Capturing Hand Gesture Movement: A Survey on Tools, Techniques and Logical Considerations

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ABSTRACT
The massive influx of computers in modern society has led to the discovery of novel approaches in how humans interact with computers. Extensive research on more "natural" mechanisms of human computer interaction (HCI) has led to the tracking of hand gesture movement, due to the fact that gestures play a predominant role in human communication. This paper analyzes numerous approaches to hand gesture capture, critically evaluating research carried out in the domains of computer vision and alternative sensor based tools and techniques. It is mainly hardware driven, but related logical considerations such as the use of gesture vocabularies and the need for following a framework based approach. For the purpose of this study, computer vision has not been generalized with other sensor based input techniques and has been evaluated separately due to the maturity of the domain when contrasted with alternative input modes.

Keywords
Ubiquitous Computing, Ambient Intelligence, Computer Vision, Accelerometers, Gyroscopes, Hybrid Frameworks, Human Computer Interaction

INTRODUCTION
In recent times, digital connectivity has advanced to such an extent that as humans we simply cannot live without it. Technology has become so embedded into our daily lives that we use it to work, shop, communicate and even entertain ourselves (Pantic et al., 2008). Many researchers and domain experts delving into HCI believe that the future holds a world of intelligent devices, capable of anticipating and responding intelligently to the needs of humans as and when they please (Bohn et al., 2005; Augusto et al., 2008). This model is known as "Ambient Intelligence" (AmI) (Aarts, 2009; Shadbolt, 2003).

However, in order to achieve this vision, many challenging and compelling issues need to be addressed. These have been discussed by numerous researchers (Edwards & Grinter, 2001; Lyytinen et al., 2004; Bohn et al., 2005) who outline the need for manageable, reliable, interoperable, easy to adapt tools and techniques.

A MOTIVATIONAL EXAMPLE

The idea of technology and users so well connected that one is indistinguishable from the other has been expressed by many researchers. In modern times, much has been done toward achieving this, however, the predominant method of HCI for the past quarter century still remains untouched, the use of a mouse and keyboard. Whilst it is true that these devices have their advantages, they are still lagging far behind in terms of what can be achieved to ease the process of how humans interact with computers. What if, however, hand gesture recognition was used instead of a traditional input device?

The following example deals with such a scenario. As you read it, try to picture the situation happening to you as you step home, after a long hard day at work.

Imagine a world where a user can intelligently interact with objects around him. As you walk into the room, tired after a long day, a flip of the mobile turns the lights on, plays some soothing music along with a customized greeting. A simple swipe towards the computer switches it on and with a flick of the wrist the individual can turn the volume down in the music player. You then recline in an armchair and operate surrounding objects intelligently using only a variety of gestures. Rather than being constricted to a single mouse click or a push on a keyboard, picture a scenario where you can push, pull, swipe, rotate, tap, swing, use a combination of these or even go to the extent of creating your own gestures and choose what action you want to trigger each time you gestures in a specific manner.

Not only would such a system ease your life and make it more efficient, it would be simple and unobtrusive making it a far richer experience than what is offered with modern day devices.

VARIOUS APPROACHES ANALYSED

In order to build manageable, reliable, interoperable, easy to adapt devices and techniques as discussed before, one would first need to understand existing approaches along with the advantages and drawbacks for each of these. For the purpose of this study**,** the literature examined has been divided into three broad areas for better readability and comprehension. These are as follows.

- **Vision Based Tools and Techniques** – Tools and techniques employing the use of machine vision for recognizing hand gestures.
- **Sensor Based Tools and Techniques** – Tools and techniques that do not employ the use of computer vision and employ sensing techniques such as the use of haptic devices, magnetic sensors, EMGs, pen based approaches etc.
- **Logical Issues and Considerations** – Other considerations that need to be made with regard to gesture recognition such as the evaluation of design, use of frameworks, gesture vocabularies etc.

Each of these areas have been explored and critically evaluated. Findings and suggestions are presented below.

Vision Based Tools and Techniques

The use of vision based tools for hand gesture recognition is a field of study extensively researched, due to its potential use in a ubiquitous computing environment. The focal point of vision based gesture recognition systems is the employment of one or more video cameras (Garg et al., 2009) that may differ based on the number of cameras used, speed, latency, capacity, technique and user requirements (Mitra and Acharya, 2007).

