CHAPTER 4

FOOT MEASUREMENT ALGORITHM AND PROTOCOL

4.1 OVERVIEW

The hardware system described in the previous chapter and in the Appendix 4 were operated by using the unique software especially designed for this application. The software system of FMS supporting the whole measurement procedure consisted of two groups of programs: the data collection programs and the data processing programs. The data collection programs were designed to run on the computerized Data and Image Processing units of FMS during the data collection procedure (Liu et al 2004). The processing softwares were designed to run on analyzing computer systems, which were of greater capacity and with more powerful computer configurations.

4.2 DATA COLLECTION PROGRAMS AND PROCEDURES

The data collection is the organized and partly automated procedure of capturing and storing the prescribed data from a sample population of people selected in a random way in the statistical sense. The collected data were foot-related, body-related, personality-related. The most important were the foot-related data, measured automatically by the FMS (Houston et al 2006). Some foot-size values were measured manually for control purposes. The body-related data were measured manually also. All the other data were issued as answers given by the subjects during measurement. The investigated person were identified with bar codes which were automatically entered. Thus the data
collection programs managed to automatically capture the graphic images, measured numerical values, bar code values and manually entered values. The target was to transform all input data into common numerical databases.

4.2.1 Numerical Data Collection Program

The numerical data collection was controlled by the program FootDat. The program FootDat is an executable program written in database language FoxPro. Its task was to support the input data flow and to save the captured data into databases of given structure (Tsung et al 2003). Information handled by the system was arranged in three master, four slave and two utility databases having the following file names (for database structures see Appendix 3):

- Master : DATA1.DBF, DATA2.DBF, DATA3.DBF
- Slave : PROFESSION.DBF, WORKING.DBF, LOCATION.DBF, DUCATIO.DBF
- Utility : SEGIT.DBF, SETUP.DBF

4.2.1.1 Master Databases

Master Databases are related through field named CODE. The manually measured data set was distributed in three parts to give the possibility for partial measurement. The field CODE is a 13 digit numeric value automatically received from the bar-code reader unit. This number satisfies the bar-code standard EAN-13 by automatic generation of 13th (control) digit from the first 12 ones (Li and Zeng 2010). Each measured person receives two consecutive bar-codes: the first 12 digits create consecutive numbers and the 13th digits are different (Chai and Hock 2005). The first bar-code was used during FootDat procedure and the second one during FootGrab measurement.
4.2.1.2 Slave Databases

Slave databases contained the different nominations applicable as choices when entering answers into master database DATA2.DBF. The number of these nominations could be increased during a measurement, therefore the contents of these slave databases could be changed in a separate data maintenance part of the program (supplementary files). The menu-like choice appearing when selecting an answer for question about profession, education, working or location can be modified. The operator is able to insert new values, but deleting for already used categories was not allowed.

4.2.1.3 Utility Databases

Utility databases were not used during normal operation, (Mauch et al 2009) but these were necessary for installation and error handling of FootDat.

The purpose of **numerical data collection** procedure was to open a new data record for each measured person and to store the collected data into computer storage for later investigations. The first step of this procedure was to assign a CODE (a pair of bar-codes) to the given person. Reading the first bar-code opened a new record, then the operator could start to enter the measured data values (DATA1). The next step was to enter the personality related data (DATA2) if answers were available. In this case the answers typically could be selected from submenus of possible answers (e.g. different kind of professions, education, etc.). The final input group was the optional body-related (apparel) data which were stored into DATA3 database. Program FootDat realized all these input tasks with specific functions and also provided the necessary support functions.
Program **functions of FootDat** were realized through a menu system, thus the overview of menu system gives the list of program functions as well.

**MEASUREMENT**  Function group of measurement data input.

**ADD**  Add new person (and data set) to database and enter shoe-related data (fields of DATA1.DBF).

**OPTION/SHOE**  Enter optional personality-related data (fields of DATA2.DBF) of actual person.

**OPTION/APPAREL**  Enter optional body-related data (fields of DATA3.DBF) of actual person.

**RETURN**  Back to the previous level of menu.

**DATABASE**  Activate database handling function group.

**NEXT**  Jump to next data record in database (next person).

**PREV**  Jump to the previous data record in database (previous person).

**SEEK**  Looking for data record of given CODE identification.

**EDIT**  Edit actual data record in database.

**DELETE**  Delete the actual data record in database. This function deletes all data records of the person (DATA1, DATA2, DATA3) related to actual CODE ID.

