One Year of Wrist Actimetry at One Second Epoch in Real Life

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Abstract—Quantitative analysis of wrist actigraphy data recorded in real life is a topic of growing interest. For historical reasons, most of that data is collected using a one minute epoch, i.e. the system stores one piece of data each minute, and recordings are limited to a few days. When the data is used for wake/sleep studies, the "gold standard" reference is the Polysomnography (PSG) and little is known about the correlation of actigraphy data with epochs shorter than one minute. It is unknown what is the quantitative impact of infradian rhythms, that could be longer than one year, on shorter recordings. To explore those two areas, the only option is to make longer recordings with shorter epochs. We present a set of data, collected as part of a larger project. For the first time, this paper makes available one year of wrist actimetry in real life, stored at one second epochs. A first evaluation of that data calls for new ways for actimetry analysis and actigraphy display. The raw data is available to the public.

Keywords-Actimetry; Actigraphy; Circadian rhythms.

I. INTRODUCTION

The terms "actimetry" and "actigraphy" are used as synonymous for motion activity measures where "actimetry emphasizes the measurement aspect of the technique and actigraphy emphasizes the descriptive aspects of the technique" [1]. Wrist actigraphy has been used in the past 30 years to monitor motion activity. Clinical guidelines and researches suggest that wrist actimetry is particularly useful in the documentation of circadian rhythms, of sleep disorders, of treatment outcomes and as an adjunct to home monitoring of several pathologies. During the day, it is possible to quantify the physical exercise and (with calibration) recognize some type and intensity of the exercise. Reviews are available in several application areas [2]-[7]. Most published data use a one minute epoch, i.e. the system stores one piece of data each minute, and recordings are limited to a few days. The reasons for that selection of parameters are mainly practical, due to the characteristics of the available instrumentation and the logistic/organizational issues of the recordings, especially in real life.

That selection of parameters sets limits on the possible evaluations of the data. When the data is used for wake/sleep studies, the "gold standard" reference is the Polysomnography (PSG), where data is presented in pages 30s long with signals in the range of 0-100 Hz, so short epochs could allow better correlations. There are infradian rhythms spanning over years and without long continuous recordings it is unknown if and how much those rhythms have an impact on shorter recordings. The technology advances offer today the possibility to record more data and in an easier way, but still few long term recordings are described in literature [8]-[14] and only few groups explore shorter epochs [19]. None of those "extended" recording is available to the public. To explore those two areas, the only option is to make longer recordings with shorter epochs and here we describe one of them.

Section II describes the modality of the recording, the export of the data from the original format and the creation of an activity file of one year. Section III explains the main characteristic of the data and options to study it. Section IV notes the most important findings of those preliminary results. We conclude our work in Section V.

II. MATERIALS AND METHODS

The subject of the recording is the author: age 62 at the start of the recording, male, BMI= 26.3, no known major chronic pathologies. Data is collected using a Motionwatch8 logger (CamNtech Ltd., Cambridge, UK) on the non-dominant wrist. Motionwatch8 is a clinical system extensively used in research [23] and it is a recognized reference in the field. The logger is programmed and data managed using the MotionWare software (CamNtech Ltd – Cambridge – UK). The logger is set to store data in an epoch of one second in "normal" mode. That means that the intensity of the movement on the axis perpendicular to the surface of the unit, is measured by an accelerometer sampled at 50 Hz. Data is transformed in a single value of a custom unit (Counts) each second. The logger acquires also a value of light intensity (Lux) each second. Details are described elsewhere by the manufacturer [15]. A maximum of 36 hours of activity and lights data is stored at 1s epoch in the unit and therefore there is the need for a data download every day. A diary is kept of major events (travels, flu, mismanagements, etc.). As usual in this kind of recordings, it is not possible to know the exact position of the unit on the wrist and if and when the photocell of the unit could be somehow obscured (garments, tools, etc.). The marker available on the logger is used to signal when the unit is not worn.

Using the MotionWare software, the values inside the marked intervals are modified from 0 to "n/a". Then, the recordings are joined in files containing more or less 10 days (one million lines) and exported as .CSV files. Using a spreadsheet (OpenCalc – Apache OpenOffice – Apache Open Foundation), lines with "n/a" are changed to "-1" and the data is divided in 9 columns: year, month, day, hour, minute, seconds, counts, lux integers, lux decimals. That format allows the files to be easily accepted by several software programming languages.