For the purpose of this study, six approaches (Table 1) and three surveys (Table 2) relating to vision based motion capture and recognition were investigated

In summary, it was found that while various devices, algorithms, and techniques were used each having its own unique strategy to perform gesture recognition, disadvantages arose mainly due to the solutions being limited to a particular device, vocabulary or algorithm. Thus, due to the lack of modularization, factors such as computational expense, low accuracy, device dependence was predominant throughout the domain.

In order to further evaluate this, three different surveys were explored. Not only do these cover a particular vision based approach, but explore the domain as a whole in order to see how issues persistent throughout the domain have been addressed. The scope of the analysis along with comments is presented in Table 2 below.

In a nutshell, vision based tools are preferred as they are cost effective, can carry "a wealth of information in a non-intrusive manner" (Zabulis et al., 2009), require a minimal level of hardware (Fang et al., 2007) and promote natural interaction (Garg et al., 2009). However, the use of computer vision for gesture recognition is not without many challenging and compelling issues.

Murthy and Jadon (2009) highlight four key requirements a successful vision based system would need to address. These are namely, robustness, computational efficiency, scalability and user tolerance. While many of the investigated solutions address these requirements to a certain extent, they fail to overcome all challenge areas successfully. In addition to this, vision based solutions are

inherently limited due to the primitiveness of available algorithms. While available tools and techniques cannot be even compared to animal vision, most approaches dealing with vision based tools and techniques are based on assumptions not suitable in a real life scenario (Garg et al., 2009)

Much of the research conducted, for example that of Liu et al (2009) and Zhang et al (2009) note computational load as another limiting factor and highlight that sometimes due to the extensive training required due to limitations of algorithms, vision based solutions may tend to be "inefficient and unnecessary" (Zhang et al., 2009).

It also should be highlighted that some of the research carried out is biased toward vision based solutions as they undermine alternative approaches without much consideration of the state-of-the-art in those domains. Most papers evaluated support the argument presented by Mitra and Acharya (2007) stating that alternative approaches such as the use of sensor based devices require "the user to wear a cumbersome device and carry a load of cables connecting the device to a computer" which may not be the case in real life taking into consideration modern technology such as wireless computing.

Sensor Based Tools and Techniques

Recent advancements in microelectronics have made it possible to reduce the size and cost of sensor based devices making them far more accessible than ever before (Pylvänäinen, 2005). This has created an increase in research on novel approaches to hand gesture recognition that utilize sensors and other devices not concerned with computer vision. For the purpose of this survey, ten different sensor based approaches employing accelerometers, EMGs, gyroscopes, inertial body-worn sensors, pen based approaches and other novel interfaces were evaluated. These have been presented in table 3 below.

Sensor based approaches are primarily advantageous as they provide a novel mechanism for integrating intelligence into devices around us. This is an essential step in furthering the "Ambient Intelligence (AmI)" paradigm (Aarts, 2009; Shadbolt, 2003). Unlike vision based techniques that are chiefly based on how an individual would perceive his surroundings (Murthy and Jadon 2009), sensor based approaches are preferred as they are immune to challenges in this regard such as background noise, variable lighting conditions etc. and are not limited by the scope of the data gathering device.

In addition to this, some sensor based approaches overcome various other foreseeable challenges in HCI such as need for alternative approaches when interacting with smaller devices (Ketabdar et al., 2010), recognition of gestures in resource constrained environments (Liu et al., 2009), and intelligently interacting with surrounding devices (Wilson and Shafer, 2003)

Disadvantages of sensor based approaches vary according to the device employed however the primary disadvantage is that sensor based solution are both less-natural and less-intuitive as they require some form of intermediate device attached to the user when performing gesture recognition. However, if day-to-day items are used as an intermediate, a sensor based approach provides a very promising modality for HCI.

Among the various sensors evaluated, the accelerometer in particular, a sensor hardly used by consumers a couple of years ago, has become one of the most frequently used sensors in modern times due to its availability in numerous consumer electronics such as gaming remotes and mobile phones. As opposed to traditional pen, glove or EMG based approaches, accelerometers are also preferred as they can be used to recognize free hand movement and does not need to be attached to the user.

