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Gabor Filter for Enhanced Recognition of Assisted Turning Events

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Abstract

Nursing facility residents at high risk for pressure ulcers are turned in bed by staff at regular intervals. In an ongoing large, multi-site randomized clinical trial (RCT) the impacts of 2, 3, and 4 hour turning intervals are being studied on pressure ulcer outcomes. In the RCT, it is necessary to objectively confirm the reported times of assisted turning by certified nurse assistants using activity data. Activity peaks in Gaussian-smoothed activity data were unable to confirm all turning events in a supporting pilot study with observer notes of assisted turns. A new technique is presented using one-dimensional Gabor filters that enhances activity peaks due to turning events and diminishes the signal during extended activity. As a result, all assisted turns in the pilot study were detected and confirmed. Moreover, the dependence of detection sensitivity on decision threshold is lowered in this method.

I. Introduction

Among important considerations for maintaining good health of the elderly in nursing facilities is a need to turn the residents regularly to prevent pressure ulcers and skin lesions. In the population of nursing facility residents at high risk for pressure ulcers due to immobility in bed, limited out-of-bed activity, diminished sensory perception, and malnourishment, approximately 11% develop pressure ulcers [1]. The health burden of pressure ulcers is significant both financially, often costing more than $50,000 for treatment per ulcer, as well as for quality of life, which is substantially diminished due to pain and long healing times for the resident [2, 3]. Nursing facilities therefore invest considerable resources in preventive care by requiring staff to turn residents in bed at regular intervals.

In a large, multi-site randomized clinical trial that is under way in USA and Canada, we are studying the impacts of turning protocols for 2, 3, and 4 hour intervals on pressure ulcer outcomes (ClinicalTrials.gov: NCT00665535). The saving of resources for a facility can be very significant if longer turning intervals can be justified by the study.

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One of the difficulties faced in the study is that of objectively confirming the turning times reported by certified nursing assistants. It is hoped that this can be achieved by measuring time-stamped activity of the resident. The study design therefore includes one week during which the resident wears an accelerometer on the non-dominant ankle. Activity data are recorded every minute and are later downloaded to a computer. For calibration and development of methods, a pilot study was done with 9 subjects that were followed over 26 hours and extensive notes were kept, including records of assisted and independent turning times.

In this paper, we report a technique that we have developed to enhance recognition of assisted turning events from activity data. In the pilot study, this has resulted in recognition of 100% of observed assisted turns. This has been achieved with Gabor filters [4] that have applications in image processing [5] and speech recognition [6]. The one-dimensional Gabor energy filter was adapted for application to activity data, and its design is presented herein. The filter resulted in increased signal strength on timescales of assisted turning and performed better than turn-detection from simple Gaussian smoothing of activity.

II. Methods

Accelerometer data fluctuates rapidly and has wide-tailed distributions even after internal preprocessing that stores the data after condensation using area under the curve in 1-minute bins. This is called the principal integrated mode (PIM), and it represents the intensity of motion during the time bin. We used standard 1-D accelerometer devices (Ambulatory Monitoring Inc., Ardsley, NY), and not the newer, more expensive 3-D accelerometers. Thus, we did not have access to orientation and angular data, which presents a serious limitation to the ability to distinguish between turns and other normal activity. However, for the use of activity data in a confirmatory role, it was expected that the 1-D accelerometer would be sufficient. Examples of activity data are presented in Fig. 1. Observe that activity patterns can be very distinct from resident to resident, which necessitates that any recognition technique for occurrence of turns must be scalable for successful application to each individual.

The observed times of assisted turns in the pilot study corresponded to spikes in the PIM activity data during which the values were raised above surrounding baseline values. An analysis of the widths of PIM activations near turns yielded a mean width of 7.14 min, with standard deviation of 2.81 min. The primary Gabor filter was constructed to approximate the pattern of activation of PIM due to assisted turning (Fig. 2). The width of the filter at half-maximum is approximately 7 min, which matches the typical turn duration. The negative lobes of the filter serve to diminish impact of continued activity, thus effectively enhancing the signal during turns and short-duration activity than during extended activity.

The one-dimensional Gabor filter is the product of a Gaussian with a cosine curve:

$$\frac{1}{\sqrt{2\pi\sigma^2}}\exp\left(-\frac{t^2}{2\sigma^2}\right)\cos\left(2\pi f_0{}^t\right).$$

The frequency of the cosine sets the central frequency f_0 of the filter response, which was chosen to be inverse of a 20-min time period. The half-width of the filter in frequency domain was set by adjusting the standard deviation σ of the Gaussian to 7.98 min, so that the half-width extended up to the dc range. The dc response of the filter was removed by subtracting a low-pass Gaussian filter with standard deviation 2σ (approx. 16 min) and weight equal to the area under the curve of the primary Gabor filter. In the orthogonal

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counterpart to the filter, cosine was replaced with sine (Fig. 2). The filters of length 100 minutes are convolved in the time domain with the activity time series. Both filters have similar Gaussian frequency response centered at f_0. An example of the impact of the filter in the frequency domain is shown in Fig. 3. The root-mean-square of the two orthogonal Gabor filter components yields the Gabor energy filter. Since this is positive definite by construction, it yields a signal that is easily compared to the positive definite original signal of PIM activity.

