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NEURAL NETWORK TECHNOLOGIES

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ANTHROPOLOGY RESEARCH PROJECT, INC.
YELLOW SPRINGS, OHIO

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13. ABSTRACT (Maximum 200 words)

This work is a continuation of research performed under The 1990 AFOSR Research Initiator Program. In this report the architecture from the previous effort was improved to support easy modification and extension. The result is a system which can be used to automatically identify human landmark from high density surface digital data.

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TECHNICAL REVIEW AND APPROVAL

AL-SR-1993-0002

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

KENNETH R. BOFF, Chief
Human Engineering Division
Armstrong Laboratory

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I. Introduction and background

The work described in this report is a continuation of research performed during 1990 under the AFOSR Research Initiation Program. That project focused on the development of a blackboard expert system which integrated several techniques in the task of landmark recognition of human subjects. It was able to successfully locate eleven landmarks on a small sample of subjects.

Although this system demonstrated the feasibility of this approach to the problem, it was a first attempt to build a program of this type and, as such, needed major reworking to support easy modification and extension. The overall design and knowledge sources were generally good, but the implementation needed a greater degree of modularity and generality.

The design of the system is described in the final report dated 15 September 1990 and entitled "A Blackboard Architecture for Landmark Identification on 3-Dimensional Surface Images of Human Subjects." Changes made to that design in the current work will be described below.

Section II of this report is a general description of the tasks attempted during the course of this research. In this section, implementation details are kept to a minimum. Section III includes a more technical discussion of design and implementation issues. Section IV presents the results obtained using the expanded and modified program on three categories of test subjects: "a" pose males, which was the category of subjects used as test data during the development of the program, "b" pose males and "a" pose females. A discussion of these results is also included in this section. Section V discusses possible directions for future work.

II. Tasks attempted/accomplished

A. Task 1 - Restructuring and expansion of the blackboard architecture

The first task accomplished in this research is a major revision and expansion of the blackboard architecture developed in 1990. Although the original design and knowledge sources were successful, as the the program grew in size and complexity it became clear that a more modular implementation using more features of object-oriented programming would allow for more efficient use of machine resources. The original program consisted of only three files. This led to two major problems: (1) Any changes or additions to a file meant recompilation of at least 1500 lines of code, which was very time consuming. (2) The amount of memory used by the Zortech C++ compiler is directly related to the size of the file being compiled, and the system had very nearly reached its limit in terms of memory required for compilation of these files. Breaking up the program into more files allows the compiler to deal with much smaller files and therefore avoids this memory barrier.

In addition to dividing the program into a large number of files, the code was rewritten to take greater advantage of C++ classes. For example, a general class of linked list is defined in the files "llist.hpp" and "llist.cpp." Specific varieties of linked lists are used in the program for such data structures as the Agenda, Hypothesis Lists, etc., and they differ from one another primarily in the type of element contained in the list. However, these new classes are defined to inherit all the functions already defined for linked lists in general. For example, once a function has been written to insert an element into a linked list, it can be used to insert into any linked list no matter what kind of element it contains. Therefore, the use of classes which inherit from a general class allow for greater reusability of code.

Once the overall framework was revised in this manner, previously written knowledge sources were incorporated with only minor revisions. The original system, however, had data structures which held information relevant to only eleven of the forty-two head landmarks now recognized. The data structures were expanded to include information on all forty-two landmarks, and integrating knowledge sources were added for all beyond the original eleven. The result is a complete system which now generates output for all landmarks. If no hypothesis is posted about a particular landmark, the output coordinates for that landmark will be 0. The process of adding new knowledge sources is simple and is described in Section III.

B. Task 2 - New techniques and knowledge sources

The original program used three primary techniques to locate landmarks: (1) local minima and maxima along a longitude, (2) changes in slope along a longitude or latitude, and (3) statistical information about distances between various landmarks. Those techniques were used in new knowledge sources as well; for example the supramenton is a new landmark which is located using minima.

Two new techniques have been added to the system. The first is a set of functions that attempt to locate the patches which have been placed on subjects at many landmark locations and which show up as voids (zeroes) in the data. The critical problem here is to distinguish those voids which represent patches from those which are caused by other factors. For example, the ear and eye regions usually contain a number of voids which are artifacts of the scanning process.