Researcher	Technique	Advantages	Disadvantages
Alon et al (2005)	Recognition of dynamic hand gestures using a dynamic space-time warping (DSTW) algorithm	• Invariant to background noise. • User can gesture in any part of the image. • Can be further enhanced through techniques such as optical flow correlation	• Temporal segmentation is not addressed and a flow of gestures may not be recognized. • Works only for fairly simple hand gestures
Fang et al (2007)	A multi-scale feature analysis method for recognition of hand gestures	• Works well with complicated backgrounds • Not confined by aspect ratio of hand image	• Computationally expensive
Francke et al (2007)	A hand gesture recognition method using active learning and bootstrap	• Obtains reasonably high results with cluttered background, variable	• Does not recognize dynamic gestures • Confusion of gestures and

		illumination, etc. • High processing speed	somewhat low recognition rate (~70%)
Chen et al (2007)	Hand gesture recognition using Haar-like features and the AdaBoost learning algorithm	• High level of accuracy • Fast / Robust detection of hands	• Tests are conducted in a controlled environment so its performance in a dynamic environment is uncertain. • Does not work with 3D hand modeling
Elmezain et al (2009)	Hidden Markov Model (HMM) based hand gesture recognition system	• Capable of recognizing gestures in real time • Supports both isolated and continuous gestures	• Requires large amounts of training data • Computationally expensive
Li and Jarvis (2009)	Locates hand movement in a 3D space using a range camera and employs Finite State Machine (FSM) method.	• Range camera eases 3D tracking • Invariant to environmental changes • User does not need to wear homogenous clothing	• Fails when hand and forearm are in the same depth range • Supports only a very limited range of gestures

Table 1 – Varied approaches to vision based hand gesture recognition

Researcher	Scope of Analysis	Comments

Moeslund and Granum (2001)	• Covers a large domain of over 130 papers discussing initialization, tracking, pose estimation and recognition of a motion capture system and discusses types of information being processed.
	• Primarily focused with full body gesture recognition
	• System functionality is broken down into 4 core processes namely
	  ○ initialization,
	  ○ tracking,
	  ○ pose estimation,
	  ○ recognition
		• The significance of this survey is that it provides a comprehensive overview of publications on motion capture for over two decades and the role machine vision plays in terms of full body motion capture discussing the state-of-the-art and how it can be taken forward.
		• Performance characteristics related to system functionality and modern advancements in each of these fields are comprehensively discussed and evaluated. It is interesting to note that while some features (consider robustness, accuracy and speed) are required in a specific domain it may not be a requirement in others. (Eg- Surveillance would need a high level of Robustness and not require high accuracy as opposed to analysis which would require the opposite.)
		• Problems predominant throughout the domain such as the lack of training data, the large amount of time required for gesture capture, lack of invariance and robustness are explored and possible solutions such as the employment of a approach similar to speech recognition, abstracting the motion layer have been investigated. While these have proven to be successful to a certain extent it is notable that almost all approaches are greatly limited due to the lack of modularization.

Poppe (2007)	• Characteristics of human motion analysis have been discussed and divided into modeling and estimation phases enabling the researcher to identify and highlight trends throughout the domain and limitations in the state-of-the-art. • The research conducted primarily focuses on large body parts and their configurations over time and not interpretations of various movements. • Concentrates largely on pose estimation as this is a preprocessing step required for human motion analysis.	• A comparison is made between the challenging problem of human motion analysis and the knowledge possessed on physical appearance. It is important to note that the deterministic factor is how this knowledge is used effectively in order to address the identification of human body models. • Investigates the use of incorporating prior knowledge with human movement in order to increase effectiveness. Hybridizations are considered in this regard which shows a great need for further exploration combining various solutions. • The need common database representing a broad range of domains such as indoor, static, dynamic and cluttered scenes is emphasized showing the need for cross domain standardization.
Mitra and Acharya (2007)	• A comprehensive survey on gesture recognition techniques particularly focusing on hand and facial movements. • Covers the use of hidden Markov models, particle filtering and condensation, finite-state machines, optical flow, skin color and connectionist models in great detail.	• The need for different recognition algorithms depending on the size of the dataset and the gesture performed is identified and various combinations can be drawn out in this regard. (Eg- A hybridization of HMM and FSM has been proposed in order to recognize a complex gesture consisting of a large range of smaller gestures, the use of a Neural network for a large dataset etc.) • From the research it is notable that any developed system should be both flexible and expandable in order to maximize efficiency, accuracy and understandability of a developed system.

