Smartphones can Recognize Stress Induced Hand Tremor

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Abstract. This paper shows that a Smartphone's accelerometers can corroborate metrics of quality of daily living. A HTC G1 application was created to capture hand tremor. The application was tested on volunteer participants, both with and without known hand tremor. Experiments were run to assess the application's ability to distinguish tremor for a participant and between participants. The application was also used to test if it could corroborate self report of sleep quality.
Our experiments were able to use the Smartphone accelerometers to easily distinguish tremor frequency and frequency change between people with diagnosed hand tremor and those that did not have it. Showing hand tremor on a mobile device has the potential to help those with hand tremor track and gain greater understanding of the tremor's manifestation over time. Such an understanding could aid in diagnosis and provide those with hand tremor indications of lifestyle factors that exacerbate or relieve certain types of tremor.
Tremor measurements were also assessed against sleep quality reports as assessed by the Pittsburgh Sleep Quality Inventory [1]. The experiments show that a Smartphone could measure tremor well enough to corroborate self-assessment of sleep quality for subjects. This demonstrates a potential use of the application as a corroborating sleep assessor.
Infact, hand tremor can be an indication of various physical and emotional stressors. Hand tremor evaluation then can be considered as a monitorable implicit input (not requiring explicit input action from user) to a system that could be used for human system interaction in a variety of scenarios.

Keywords: Hand tremor, healthcare, mobile device, mobile phone; accelerometer, Android, Smartphone, novel interface.

1 Introduction

As the baby boomer generation ages, the US census predicts a dramatic increase in persons older than 65 [2]. Muscle tremor dramatically increases with age [3], and doctors can expect an increased number of patients exhibiting tremor. Diagnosing tremor should include a thorough history and should explore onset, exacerbating and relieving factors, medications, family history, and associated symptoms [4]. Coping with the influx of healthcare needs will require novel solutions. Since severity of hand tremor varies over time [3], we predict an increasing need for longitudinal data as well as additional means to help people identify lifestyle factors that exacerbate or relieve their tremor.

As well, all humans exhibit tremor to some degree and tremors are modulated by many common health factors such as sleep, stress, and strong emotion [5, 3]. Simple tremor measurements might hold some potential as an implicit sensor of personal weariness caused by poor sleep, changes in routine or other stresses.

Mobile devices equipped with triaxial accelerometers are increasingly common, with hundreds of millions of Smartphones now shipping annually [6]. Such devices are often naturally available to users throughout the day and present an opportunity to measure the varying state of hand tremor.

1.1 Tremor Background

Tremor, a rhythmic, involuntary, oscillatory movement of body parts, is the most common movement disorder [4]. There are various kinds of tremor, which are classified by clinical features and cause of origin [4]. All people exhibit physiologic tremor, a benign, high-frequency, low-amplitude postural variation in muscle tone [7]. Usually invisible to the naked eye, it can be amplified by holding a piece of paper on the outstretched hand or pointing a laser at a distant screen [8, 9]. It can be seen in all voluntary muscle groups, but the hands are most often affected [4].

Tremors are classified as rest or action tremors. Rest tremor occurs when the affected body part is completely supported against gravity (e.g., hands resting in the lap) [3]. Action tremors are produced by voluntary muscle contraction. They are further divided into postural, isometric, or kinetic tremor [4]. Although this classification helps in determining cause, the presentation of tremor syndromes varies [4].

Although symptoms can appear at any age, onset of tremor as a movement disorder is most common after age 40 [7]. Tremor may be heightened by many factors such as strong emotion (e.g., anxiety or fear), physical exhaustion, hypoglycemia, hyperthyroidism, heavy metal poisoning, stimulants, alcohol, alcohol withdrawal, or fever [3]. Other factors such as sleep [5] and smoking have been shown to affect tremor significantly: in a study of the effect of smoking on muscle tremor, amplitude of muscle tremor, when tested in 30 subjects, was increased to a significant degree immediately following the smoking of one cigarette [10]. Tremor amplitude continued to be significantly increased one-half hour after smoking ceased [10]. Sensing the above physiological and psychological situations could have many uses.