 ISBN: 978-1-61208-660-6

With programs we wrote in Octave [21], activity Counts are extracted, saved as .MAT files and joined in one year long file, for a total of 31.576.501 data lines. The time of the file is continuous, aligned to "summer" time used in Italy in June, at the beginning of the recording (UTC+2: 27 March to 30 October 2016; 26 March to 29 October 2017). Evaluations and graphics of this article are computed from that file using programs we wrote in Octave.

III. RESULTS

Out of 31,576,501 samples, there are 24,936,212 zeros (78.97%), 1,034,485 n/a (3.28%) and 5,605,804 (17.75%) non-zero values. If we compare data stored at one second epoch with data stored at one minute epoch (most used epoch in published articles), we find a completely different ratio between zero and non-zero samples. Over the 1440 minutes of a day, a typical result for one minute epoch would be 555 (39%) zero and 884 (61%) non-zero epochs while for the one second epoch, zeros are about 80 % of the total. How is that possible? The answer is that one minute epochs are computed as the arithmetical sum of 60 one second samples and most of those samples are zero, as shown in Figure 1. For instance, in the lower line, minutes 02.41, 42 and 43 would be counted as 3 active minutes using a one minute epoch, while there are only 5 seconds of movement.

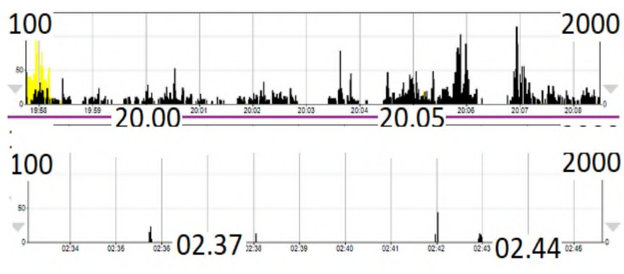

Figure 1. Examples of recordings at epochs of one second: day upper side, night lower. Actimetry in Counts (black) with range on the left, light in Lux (yellow) with range on the right.

Then, we need to extract information from those zero values. A first option for data analysis of zero values could be to consider the percent of zeros inside a time interval. For instance, we may consider one day, divide it in two pieces, like from 10 am to 11. pm and from 11 pm to 10 am, and compute for each day the zero values percent of the two segments. If we plot those values for the full year (Figure 2), the two segments show a quite different behaviour. (Few days with more than 5% of n/a data is removed for a better graph display.). We can get further details if we divide the day in eight segments of 3 hours (Figure 3). It is possible to see that also in that segmentation, a percent of zero values lower than 50% (internal circumference) is exceptional. The circadian behaviour is consistent over the year. The change of the clock to summertime (27 March to 30 October 2016; 26 March to 29 October 2017) may be responsible for some asymmetry that is noted both in Figure 2 and in Figure 3; solar time is from day 135 to day 285.

Another option for data analysis of zero values could be to show not the single epoch values, but the length of the succession of series of zero and non-zero values.

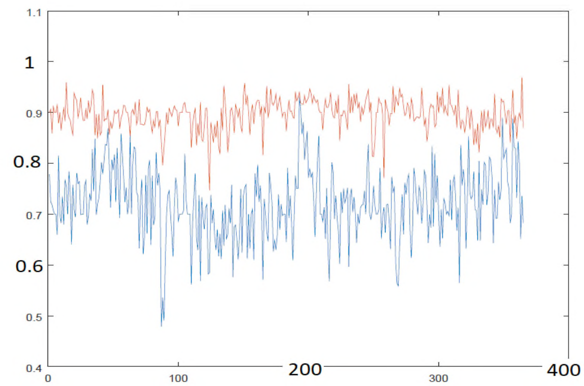

Figure 2. X axis: day of the year - Y axis: zeros percent in the time intervals 10am-11pm (blue) 11pm-10am (red).

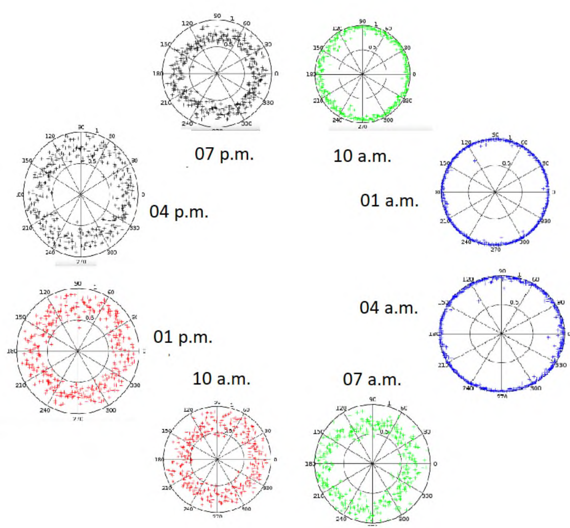

Figure 3. Full year. Zero values percent of 3 hours segments. The time is the start of the 3 hours segment. Circumference is one year, divided in months, 0 is 17 June 2016.

