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Integration of Close Range Photogrammetry and Expert System Capabilities in order to Design and Implement Optical Image Based Measurement Systems for Intelligent Diagnosing Disease

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Abstract

In medical applications and disease diagnosis devices, image is considered as a tool for measurement and data acquisition. Most of the imaging methods usually used in medical applications are invasive and have several side effects on human body. So, other types of image based measurement systems should be developed for medical applications. The systems must be able to use the images captured in visible part of the electromagnetic spectrum. In this research a new image based disease diagnosis method has been developed which uses optical images for measuring required symptoms. In the systems which are implanted based on the suggested method measurement capabilities of close range photogrammetry and decision making ability of expert system are integrated. The integrated system can be used for the diseases whose symptoms are visible or appear as deformations out of body and around the affected area. For evaluation of the suggested method, an integrated system has been designed and implemented for intelligent diagnosing foot deformity.

Keywords: Disease diagnosis, Expert system, Integrated system, Medical image, Measurement, Photogrammetry.

1-Introduction

Measurement plays an important role in medical applications [1]. In medical applications and disease diagnosis devices, image is considered as a tool for measurement and data acquisition. Using images and their interpretation in medical sciences is known as a beneficial and valuable tool in a way that nowadays medical imaging is mostly used and the best tool for disease diagnosis. According to increasing requirements in this field and software and hardware developments, presented methods and devices are being improved. The methods such as Computer Tomography (CT), Magnet Resonance Imaging (MRI), Color Doppler Ultrasound (US), Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET are only capable of capturing 2D images) [2]. In some cases it is essential to reconstruct 3D model of desired location in the body. So, methods such as 3D Ultrasound [3] ,Space encoding projector [4], Laser scanning [5-9] and X-ray [8] are used. Most of these methods are useful for the cases such as examination of internal parts of body or bone inspection in which unequipped eye can not see the affected area.

In some diseases related to outer parts of body, although medical experts can fully see the site for examination, according to some limitations such as inability to direct contact, inability to do precise measurement, etc, it is necessary to develop a method which could be able to process the images captured at visible part of electromagnetism spectrum. The method suggested to overcome the problems is Close-Range Photogrammetry (CRP) which is capable of generating accurate and precise 3D model of an object using overlapped images.

In the image-based medical diagnosis instruments, interpretation of acquired images is an important step. Usually, interpretation process is carried out by human experts who do it based on their knowledge and experience. According to developments in the field of intelligent systems, using the capabilities of these systems can improve the interpretation process of medical images. One of the systems can be used for intelligent interpretation of medical images is Expert System. Expert system is capable of decision making using human expert's knowledge and is used as an intelligent decision making unit in a medical devices [10].

Recently, some investigations have been carried out in the field of integration of medical imaging and expert system capabilities for disease diagnosis [11-13].

According to the measurement capabilities of close range photogrammetry as a data acquisition method and expert system abilities as an intelligent decision making system, the main idea in the research is to suggest an image based medical diagnosis method by integration of these systems which can be useful in clinical environments for non-expert operators. In the system designed and implemented based on the suggested method in this research, accurate measuring of 3D coordinates of selected points around the area which includes the symptoms is used instead of direct examination of the affected area. 3D model generated using the measured points is processed and analyzed by the expert system and the disease is diagnosed intelligently.

2. Background

2.1. Close-range Photogrammetry

Close range photogrammetry is a high precision 3D spatial data capture technique using 2 or more images of scene [14]. Its basis is triangulation, whereby intersection of converging rays in space is used to determine the position of points in all three dimensions. To do so, the orientation of cameras for each captured image is needed. The orientation parameters of cameras are calculated through resection process. To be able to run this process, at least 12 well-disturbed points on each image are needed. Some advantages of close range photogrammetry as a measurement technique are:

- It is a non-contact, non-invasive and instantaneous technique (synchronized for all measurements)
- It offers high-accuracy measurements
- It provides possibility of measuring any number of points on the object [9]
- It provides possibility of a fully automatic measurement [15]
- It uses optical images which are remotely taken and has no side effect to the human organism [16]

According to the advantages and capabilities of the close range photogrammetry, nowadays, one of the special domains which it is applied, is medicine. In this application, the subject of imaging is human and the method called Medical Photogrammetry. The aim of medical photogrammetry is to assist in health matters. It usually is used to diagnose a disease or monitor its effects. It also is applied to prevent diseases which are probable during sports and ergonomic studies [17].

2.2. Expert System

Expert systems are computer programs designed to emulate the work of experts in specific domains of knowledge. An expert system stores the knowledge and uses it to make decision.

An expert system has 4 main elements as follows[18]:

- knowledge-based (KB)
- Inference engine
- Explanatory interface
- Knowledge acquisition module

Knowledge base is the most important part of an expert system and as mentioned in [19], power of an expert system depends on its knowledge base. The knowledge after acquisition in specific domain is stored and represented in the knowledge base as rules. The rules are used as the representation of knowledge in the knowledge base [13]. The inference engine analyses and interprets the stored knowledge. Explanatory interface is the part of an expert system which user can interact with system, enter questions about a problem and get the responses of the system. Knowledge acquisition module allows the user to enter new knowledge to the knowledge base and develop its knowledge domain. Figure 1 illustrates relations between elements of an expert system.

Figure 1: Main structure of an Expert System

Medical Expert System is a common type of intelligent systems in medical applications. The knowledge of a medical expert system is usually defined in a limited specific domain. So, as a medical expert, a medical expert system can make decision about limited domain of diseases.

3. Integration of Close Range Photogrammetry and Expert system for Medical Applications

The suggested system needs 3 main sections in order to have an acceptable responsibility during disease diagnosis process. These sections are:

1) Data Acquisition section for getting required data from affected area
2) Data processing section
3) Decision maker section

In order to increase the system capability, avoid any user error and diagnose a disease instantaneously, these sections should be integrated. Interoperability is an important factor which should be considered in the integration of these sections. Interoperability is the ability of two or more hardware or software components to directly cooperate or communicate despite of their differences in programming language, interface and execution platform. As a new constraint in selection of the system sections, each section of the system should be able to co-operate with other sections. For example each section should support other sections input/output format. Development of a successful interoperability strategy requires standardization that provides channels and formats needed for direct exchange of data and information [20]. Component Object Model (COM) which its technical characteristics have been explained in [21] is a standard enhances software interoperability by allowing different software components to communicate directly. So, in this research, COM is used to integrate the needed systems and provide a high level interoperability between the integrated system components. Using COM for integration of several systems requires that the systems and the programming language used for implementation of the interface system, support this standard [22].