Given a particular user and a particular situation, tremor sensing might be used for a variety of purposes. Previous attempts to measure tremor were used to improve cellphone user interface. Quek for example, set out to use body motion in tremor to recognize when a phone was being held; unfortunately this effort was not able to reliably distinguish phone in the hand vs. not in the hand [11]. Another interesting project sought to improve the user's experience with the device by reducing the impact of tremor to the user experience [4]. Indeed, tremor has been a problem in user experience design for some time. The TrackPoint in-keyboard pointing device, for example, included algorithms to reduce tremor's effects on small target selection; it also used tremor to know when a person's finger was on the device, so as to avoid recalibration when it was in use [12]. As Quek, the Smart Helmet attempted to use normal body motion to discover when a person was wearing it. Unlike Quek's quest or experiments in this paper, the helmet included a custom computer with an associated accelerometer circuit. Its accelerometer circuit and software did in fact succeed at distinguishing normal head motion from the stillness of a helmet in storage. It used this to activate the helmet and turn on running lights when the bicyclist put it on for riding [3].

This paper addresses three outstanding questions. First, can tremor be measured reliably with Smartphone sensors in a cellphone (shown to be problematic in earlier work [11])? Second, can such data reliably note the physiological status of users? Third, can such status be useful both for chronic tremor diagnosis and for episodic stress (as portrayed by sleep quality)? As

well, this paper is a call to build new kinds of smart interfaces which will use mixed initiative allowing both the person and the system to initiate communication to interact us about subtle, complex internal and personal experiences.
An observer might have many indications that a person has not slept. It often takes reflection about the *implicit* information available in our physiological condition and reactions to ascertain the reason we think they haven't slept, and further interaction or reflection to determine if something is wrong. While tremor is one such piece of information that might be sensible it might also be a indicator of a variety of things. Like heart rate, sweat and even heart rate variability, tremor changes can come from many sources. Such implicit indicators of physiological condition should rely on other contextual information to be interpreted. While the sources of tremor are central to human experiences, they might even elude introspection and require doctors to interpret. Physiological metrics like heart rate, respiration, skin conductivity, or muscle tremor can be sensed as implicit communication that a person doesn't explicitly enter into with a user interface. Such sensed phenomenon might even be more stable and reliable than explicit communication with voice or keyboard that a person consciously projects to the system. Even implicit communication channels can be used as explicit ones; to make a point people sometimes project, as an actor might, amplifying or even fabricating physiological manifestations of emotional or physical states to express a feeling or story about physical or emotional stresss with sweat, tears shaking facial color changes, etc.
Furthermore, tremor can be a form of body language or (involuntary) physical communication to others. The Smartphone might harvest data without explicit communication from the user. For example, measuring tremor could replace the use of a sleep inventory or a sleep journal, or be used to help evaluate medical conditions and treatments. It might be more reliable than subjective measurements such as questionnaires when titrating medication or making other medical treatment decisions.
To the extent that tremor gives insight into a person's state, it might be used as part of an interface that sets system expectations for that person. Tremor input represents a channel that might not in itself be a statement of what has happened or is true; rather, it is an indicator that, when used with other information, can help people know what is going on. And so an interface could be used to document a known physiological state (such as sleep deprivation) for a variety of decisions about adjusting dosage, changing exercise routine, etc. The interface could be an educational tool for showing the effects of physiological and substance impacts on the body. It might even make suggestions, such as to get some sleep, or to take a break to relax, or to not drink another cup of coffee. It might even be used in a similar way as alpha wave recorders, to help a person get to a more relaxed and physiologically comfortable place.

2 Method

2.1 System

An application was written in Java to measure hand tremor. This system was developed for the HTC's G1 phone, running the Android 1.6 operating system.
Most hand tremor is in the 3-6 Hz range, although certain types of tremor can get as high as 12 Hz [9]. Following sampling theory, we don't expect that more than 24 Hz should be needed to measure it. Still, we created a system that measured tremor at a higher frequency because we could. The application samples at 40-50 Hz. The reason for this variation is that the accelerometer is set to record at its fastest setting. Whenever any of the axes detect a value change, no matter how small, the application recorded a reading. While the application records

accelerometer values as quickly as it is able to, many factors in our simple application caused us to be concerned about sampling rate. We had written our application as a JADE agent which added a code base and a layer in the phone as well. The Android is a multi-tasking operating system, and other activity on the device (e.g., garbage collection, receiving an email in the background, etc.) can impact this sampling rate as well. A product with a tremor detection subsystem would probably use a variety of real-time computation and polling techniques to reduce tremor measurements' system requirements. While the application records when any change is detected, we also found that if the device were artificially stabilized (e.g., laying flat on a table surface), then the sampling rate would drop. This is because there were fewer opportunities for the accelerometer to register a change, as there were fewer changes. For our purposes, however, this was not a major factor.
Merely speaking at the device while it lay on a table generated enough movement to result in accelerometer value changes, and even the steadiest of hands provided enough movement to mitigate this effect. Obviously this coarse early finding itself points out that such phones should be able to detect almost any kind of movement such as able-bodied peoples' tremors. In all of our tests, the sampling seldom fell below 40 Hz and in those cases only by a few Hz.