For instance, the sequence ...,0,m,n,0,0,0,p,q,r,0.... will be described using positive and negative integers as …,2,-3, 3,...In the recorded year, there is a sequence of 1.429.113 zero series and, of course, the same amount of non-zeros ones. The distribution of lengths of series at one second epoch in the year is shown in Figure 4, with non-zero series on the right and zero series on the left. The zero series can be long up to 7400 seconds, the non-zero series up to 623 seconds. There is a peak of several hundred thousand series around few short lengths. If we zoom in Figure 4, we see (Figure 5) that over one year, the number of zero and non-

 ISBN: 978-1-61208-660-6

zero series longer than 10 seconds is a small percent of the total.

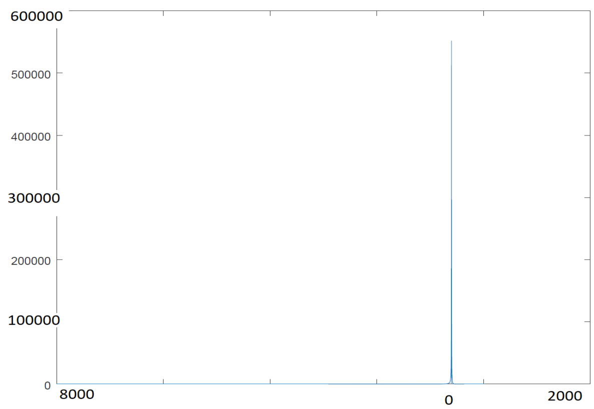

Figure 4. Full year. X axis: length of the series. Zeros series on the left, non-zero series on the right. Y axis: number of series.

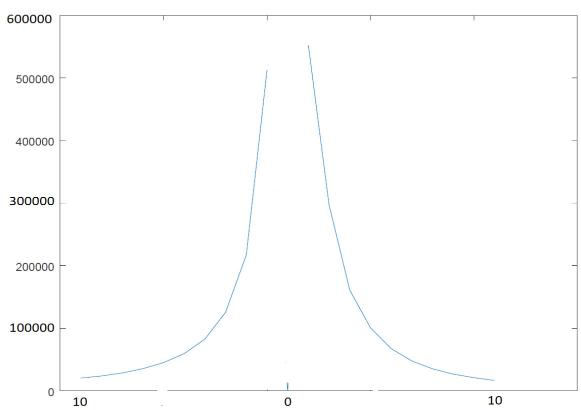

Figure 5. Full year - Zoom of Fig.4 X axis , zeros series on the left, non-zero series on the right Y axis– number of series.

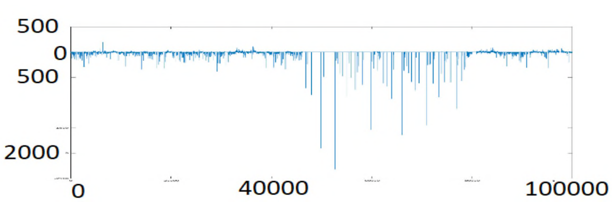

Figure 6. Day one, Start time 09:52:00. X axis: 100,000 seconds – Y-axis: length of the series in seconds: non-zero series up, zero series down.

But, that small percent of lengths are not distributed randomly. If we plot the series, with non-zero series up and zero series down and the distance between the series equal to the length of the series, we get a graph as shown in Figure 6. The pattern is clearly bimodal and that daily profile is consistent over the year.

We may also imagine studying those series as states and search for models of their dynamics. For instance, we may evaluate one step from zero series or from non-zero series. If we plot the length of zero series as negative values and non-zero series that follows them as positive, as in Figure 7, we see that only short zero series can move to long non-zero ones. In the same way, Figure 8 shows that only short non-zero series can move to long zero ones, This suggests that, for instance, a model like the one in Figure 9 and the possibility to make statements on the data dynamics without any a priori hypothesis on the physiology.