This system has been suggested for use in clinical environments and by non-expert operators, so design and development of a user friendly interface is very important [23]. Visual Basic (VB) programming language supports COM and is very flexible for establishing relations with other software environments [24]. Therefore, in this research, VB can be applied for implementing the interface system. In the following sections, the method of choosing appropriate tools for implementing each part of the integrated system has been explained

3.1. Data Acquisition Section

In order to choose an appropriate technique for implementation of the data acquisition section, 4 following factors should be considered:

-using the system should be simple enough for non-expert operators at clinical environments

-the system should be affordable

-the system should be safe for patients and has no side effect on human body

-the system should be capable of reconstructing 3D model with high accuracy and precision

According to the advantages of close range photogrammetry which were explained in previous sections, close range photogrammetry can be used for implementation of the data acquisition section in the integrated system.

3.2. Data processing section

After obtaining data, a data processing section is needed to prepare acquired data, do required measurements and make them understandable for decision maker section. This section also should have the following capabilities:

- Supporting output format of close range photogrammetry
- Supporting COM standards
- Transferring processed data to show interactively for operators

According to the capacities of CAD environments [25-26], using an standard CAD environment such as AutoCAD or Microstation can meet the needs.

3.3. Decision-maker section

The disease diagnosis section needs a system which could detect input data, play the role of a medical expert and fulfill several expectations such as:

- Containing enough rules to support decision making process
- Doing complicated inferences using simple rules
- -Supporting fuzzy rules
- Answering user questions and explaining the results

One of the useful systems in this field is expert system which is interesting for researchers in medical applications [27] and can be utilized as the decision maker section in this research. For implementation of the decision maker section, three tools include:

- Artificial intelligence programming language
- Expert system shell
- Expert system developing environment

can be used. Artificial intelligence programming language is more flexible than the other implementation tools [18]. So, it is a good choice for implementation of the decision maker section.

Main architecture of the suggested system is shown in figure 2.

Figure 2: Main architecture of the suggested system

4. Implementation and Evaluation of the Integrated System

As discussed in the previous sections, the suggested system is a medical diagnosis system. Its application is disease diagnosis and proposing some comments to cure the disease. This system is applicable for different types of medical problems chosen according to imaging system characteristics.

In data acquisition section of the system, imaging operation is carried out in a visible part of the electromagnetic spectrum. So, the integrated system can be used for the diseases whose symptoms are visible or appear as deformations out of body and around the affected area.

A group of disease with such characteristic is deformity. Deformity is a type of disease in which a part of the patient's body changes from its healthy and natural form and in some cases it can cause physical and visible changes out of the body.

One of common deformities is foot deformity. So, in this research, it has been selected for implementation and evaluation of the integrated system based on the suggested architecture.

Flat foot deformity has some visible changes and abnormalities on [28-29]:

1. Heel : The valgus deformity of foot
2. Arch : The longitudinal arch is lower or higher than standard mode
3. Forefoot : It shows abduction
4. Outer side of foot: Usually some deformities appear in this part

In the following sections, steps of the system implementation and evaluation have been explained.

4.1. Acquiring desired data from patient

The first step is to implement the data acquisition section of the system for generating 3D model of the selected organ (foot). The most important hardware in this step is an appropriate camera for capturing needed images. A non-metric digital camera was used to capture the images. The camera specifications are introduced in table 1

Table 1: Specifications of the digital camera used to capture the images

Data acquisition process can be summarized in the four following steps:

1. Camera calibration
2. Network design
3. Capturing the images
4. Generating 3D model

Camera Calibration: The internal parameters of the camera including distortion parameters were determined as off-line using a 2D portable target sheet with white background and black targets (Figure 3). 12 convergent images (4 of them by +90 degrees rotation and 4 by -90) of the targets were captured for calculating the calibrated focal length, the coordinates of the principle point and the parameters describing the distortion of the lenses. After capturing the images, interior and exterior orientation parameters of the camera were calculated using bundle adjustment method. Result of the camera calibration process is shown in table 2. The principal of the method has been described completely in [30-32].

Figure 3: Target sheet with 100 targets including 4 coded targets

Table 2: Result of Camera Calibration Process

Network Design: The first step in network design is to design targets according to desired accuracy. In this case study, the foot was targeted using a black marker. Targets were circles with 2mm diameter. The key areas of foot (around heel, forefoot and arc) were covered with the targets. Also, some coded targets were installed around the feet. In order to set scale for the model, a scale bar was put in the scene. Six positions were considered for imaging in a way that the angle between sight lines from two adjacent stations became about 60 degrees and maximum distance between camera and the subject became 50cm.

Capturing the Images: If we have enough cameras, required images from all selected positions should be captured simultaneously. Synchronizing between the cameras can be carried out using the tool called frame grabber. Four sample images are shown in figure 4.

Figure 4: The sample images

Generating 3D model: 3D coordinates of the targets were calculated using bundle adjustment method and 3D model of the foot was generated based on the targeted points (Figure 5). In order to have better vision and make the model understandable, some lines and surfaces were added to the 3D points cloud using CAD environment tools. The overall RMSE of the project became 0.51mm which was appropriate for measurements needed in this case study.

Figure 5: 3D model of the foot generated based on the targeted points

4.2. Standard CAD Environment

The model generated by data acquisition section is ready for measurement. According to the disease symptoms, required elements which should be measured on the model are determined. The elements can be determined intelligently by decision maker section of the system using the knowledge stored in the knowledge base. For automatic measuring the determined elements, intelligent measurement tool are needed. These tools are not available in CAD environments. So, some intelligent measurement tools must be developed in CAD environments

In this case study AutoCAD was utilized as a standard CAD environment. AutoCAD supports VB programming language for developers of the CAD systems. By the use of VB and internal functions of AutoCAD, an intelligent measurement tool was implemented. The tool measured needed lengths such as foot length, foot mid-length, foot height, etc automatically. Operation of the developed measurement tool is shown in figure 6.

The algorithm used to implement the intelligent measurement tool consists of the following steps

1. A 3D model of foot containing key points has been stored in CAD environment as a standard template.
2. A cloud of 3D points of the foot is generated using the targeted points.
3. The points of the template are associated to the points of the point cloud by the nearest neighbor criterion.
4. Transformation parameters are estimated using mean square cost function.
5. The Points of the template are transformed using the estimated parameters.
6. Previous steps are iterated from step 2 while geometric difference between transformed template and the point cloud is greater than pre-defined value.
7. Distances between key points of the transformed template are calculated as outputs of the intelligent measurement tool.

Using coded targets for key points on the foot, there will be no need to implement the intelligent measurement tool.

Figure 6: Operation of the developed measurement tool in AutoCAD environment

In this case study, the knowledge which is the base of decision making process, is fuzzy. So, the next step was fuzzification of the measurements. By fuzzification, the measured data was translated to the expert system understandable language. This step was carried out using fuzzy logic which is based on Lotfi zadeh's theory of fuzzy sets [33].The application of fuzzy sets and logic is fundamental if one wishes to model common terms involving vagueness or imprecision. Modifiers such as very and more, control the amount of vagueness and such terms are frequently used in natural language [13]. Fuzzy logic is a representation method for uncertain or vague notions which are common in medical applications.