2.2 Tremor collection User Interface

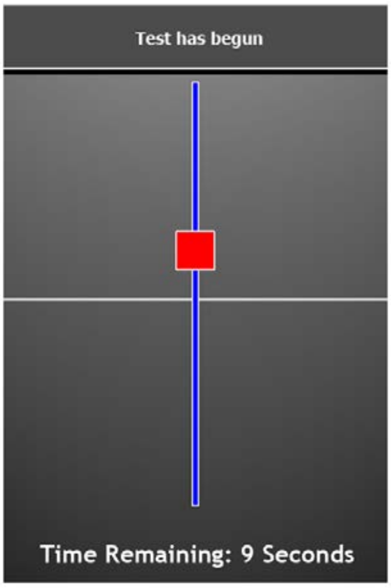

Fig. 1. Initial UI Measurement Screenshot

Fig. 2. Final UI Measurement Screenshot

An early design simply displayed X, Y and Z acceleration values as three numbers on the screen.. This was very difficult to view or interpret while holding the phone. A few different indicators were experimented with. A user interface goal in these iterations was to have the system register and give feedback concerning hand motion as the system recorded their tremor. We tried introducing a bar that represented the Euclidean distance between measurements. It was colored to show highest and lowest values. Other versions showed a time course of tremor; after the 30-second measurement, the system presented a red rectangle which moved up and down on a vertical bar showing tremor value as a tool to help view tremor amplitude. As described below we eventually found that only displaying the words "Remain as still as possible for the duration of the test" on the Smartphone as shown in Figure 2 for the 30 second measurement while data was taken allowed us to get more predictable subject behavior.

2.3 Data Analysis

The application requires the subject to hold the Smartphone at arm's length for 30 seconds. During that time, the application records accelerometer readings in three axes: X, Y, and Z. Acceleration units are given in SI units (meters/second^2).

After the measurement is recorded, an on-device analysis is run on the data. For each time point, a composite score is generated to represent aggregate movement on all three axes. The composite score is calculated by: the square root of the some of the squares of the motion.
Using these composite scores, the analysis then identifies maximums and minimums in the range typical of hand tremor (i.e., under 12 Hz). The number of minimums is primarily for verification, corroborating the number of maximums identified. In all, the application calculates and records:

- Number of amplitude maximums and minimums and, in turn, tremor frequency,
- Amplitude average, minimum, and maximum,
- Period average, minimum, maximum, and standard deviation of period.

This information is time stamped and stored locally on a micro SD card in the G1 phone.

3 Results

3.1 Pilot Experiments

Pilot tests were conducted at Carnegie Mellon's Silicon Valley campus (CMUSV). Data were first collected from volunteer students, faculty, and staff at CMUSV. These data were used to decide how long to record data, to develop indicators that wouldn't distract or confuse people, and to calibrate the system as to what could be measured.
For each measurement, the phone's display presents text which first instructs a user to:

> "Hold the phone comfortably in your dominant hand with the screen facing you. As long as you comfortably can, extend your arm fully while keeping it perpendicular to your body. Remain as still as possible for the duration of the test."

We experimented with various user interfaces as described above in Method. Most involved the use of a vertical bar with an indicator starting in the middle of this bar, which then adjusted its position according to the severity of the tremor being measured. There were several problems with this approach. While several participants reported enjoying the interface, the majority found it confusing or distracting. Even when instructed not to, some participants would try to "play" with the indicator by introducing artificial tremor. For this reason in this experiment "enjoyable" was not necessarily a desirable characteristic for the interface. Another problem was that the interfaces relied on signal amplitude which was shown not to be an important metric.

To mitigate these concerns, we opted for a static interface that used a simple text statement. It instructed participants to “Please remain as still as possible” and displayed the time remaining, as shown in figure 2.

When the protocol was established, the formal data were collected from our subjects with diagnosed tremor. A second set of subjects were later engaged: older adults at the Mountain View Senior Center in Mountain View, CA. The instructions quoted above were verbally repeated to these subjects, as many participants suffered visual impairment.