**GOTO**  Jump to the data record given by a serial number.

**TOP**  Jump to the first data record in database.

**BOTTOM**  Jump to the last data record in database.

**NUMBER**  Jump to the data record given by its physical RECNO.
RETURN  Back to the previous level of menu.

LIST  The function group of system listed outputs. Different lists could be generated using this function about main data (DATA1), optional personality data (DATA2) and optional body data (DATA3).

UTILITY  The function group of setup and maintenance procedures of program.

INDEX  The data records marked logically for deleting were deleted physically and new index files were generated.

PACK  Physical erasing of data records marked for deleting earlier.

SUPPLEMENT  Maintenance function of slave databases. Operator could maintain using this function the following data:
- Profession
- Mode of working
- Location (region+city)
- Education

DRIVE  Operator could setup the data path using this function.

SAVE DATA  Operator could save the measured data to floppy discs.

LOAD DATA  Operator could load earlier measurement from backup devices

QUIT  Exit from program FootDat. This function could be activated also by pressing keys CTRL + X simultaneously.

The flowchart of the FootDat program is shown in Figure 4.1.
Figure 4.1 Flow Chart of the FOOTDAT program
4.3 GRAPHIC DATA COLLECTION PROGRAM

The task of graphic data collection was to retrieve a set of visual “picture” information about a foot, to convert them into numbers having geometric meaning. This procedure substituted the difficult and slow piece-by-piece manual measurements using up-to-date computer programs and methods.

4.3.1 Overview of Measurement with FootGrab

As mentioned earlier the human foot is a complex three dimensional object containing both convex and concave surface elements. It would be very difficult to collect the necessary numerical data describing a foot by traditional manual measuring methods. Based on the results of earlier mass foot measuring projects, the program system Foot applied the essentially new method for data sampling. This method was called “video digitizing.” Two video cameras were monitoring the measured object from orthogonal (bottom and side) positions. The live pictures were grabbed and digitized. The digitized data were stored as “picture-files”, ready for later computer procedures of data retrieve. These procedures included the transformation of pixel-graphic picture-file into a vectorized data stream describing the contour of shapes (Pavlovich et al 2002). The curve of this contour could be analyzed by mathematical methods and any measuring data, e.g. point coordinates, sizes, distances, angles could be retrieved from the computer.

The program realized the data collection functions of above described procedure named FootGrab. Its basic task was to take “computer-photos” i.e. to capture pictures of the foot from two point of views.

The two graphic files created by the program were named according to the bar-code identifier related to person actually measured. FootGrab provided a
set other functions related to the hardware-software connection between the measuring equipments (IPU, CU) and the computer. The hardware video interface card received the video signals from two separate video channels: one for bottom view and one for side view. Only one video channel could be active at the same time, therefore the computer had to provide the correct selection of the proper video channel. It was done automatically by FootGrab.

The light sources were two pairs of 12V halogen lamps. These lamps were controlled also automatically according to the actual video source. It was possible to regulate the intensity of light as well.

The digital picture's photographic parameters were also easily adjustable from the program. These were the brightness and the contrast parameters. The proper setting of light intensity, brightness and contrast resulted in the characteristic digital photo, being necessary for valuable post-processing of pictures. The setting were always stored, thus the program started with the last settlement as default.

4.3.1.1 The Captured Graphic Image Files

The “computer pictures” received from the application of FootGrab are so called “bit-map” files. This is a common method for digital storage of graphic objects. The practical essence of this method was based on distributing the whole picture for rows and columns with a given resolution. The small object belonging to one row and one column index was named as “dot” or “pixel.” The number of such dots per inch (DPI) characterized the quality of resolution. Each pixel was qualified with one or more bits representing the pixels's darkness or color. These bits of unique pixels collected e.g. in a row-by-row system and joined into a digital data file were creating the so-called “bit-mapped” digital picture (Wu et al 2006). The interpretation (reading and displaying) of such
picture equals with the point-to-point analysis of the bit-mapped file according to its built-in system (e.g. row-by-row) and replacing the bits with their meaning (gray shading or color).

There are a large variety of standardized methods for bit-mapped and compressed storage of pictures. And there are conversion methods as well to convert one standard format to another. The most familiar picture formats are identified by their special file-name extensions, e.g. PCX, PIC, GIF, BMP, TIF etc. (Rotem and Stockinger 2005).