There are no exact domains for flat foot deformity measurements. So, in order to avoid any unsolvable vagueness in diagnosis process, fuzzy logic was used. As discussed in section 4, four parameters are considerable in flat foot deformity: heel, longitual arc, forefoot and outer side of foot. In addition to these parameters, another parameter called "arch height ratio index" should be considered to have more precise diagnosis. To calculate the arch height ratio, foot height in the middle of foot length should be divided by the foot length [34]. For fuzzification process these parameters were considered as fuzzy variables and for each parameter fuzzy values were assigned (Table 3).

Table 3: Fuzzy Values for foot deformity parameters

In the case study, the fuzzification process was carried out based on collecting observations about different feet and doing the same process on them. Figure 7 illustrates the output of this section stored in a file and includes fuzzy information about a patient.

Figure 7: Fuzzy information about a patient

4.3. Decision making process

The main sources for developing knowledge base of the expert system are the knowledge and experience of human experts and published sources. In order to obtain required knowledge, a set of interviews organized with medical experts. Most of the knowledge acquired during the interviews had been expressed in human language which was not utilizable directly in the expert system. There are several knowledge extraction methods which one of the common methods is Cognitive Task Analysis (CTA) and was used in the case study. Its focus is on describing the representation of the cognitive elements which define goal generation and decision-making. It is a reliable method for extracting human knowledge because it is based on the observations or an interview [23].Through knowledge engineering process, useful and basic knowledge was extracted and became ready to represent as rules in the form of "If (condition) Then (conclusion)". For instance, in figure 8 the rule named "condition" describes that:

IFpatient's

Fore foot is deviated high and

Longitual arc is healthy and

Heel is healthy and

OuterSide of foot is healthy and

AHR Index is moderate Then The condition is m6

In KB, m6 = "The patient has problem in fore foot and there is no sign of flatfoot deformity."

Figure 8: Representation of knowledge in the knowledgebase in the form of "If ... Then..."

In the case study, fuzzy inference method was used for decision making process base on the fuzzy knowledge stored in the knowledgebase. The output of fuzzy inference process is a set of fuzzy values (with 5 members) for which difuzzification process should be done.

The rules stored in KB are two types: first the rules which are used to diagnose disease and second the rules which are used to propose some comments for patients and make some predictions about upcoming situation of the disease.

4.4. The System Evaluation

In order to test the integrated system and evaluate the sub-sections operation in related to each other, ten patients were chosen: five male and five female. After targeting their feet, from six positions of the designed network the required images were captured and 3D models of the feet were generated and processed by the integrated system. The results have been shown in table 3.

Table 4: Results of the system evaluation

5. Conclusion

Integration of image based measurement methods and expert systems is a good approach for developing and utilizing artificial intelligence and intelligent systems in medical applications. Close range photogrammetry as an image based precise measurement method can be used to improve disease diagnosis capabilities in different applications of medical science. The system designed in this research, is a semi-automatic intelligent diagnosis system and can be used for the diseases whose symptoms are visible or appear as deformations out of body and around the affected area.

Implementation and evaluation of the integrated system based on the suggested architecture during the selected case study shows that:

- Close range photogrammetry and the intelligent measurement tools developed in CAD environment provide required accuracy for measurements needed in disease diagnosis.
- Integrating capabilities of image based measurement methods and expert systems for developing medical devices, simplifies utilization of the devices, increases the automation level and reduces the need for a permanent presence of experts in clinical environments.
- The system shows perfect performance about most patients. But there are some exceptions that the system is unable to make true decision about them. Studying the exceptions and finding solutions for managing them can cause to improve the system performance and prevent form next bugs.

Acquiring and engineering knowledge about other diseases whose symptoms are visible or appear as deformations out of body and also developing new intelligent measurement tools in CAD environment according to the requirements of diagnosis method of the diseases are suggested for future studies.

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Figure 1

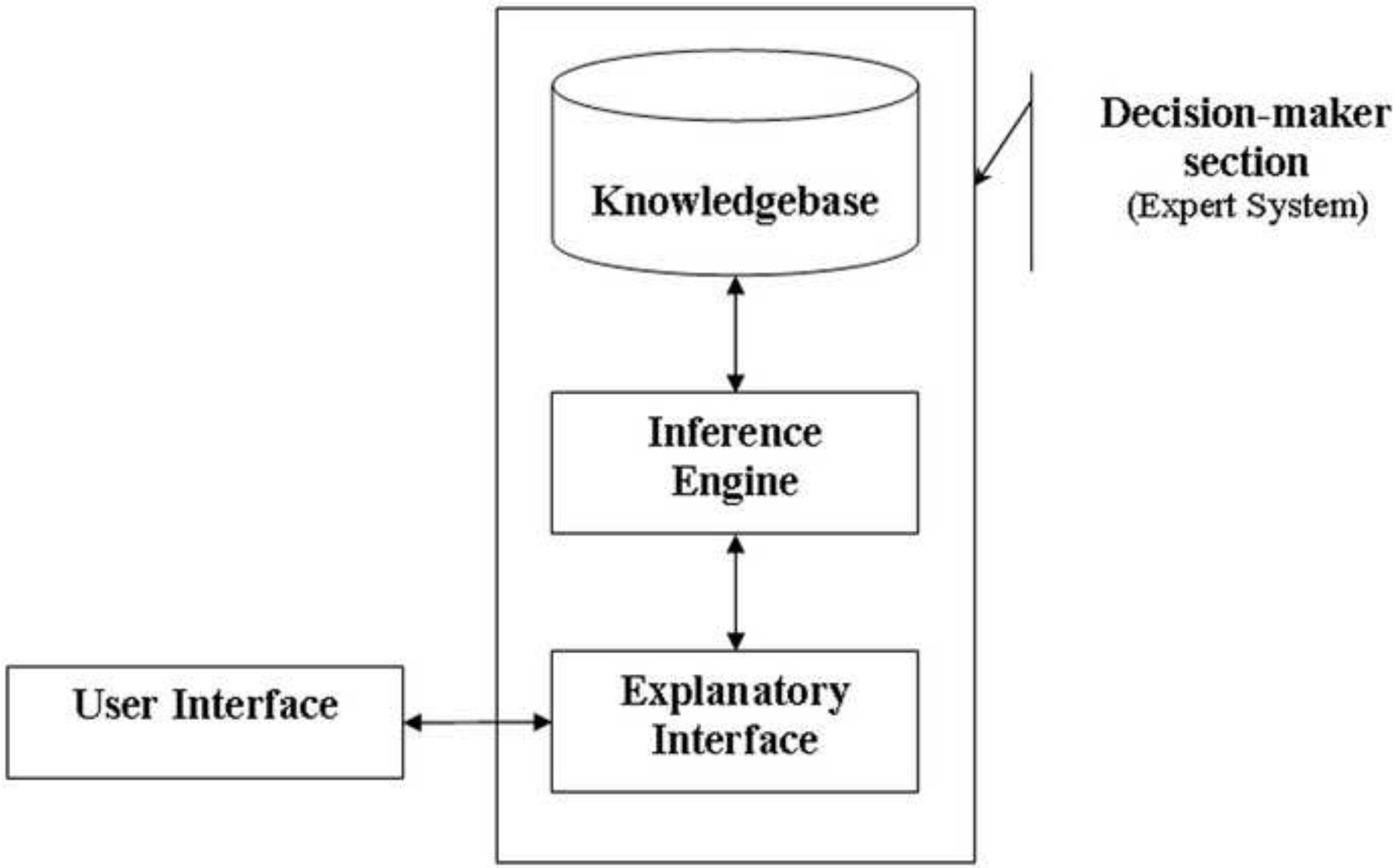

Knowledgebase
Inference Engine
Explanatory Interface
User Interface
Decision-maker section
(Expert System)