Initial data came from one person with a tremor movement disorder and numerous volunteers with no known history of hand tremor. The participant with diagnosed tremor agreed to use the application regularly for a week. Several times each day the participant took a measurement, noting whether this person’s own perception was that there was no tremor (N=8 times), slight tremor (N=4 times), or clearly visible tremor (N=7 times) during the tremor measurement session. Throughout the week, the participant did not see any of the scores recorded by the application.

Upon analysis, the application’s data corroborated the participant’s own perception of tremor experience allowing easy distinguishably between “no visible tremor”, “slight tremor” and “visible tremor”, as shown in figure 3.

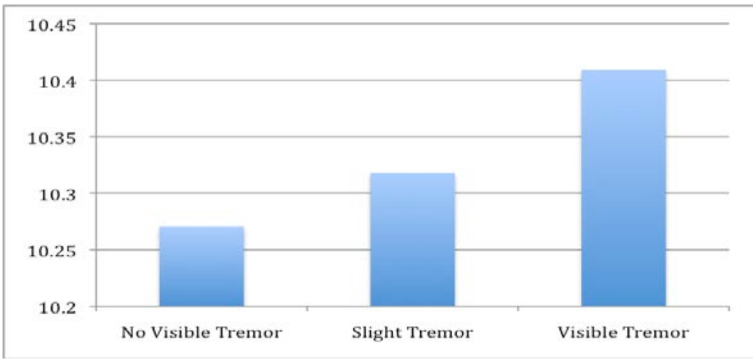

Fig. 3. Mean Amplitude Maximum (m/s^2)

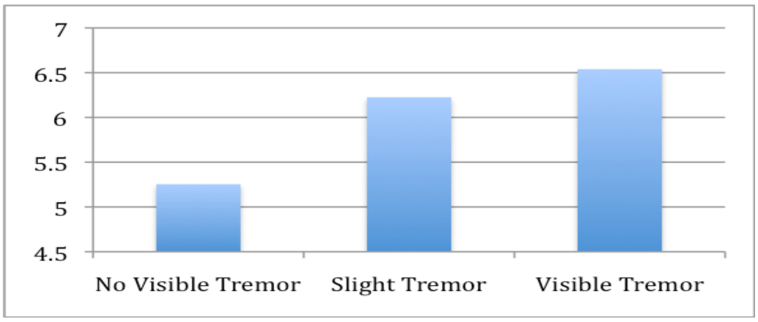

Fig. 4. Mean Tremor Frequency (Hz)

Interestingly, these *amplitude* results did not distinguish the volunteer with diagnosed tremor from other participants.

Although the other participants reported no history of hand tremor, they exhibited mean amplitude maximums both lower than the tremor participant's mean "no visible tremor" and higher than the tremor participant's mean "visible tremor" scores.
Tremor *frequency* also increased with all participants' own perception of tremor in figure 4.
Unlike amplitude, however, frequency clearly distinguished the participant with known tremor. Of all the preliminary participants, none recorded a frequency above 5 Hz, which was even lower than the participant with known tremor's mean "no visible tremor" score. Most scored in the 3-4 Hz range.
Early versions of the application did not measure the regularity of the period. Upon seeing the effectiveness of frequency in between participant comparisons, we examined the standard deviation of the period as shown in figure 5.

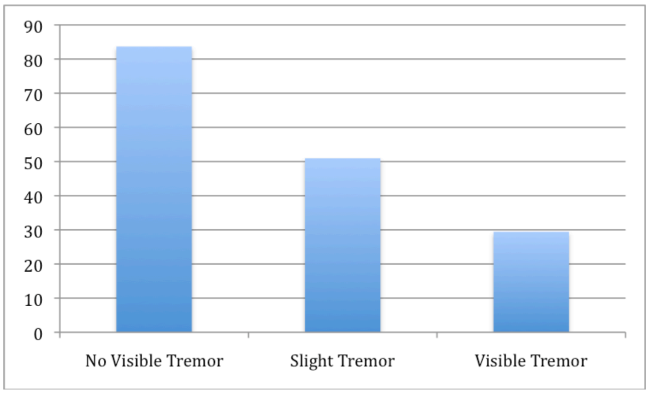

Fig. 5. Mean Standard Deviation tremor time period (milliseconds).

This also proved to be an excellent distinguishing measure for both between and within subject comparisons. No other preliminary participant recorded a standard deviation as low as the tremor participants mean "no visible tremor" score.