The picture specifications applied in FootGrab are described as follows:

Format standard : .BMP (Windows standard graphic file format)
Resolution : 640 x 400 pixels
Colors : 256
File size : 256 K

A pair of pictures grabbed from a sample foot shown in the following figures:

Figure 4.2 Image Grab of the Bottom View of the foot
4.4 DATA COLLECTION PROCEDURE FROM THE CAPTURED IMAGES

The graphic data collection is the most important part of a survey (the procedure is described in Figure 4.4). The measurements usually are not repeatable later. The operators of FMS have to prepare carefully for each measurement series by performing test measurements. The test measurements are necessary also to calibrate the measurement unit for modifying the transformation parameters when using FootProc during final processing of pictures. The operating parameters also have to be adjusted according to environmental changes (e.g. increased external light) or object changes (e.g. different skin colors).

The measured persons are identified by two consecutive bar-codes. The files created by FootGrab are also using these codes: the files are identified with the middle 11 digits of the two bar-codes. In both cases the first digit is omitted, the next 8 digits will be the file name and the next three digits are the name extensions. Thus the picture of bottom view will have an ‘even’ extension and side view will have an ‘odd’ extension.
The sizes of the picture files are relatively large: 2 measurements = 4 pictures = 1 MByte. Therefore the storage of pictures on the hard drive is limited. The solution is the application of digital tape drive subsystem built into graphic DPU. This unit is capable to store 250 or 500 complete measurements. Using the attached special backup software the contents of hard drives have to be copied regularly to digital tapes, releasing free spaces for new measurements.

4.4.1 Using the FootGrab Software

The application of program FootGrab requires the units IPU, CU, FMU. All the available functions are single-key activated without using menu structure. This method provides for a quick adjustment, sampling and archiving necessary for mass foot survey (Harris et al 2009).

The HELP-key is F1. Pressing this key will result to display on the screen a list summarizing the active function keys and their effects.

There are two basic methods of using FootGrab. One is the interactive method, when each step of procedure has to be initiated by pressing the proper function keys. The other is the automatic method, when a single key performs the whole procedure without additional interactions.
Figure 4.4 Flow Chart of the Data Collection Procedure from the captured Images
4.4.1.1 The Key–Commands of FootGrab

F1  Help

This function gives you the list of the program's functions and its hot keys. Press any key to exit Help.

Message: The whole help screen

1  Switch to video channel #1

After pressing this key the first video channel and appropriate lamps will be activated and the bottom view appears on the screen.

Message: Video source: bottom view

2  Switch to video channel #2

After pressing this key the second video channel and appropriate lamps will be activated and the side view appears on the screen.

Message: Video source: side view

F  Freeze the Picture

After pressing this key the online digitizing process is frozen and the static picture could be analyzed on the screen. Press any key to return to online process.

Message: Image frozen.

N  Assign Barcode

After pressing this key the barcode to be used for saving could be inserted in 13 decimal digit format. This can be done from the keyboard or with a Barcode reader device. The 12th digit must be an even digit.
Message in upper right corner: the entered number.

S  Save the picture

This key is applicable for saving the screen's contents into a file. The file name generates the program from the entered 13 digit Barcode number with the Assign Barcode function. This function doesn't need the picture to be frozen, after pressing the “S” key the freezing will be done automatically.

Message while saving: Saving image to xxxxxxxx.xxx, please wait...

B  Setting The Brightness

This key turns the keyboard to setup mode. The arrow keys modify the brightness value in range 0-256. For up/down keys the increment/decrement is +1/-1, for left/right it is +10/-10. Press Enter key to return.

C  Setting The Contrast

1. Read barcode as file name #1 (Function N)
2. Select camera and lamps #1 (Function 1)
3. Freeze picture (Function F)
4. Capture and save bottom view (Function S)
5. Generate file name No.2
6. Select camera and lamps No.2 (Function 2)
7. Freeze picture (Function F)
8. Capture and save side view (Function S)
9. Return to online mode This key turns the keyboard to setup mode. The arrow keys modify the contrast value in range 0-256. For up/down keys the increment/decrement is +1/-1, for left/right +10/-10. Press Enter key to return.
L  **Light intensity setting**

This key turns the keyboard to setup mode. The arrow keys modify the intensity value of the lamps belonging to the actual video channel in range 0-16. For up/down keys the increment/decrement is +1/-1. Press Enter key to return.

G  **Go and start sampling procedure**

This key activates a procedure containing a series of stand-alone functions detailed above. This series is:

*Message:* Video source: bottom view

Q  **Quit to DOS prompt**

After pressing this key the program will save the values of settings, and return to main menu. The “Esc” keystroke will cause the same result.