The first step in designing a patch recognizer was to write code to extract radii from a particular region from the complete data set, which is much to large to manipulate. A function was developed which is given the region boundaries and retrieves the radii in that region. The region may be up to 50 by 50 in size. The patch recognizer first looks for areas of contiguous zeroes in that region. It rejects areas that have more than 20 zeroes, since it is unlikely that a patch will be that large. It returns a list of remaining possibilities to the knowledge source which requested the patch location. It is then up to the knowledge source to evaluate the possibilities. usually based on where a patch is expected. This technique was used with great success in locating the glabella, left and right frontotemporale, zygofrontale, inframalar and infraorbitale. It will also be useful in future work in recognizing other landmarks such as the left and right tragion, zygion and infrazygion.

The second technique added to the system is a neural network. Currently, the neural net is limited to only one knowledge source (KS 70), which attempts to locate the right endocanthus. Work on this technique is incomplete; it has been demonstrated that it functions, but the weights used in the testing of the system were generated by training techniques that need to be revised and trained on a larger number of data sets. Once this has been done, the neural net code should be extracted from KS 70 and put into a general function that can be called by multiple knowledge sources.

C. Task 3 - Testing on "a" pose, "b" pose and female subjects

The system was developed and debugged using data on 18 male subjects in the "a" pose. At the end of the contract period, testing was done on 10 additional subjects from the same category and these results are presented and discussed in Section IV.

Although the system was developed using male subjects in the "a" pose, one of the tasks accomplished in this research was to run the system on other types of subjects, particularly males in the "b" pose and females in the "a" pose. This was done as an investigatory measure, to see what kind of results would be obtained. It was not expected that the system would be as successful on these subjects, but it was unclear whether or not it would work at all on different types of subject files. The system was run on 5 subjects in each of these categories, and the results are presented in Section IV. Briefly, it was demonstrated that some landmarks were located successfully despite these differences, but that adjustments will have to be made in many knowledge source parameters when subjects of different types are used.

D. Task 4 - User-friendly front end

Due to the limited contract period, this task was not attempted. It is an important task, however, and should be part of future work done on the system.

E. Task 5 - Output format

The original version of the system sent output to the screen with its findings. The current version was modified to produce a file in the same format as the landmark files produced when points are manually located. The system uses a different naming convention than that used for the landmark files; current landmark file names consist of "out" (or "outf" for female subjects) followed by the data file name. For example, the landmark file corresponding to data file "s195.a" would be "out195.a". The blackboard system produces a file called "s195.out." This prevents the original landmark file from being overwritten.

For comparison purposes, the system also produces a file containing the variances between results in the manually picked and system generated landmarks. These are found in a file with that same name as the result file, but with the extension "cmp."

III. Implementation details

A. File structure

As discussed above, the system has been divided into a total of 16 files. Successful linking and compilation of the system depends upon and understanding of the relationships among the files. Most files have one or more "include" statements at the top, which indicate to the compiler that the function and data definitions contained in the included file may be referenced as though they were part of the file being compiled.

To describe the include file chain, the following convention is used:

```
<file a> <-- <file b>
                 |
                 |
                 |
             <file c>
```

means file b has an include statement for file a, and file c has an include statement for file b. The include chain for the program is set up as follows:

```
bb.hpp <-- llist.hpp <-- hyp.hpp <-- agenda.hpp <-- bbdata.hpp
              |                                        |
              |                                        |
              |                                        |
          llist.cpp                                agenda.cpp
          region.cpp                               bb.cpp
                                                   bbdata.cpp
                                                   hyp.cpp
                                                   globals.cpp
                                                   ks0.cpp
                                                   ks57.cpp
                                                   ks70.cpp
                                                   iks.cpp
```

It should also be noted that references in a particular file to the contents of files that are not included may be done using "extern" statements for access to data structures, and function prototypes for function definitions. These are used in C++ to ensure type compatability.

General File Descriptions:

agenda.hpp - class definitions for Agenda and History List and associated node types

agenda.cpp - function definitions for classes defined in agenda.hpp

bb.hpp - contains globally used constants

bb.cpp - contains the main program code

bbdata.hpp - defines the class BlackBoardData which includes most data structures used by knowledge sources bbdata.cpp - function definitions used to manipulate BlackBoard data structures

globals.cpp - a few data structure declarations that are used globally, and definitions of some frequently used functions that are not associated with a particular class

hyp.hpp - class definitions for hypothesis lists and associated node types

hyp.cpp - function definitions for classes defined in hyp.hpp

iks.cpp - function definitions for all integrating knowledge sources

ks0.cpp - knowledge source functions for ks0 and ks51-56

ks57.cpp - knowledge source functions for ks57 through ks69

ks70.cpp - knowledge source functions for ks70 through ks86

llist.hpp - class definitions for a general linked list class and associated node types; also includes definitions of several specific linked lists types.

llist.cpp - function definitions for the classes defined in llist.hpp

region.cpp - function definitions for finding and manipulating regions, including the patch recognizer code

Besides the subject data file, two other data files are also used by the system. The file "trig.dat" contains one line for each landmark. On that line is a list of the knowledge sources which are triggered when a hypothesis for that landmark is posted. At the beginning of each program run, this information is read into an array of linked lists called Triggers, which is part of the BlackBoard data structure. When a hypothesis is posted, the linked list associated with that landmark is traversed and a knowledge source activation record (KSAR) is added to the Agenda for each knowledge source on that list. When a new knowledge source is added to the system, its number must be added to at least one of these lines or it will never execute.