Figure 2

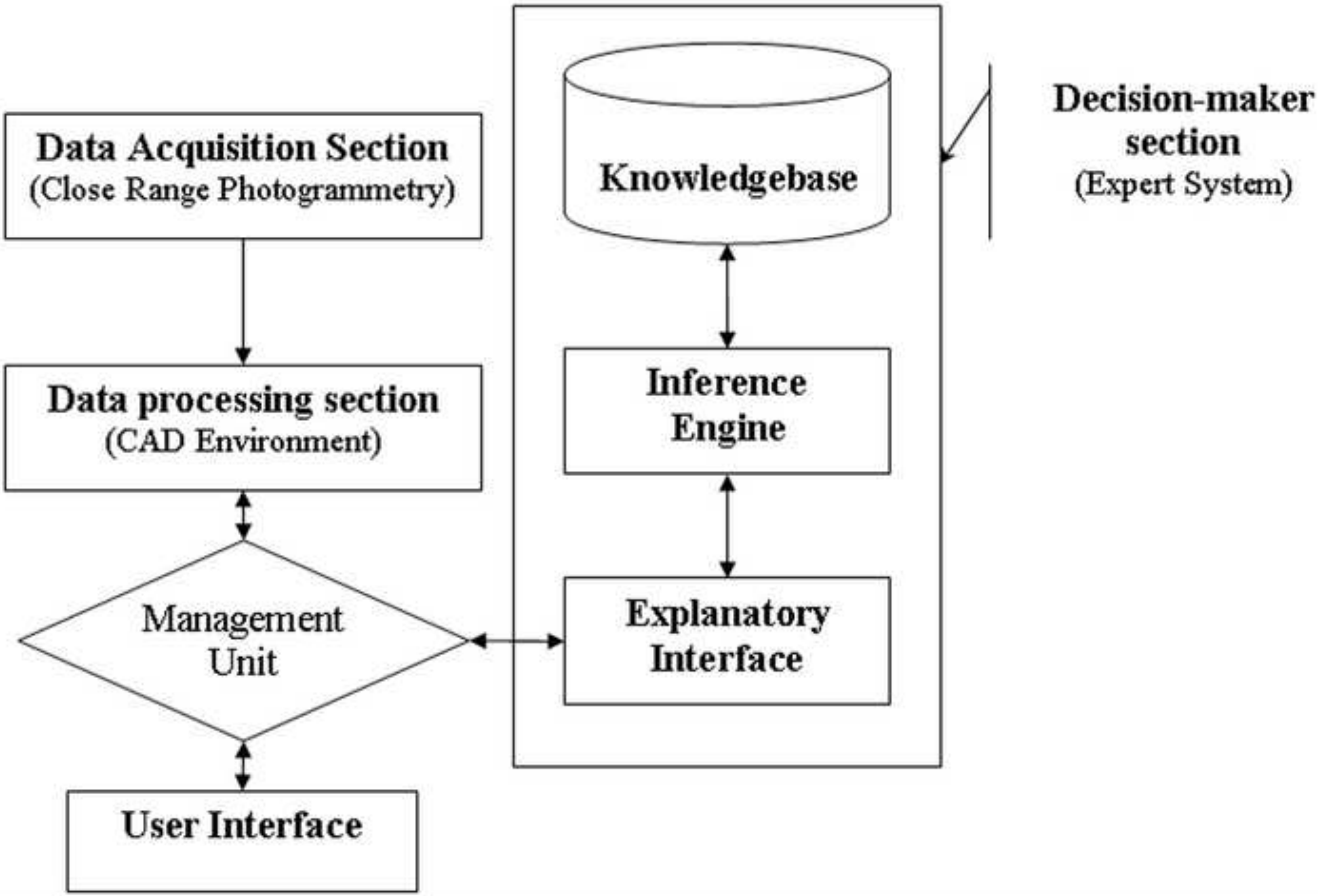

Data Acquisition Section
(Close Range Photogrammetry)
Data processing section
(CAD Environment)
Management
Unit
User Interface
Knowledgebase
Inference
Engine
Explanatory
Interface
Decision-maker
section
(Expert System)