Table 2 – Analysis of comprehensive surveys related to vision based motion capture and recognition

Researcher	Technique	Advantages	Disadvantages
Wilson and Shafer (2003)	A novel wireless sensor package that is inbuilt with an Accelerometer, magnetometer, gyroscope, FM transceiver, microcontroller and IR LED termed "XWand"	• Leverages user and environment intelligence to determine meaning of a gesture • Provides a novel mechanism for interacting with an intelligent environment	• Expensive to implement • Requires an infrastructure supporting an intelligent environment through networked devices. • Hardware device is quite cumbersome to use and can be minimized
Tsukada et al (2004)	An attachment to the finger which employs bend, touch and Accelerometer sensors to detect basic hand gestures	• Lightweight device • Easy to use control methods • Promotes natural interaction	• Works only with very basic hand gestures • Expensive to build as it employs multiple sensors
Mäntyjärvi et al (2004)	Accelerometer based gesture recognition technique employing the use of a discrete HMM	• SoapBox based approach makes it portable • High rate of recognition	• User independent recognition is not addressed • Does not provide tactile feedback
Amft et al (2005)	Use of inertial body-worn sensors for the detection of gestures related to eating and	• Novel approach to monitoring dietary activities	• Employs too many sensors and may not be cost effective • Devices are attached to user and

	drinking		cumbersome.
Wobbrock et al (2007)	A novel easy to use gesture recognition algorithm is proposed for pen based inputs	• Requires less computational load • High level of accuracy • Easy to implement • Provides optional rotation and scale invariance	• Does not work with gestures that depend on orientation and aspect ratio • Troublesome gestures are hard to identify • User needs to understand how variations are handled if new gestures are to be defined and used effectively • Does not work with 3D gesture interfaces
Liao et al (2007)	A paper augmented digital document interaction mechanism termed "PapierCraft"	• Supports an extendable command set • Employs a pen based approach targeted at bridging the paper-computer gap	• In order to be useful in a real world scenario both hardware and software needs to be more widespread and design revised
Kim et al (2008)	EMG based interface for hand gesture recognition and Biosignal Interfacing	• High rate of recognition • Easy to use interface • Subjects can familiarize with the controlling interface quite fast	• Gesture needs to be precisely performed so the user has to practice prior to using the interface • Attachment of cables on forearm makes the approach cumbersome
Liu et al (2009)	A DTW based approach for recognizing hand gesture movement using an Accelerometer	• Tested against a large dataset with very high accuracy • Works well on resource constrained systems such as mobile phones • Only requires a single training sample to start	• Accuracy drops by more than 20% when performing user-independent gesture recognition • Tilt cannot be addressed to a great degree as only one Accelerometer is employed
Amstutz et al (2009)	A wristwatch device with an integrated HMM based gesture recognition interface	• A novel gesture recognition mechanism in a highly resource constrained environment • Requires less computational load	• Works with a very limited set of gestures • Number of supported gestures and recognition accuracy are trade-offs.
Pandit et al (2009)	Glove based hand gesture recognition device using iMEMS Accelerometer.	• Attractive modality of non-tactile based gesture interaction • Wireless approach gives user more freedom.	• Cumbersome to use as it is a glove based approach • Customization is difficult as that requires modification of both hardware and software

Table 3 – Varied approaches to sensor based hand gesture recognition

Logical Issues and Considerations

While both vision and sensor based devices provide alternative modes for hand gesture recognition, in order to be attractive to a user, various other considerations such as extensibility and the use of a gesture vocabulary need to be examined and evaluated.