The file "ks.dat" contains the following information each knowledge source other than integrating knowledge sources: (1) its priority (in the range 0.0-1.0), and (2) three (or fewer) landmarks whose values are used in the code of this knowledge source function. This information is read into the BlackBoard data structure arrays Priorities and Relatives, respectively. They are used when KSAR's are created; the Priorities information is used to determine the order in whish KSAR's are picked from the Agenda for execution, and the Relatives array is used to determine if a knowledge source picked off the Agenda should be executed based on the History List and the previous and current values of those landmarks that are considered Relatives.

Since all IKS's have a priority of 10 and should be executed whenever they are put on the Agenda, there is no need to include this information for them in the ks.dat file.

B. Knowledge sources

Knowledge source numbering is determined as follows. KSO is the knowledge source that reads the binary data files and creates min and max files. Since this takes several minutes to execute, once those files are created, it is more efficient to alter the main program so that KSO does not execute. This is done by commenting out the lines in the main program in which an activation record for that knowledge source is placed on the Agenda.

KS1 through KS42 are the integrating knowledge sources and their numbers correspond to the landmarks that they handle. KS43 through 50 are intentionally omitted to accommodate the possible inclusion of new landmarks in the future. KS51 through KS86 are the other knowledge sources that post hypotheses about landmarks, and their numbering does not follow a pattern. KS51 is initially placed on the Agenda in the main program, since its function is to read the min and max files into arrays for use by other knowledge sources. KS52 is also placed on the Agenda; its function is to post a hypothesis about the promenton. The posting of this hypothesis then causes the normal triggering cycle to begin. The other knowledge source functions are documented in the code.

When a new knowledge source is added to the system, the following steps must be taken:

(1) In the file "bbdata.cpp" there is a list of all knowledge source function prototypes, and its prototype must be added to that list.

(2) In the same file, an array of pointers to functions is initialized so that each array position has the name of the function that should be executed when that knowledge source is activated. A line should be added to this initialization code which corresponds to the new knowledge source.

(3) A global constant, Numof KSs, found in the file bb.hpp, should be incremented once for each new knowledge source. Its value should be one higher than the number of the last knowledge source.

(4) The file "ks.dat" must be updated to include information on the new knowledge source.

(5) The file "trig.dat" must be updated so that the posting of a hypothesis on at least one landmark will trigger the new knowledge source,

C. Patch recognition

One of the new techniques used in the system is the patch recognizer, which was discussed in Section II. The algorithms used in the implementation of this technique are described in this section. The primary function responsible for the process is function getvoids, found in the file "region.cpp." Additional code, primarily class definitions, is found in "llist.hpp."

The first stage in this process is the location of all occurrences of zero in the region being investigated. A linked list is constructed in which each node contains the coordinates of one occurrence of zero and the number of neighboring locations (out of eight possible) which also contain zeroes.

Function markmistakes attempts to locate areas of contiguous zeroes and remove them from consideration if they are too large to be patches. It traverses the linked list created in stage one. For each node whose coordinates contain a zero (initially all nodes), it calls function growcore which changes the zero to a value of -100, and then marks the area it belongs to by "growing" it from the original location. That is, it looks at the contents of all locations which are a distance of one from the original coordinates, and changes each zero to -100 if it has at least one neighbor which is part of the area being marked. It then proceeds to check the circle of locations which are a distance of two, and so on, counting the number of zeroes in the area as it makes these changes. The termination condition is a checking a complete circle without finding any zeroes. At that point, all the zeroes in the area have been changed to -100's and we know how many of them there are. An area which is too big is currently defined to be one which has more than 20 zeroes. If such an area is found, the -100's are left in place. If the area has 20 or fewer zeroes, function growcore is called again, but this time it changes the -100's back to zeroes, and this area remains a patch candidate.

As function markmistakes traverses the linked list of zeroes, it also destroys it. When it has completed its task, the initial process of locating zeroes and putting them into a linked list is repeated; however, this time the list will be much smaller because the large areas of zeroes which are unlikely patches have all been changed to -100's. This linked list is returned from the call to function getvoids.