As a baseline for comparison of the ability to detect turning events, simple Gaussian smoothing was employed with the same filter length and with parameters identical to the Gaussian component of the Gabor filter. Smoothing is preferred over the original series due to its strong, wide-tailed fluctuations that result in hundreds of peak detections per day even at the high thresholds.

Sections of data were selected from each subject that were during the period of observation. The data length was set uniformly at 24 hours plus 100 minutes, i.e. 50 minutes on either side of the central 24-h period to compensate for loss of ends due to filtering. Since each subject had been observed on a Sunday night beginning at 10 pm, the central 24-h period was set to start a half hour later at 2230 hours on Sunday and end at the same time on Monday.

It was demanded that peaks in the filtered activity signals at assisted turning events must exceed a threshold. The sensitivity to threshold was studied by selecting three values that were based on percentiles of distribution (within an individual) of the filtered activity signal. The thresholds were set at the following percentiles: 38.2 (low), 50 (medium), and 61.8 (high). The first and the last percentiles correspond to the division of an interval in the golden ratio, while the middle threshold corresponds to the median.

For each threshold, a list of times and magnitudes of all peaks was produced and peaks that were within 20 min of each other were counted as one, represented by the stronger peak. Peaks detected within 20 min of the noted time of assisted turning were considered matches or recognized turning events. True detections and false positives (i.e. activity peaks that are not due to assisted turning) were counted. It may be expected that day-time activity might create more activity peaks that could be confused with turning events. False positive rates were therefore tracked separately for night (2230 to 0530 hours) and day.

III. Results

All 31 assisted turning events that occurred during the selected data intervals for the 9 subjects were identified in the technique that employed the Gabor energy filter. Moreover, there was lower dependence on the threshold for this method compared to detection of peaks using simple smoothing. Sensitivity dropped 19.4% between the low and high thresholds for simple smoothing versus 12.9% for the Gabor filter. The 100% detection rate for the Gabor filter held true for the low and medium thresholds, and dropped to 87.1% for the most conservative threshold. The detection rate based on simple smoothing was lower and more variable, ranging between 74.2% and 93.6% (Table I).

Majority of assisted turns (17 of 31) were during the 7 hours of night and the remaining (14) were during 17 hours of day. The rate of false positives was distinctly higher during the day than at night. During the day, assisted turns correspond to approximately 1 of 8 detections at best and 1 of 14 at worst. During night, assisted turns corresponded to approximately 1 of 2 detections at best and 1 of 3 at worst. Smoothed activity generally detected fewer peaks and fewer false positives, however the lowest false positive rate was provided for night-time activity by the Gabor filter method with a high threshold (Table II).

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The reason for improved performance with the Gabor filter can be visualized in Fig. 4. The design of the filter enhances fluctuations that occur on the timescale of typical assisted turning durations. Moreover, filtered signal is diminished when activity is extended, as often happens during the day. This serves to reduce the median and all decision thresholds. Three assisted turning events are marked in Fig. 4. There is visible enhancement due to the Gabor energy filter of the peaks at turns relative to peaks from other activity. The peaks due to assisted turns are thus more likely to cross the threshold for detection.

IV. Discussion

The Gabor energy filter designed with parameters based on a typical activity pattern resulting from an assisted turning event has yielded excellent ability to detect turning events with low dependence on decision threshold. The filtering enhances the signal in the frequency range of turning events and diminishes the signal in regions of extended activity. Detection sensitivity was 100% for assisted turning events in the pilot study. False positives are an important consideration in a stand-alone application. However, when used as a tool for confirmation of reported turning events, the concern about false positives is diminished. The use of this technique with a low threshold of detection is thus justified for confirmatory application.

Effective as the technique is for confirmation of reported turns, there is no fundamental way to distinguish between turning events (assisted or independent) and common activity spikes of short duration using 1-D accelerometry. The false positive rate for assisted turning is therefore high, especially during the day. Use of the method for automated, independent detection of turning is not recommended. However, if it is used in a stand-alone capacity for recognizing occurrence of assisted turns, the lowest false positive rates (56.7%) are obtained during night using the Gabor filter and a conservative threshold for detection. This is not too limiting since the importance of repositioning is greater at night. Some of the false detections may also correspond to independent turning events, which are arguably not truly false detections from the standpoint of preventing pressure ulcers.