Figure 3

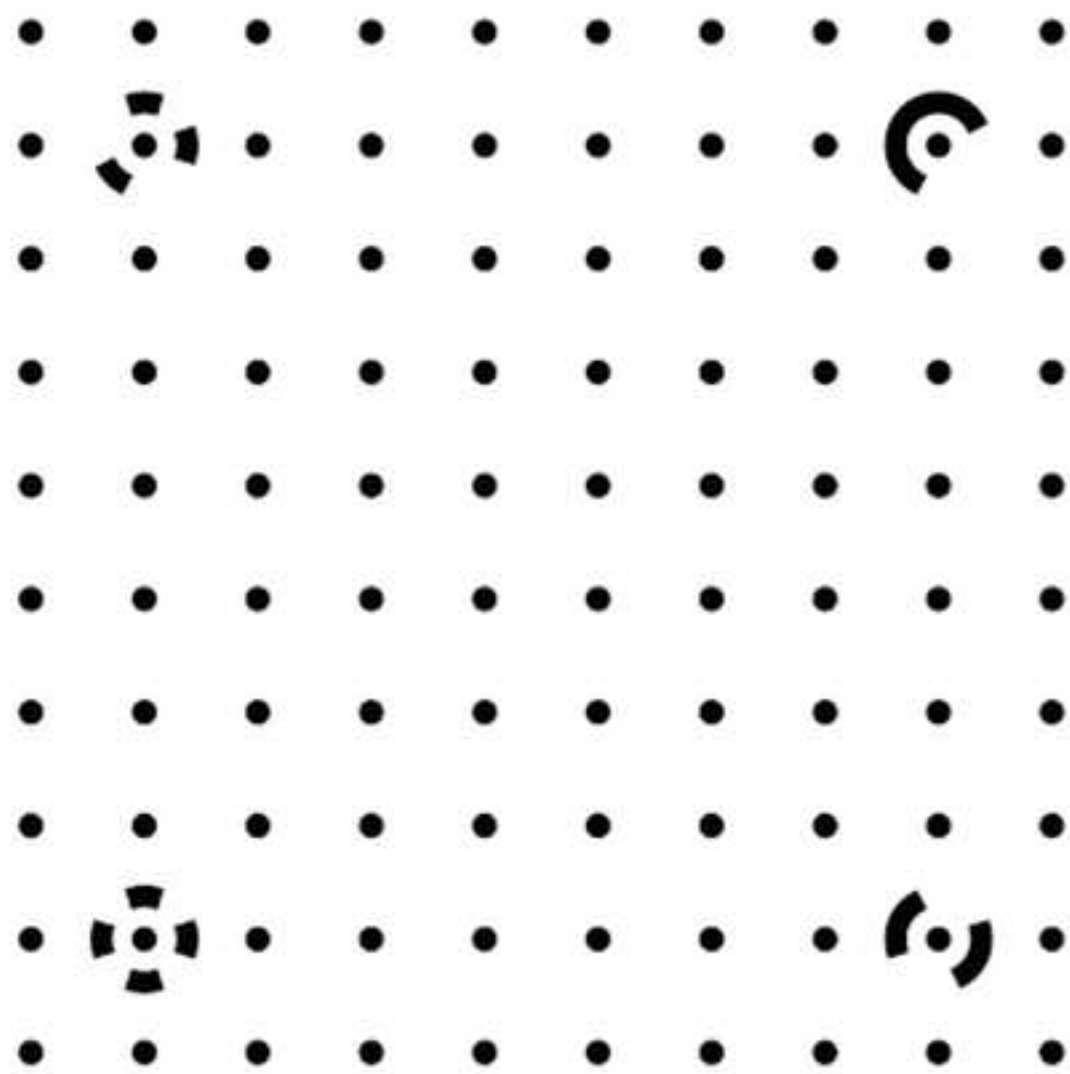


Figure 4

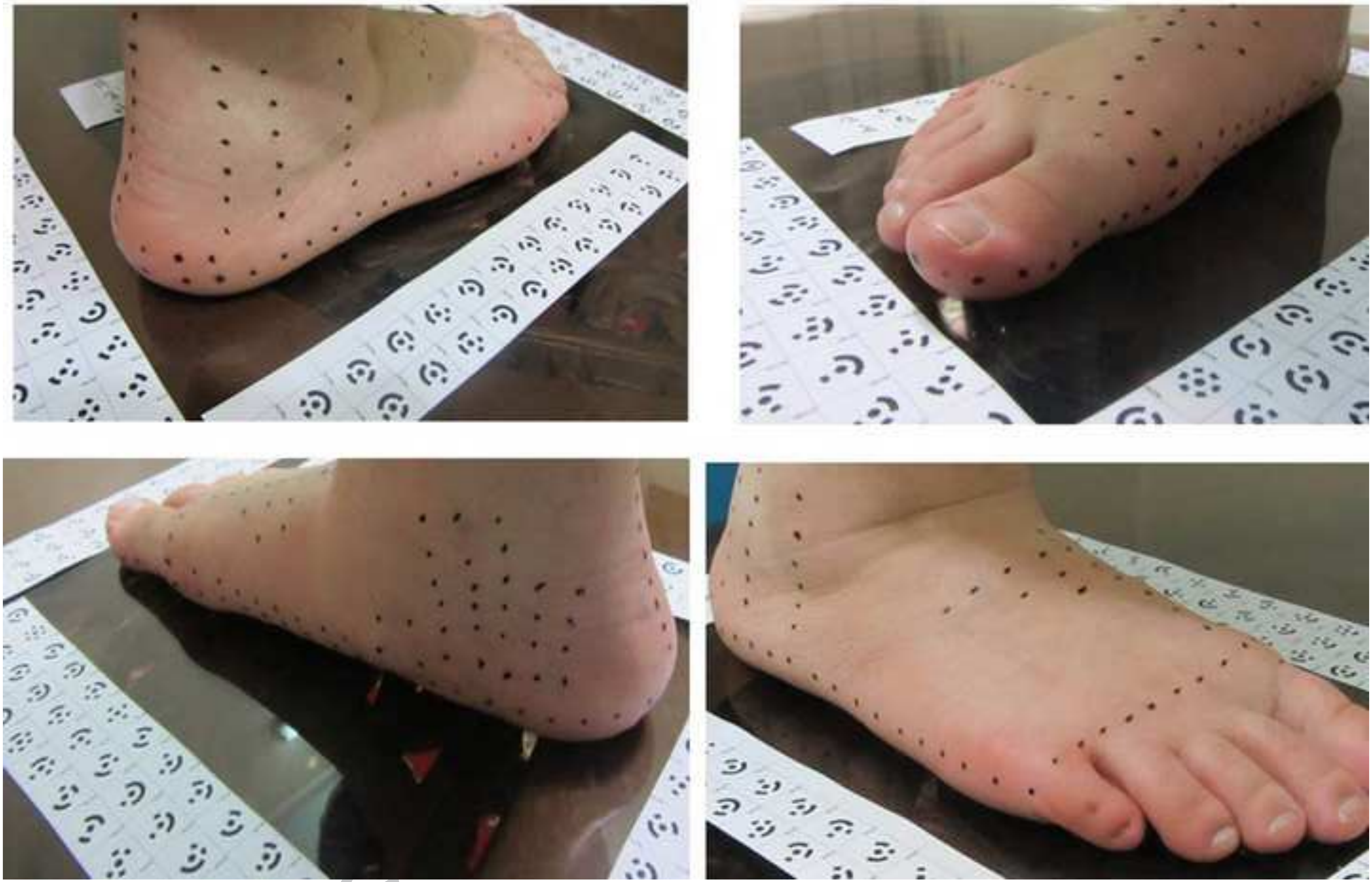


