6 Summary and Conclusions

6.1 Summary

This thesis has described the design, implementation and testing of a gesture-based user interface using visual recognition. Two aspects of the problem have been examined, the technical aspects of visual recognition of hand gestures in an office environment, and the more abstract issues concerning the usability of such an interface and the best way to take advantage of the power of hand gestures.

The design of the system has incorporated several advances in visual recognition including an improved training algorithm for color based segmentation. With most other work using color segmentation, the background is limited. Typically they look down on the hand to image it against either the keyboard [Qu95] or a region on the desk beside it. The interactive training algorithm described here allows the camera to look back at the user and reliably locate the hand against a much more difficult background than has been previously possible. While segmentation is not perfect, it is fast, of generally good quality, and sufficiently reliable to support an interactive user interface.

Neural nets have been used to provide appearance-based hand pose recognition for the first time. Instead of extracting some type of feature vector describing the hand pose, the nets find the most similar training pose on the basis of appearance. Unlike most pose recognition work, the gray level information on the interior of the hand is used for pose classification, not simply the outline or silhouette. This has been shown to produce a more robust recognition of the pose. Being appearance based, we have made the assumption that the appearance of the hand in the image is relatively constant, but given the stable environment of the system, this assumption is generally valid. Of course some variation does occur, especially between people and even between poses formed by one person. This has been taken into account both by using a representative set of training images, and by varying those images during training. Variations in lighting are handled by preprocessing the image to reduce its effect. A final contributor to the success of the networks is a step where images which have been misclassified by the net after initial training, are added to the training set. This helps to fine tune performance on difficult cases.

The path of the hand is smoothed with a novel algorithm which has been designed to compensate for the types of noise present in the domain, but also to leave a cursor movement which is easy for the system to examine for motion features, and appears natural to the user.

Unlike other work in visual gesture recognition, this system makes use of direct selection of objects on the screen. Rather than guide the cursor indirectly, as with a mouse, the user points directly at the object they wish to manipulate, then perform a pose or motion to indicate how it should be manipulated. This interaction style is better suited to hand gesture and results in a very natural feeling interaction. It has been shown to perform as well as a mouse for selecting large objects in spite of a significantly slower tracking rate. The selection time has been modeled by adapting Fitts' Law to the noise present in the hand path, and the model used to examine the limits of free-hand pointing performance.

Just as with natural gesticulation, motion and pose both play a role in the meaning of a gesture. Symbolic features of the motion path are extracted and combined with the classification of the hand's pose at key points to recognize various types of gestures. An interaction language made up of these gestures is defined using a transition network incorporating some aspects of ATNs. This makes it possible to flexibly integrate near arbitrary combinations of motion and pose features into a coherent whole. For efficiency, expensive feature extraction operators are only performed under control of the transition network. In other gesture recognition systems where transition networks or finite state machines have been used, they play a minor role, such as temporally parsing a movement to find when the real gesture begins [DS93] or spatially parsing an image to check for a particular pose [Qu95].

The result is a working system which allows a user to control windows in a standard user interface using hand gestures. The flexibility built into the system has made it possible to try out different hand gesture interaction styles. This has produced observations about how gesture is best used to interact with objects on a screen. Problems with integrating gesture into current interface technology have been pointed out, such as the design of menus and proliferation of small control icons. This work has also pointed out inherent characteristics of gesture that must be considered in the design of any gesture-based interface. These include the need for memory aids to help the user remember the possible gestures, and the fact that hand gestures tend to be sensitive to the user's gesturing rhythm. The difficult learning curve for a hand gesture interface was discovered, its causes analyzed and suggestions made to reduce it. Finally the paper has made suggestions on the best way to make use of gesture in an advanced user interface.

6.2 In Conclusion

While this thesis has shown that gesture can be made to work as a reliable interface modality in the context of today's graphical user interfaces, it leaves a significant high level question unanswered; Can gesture provide sufficient benefits to the user to justify replacing current interface devices? In the form presented in this work, as an add-on to an essentially unmodified GUI, the answer is probably no, but in the context of a system designed to take advantage of its strengths, it could be the final piece of an environment that does away with physical interface devices.