Acknowledgments

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References

[1]. Centers for Medicare and Medicaid Services. Nursing Home Compare. Apr 14. 2011 Available: http://www.medicare.gov/NHCompare/

[2]. Pieper B, Langemo D, Cuddigan J. Pressure ulcer pain: A systematic literature review and national pressure ulcer advisory panel white paper. Ostomy Wound Management. 2009; vol. 55(no. 2): 16–31.

[3]. Kuhn BA, Coulter SJ. Balancing the pressure ulcer cost and quality equation. Nursing Economics. 1992; vol. 10(no. 5):353–359. [PubMed: 1465158]

[4]. Gabor D. Theory of communication. J. Inst. Elec. Eng. 1946; vol. 93:429–457.

[5]. Daugman JG. Uncertainty relation for resolution in space, spatial frequency, and orientation optimized by two-dimensional visual cortical filters. Journal of the Optical Society of America A. Jul.1985 :1160–1169.

[6]. Ezzat, T.; Bouvrie, J.; Poggio, T. Spectro-Temporal Analysis of Speech Using 2-D Gabor Filters. Proc. Interspeech 2007; Belgium. 2007;

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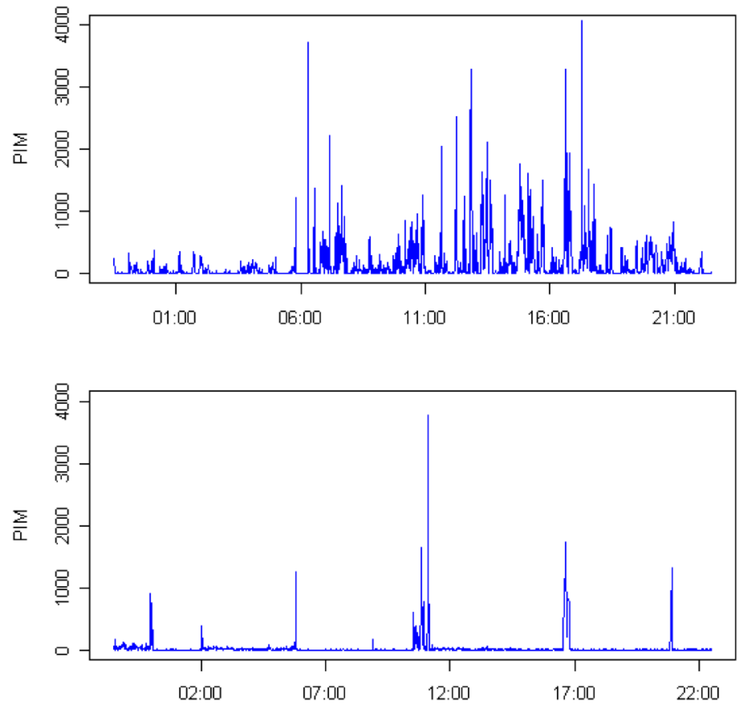

Fig. 1.
Examples of activity data over 24 hours from a relatively active subject (top panel) and an inactive subject (bottom panel).

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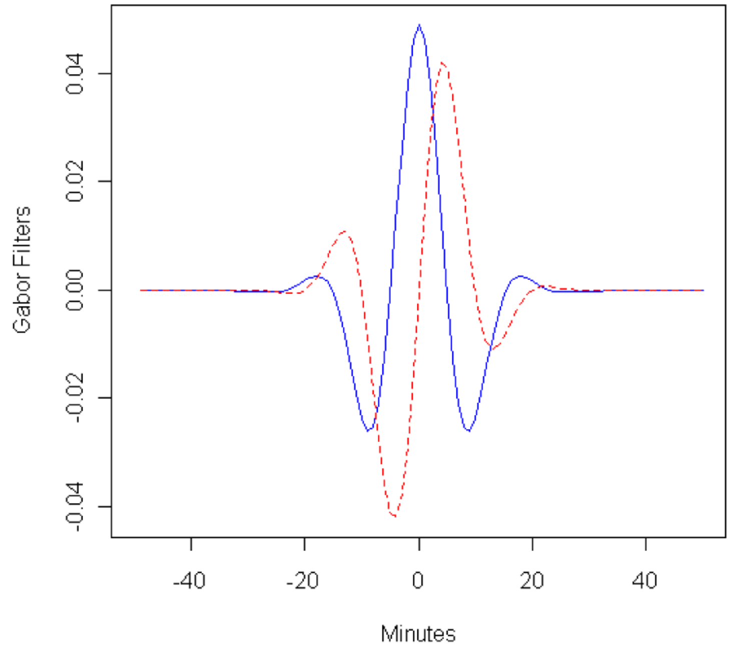

Fig. 2.
Gabor filters designed for turn-recognition. The two curves correspond to orthogonal cosine (solid curve) and sine (dashed curve) components.