3.2 Surveys

In addition to a tremor measurement, participants were asked to fill out two surveys. Given the age range and vision problems that many of the participants are living with, all participants were given the option to have the experimenter read the survey to them and to record their responses.
The first survey assessed the participant's history and current experience of hand tremor. The second survey was the Pittsburgh Sleep Quality Index (PSQI) [1]. This survey presents subjects with a standard methodology used by the medical industry to assess sleep quality. The survey was developed to measure sleep quality during the previous month and to discriminate between good and poor sleepers. Sleep quality is a complex phenomenon that involves several dimensions, each of which is covered by the PSQI [10]. The covered domains include subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medications, and daytime dysfunction [1].
The first overview survey and collection protocol were administered to 19 volunteer participants interacting with a Smartphone as a tremor sensor. Of these, 16 completed the PSQI survey as well (3 participants chose not to complete it or only partially fill it out).
Of these 19, 5 reported a history of hand tremor. In these tremor subjects as in the pilot experiment tremor subject, comparing the *amplitud*e profiles did not result in distinctions

between tremor and no-tremor participants. Indeed, the mean amplitudes between the two groups at the Mountain View Senior Center were almost identical as shown in Table 1.

Table 1.. Mean tremor amplitude between reported tremor group and no tremor group

No History of Hand Tremor: N= 14	History of Hand Tremor : N= 5
Mean Amplitude Maximum (m/s^2)	
10.28	10.30

Table . 2. Mean tremor frequency between diagnosed tremor group and no tremor group

No History of Hand Tremor N= 14	History of Hand Tremor: N= 5
Mean Frequency (Hz): t-score 5.06	
3.52	4.95
Mean Period Standard Deviation (ms): t-score 3.70	
138.29	77.11

In Table 2, the difference between frequency domain measurements is statistically significant. Comparing the two groups on frequency yields a t-score of 5.06 for one degree of freedom of the two groups, this gives a probability of less than 0.1 of the result occurring by chance. Comparing the two groups on mean period standard deviation yields a t-score of 3.70 with a probability of less than 0.1 that the result occurred by chance.

As with pilot results, the reported tremor group and no tremor group showed different tremor frequency and regularity, as shown in Table 2.

Scores of the 16 participants that completed the PSQI ranged on the survey from 1-15, with a mean of 6.6, as shown in figure 8. The sleep index graph shows a simple correlation with hand tremor frequency (with one high frequency and two low frequency exceptions). Given the many things that tremor is associated with, it is impressive to find the 16 senior center residents' to have tremor frequency simply correlated with a self reported sleep index.

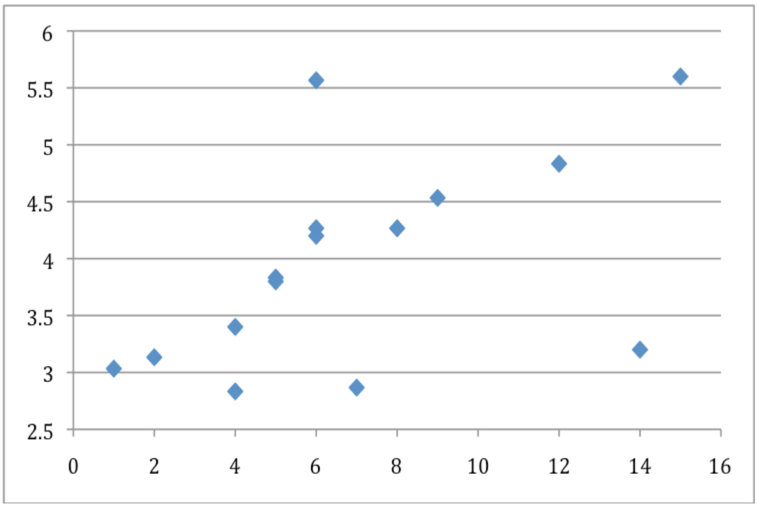

Fig. 8. Scatter plot of PSQI Scores (x-axis) and hand tremor frequency (y-axis).

A correlation analysis of PSQI scores and tremor frequency yields an r-score of 0.557 with a probability of less than 0.05 that the result occurred by chance.

4 Discussion

Even with a small subject pool, Smartphone measurements of tremor corroborated self report. Specifically, tremor frequency and standard deviation of frequency measurements significantly correlated with self-reported history; tremor amplitude was not a useful indicator. Results support the application's ability to differentiate tremor both within participants and between participants to corroborate self assessments of tremor and to correlate it with sleep quality survey results. The use of such an application to better address the healthcare needs of those with tremor appears feasible.