Additional details may be found in the documentation associated with these functions.

IV. Results

Tables 1 through 4 show the results obtained by the program on four different subject groups. Each table presents the variances between manually picked and system generated landmark coordinates. Also shown for each coordinate is the average variance and the count of system generated coordinates which are within 3 of the picked points (i.e., a close match), in the range 4-6 from the picked points (i.e., in the general vicinity), and those over 6 away (i.e., seriously off). A failure to post a hypothesis for a landmark is added to the count of those over 6 away. These counts are important because a serious error in the generated landmark in one subject can have a major impact on the average since the sample is so small. It is more informative to look at the number of cases in which the system generated the same (or different) results as those found in the manually picked landmark file.

It should also be noted that the manually picked points are not error free. For example, the picked longitudes of the menton and promenton in file out06.a differ by 12, which is highly unlikely.

A total of 21 landmarks are currently recognized by the system. The supramenton is difficult to evaluate because it has been manually picked on only three of the test subjects. The supramenton has been omitted from the tables for this reason. In all three cases, however, the generated and picked points agree exactly, and inspection of the other generated supramentons show a reasonable position relative to the promenton and stomion. There are knowledge sources in place that attempt to locate the tragions, which are not counted in 21 landmarks mentioned above, but since these show little accuracy at the present time these results have not been included.

Another point that should be made before discussing specific results is that there are two landmarks which the system initially locates without reference to any other landmarks. The promenton coordinates are determined by using max and min data, and the glabella is located using max data and the patch recognizer. In all cases, the system is correct on at least one of these two points. When they are inconsistent, particularly with regard to longitude, the system must choose between the hypothesized longitudes to use as a basis for locating other landmarks on the mid-sagittal plane. Currently, the promenton knowledge source is considered to be more reliable. If the patch hypothesized to represent the glabella is greater than 10 longitudes from the promenton longitude, another patch is sought whose longitude is closer to that of the promenton. When the promenton longitude is incorrect, most other landmarks will be incorrectly located as well. Clearly, more work needs to be done to make this initial decision more reliable. Similarly, if the promenton latitude is incorrect, the latitudes of other landmarks will most likely be in error.

Looking at male subjects in the "a" pose, the category for which the knowledge sources were developed, we have Table 1 which includes those subjects used during program development (hereafter referred to as development subjects), and Table 2 which includes new subjects tested only after this stage of program development was completed (test

		s006	s017	s021	s036	s053	s076	s085	s091	s099	s103	s149
RFronto	long	nf	1	0	0	0	28	1	0	0	0	1
	lat	nf	3	1	0	1	6	0	0	0	0	0
RZygo	long	nf	0	1	0	1	34	1	0	0	0	1
	lat	nf	0	0	0	0	7	0	0	0	0	0
RInfMalar	long	0	10	0	1	0	np	1	12	0	0	1
	lat	0	7	0	0	1	np	0	4	0	1	1
REndo	long	18	5	4	5	3	23	22	6	12	7	3
	lat	3	5	3	4	1	5	1	1	2	0	1
RInfraorb	long	1	1	1	0	1	1	1	0	0	2	0
	lat	0	0	0	0	0	0	0	0	0	1	0
Glabella	long	9	1	1	1	2	21	2	0	1	1	0
	lat	8	0	1	0	0	8	1	0	0	0	0
Sellion	long	4	1	2	3	1	7	2	2	0	1	2
	lat	3	5	2	0	0	2	4	2	1	1	0
Pronasale	long	0	2	1	1	3	1	1	2	1	2	4
	lat	5	3	0	9	5	22	7	17	9	3	5
Subnasale	long	1	1	1	1	2	1	1	2	0	2	4
	lat	2	4	1	3	2	16	2	13	11	1	10
Promenton	long	1	1	1	2	4	1	3	1	1	1	1
	lat	2	3	0	1	2	6	2	2	3	1	5
Menton	long	11	2	2	3	4	1	3	2	2	2	1
	lat	1	0	2	2	1	2	1	2	2	0	0
RChelion	long	6	0	5	2	13	2	2	1	7	1	7
	lat	7	0	1	1	3	8	0	6	4	3	6
Stomion	long	1	0	0	3	5	1	2	0	1	2	3
	lat	8	1	1	1	1	8	1	5	4	0	5
LChelion	long	8	3	5	2	19	1	3	0	10	7	8
	lat	8	2	2	1	1	10	1	8	4	2	6
Submand	long	0	3	2	1	3	1	0	2	0	2	4
	lat	1	0	3	3	9	19	3	10	3	8	0
LInfraorb	long	2	6	1	0	1	1	1	27	1	0	1
	lat	1	14	0	1	0	1	0	14	1	0	0
LEndo	long	2	10	1	6	5	7	3	3	13	8	1
	lat	3	3	3	3	2	2	2	2	2	0	1
LFronto	long	nf	0	0	0	0	0	1	1	1	1	8
	lat	nf	0	1	3	1	0	1	7	0	0	0
LZygo	long	nf	1	0	1	1	1	1	3	0	1	16
	lat	nf	4	0	5	1	0	1	6	0	0	1
LInfmalar	long	3	0	6	np	1	0	0	33	1	18	0
	lat	1	0	0	np	0	0	0	9	1	2	0