*Message:* Video source: bottom view

**Error Messages**

*Internal video error*

Reflects to an internal system error. Leave the program, restart the computer with RESET key. Start again Foot and FootGrab from main menu.

*Disk full*

Too many graphic files were saved to hard drive. Leave the program, start TAPEBACK from main menu, backup all unnecessary data files to cartridge. Start again Foot and FootGrab from main menu.

*Invalid Barcode*

The string given as barcode is invalid. Check whether its length is 13 digits. Check whether the 12th character is even. Enter the proper barcode again.
4.5 GRAPHIC DATA PROCESSING PROGRAMS AND PROCEDURES

The task of graphic data processing is to analyze the graphic images, to perform the necessary conversions (mathematical transformations) and to produce numerical data, i.e. numbers describing the measured foot (Shadish et al 2009). This analysis has to be performed on a great amount of images created by the program FootGrab during the first, data collecting phase of the this survey project.

4.5.1 Graphic Image Correction Procedure

The program designed to perform automatically all these analyses and transformations was the program FootProc. The successful application of this program required good quality graphic images satisfying a set of different photometric and geometric conditions. In case of good application of FootGrab these conditions were provided automatically, but in case of any misuse of grabbing equipment and program the resultant pictures were incompatible with the program FootProc (Bouwens et al 2001).

4.5.1.1 Using Paintbrush to Repair Pictures

To disclose these incompatibilities the picture-pairs had to be supervised before final processing. For this purpose any kind of graphic editor with ability of bitmap editing could be used such as PaintBrush, available e.g. from Windows Accessories group (Leong et al 2003). After starting the program select Options and Image Attributes to prepare the image format described earlier. Set up the following values:
Unit | pels (pixels)  
---|---
Width | 640 (640 pixels/each row)  
Height | 400 (400 pixels/each column)  
Colors | colors (256 colors/each pixel).

Figures 4.5, 4.6, 4.7, 4.8, 4.9 and 4.10 illustrate the image correction procedure.

**Figure 4.5** Image Error due to wrong light source setting for Bottom View

**Figure 4.6** Image Error due to wrong light source setting for Side View

**Figure 4.7** Image Background Correction for Bottom View

**Figure 4.8** Image Background Correction for Side View

**Figure 4.9** Corrected Image for Bottom View

**Figure 4.10** Corrected Image for Side View
Then the image was loaded using *Open* and *File*. There were two consecutive files belonging to the same foot: the two file names must be equal except the last digit in the file name extension. If anyone of such two paired files was missing or could not be successfully repaired, then both files would be omitted. We have to decide whether there are any errors (reflections, mirror lights etc.), and if yes then we have to start the correction procedure by setting up the pen color and filling the color to black. Using the *filled polygon tool* to draw round the foot’s contour the unnecessary objects could be eliminated. Finally *Save* the modified picture to the same name.

### 4.5.2 Graphic Image Processing Program

Images created by the FootGrab program are digitized “photos” taken from the respondents' feet from two (bottom and side) views. The target was to produce the given sizes of feet in standard numeric form – because of the large amount of data - ordered into databases. The system realizing this target was the program FootProc.

#### 4.5.2.1 Concept of FootProc: Principles of Converting

FootGrab program created image files in 640x400 pixel resolution, within 256 gray scales. The first task was to convert this image into a monochrome (2 color) bitmap. This required a brightness threshold value, to be chosen by the user (according to the brightness of the currently processed image). The contour sharpness of feet and the presence of other disturbing light sources depended on this value. Therefore, the first factor which defined the quality of the whole converting process was this *brightness threshold*. An incorrectly selected value could introduce errors, which cannot be corrected during the following steps.
Now we had a monochromatic bitmap including the print of the feet, and other disturbing spots that came from outer lights, or from misplacing of light sources. These spots don't disturb the analyzing process until they are separated from the main object (the print of the measured feet) – they can easily be dropped off later.

The next step was to find each object on the monochrome bitmap. FootProc scanned through the entire bitmap from top to bottom, left to right direction. After various sorting and collecting processes the bit-mapped image appeared as a vectorized data stream which described the contour of all objects on the sample. The next step was selecting one object (representing the contour of the feet), which would be handled as the main object - in other words: to suppress all other disturbing objects that had not been filtered within the preceding steps. All following measuring procedure operated on this (main) object only.

There were other kind of errors, that could not be filtered during the preceding phases (Ouyang and Dwyer 1998). These errors came from placing the improperly measured foot into the Measuring Box (it is rotated at a certain angle). Thus in the next step it was possible to rotate bottom- and the side views of foot into the correct direction.