Many people see speech recognition as a major player in the interface of future workstations because of the freedom it provides the user [Hu96], but speech by itself can not make a complete interface. There are some operations that it simply can not express well, or which are much more concise with some type of spatial command. Mice, however, will become increasingly impractical as we move away from traditional screen-on-desk environments. Gesture provides many of the same benefits for spatial interaction tasks as voice does for textual tasks.

Together, speech and gesture have the potential to dramatically change how we interact with our machines. In the near term they can remove many of the restrictions imposed by current interface devices. In the longer term they offer the potential for machines to operate by observing us rather than by always being told what to do. It is my sincere hope that this work has contributed to realizing that potential.

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Appendix

```
; Language to control windows using three poses
; Palm vs. Point in the first pass to select a system menu or window
; Palm vs. Point vs. Spread on the second pass to select a
;  window menu, move the window or resize the window

; Syntax: NODE nodename
;  followed by any number of lines of the form of:
;           ACTION        action-identifier  <action modifier>
;           MENULINK      item-string        destination
;           POSELINK      item-string        destination
;           LINK          condition          destination

; A Semicolon implies comment to end of line
; The start node must be named "Start".

 ;The semantics are: when the traversal arrives at a node,
;  it executes all ACTIONS, then follows an Immediate
;  link if one exists
;  Otherwise, it pops up a menu of any MENULINKs
;  and follows the one the user selects.
;  If there are no MENULINKs, it examines the saved pose
;  image for the poses specified by POSELINKs
;  If there are no POSELINKs, it follows the first
;  LINK (in order of definition) who's condition tests
;  true.


NODE Start
            LINK          HandP              IgnoreMvt1

NODE IgnoreMvt1
            LINK          HandGone           Start
            LINK          Up                 Track1

NODE Track1
            ACTION        RecordLoc
            ACTION        RecordPose
            ACTION        ShowCursor
            LINK          HandGone           Pose1
            LINK          Comma              Pose1
            LINK          Pause              Pose1
            LINK          DownMedium         FollowDown
            LINK          Otherwise          Track1

NODE FollowDown
            LINK          HandGone           Pose1
            LINK          Comma              Pose1
            LINK          Pause              Pose1
```

```
        LINK        DownMedium  FollowDown
        LINK        Otherwise   Track1

NODE Pose1
        POSELINK    Palm        SysMenu
        POSELINK    Point       Select

NODE SysMenu
        MENULINK    Continue    Start
        MENULINK    Exit        Exit

NODE WinMenu
        MENULINK    Select      Select2
        MENULINK    Move        MoveWin
        MENULINK    Resize      ResizeWin
        MENULINK    Maximize    MaxWin
        MENULINK    Restore     RestoreWin
        MENULINK    Exit        Exit

NODE Select
        ACTION      SelectObject
        LINK        HandGone    VerifyGone
        LINK        Otherwise   Delay

NODE Select2
        ACTION      SelectObject
        LINK        Immediate   Start

NODE Delay
        LINK        Immediate   WaitForPause

NODE WaitForPause
        ACTION      RecordPose
        LINK        Pause       Pose2
        LINK        HandP       WaitForPause
        LINK        Otherwise   VerifyGone

NODE VerifyGone
        LINK        HandP       WaitForPause
        LINK        Otherwise   VerifyGone2

NODE VerifyGone2
        LINK        HandP       WaitForPause
        LINK        Otherwise   Start

NODE Pose2
        POSELINK    Palm        WinMenu
        POSELINK    Point       MoveWin
        POSELINK    Spread      ResizeWin

NODE MoveWin
        ACTION      MoveWin
        LINK        Immediate   Start

NODE ResizeWin
        ACTION      ResizeWin
        LINK        Immediate   Start

NODE MaxWin
        ACTION      MaxWin
```

```
        LINK        Immediate      Start

NODE RestoreWin
        ACTION      RestoreWin
        LINK        Immediate      Start

NODE Exit
        ACTION      Exit
```