Results suggest the feasibility of using Smartphone accelerometers to measure tremor as a health metric for anyone wishing to gain greater insight into their own well-being. We examined a single factor, sleep quality, using a population—the majority of whom reported no history of hand tremor—and found a positive correlation with scores on the PSQI. This showed repeatable fidelity in tremor recording. Tremor is also associated with smoking, caffeine use, physiological or emotional stress--all factors that could be examined to allow users to gain a better understanding of their health.

Other more telling metrics associating tremor to the stress of not having enough sleep were only available after post-measurement analysis. A future version could be optimized to create a real-time tremor frequency analysis on the Smartphone. Such an optimization would require us to re-write our system so it would not rely on the JADE agent layer we have utilized. Furthermore, using tremor amplitude as a focus turned out to have many other problems as we learned in the data. As well, even amplitude were good for feedback or interpreting tremor, it has large intra-subject differences which would require calibration based on personal historical data.

The results clearly show that while Queck [11] didn't achieve it, his goal of detecting a person through background tremor on a Smartphonel is easily achieved. Evaluating tremor frequency and period standard deviation distinguished tremor from a wide variety of subjects ranging from their early 20s into their early 80s. These metrics of frequency and frequency variation gave signals that allowed comparisons across people without calibration. We showed how such metrics indicate correlation with diagnosed tremor and of sleep quality. We showed the importance of not biasing subjects with positive feedback while taking tremor data.

Still we haven't come close to telling the whole story of tremor as a input to a computing system. We would love to have explored the space further. With more subjects and more extensive surveys, we could see sensitivity to a variety of effects beyond sleep. With more experiments our goals actually would be to evaluate using tremor sensing to support more and interesting uses of the Smartphone.

Indeed our system and experiments are designed to spur the research community to explore the use of tremor sensing in Smartphones for a wide variety of purposes. We also hope that by expanding the exploration for uses of tremor, we all learn how to start using complex implicit inputs from people in ways that use contextual data from yet un-tapped sensors and from analysis to perform new and interesting functions of value to users.

5 Future Work

The aforementioned longitudinal hand tremor data has the potential to improve doctors' abilities to prescribe medication with dosage and frequency appropriate to the patient's pattern of tremor. Further study should examine how best to present such data in a clinical setting for creating the best-suited user interfaces for doctors.

The tremor application shows that a Smartphone tremor recording application might be able to help people quantify "good days" and "bad days" and to correlate such results with health factors. The current study demonstrates how tremor is related to self-reported sleep quality. The literature indicates many other factors that can result in change in tremor characteristics as well [4]. Future work should examine using a Smartphone to corroborate factors such as stress, smoking, caffeine consumption, and various medications.

Additionally, future work should examine user interfaces that provide feedback in ways that encourage reduced tremor in able-bodied people, since tremor in people not diagnosed with tremor disorders is an indication of a less optimal emotional or physiological condition. This could start as a simple recording of tremor period deviation over time, or the data could be used to generate feedback and suggestions for stress reduction. Feedback might be as simple as the color changes of a mood ring, summing up deeper physiological conditions than the finger's temperature of the mood rings we have today.

Corroborating sleep history with tremor measurements opens the door for many possible new kinds of interface. As noted before tremor may be heightened by many factors such as strong emotion (e.g., anxiety or fear), physical exhaustion, hypoglycemia, hyperthyroidism, heavy metal poisoning, stimulants, alcohol, alcohol withdrawal, or fever [3 Feelings as input to user experiences have been rarely explored.

- Such new interfaces could be used to document a known physiological state for a variety of decisions about adjusting medication dosage, changing exercise routine etc.

- Such new interfaces could be as simple as recording one's current stress level in a "journal" for later reflection. Like a written journal, a physiological record including tremor could be used as an interactive reflective tool to identify and corroborate one's feelings about things that happened. Such a record, like a reported feeling, is not so much a direct measure of a problem as an indicator that, when used with other information, can help form useful conclusions.

- The interface could be an educational tool for showing the effects of behaviors and substance use/abuse impacts on the body.

- The interface could also be used as a reflective element in a more personal quest such as the sensory basis for a persuasive system to help the user in solving personal physiological or substance abuse problems.

- The interface could simply help as a caring friend who might indicate it is time for sleep or time to relax.

- Finally, the interface could be simple episodic indicator to help spiritual quests.

Indeed, we see tremor as the kind of subtle and interesting input that can take user experience forward into the subjective and interesting realms of personal experience and interpersonal exchanges that might elude explicit computer input devices.

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