Before measuring each view, all measuring points had to be placed onto the side- and bottom view contour. The program tried to place them into their default locations, but the measuring points could be moved on the contour using the mouse. After placing all points the software calculated the described parameters (distances, angles and factors), and wrote them into a dBase compatible database file for the statistical operations.
4.5.2.2 Screen Template

The steps of analyzing and converting procedure could be stepped forwards and backwards – this method made possible to apply the trial-and-error technique for inexperienced users.

FootProc is featured with full graphic control. Necessary parameters could be changed using the mouse, but keyboard could also be used (for experienced users) to achieve higher performance when processing big amount of samples. The result corresponding to the current phase was displayed in the client area (the upper part of the screen). The lower-right part displayed information about the currently processed file/directory, while an help line could be seen in the bottom line of the screen - this displayed one-line information on the current process/context. The control buttons were located on the lower-left corner of the screen.

4.5.2.3 The Control Buttons

Figure 4.11 Control Button – Screen 1

There were four control buttons that remained on the screen: OK, CANCEL, BACK and QUIT. Button CANCEL was used to delete the last operation, while BACK returned to the previous phase of procedure.

Figure 4.12 Control Button – Screen 2
4.5.2.4 Usage of FootProc: Processing of a Sample

Usage of FootProc was a systematic application of a predefined and preprogrammed series of graphic transformation procedures with the very convenient possibility of back stepping, checking and repeating transformation phases according to the actual results. All manipulations had to be performed for bottom and for side views as well. In case of a pair of ideal pictures without photographic errors, the program provided the automatic procedure, when the operator would use only RETURN or OK buttons. Although in usual cases the image parameters were not optimal, thus some manual and semi-automatic solutions were applied. The samples captured in the same session were creating a series of files. The files followed each other automatically.

The procedure began with entering the starting file-name. This file-name later would be automatically increased supporting the file-name conventions used earlier by program FootGrab. Then a numeric factor was questioned. This factor was used for final corrections of numeric sizes retrieved from this procedure. This factor was interpreted as a calibration factor calculated from comparisons of manual and FMU measurements of samples. Finally we had to specify the name of database assigned to collect the calculated numeric values of samples belonging to the same series.

After entering (or accepting default values) of above data, the gray-scale bit-map image of bottom view would be displayed (see Figure 4.13).

4.5.2.4.1 FIRST STEP: Image Conversion: Bottom View

The first step in the image processing method was to convert 256 gray-scaled digitized image into a monochrome bitmap (Qin et al 2011). For the conversion, it was necessary to choose a brightness threshold value.
FOOTPROC first showed the image in the original color depth (Figure 4.14). Within this screen, the threshold could be chosen using the “+” and “-” keys on the numeric keyboard. Each pressing of “+” key increased, pressing “-” decreased this threshold value, and the resulting image (imitating the converted monochrome bitmap) would be displayed. (Note: the image on this screen would be displayed in half resolution than the original image.) The “ENTER” key continued with the next step. It was possible to omit the currently processed sample by pressing the “Esc” key.

Figure 4.13 Grey-scale bit-map image of bottom view

Figure 4.14 Image of the Bottom View in the original color depth
One had to change threshold value until the main object stood separated from the disturbing objects. The target was not to eliminate these other objects – they could be excluded from the following steps – because an extremely chosen threshold leads to distortion of the main object. If the main object cannot be freed from disturbing objects (or at the expense of large amount of distortion only), the sample should be excluded using the “Esc” key. (See different stages of B/W conversion in Figures 4.15, 4.16 and 4.17).

Figure 4.15 B/W Conversion of Bottom View – Stage 1

Figure 4.16 B/W Conversion of Bottom View – Stage 2
4.5.2.4.2 SECOND STEP: Dropping Off Disturbing Objects in the Bottom View

Within this phase one is able to select a rectangular area from the whole image. This is useful if the image contains objects, which are in connection with the print of the foot (this is typical to the side view images, where on the bottom half of the foot mirroring appears). Otherwise it is not necessary to use this feature, because in the next phase the main object can be easily (and in most cases automatically) separated (Zhao et al 2011).

After finishing manipulations, one should click CONTINUE button (or alternatively pressing either the “ENTER” or “C” key). This initiates the scanning procedure to find each object on the image.