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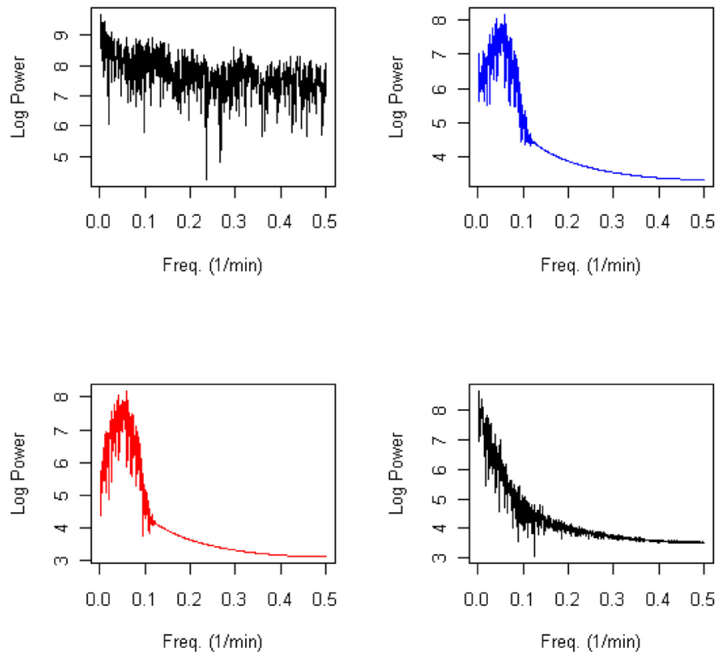

Fig. 3.
Power spectra for activity of a resident from the study: the demeaned original activity signal (top left), the signal filtered with Gabor filters with orthogonal components (top right and bottom left) and the de-meaned combined Gabor energy filter (bottom right.)

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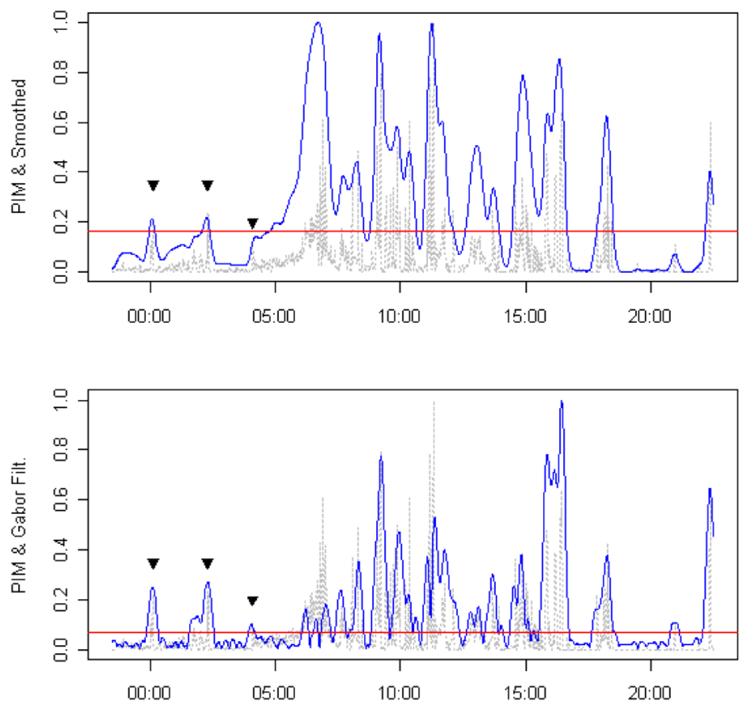

Fig. 4.
Smoothed series (top) with median line, and Gabor energy filtered series (bottom) with median line. The original series is shown in both panels with dotted grey lines. All series were normalized to have range between 0 and 1. Observed assisted turning events are marked with triangles. In the bottom panel, note the enhancement of peaks due to turns as well as reduced signal strength during day.

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TABLE I

Sensitivity of detection of assisted turning events

Detection Method	Low Threshold	Medium Threshold	High Threshold
Simple smoothing	93.6%	87.1%	74.2%
Gabor energy filter	100%	100%	87.1%

Low, medium, and high thresholds are decided by the 38.2, 50, and 61.8 percentiles of the signal distribution for an individual

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TABLE II

False positive rates

Detection Method	Day/ Night	Low Threshold	Medium Threshold	High Threshold
Simple smoothing	Night	65.1%	60.6%	64.0%
Gabor energy filter	Night	69.1%	62.2%	56.7%
Simple smoothing	Day	90.9%	89.5%	88.1%
Gabor energy filter	Day	92.9%	92.0%	90.4%

Low, medium, and high thresholds are decided by the 38.2, 50, and 61.8 percentiles of the signal distribution for an individual