Figure 5

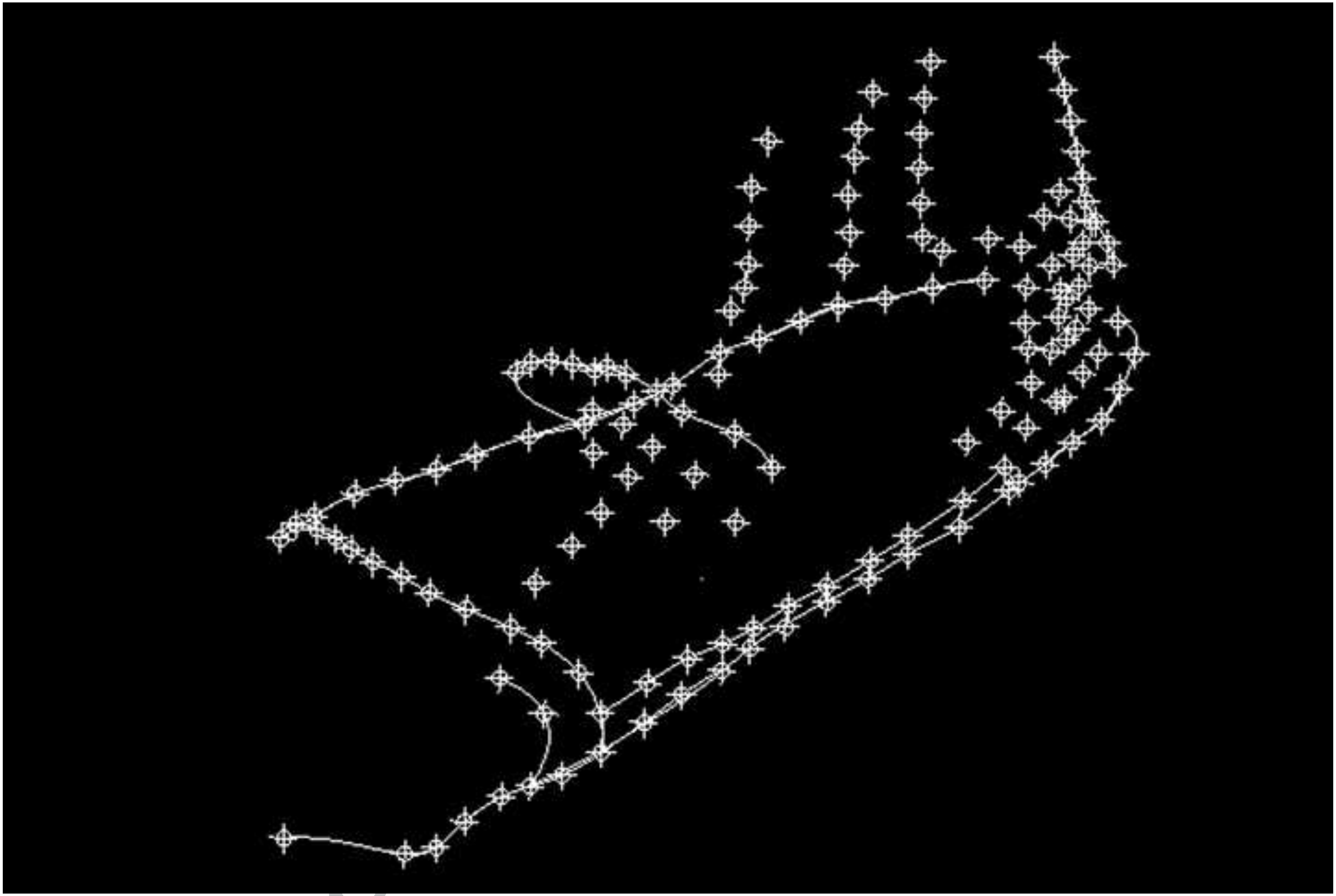


Figure 6a