Frameworks and Protocols

Regardless of the methodology used for hand gesture recognition, Einstien et al (2003) outline two notable constraints that limit the scope of a given approach. These are namely, lack of extensibility and device dependence.

In order to successfully overcome these two issues, several frameworks and protocols were investigated with the purpose of abstracting devices, methodologies and applications. The findings are presented below (Table 4).

Researcher	Tool	Advantages	Disadvantages
Signer et al (2007)	A stroke based gesture	• Hardware device	• Limited to stroke based gestures

	recognition framework termed “iGesture”.	independence through an abstract input device interface • Application independence through a mark-up language to handle import and export of gesture data • Algorithm independence through defined API	and cannot be extended to support gestures using other mechanisms such as machine vision or accelerometer, EMG data. • Cannot be used in a distributed approach without further modification of framework
Joselli and Clua (2009)	A mobile based touch and Accelerometer gesture recognition framework titled “gRmobile”	• Works even with the limited hardware on mobile phones • Device independency attained to a certain extent. • Works with somewhat resource low hardware environments such as mobile platforms • Supports both touch and accelerometer gestures	• Dependant on JVM so it does not work with non-Java enabled mobile platforms. • Recognition layer employs a HMM and does not provide a mechanism for algorithm independence. • Application independence is not achieved
Einstien et al (2003)	A glove based gesture recognition framework	• A semantic description based approach is proposed making gestures device independent • Template based approach to be able to recognize new gestures without relearning old gestures of a particular type.	• Does not achieve application independence • Temporal predicates are not tested • Recognition layer employs a feedforward neural network and does not provide a mechanism for algorithm independence
Alexander et al (2009)	Machine vision based hand gesture capture and recognition framework named “Gestur”	• Provides abstraction of capturing gestures, calibration, training and classification through a defined API • An event driven architecture enabling application programmers to implement the solution with ease	• Works only with machine vision based solutions • Approach is not scalable
Kaltenbrunner and Bencina (2007)	A table-based tangible interaction framework based on machine vision titled “reacTIVision”	• Cross-platform support • Defined transport protocol for transmission of object states • Distributed design approach	• Works only with limited computer vision techniques • Does not support air gestures.

Table 4 – Evaluation of gesture recognition frameworks

While most evaluated frameworks address device independence and extendibility, this too can be further modularized. A defined API capable of abstracting gesture recognition algorithms and the exportation of gesture data through a mark-up language similar to the solution investigated by Signer et al (2007) is proposed in this regard and in addition to this, a distributed design approach similar to Kaltenbrunner and Bencina (2007) allowing states to be transmitted via a local or wide area network is also preferred. Alexander et al (2009) provide an abstraction of modules such as capture, tracking and utilities within the framework which is also preferred due to its ability to operate in a vast range of conditions primarily due to modularity.

Thus, with the purpose of a distributed design approach in mind, the Touch User Input Output (TUIO) protocol (Kaltenbrunner et al., 2005) and the Open Sound Control (OSC) protocol (M Wright, 2005) were evaluated. A brief summary of these protocols are as follows.

TUIO is a framework that utilizes a common protocol and API for multi touch surfaces. The approach used involves

transmission of encoded control data from a tracker application to any client application that is capable of decoding the protocol. This can be used to connect a multi touch application with a variety of devices that support TUIO inputs.

OSC on the other hand, is a protocol used for communication among computers, sound synthesizers and various other multimedia devices. It is a transport independent; message based protocol and has dozens of implementations. OSC is widely used across distributed music systems, inter-process communication and even for a single application.

In order to achieve the vision of a decentralized, hybrid approach for gesture recognition utilizing an approach similar to TUIO and OSC would be useful as they are already proven approaches in their respective domains. Various layers can be abstracted through the usage of Transmission Control Protocol (TCP) or User Datagram Protocol (UDP) for data communication

Vocabulary

Unlike many other pattern recognition problems such as speech recognition, gesture recognition lacks a standardized vocabulary and users often find it desirable to create their own gestures to perform tasks (Liu et al., 2009). Both these requirements need to be satisfied by providing the flexibility to add user defined gestures in addition to a pre-built gesture vocabulary.