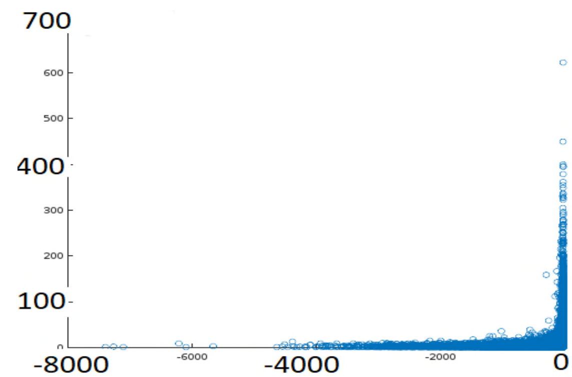

Figure 7. Full year. X axis: zeros series, length in seconds. Y axis : non- zero series that follow, in seconds.

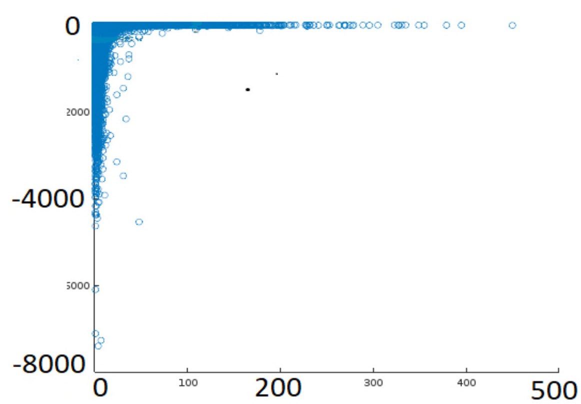

Figure 8. Full year. X axis: non-zeros series, length in seconds. Y axis: non-zero series that follow, length in seconds.

 ISBN: 978-1-61208-660-6

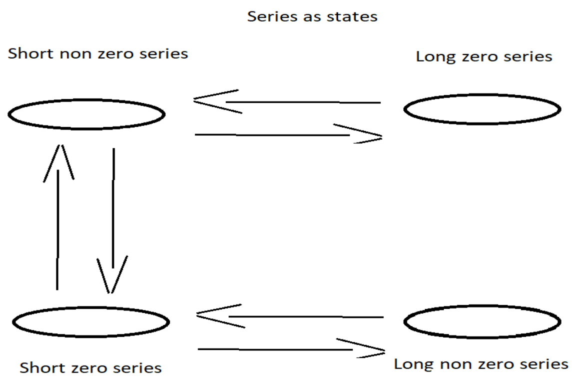

Figure 9. Model of series as states.

IV. Discussion

A first qualitative description of the dataset offers 3 unexpected results. First of all, there is the large number of zero values in the one second epoch recordings compared with the one's with one minute epoch. Traditionally, actigraphy is analysed as a table of a dependent variable (activity counts) and an independent one (time) with fitting methods like Cosinor [16]. That approach is quite difficult when 80% of values are zeros and push to focus on the study of those zero values. Over the years, there were studies on zero values, also called “immobility” [17]. It is one area of studies that is getting new attention [18] and the higher granularity of one second epochs has already shown some potential [19]. The quantity of non-zero values (activity intensity) and quantity of light (light intensity) could provide useful additional information to the study of zero values even if their contribution is based on data more open to artefacts and noise.

The second unexpected result is the permanent circadian distribution of the percent of zero values as shown in Figure 2 and Figure 3. Finding which time interval, and which segmentation of it, would better suit to describe the data, is a research task similar to the well-known Non-Parametric Circadian Rhythm Analysis (NPCRA) method [20].

Last, the pattern in Figure 6 shows, in a different data space, the information of Figure 2 (higher zero percent during the night) but with a more detailed time relationship. It also shows that very long series of zero values, during this year, are allowed only during sleep (personal communication). Their length seems not to be related to sleep stages and co-recording of polygraphic data is needed to explore that relationship. The exploration of series and their dynamics is , as far as I know, a new area of research for actigraphy analysis.

All the above information is easy to see from the proposed graphic displays. That means that there is a very high probability that artificial intelligence algorithms will be able to recognise those patterns and offer better insights (hopefully quantitative) on the data.

V. Conclusion and Future Work

For the first time, we make available one year of wrist actimetry in real life, stored at one seconds epochs. Most of the activity values stored by the Motionwatch8 are equal to zero. Examples of ways to study those zeros and to display them are introduced. The raw data described in this article are freely available to researchers on the National Sleep Research Resource (NSRR) platform [22]. Hopefully, other researchers will look for new tools to analyse human motor activity and clarify the role of actigraphy in the personalised medicine.

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