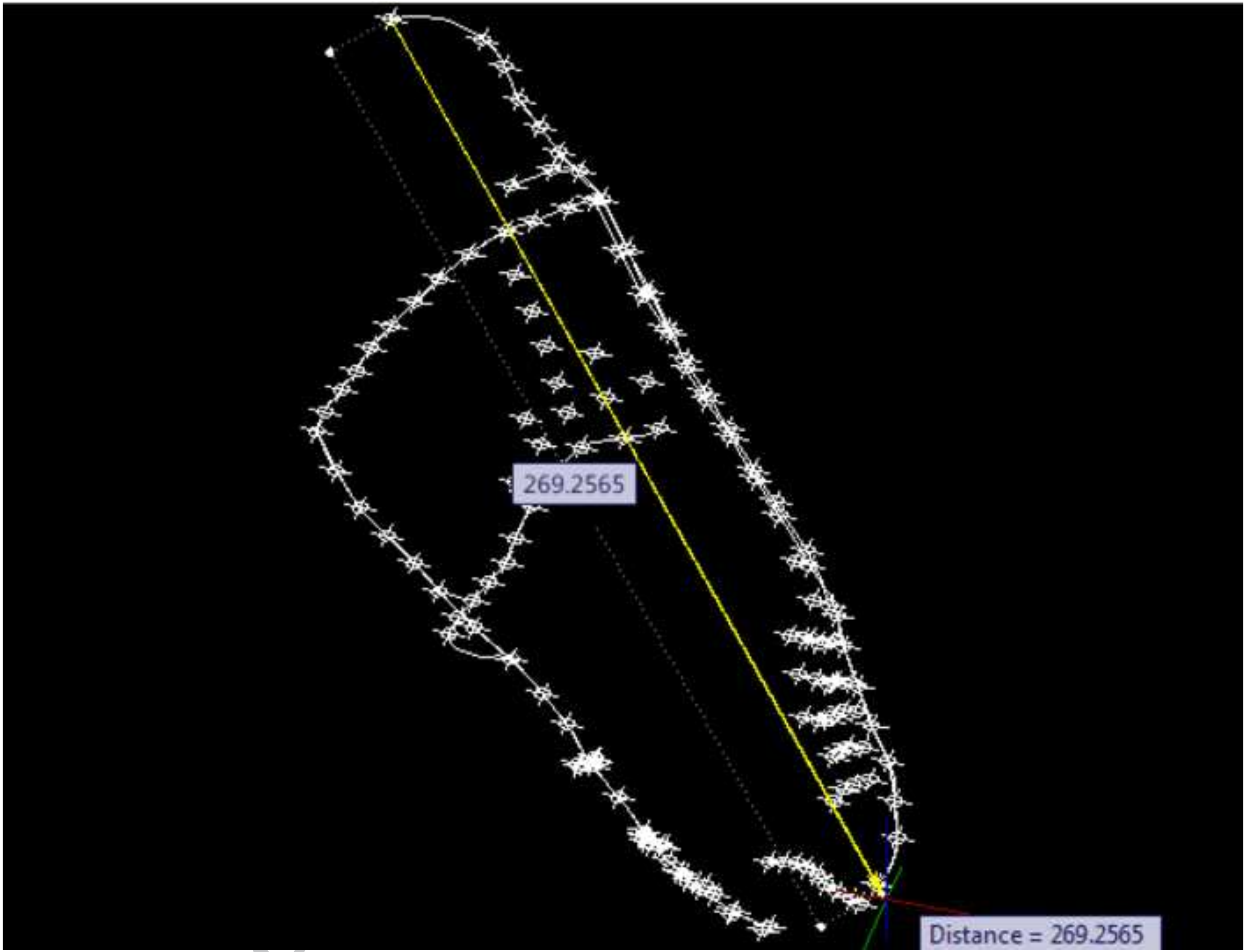
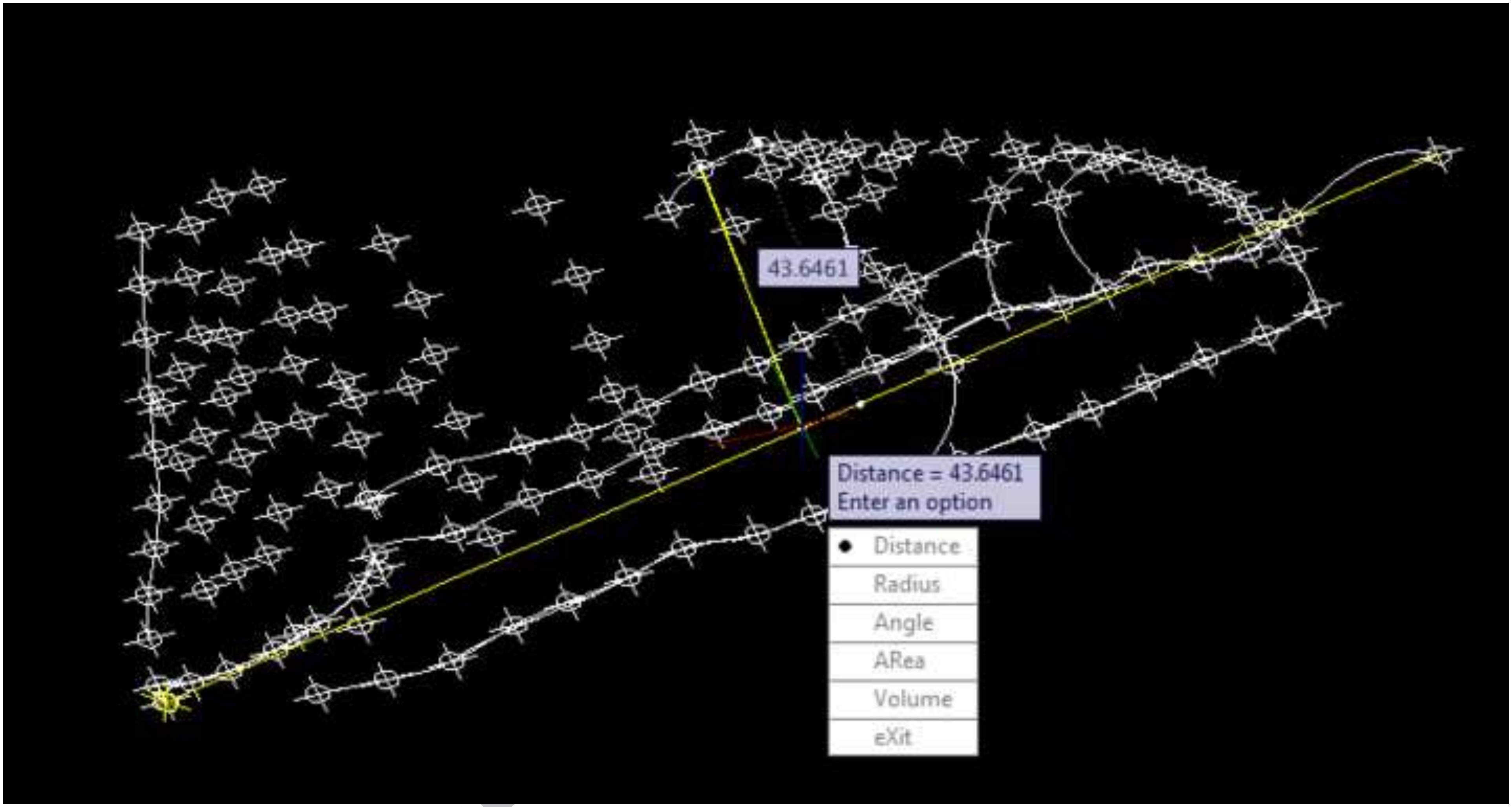