nf = not found by the system np = not manually picked
c<4 = count of variances less than 4 for each landmark coordinate
c4-6 = count of variances from 4 to 6 for each landmark coordinate
c>6 = count of variances greater than 6 for each landmark coordinate
avg* = average variances, excluding data on subjects s045 and s137
avg = overall average variances

Table 1. Variances between generated and manually picked coordinates for male subjects in "a" pose (development group). (continued on next page)

		s150	s161	s176	s195	s200	s045	s137	avg*	avg	c<4	c4-6	c>6
RFronto	long	1	1	nf	1	nf	np	1	3	3	12	0	5
	lat	0	1	nf	0	nf	np	1	1	1	13	1	3
RZygo	long	1	2	nf	0	nf	22	0	3	4	13	0	5
	lat	0	0	nf	1	nf	26	0	1	2	13	0	5
RInfMalar	long	1	1	0	1	0	40	np	2	4	13	0	3
	lat	1	0	1	0	0	4	np	1	1	13	2	1
REndo	long	7	6	0	11	4	26	9	9	10	3	6	9
	lat	4	0	1	3	2	18	2	2	3	13	4	1
RInfraorb	long	2	2	21	0	0	34	0	2	4	16	0	2
	lat	0	11	5	0	0	10	0	1	2	15	1	2
Glabella	long	0	1	0	0	1	28	1	3	4	15	0	3
	lat	0	1	1	0	1	18	1	1	2	15	0	3
Sellion	long	0	1	1	2	1	27	3	2	3	15	1	2
	lat	1	4	1	2	4	20	1	2	3	13	4	1
Pronasale	long	0	2	0	1	1	24	0	1	3	17	0	1
	lat	2	1	4	1	5	5	32	6	8	6	6	6
Subnasale	long	1	2	0	1	1	24	0	1	3	17	0	1
	lat	2	1	3	0	0	10	25	4	6	11	1	6
Promenton	long	1	0	0	np	np	28	2	1	3	14	1	1
	lat	0	1	1	np	np	1	17	2	3	13	2	1
Menton	long	18	0	0	1	1	29	2	3	5	15	1	3
	lat	0	1	1	2	3	2	17	1	2	17	0	1
RChelion	long	3	10	3	2	2	31	11	4	6	10	2	6
	lat	1	2	3	0	0	2	22	3	4	12	3	3
Stomion	long	13	2	0	np	3	26	0	2	4	14	1	2
	lat	1	5	3	np	1	2	23	3	4	10	4	3
LChelion	long	0	15	4	1	4	26	7	6	7	7	3	8
	lat	2	3	4	1	0	6	21	3	5	10	4	4
Submand	long	2	5	1	5	1	29	0	2	3	14	3	1
	lat	1	4	9	2	14	5	10	6	6	9	2	7
LInfraorb	long	3	2	1	0	1	11	1	3	3	15	1	2
	lat	4	11	10	1	0	22	1	4	5	12	1	5
LEndo	long	0	1	0	8	7	38	4	5	7	9	2	7
	lat	0	0	1	3	2	18	3	2	3	17	0	1
LFronto	long	0	5	nf	1	nf	27	1	1	3	12	1	5
	lat	0	13	nf	1	nf	23	0	2	3	13	0	5
LZygo	long	1	0	nf	1	nf	39	0	2	4	13	0	5
	lat	0	0	nf	0	nf	27	0	1	3	11	3	4
LInfmalar	long	0	0	0	1	1	9	0	4	4	13	1	3
	lat	0	1	1	0	1	4	0	1	1	15	1	1

nf = not found by the system np = not manually picked
c<4 = count of variances less than 4 for each landmark coordinate
c4-6 = count of variances from 4 to 6 for each landmark coordinate
c>6 = count of variances greater than 6 for each landmark coordinate
avg* = average variances, excluding data on subjects s045 and s137
avg = overall average variances