One is able to return to the previous screen (to modify the threshold value if required) either by clicking BACK button using mouse or pressing the “B” key.
4.5.2.4.3 THIRD STEP: Selecting Main Object in the Bottom View

After all objects on the image are scanned, and stored separately in the object database, the main object - on which the measuring process will be performed - must be selected. This operation (in most cases) can be done automatically, since under normal conditions this object has the largest surface (Ilango and Marudhachalam 2011). When entering this screen FootProc highlights the object with the largest surface. If it is necessary to select another object, this can be done by clicking the proper object with the mouse. To leave this screen click either CONTINUE button or press the “ENTER” or “C” key.

Figure 4.18 Selection of Main Object in Bottom View

Figure 4.19 Checking Object contour in Bottom View
4.5.2.4.4 FOURTH STEP: Checking Object Contour

To get correct and exact results within the measurement, it is very important that the contour describing the main object to be clear and be free from any enclosed part object. This fact depends on various conditions that can be changed within the preceding phases of image processing (Senel et al. 2002). Therefore, after the main object has been selected during the previous step, FootProc displays the resulting contour for verifying purposes. If the contour is not 100% free from errors listed below, one must re-execute the preceding steps, make the necessary corrections, and when returned to this screen, newly inspect the contour. If the processing parameters within the preceding steps cannot be modified to ensure that the contour of the foot shape is correct, then the sample must be excluded from the first phase of analysis itself.

*It is important that one should not* continue with the measuring process (see following sections) until the contour is perfectly correct (see Figure 4.20). Otherwise, it produces false resulting values in the output database file.

![Correct final contour of the Bottom View](image)

Figure 4.20 Correct final contour of the Bottom View
4.5.2.4.5 FIFTH STEP: Correcting the Angle of Bottom View

This phase offers the possibility to correct the problem, which occurs, when a respondent's feet were placed in the wrong angle/direction into the measuring box. This operation is only important for the proper placement of the horizontal measurement axis (Rankand and Unbehauen 1992).

![Correcting the Angle of Bottom View](image)

**Figure 4.21 Correcting the Angle of Bottom View**

4.5.2.4.6 SIXTH STEP: Placing the Horizontal Axis in the Bottom View

The measuring phase requires a horizontal and a vertical axis from which all measurement originates (Pengand and Lucke 1995). The position of the vertical axis can be selected automatically, since it is placed onto the right most point of the foot. Horizontal axis must be placed manually; this can be done within this step.

On the screen appears the bottom view of the foot, the vertical axis displayed with red, and the horizontal axis displayed with white color. On the left most point of horizontal axis there is a small circle, which acts as a handler. Moving of horizontal axis is possible as follows:
- click handler on left side of the horizontal axis;
- while holding down mouse button drag axis to its proper position by moving mouse;
- release mouse button.

Figure 4.22 Placing the Horizontal Axis in the Bottom View

4.5.2.4.7 SEVENTH STEP: Arranging measuring points in the Bottom View

This step performs the final preparation of the bottom contour for automatic measurements. (It is important to remember: it is supposed to have images from the right foot, thus “inner” means left and “outer” means right when applying these phrases to bottom view.) There are nine characteristic points along the bottom contour which have to be assigned according to the following conventions:
A1 = inner heel point,  
A2 = outer heel point,  
A3 = outer shank point,  
A4 = outer ball point,  
A5 = inner ball point,  
A6 = outer small toe point,  
A7 = inner big toe point,  
A8 = small toe edge point,  
A9 = big toe edge point.  
(See also Appendix 1)

**Figure 4.23 Arranging measuring points in the Bottom View**

The measurements were performed using the coordinates of these points, therefore the proper positioning of those are very important.

**Figure 4.24 Corrected and Final Arrangement of measuring points in the Bottom View**

The program examines the bottom contour and tries to produce an automatic arrangement (Figure 4.23). This automatic configuration could be accepted only if all points are located in their proper geometric sequence (see Appendix 1) and their geometric location also fits to the appropriate characteristic foot-points detailed above. If something fails it is possible to
repair the configuration by moving the point along the contour to the proper place (Amintoosi et al 2009):

- move the mouse cursor to the point to be modified and “pick it up”;
- relocate the point by pressing continuously the mouse button;
- release the mouse button.