Figure 6b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Enter an option
Distance
Radius
Angle
ARea
Volume
eXit

Figure 7

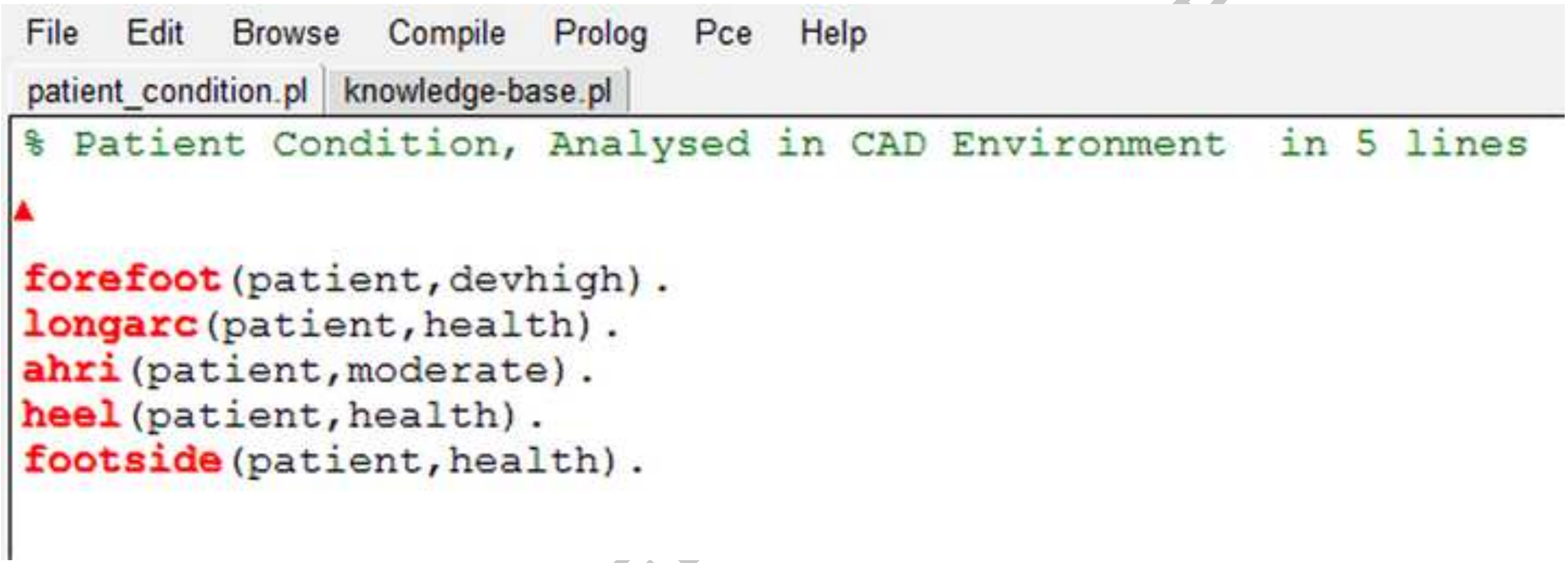
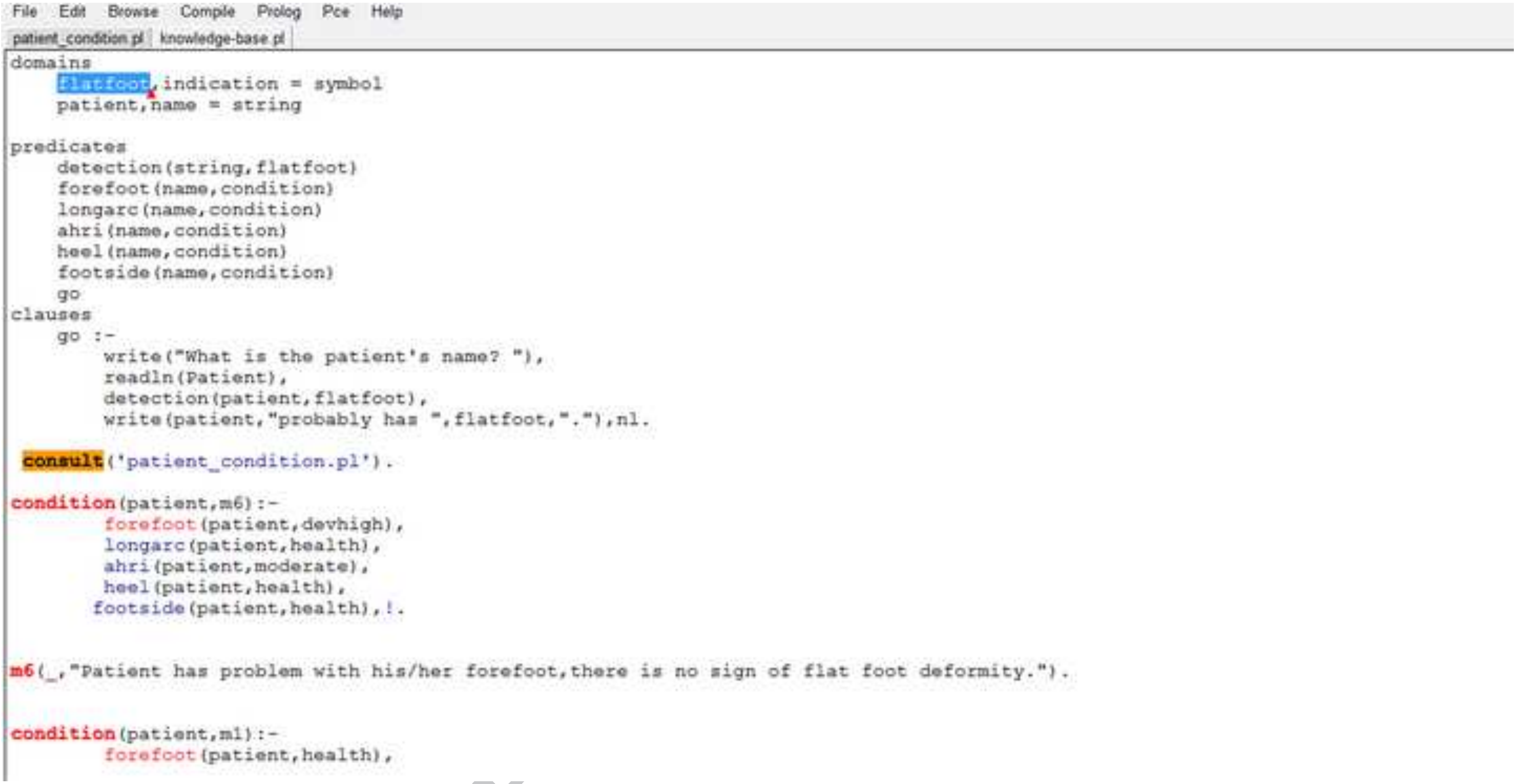

File
Edit
Browse
Compile
Prolog
Pce
Help
patient_condition.pl
knowledge-base.pl
% Patient Condition, Analysed in CAD Environment in 5 lines
forefoot(patient,devhigh).
longarc(patient,health).
ahri(patient,moderate).
heel(patient,health).
footside(patient,health).

Figure 8




```
domains
    flatfoot,indication = symbol
    patient,name = string

predicates
    detection(string,flatfoot)
    forefoot(name,condition)
    longarc(name,condition)
    ahri(name,condition)
    heel(name,condition)
    footside(name,condition)
    go
clauses
    go :-
        write("What is the patient's name? "),
        readln(Patient),
        detection(patient,flatfoot),
        write(patient,"probably has ",flatfoot,"."),nl.

 consult('patient_condition.pl').

condition(patient,m6):-
        forefoot(patient,devhigh),
        longarc(patient,health),
        ahri(patient,moderate),
        heel(patient,health),
       footside(patient,health),!.


m6(_,"Patient has problem with his/her forefoot,there is no sign of flat foot deformity.").


condition(patient,m1):-
        forefoot(patient,health),
```

Table 1

Camera Specifications	
Name	Canon
Model	SX230 HS
format size	6.1976×4.6482
focal length	5mm

Table 2

Parameter	Value	Deviation
F - Focal Length	5.136029 mm	6.6e-004 mm
Xp - principal point x	3.006705 mm	7.3e-004 mm
Yp - principal point y	2.254518 mm	8.3e-004 mm
K1 - radial distortion 1	1.164e-003	2.0e-005
K2 - radial distortion 2	-7.818e-006	1.6e-006
K3 - radial distortion 3	0.000e+000	
P1 - decentering distortion 1	1.467e-003	9.7e-006
P2 - decentering distortion 2	-6.603e-004	1.1e-005

Table 3

Parameters-fuzzy variables	Fuzzy values
Heel	Healthy Deviated: • Low • Medium • High
Forefoot	Healthy Deviated : • Low • Medium • High
Outer side of foot	Healthy Deviated : • Low • Medium • High
Longitual arc	Healthy Deviated : • Low • Medium • High
Arch height ratio index (AHR Index)	Slight Fair Moderate Substantial Almost perfect

Table 4

Patient Number	Gender	Result of Process	Solution
1	Male	The RMSE of the measurements exceeded the standard value	The model generation step was repeated more precisely
2	Male	The process was completed with no problem.	-
3	Male	The process was completed with no problem.	-
4	Male	The process was completed with no problem.	-
5	Male	The process was completed with no problem.	-
6	Female	The system was unable to distinguish the different points on the model	The points were coded in the model generation step
7	Female	the heel was detected as “Deviated-High”, which was not true according to the expert idea	The reason of the problem was in the targeting stage. The number of targets on the heel was more than enough, so the points had some displacements and it had affected the RMSE of the measurements. So, some of the targets were removed according to size of the heel.
8	Female	The process was completed with no problem.	-
9	Female	The process was completed with no problem.	-
10	Female	The process was completed with no problem.	-

Highlights

- In this research a new image based disease diagnosis method has been developed.
- This method uses optical images for measuring required symptoms.
- The symptoms must be visible or appear as deformations out of body.
- In the method, measurement capabilities of close range photogrammetry are used.
- For test, an integrated system has been implemented for diagnosing foot deformity.