Table 1. (cont'd) Variances between generated and manually picked coordinates for male subjects in "a" pose (development group).

		s012	s022	s124	s111	s133	s154	s169	s188	s109	s135	avg*	avg	c<4	c4-6	c>6
RFronto	long	1	3	1	1	30	1	0	nf	19	0	5	8	7	0	3
	lat	0	14	0	12	21	0	0	nf	54	6	7	14	4	1	5
RZygo	long	0	nf	0	nf	27	0	1	nf	nf	0	6	7	5	0	5
	lat	0	nf	0	nf	24	0	0	nf	nf	1	5	6	5	0	5
RInfMalar	long	31	np	1	0	14	0	0	21	19	0	10	8	5	0	4
	lat	1	np	0	1	3	1	0	3	18	0	1	4	8	0	1
REndo	long	6	5	7	13	9	12	8	9	16	4	9	10	0	3	7
	lat	2	0	0	5	1	2	1	1	47	3	2	7	8	1	1
RInfraorb	long	31	3	1	2	0	0	0	1	21	0	5	4	8	0	2
	lat	10	0	0	1	0	1	1	11	19	0	3	4	7	0	3
Glabella	long	1	12	0	12	2	0	0	0	11	1	3	5	7	0	3
	lat	0	17	0	20	27	0	1	0	45	0	8	14	6	0	4
Sellion	long	0	9	0	4	1	0	0	1	11	1	2	3	7	1	2
	lat	3	1	2	2	3	0	2	2	44	5	2	7	9	0	1
Pronasale	long	3	2	2	1	1	3	3	1	12	2	2	3	9	0	1
	lat	6	5	4	6	2	0	4	6	1	0	4	4	4	6	0
Subnasale	long	3	3	2	1	1	3	3	2	12	2	2	3	9	0	1
	lat	1	3	1	1	5	0	10	3	7	1	3	4	7	1	2
Promenton	long	3	0	0	2	0	2	0	1	14	5	1	2	8	1	1
	lat	1	1	1	4	2	0	3	8	12	18	3	4	7	0	3
Menton	long	2	1	1	4	1	2	0	1	15	7	2	3	7	1	2
	lat	1	2	2	2	0	0	3	11	11	16	3	4	7	0	3
RChelion	long	4	1	11	6	4	4	2	2	9	6	4	5	4	4	2
	lat	1	6	2	0	2	1	4	1	12	11	2	4	6	2	2
Stomion	long	1	1	1	3	1	3	np	0	14	1	1	3	8	0	1
	lat	1	4	0	1	0	1	np	1	12	11	1	3	6	1	2
LChelion	long	2	5	13	2	5	1	5	2	14	1	4	6	5	3	2
	lat	1	6	2	0	2	0	3	2	12	8	2	3	7	1	2
Submand	long	5	8	2	1	0	2	2	2	12	2	3	4	7	1	2
	lat	4	6	4	3	0	2	6	1	18	11	3	5	4	4	2
LInfraorb	long	36	2	1	0	23	0	1	29	11	1	12	8	6	0	4
	lat	9	0	0	1	16	0	1	13	20	10	5	6	5	0	5
LEndo	long	6	14	7	1	1	8	5	8	6	8	6	6	2	3	5
	lat	1	0	0	4	1	2	2	1	46	0	1	7	8	1	1
LFronto	long	1	3	0	11	27	0	1	nf	5	0	6	7	6	1	3
	lat	0	13	1	14	26	0	1	nf	52	1	8	15	5	0	5
LZygo	long	1	nf	1	nf	23	0	0	nf	nf	0	5	6	5	0	5
	lat	0	nf	0	nf	28	0	0	nf	nf	4	6	7	4	1	5
LInfmalar	long	26	0	0	0	33	0	0	37	5	0	12	9	6	1	3
	lat	3	0	0	0	37	0	0	6	22	0	6	8	7	1	2

nf = not found by the system   np = not manually picked
c<4 = count of variances less than 4 for each landmark coordinate
c4-6 = count of variances from 4 to 6 for each landmark coordinate
c>6 = count of variances greater than 6 for each landmark coordinate
avg* = average variances, excluding data on subjects s109 and s135
avg = overall average variances

Table 2. Variances between generated and manually picked coordinates for male subjects in "a" pose (test group).