**Figure 4.25 Selection of Main Object in Side View**

**Figure 4.26 B/W side view with default threshold**

### 4.5.2.4.8 EIGHTH STEP: Image Conversion of Side View

In the following steps we have to repeat the operations performed earlier in case of the bottom view. The first step here also was to convert the 256 gray-scaled digitized image into a monochrome bitmap (Wang et al 2004). It is
necessary to choose a brightness threshold value. FootProc at first will show the image in original color depth (Figure 4.25). The “+” and “-” keys on the numeric keyboard are used to change the threshold setting. Each pressing of “+” key increases, pressing “-” decreases this threshold value, and the resulting image (imitating the converted monochrome bitmap) will be displayed. The “ENTER” key continues with the next step. It is also possible to omit the currently processed sample with pressing the “ESC” key.

The first keystroke of “+” or “-” will result in the display of B/W side view with default threshold (Figure 4.26). This threshold value should be changed until the main object stands separated from the disturbing objects. (See different stages of B/W conversion on Figures 4.27, 4.28, and 4.29).

![Figure 4.27 B/W Conversion of Side View – Stage 1](image)

![Figure 4.28 B/W Conversion of Side View – Stage 2](image)
4.5.2.4.9 NINTH STEP: Dropping Off Disturbing Objects in the Side View

Here we have to remove the unnecessary objects from Side View. The objects to be investigated should be bordered with a rectangle using mouse. Anything out of this border will be omitted (Lowe 1999).

Figure 4.30 Selection of Main Object in Side View

After finishing the manipulations, one should click on the CONTINUE button (or alternatively pressing either the “ENTER” or “C” key). This initiates the scanning procedure to find each object on the image.
One is then able to return to the previous screen (to modify the threshold value if required) either by clicking BACK button using mouse or pressing the “B” key.

4.5.2.4.10  TENTH STEP: Selecting Main Object in the Side View

After all objects on the image of side view were scanned, and stored separately in an “object database”, the main object – on which the measuring process are performed – must be selected. This operation (in most cases) can be done automatically, since under normal conditions this object has the largest surface (Marini et al 1999). When entering this screen FootProc highlights the object with the largest surface. If it is necessary to select another object, this can be done by clicking the proper object with the mouse. To leave this screen click either CONTINUE button or press the “ENTER” or “C” key (Figure 4.31).

Figure 4.31 Checking Object contour in Side View

4.5.2.4.11 ELEVENTH STEP: Generating Object Contour

To get correct and exact results within the measurement, it is very important that the contour describing the main object be clear and be free from any enclosed part object. This fact depends on various conditions that can be
changed within the preceding phases of image processing (Alvarez et al 1992). Therefore, after the main object has been selected during the previous step, FootProc displays the resulting contour for verifying purposes. If the contour is not 100% free from errors listed below, you must re-execute the preceding steps, make the necessary corrections, and when returned to this screen, newly inspect the contour. If the processing parameters within the preceding steps cannot be modified to ensure that the contour of the foot shape is correct, then the sample must be excluded from the first phase of analysis itself.

*It is important that one should not* continue with the measuring process (see following sections) until the contour is perfectly correct. Otherwise, it produces false resulting values in the output database file.

![Figure 4.32 Correct final contour of the Side View](image)

**4.5.2.4.12 TWELFTH STEP: Correcting the Angle of the Side View**

This phase offers the possibility to correct the geometric problems in case of wrong positioning of foot vis-à-vis its angle of placement or direction of placement (Oh et al 2001). This operation is also important for the proper displacement of the vertical (Height=\(z\)) measurement axis.
4.5.2.4.13 THIRTEENTH STEP: Placement of the Horizontal Axis of Side View

The measuring phase requires a horizontal and a vertical axis from which all measurement values are originated (Tomasi and Manduchi 1998). The horizontal position of the vertical axis will be selected automatically, since it is placed onto the rightmost point of the foot. The vertical position horizontal axis must be placed manually within this step.

When the side view of the foot appears, the vertical axis is displayed in red and the horizontal axis is displayed in white color. On the leftmost point of horizontal axis there is a small knob which acts as a handler. The horizontal axis can be moved as required:

- click handler on left side of the horizontal axis;
- while holding down mouse button drag axis to its proper position;
- release mouse button.
4.5.2.4.14 FOURTEENTH STEP: Arranging measuring points in the Side View

This step performs the final preparation of the side contour for automatic measurements (Tumblin and Turk 1999). There are ten characteristic points along the side contour which have to be assigned according to the following convention:

- P1 = heel back-point,
- P2 = heel curve-point,
- P3 = heel bottom-point,
- P4 = upper instep-point,
- P5 = ankle curve-point,
- P6 = upper waist-point,
- P7 = lower waist-point,
- P8 = upper ball-point,
- P9 = lower ball-point.
- P10 = upper big toe-point.