For this purpose various approaches were investigated and it was found out that while some researchers prefer to define their own gesture vocabularies (Corradini, 2002; Nielsen et al., 2004) other researchers (Akl and Valaee, 2010; Liu et al., 2009) use standardized vocabularies similar to that identified by Nokia Research (Kela et al., 2006). Due to the need for consistency and standardization the use of the latter is preferred.

Other Design Considerations

Various other considerations such as the cultural background, facial expressions and the use of full body motion detection of a user can be crucial in selecting the correct gesture match. A hybrid in this regard is proposed, as these can be used to further improve the accuracy of the gesture detected. Culture can be grasped in computation by detecting various patterns of expressivity and by combining this with machine learning. Approaches such as the use of a Bayesian network model for mapping cultural influences (Rehm et al., 2008) may prove useful in this regard. The expressivity and mood of the user can also prove useful and may be captured using facial expressions and full body motions. The use of a face partition based model to distinguish complex facial expressions (Martin et al., 2006), and various pose estimation techniques (Moeslund and Granum, 2001) show promising results in these domains.

The importance of integrating techniques such as these should be highlighted as not only would this increase the user adaptation; it would also greatly increase the recognition accuracy of a gesture performed.

However, factors such as computational efficiency and the effort required in training such a system should also be taken into consideration prior to implementation.

CONCLUSION

Gesture recognition is a broad application domain covering a variety of tools and techniques. This paper starts by delving into a motivational example with regard to the vision for the future and then continues to explore the state of the art in gesture recognition. Information evaluated has been structured into three key areas for better readability and comprehension.

First, tools and techniques that use computer vision as a mechanism for hand gesture recognition is explored. Six unique approaches are evaluated and it was found that that while various devices, algorithms, and techniques were used by a variety of researchers, disadvantages arose mainly due to the lack of modularization. Thus, in order to further evaluate this, three different surveys exploring computer vision are examined. It can be said that while vision based tools are preferred as they are cost effective, non-intrusive and carry a wealth of information, they are also limited due to the primitiveness of available algorithms, computational load, background noise, variable lighting conditions, limited scope, limited range and as many approaches are based on assumptions not suitable in a real life scenario. It was also found that most research quickly evade evaluating alternative sensor based approaches and often support the argument presented by Mitra and Acharya (2007) stating that approaches such as glove-based require “the user to wear a cumbersome device and carry a load of cables connecting the device to a computer”. However, this is not the case given the state of

the art in computing and much is yet to be explored in this regard.

Thus as an alternative, sensor based tools and techniques were evaluated second and ten different surveys were explored in this regard. While sensor based solutions are often both less-natural and less-intuitive than computer vision based solutions, it is to be noted that they provide a novel mechanism for integrating intelligence into devices around us especially with regard to sensors such as accelerometers and gyroscopes. It was found that unlike vision based techniques that are chiefly based on how an individual would perceive his surroundings, sensor based approaches are immune to challenges inherent to computer vision such as background noise, variable lighting conditions, limited scope and limited range. The availability of accelerometers in particular and its availability in numerous consumer electronics such as gaming remotes and mobile phones is also emphasized as it shows great promise for further research.

Finally, cross domain issues and logical considerations that need to be made were evaluated, and five different frameworks and protocols such as Touch User Input Output (TUIO) and Open Sound Control (OSC) were explored. It was found that in order to accommodate a larger number of devices and applications abstraction of various aspects is preffered. In order to increase scalability protocols such TCP or UDP can be used. In order to accommodate the need for a gesture vocabulary the use of standardized vocabularies similar to that identified by Nokia Research while also giving the user the ability define his own gestures is proposed. In order to increase recognition accuracy, coupling the gesture recognition system with full body motion detection and the utilization of various machine learning techniques for detecting the users' mood and culture is also suggested. A cautious note on the impact this would have on computational efficiency and the effort required in training such a system should also be taken into consideration.

It is strongly believed that the way forward is through modularization, scalability and essentially decentralizing the entire approach from gesture capture to recognition. This way, multiple devices and applications can be bridged with the solution allowing developers, researchers and users to both improve and extend the system promoting better participation and thus better interoperability overall as it builds an eco-system of both developers and users. This is a good starting point for further investigation and evaluation.

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