		s33	s46	s79	s84	s155	avg	c<4	c4-6	c>6
RFronto	long	nf	nf	13	nf	nf	13	0	0	5
	lat	nf	nf	56	nf	nf	56	0	0	5
RZygo	long	nf	nf	nf	nf	nf		0	0	5
	lat	nf	nf	nf	nf	nf		0	0	5
RInfMalar	long	0	0	0	0	1	0	5	0	0
	lat	0	0	1	0	1	0	5	0	0
REndo	long	3	9	14	7	1	7	2	0	3
	lat	5	56	54	22	69	41	0	1	4
RInfraorb	long	0	1	0	0	0	0	5	0	0
	lat	1	1	0	0	0	0	5	0	0
Glabella	long	6	4	2	5	0	3	2	3	0
	lat	159	59	60	29	74	76	0	0	5
Sellion	long	5	1	3	5	1	3	3	2	0
	lat	8	60	58	25	74	45	0	C	5
Pronasale	long	4	1	5	5	1	3	2	3	0
	lat	1	1	1	2	1	1	5	0	0
Subnasale	long	3	1	3	4	1	2	4	1	0
	lat	5	1	2	3	6	3	3	2	0
Promenton	long	2	3	5	1	2	3	4	1	0
	lat	22	6	10	5	19	12	0	2	3
Menton	long	np	np	3	4	3	3	2	1	0
	lat	np	np	4	1	17	7	1	1	1
RChelion	long	14	7	14	16	12	13	0	0	5
	lat	5	1	3	5	6	4	2	3	0
Stomion	long	3	0	4	2	0	2	4	1	0
	lat	9	4	6	0	11	6	1	1	3
LChelion	long	0	7	17	18	16	12	1	0	4
	lat	3	1	3	5	6	4	3	2	0
Submand	long	0	23	16	20	15	15	1	0	4
	lat	7	2	2	3	15	6	3	0	2
LInfraorb	long	1	1	22	14	1	8	3	0	2
	lat	0	0	11	8	0	4	3	0	2
LEndo	long	11	9	14	15	12	12	0	0	5
	lat	16	55	53	23	70	43	0	0	5
LFronto	long	nf	nf	16	nf	nf	16	0	0	5
	lat	nf	nf	53	nf	nf	53	0	0	5
LZygo	long	nf	nf	nf	nf	nf		0	0	5
	lat	nf	nf	nf	nf	nf		0	0	5
LInfmalar	long	0	0	1	0	1	0	5	0	0
	lat	1	1	0	1	0	1	5	0	0

nf = not found by the system np = not manually picked
c<4 = count of variances less than 4 for each landmark coordinate
c4-6 = count of variances from 4 to 6 for each landmark coordinate
c>6 = count of variances greater than 6 for each landmark coordinate
avg = overall average variances

Table 3. Variances between generated and manually picked coordinates for male subjects in "b" pose.

		f10	f29	f53	f159	f187	avg	c<4	c4-6	c>6
RFronto	long	1	nf	nf	nf	38	20	1	0	1
	lat	0	nf	nf	nf	32	16	1	0	1
RZygo	long	0	nf	nf	nf	43	22	1	0	1
	lat	0	nf	nf	nf	32	16	1	0	1
RInfMalar	long	9	48	12	18	44	26	0	0	5
	lat	9	8	14	26	4	12	0	1	4
REndo	long	13	0	15	2	2	6	3	0	2
	lat	1	1	17	8	24	10	2	0	3
RInfraorb	long	0	32	1	nf	26	15	2	0	3
	lat	0	10	1	nf	13	6	2	0	3
Glabella	long	0	1	0	3	8	2	4	0	1
	lat	0	0	14	1	28	9	3	0	2
Sellion	long	4	0	2	2	7	3	3	2	0
	lat	1	0	18	8	25	10	2	0	3
Pronasale	long	1	2	4	2	0	2	4	1	0
	lat	1	19	1	12	3	7	3	0	2
Subnasale	long	2	1	4	2	0	2	4	1	0
	lat	4	20	1	10	6	8	1	2	2
Promenton	long	2	3	np	1	0	2	4	0	0
	lat	0	16	np	23	4	11	1	1	2
Menton	long	2	3	np	0	1	2	4	0	0
	lat	1	20	np	25	3	12	2	0	2
RChelion	long	2	1	1	2	1	1	5	0	0
	lat	11	14	0	13	4	8	2	0	3
Stomion	long	1	2	3	1	1	2	5	0	0
	lat	1	13	0	14	3	6	3	0	2
LChelion	long	2	1	5	3	2	3	4	0	1
	lat	1	15	1	14	3	7	3	0	1
Submand	long	2	2	3	2	0	2	5	0	0
	lat	4	7	5	25	2	9	1	2	2
LInfraorb	long	0	35	15	nf	26	19	1	0	4
	lat	0	12	19	nf	13	11	1	0	4
LEndo	long	9	2	16	4	12	9	1	1	3
	lat	2	2	17	9	24	11	2	0	3
LFronto	long	2	nf	nf	nf	34	18	1	0	4
	lat	0	nf	nf	nf	35	18	1	0	4
LZygo	long	1	nf	nf	nf	25	13	1	0	4
	lat	0	nf	nf	nf	30	15	1	0	4
LInfmalar	long	1	52	6	17	41	23	1	1	3
	lat	0	5	11	30	11	11	1	1	3