(See Appendix 1)
The measurements are performed using the coordinates of these points, therefore the proper positioning of those are very important. The program analyzes the side contour and tries to produce an automatic arrangement (Figure 4.35). This automatic configuration could be accepted only if all points are located in their proper geometric sequence (see Appendix 1) and their geometric location also fits to the appropriate characteristic foot-points detailed above. If something fails it is possible to repair the configuration by moving the point along the contour to the proper place:

- move the mouse cursor to the point to be modified and “pick it up”,
- relocate the point by pressing continuously the mouse button,
- release the mouse button.

Figure 4.36  Corrected and Final Arrangement of measuring points in the Side View

4.5.2.4.15 FIFTEENTH STEP: The Automatic Measurement

The fifteenth step is the measurement itself. During earlier phases the program generated the two contours, and nine points on the bottom view
(A1, ..., A9) and ten points on the side view (P1, ..., P10) were positioned. These points have their own graphic/geometric coordinates in three dimensions (x, y, z). It is possible to calculate the distances between two points, to calculate additional coordinate values, angles, lengths etc. using these geometric data. Thus the automatic measurement procedure is a set of mathematical calculations using the co-ordinates of characteristic points of the foot. Calculations also include the application of transformation factor entered on opening of the screen of FootProc. This factor transforms the screen coordinates to millimeter coordinates (Canny 1986). This factor’s value is a result of calibration measurement to be performed after each new installation of FMU.

Program FootProc performs automatically all the calculations described in Appendix 2. In case of each unique measurement the calculation results are collected into one data-record which is written into the selected database (their structure is given in Appendix 3).

For exact interpretation of variables represented by different FIELD_NAMES: see Appendix 3). Each variable has its own geometric and mathematical meaning, and all values are stored as millimeters. The precision of calculations preserves the precision of images i.e. should be under one millimeter.

The flowchart of FootProc is shown on Figure 4.37.
4.5.3 Graphic and Numeric Data Elaboration Procedure

Figure 4.37 Flowchart of FootProc Program
The so called numeric data collected by the manual entering of data into FootDat program (see paragraph 3.1) were stored in different kinds of databases. As it was described in paragraph 3.2 the so called graphic data, i.e. the data with graphic origin from FootGrab and FootProc were also collected into databases. The two groups of data are chained through the CODE field containing the barcode identifying the investigated persons. In the following phase of survey we have to handle these two groups of data together. To realize this unity there are two procedures necessary to proceed: rough filtering and structural joining.

4.5.3.1 Filtering and Sorting

The measurement procedure produces many kinds of inconsistencies which will appear in the contents and in the form of retrieved data. The causes of errors are very different. E.g. the measurement could be successful but the data stored on hard drives or digital tapes are not readable again, or the measurement was done but the resulted picture’s quality is not compatible with the system, etc. (Simoncelli 1997). The typical main errors are the following:

Missing Numeric Data Field

Could appear in case of numeric data only, e.g. operator forgot to measure or enter some data. If optional data fields are missing the record still remains useful. However, in the case of missing the main data field we have to omit the record.

Missing Graphic Data Field

Could appear in case of graphic data only, when one of the views namely bottom or side view was an absolute wrong picture but the operator forgot to omit i.e. to ‘step over’ the record by pressing “ESC”. In this case the strange or incomplete results produced by automatic calculations will be omitted.
Missing Numeric Data Record Pair

This is the case when the graphic data belonging to a given CODE exists, but the appropriate numeric data record is missing. The graphic data record has to be omitted, in this case.

Missing Graphic Data Record Pair

This is the case when the numeric data belonging to a given CODE exists, but the appropriate graphic data record is missing or wrong. The numeric data record has to be omitted, in this case.

Redundant Data Record Pair

This case could occur when the same barcode identifier was applied more than one time during the same survey: there are two or more numeric or graphic data records belonging to the same CODE value. The records must be studied and the best data record pair will be selected, the others will be omitted.

The procedure of filtering the records belonging to any of above errors have to be performed in a database program environment. Using e.g. dBase, FoxPro or Clipper these databases are indexed on the field CODE establishing a direct relationship between them. The following step is the data comparison and elimination of errors.

4.5.3.2 Merging Graphic and Numeric Data

After the filtering procedure, the data of two groups are ready to be merged. After having indexed both databases by ascending CODE field they are merged (Tsin et al 2001). The resultant database will contain all the data necessary to start the statistical investigations.