain the facts that the swimming speed becomes steady value of 1.2 m/s after 3 cycles and that the maximum thrust reaches 86 N when the left and right hands push the water. Those graphs can be exported to Windows' clipboard, Windows meta file and Postscript file. On the animation window, the direction and magnitude of the fluid force acting on each part of the human body are represented as direction and length of line from the human body. For example, in the case of Figure 5, it can be found that the left hand pushes the water and produces the thrust at this moment.
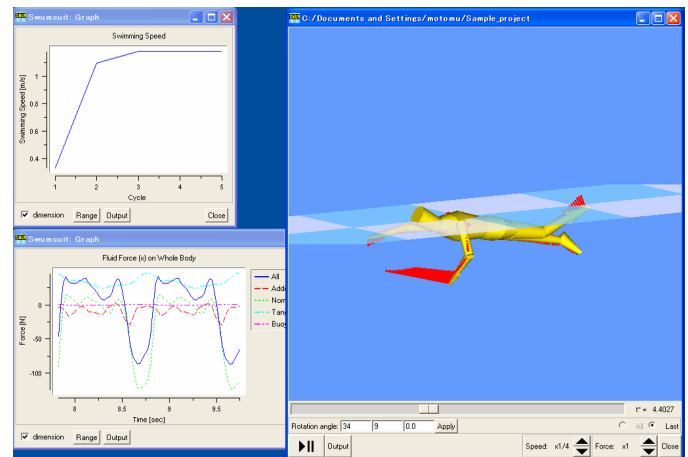

Figure 5: Simulation results and their outputs

CONCLUSIONS
A computer simulation software to analyze mechanics of human swimming was developed. This software, Swumsuit, is intended to be broadly used for research and education about mechanics of swimming. During the time of demonstration in the conference, the software will be freely distributed with USB flash memory and CDROM, and participants of the conference will be able to play with it from the day of presentation.

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