nf = not found by the system np = not manually picked
c<4 = count of variances less than 4 for each landmark coordinate
c4-6 = count of variances from 4 to 6 for each landmark coordinate
c>6 = count of variances greater than 6 for each landmark coordinate
avg = overall average variances

Table 4. Variances between generated and manually picked coordinates for female subjects in "a" pose

subjects). Table 1 shows a greater degree of accuracy than Table 2, which is to be expected. In Table 1, it can be seen that the results of only 2 subjects of 18 are largely incorrect (s045 and s137). In Table 2, 2 of 10 (s109 and s135) are largely incorrect. These subjects were omitted from the averages shown in the columns labelled "avg*" but were included in all counts and the overall average (column "avg").

Table 1 (development subjects) shows that when the promenton is correctly identified, there are only 9 coordinates showing an average variance of 4 or greater, out of a total of 40 coordinates. Of this group of 9, only 1 shows an average variance greater than 6. For the test group (Table 2), however, 20 out of 40 coordinates show a variance of 4 or more, even when the promenton is correctly identified.

Counts tell a slightly different story. Keeping in mind that 2 of the 10 datasets in the test group have an incorrect promenton, which affects most other landmarks, 20 coordinates out of 40 are found with high accuracy (variance of 3 or less) in at least 70% of the subjects. Generated coordinates are in the vicinity (variance within 6) of picked coordinates in at least 70% of the subjects for 28 out of 40 points. The only coordinate which was completely missed (variance over 6) in the majority of subjects is the right endocanthus longitude.

Table 3 shows the results for 5 male subjects in the "b" pose. There are some interesting observations that can be made. First, the promenton longitude (and therefore the mid-sagittal plane) was successfully located in all subjects, with variances ranging from 1 to 5. The promenton latitude, however, was seriously off in 3 of the 5 cases, leading to errors in the latitudes hypothesized for most of the other landmarks. Despite this, there were three landmarks that showed perfect matches between generated and picked points: the right and left inframalar and the right infraorbitale, all of which are located using the patch recognizer. The pronasale and subnasale were located with good accuracy as well. It is likely that modifications to knowledge source parameters will allow the system to generate results on "b" pose males that are comparable to "a" pose males.

Table 4 shows the results for 5 female subjects in the "a" pose. Subject f10 shows remarkably good results, comparable to the best male "a" pose subjects. In the others, the promenton longitude is found with good accuracy, but there are major errors in latitude, as was the case with "b" pose males. This is apparently an important area to investigate. Unlike the "b" pose males, the landmarks located using the patch recognizer were not found very well, but it may also be the case here that alterations in knowledge source parameters will produce more acceptable results.

V. Future Work

There are several directions in which work should proceed on this system. Many of these have been mentioned in other sections of this report, but they are summarized below.

A. Neural network completion

The training of neural networks to aid in the recognition of landmarks should be continued. If this technique is successful on the test case (right endocanthus), other areas in which it may be useful should be investigated. The eye area landmarks are clearly in that category, and the chelions may also be found in this way with greater accuracy than the system currently exhibits.

B. Development of integrating knowledge sources

There are many instances where the system has a correct hypothesis for a landmark's location, but chooses an incorrect hypothesis instead. This is the work of the integrating knowledge sources, which should be the "most intelligent" part of the system. This area is one which definitely needs further development. More heuristics must be built into this part of the system to improve the decision-making ability of the IKS's.

The incorporation of more knowledge sources with information about new landmarks should improve system performance as well, especially if more landmarks can be located by manipulating the raw data rather than using previously identified landmarks as a reference. These "independent" landmark locations can then be compared more easily to one another to check for consistency. This is currently the case only with the glabella and promenton, so it is difficult for the system to choose the correct one when they are not consistent.

C. User interface

There are several ways in which user interaction may be added to the current system. If a graphics module is added to the system so that an image of the subject is displayed with hypothesized landmarks, it will be possible for the user to have some input in the recognition process. For example, if the hypothesized locations of the glabella and promenton are inconsistent, as discussed above, it would be possible for the system to allow the user to make the decision as to which is more correct.

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