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MANIFESTO

Think Positive
Think Deeper
Think Global
Think like a Dreamer
Think Healthy
Think Timeless
Think Minimal
WE see ourselves as early explores of the Internet of Furniture and we think that the space around us shall be our next smart device.

WE decided to improve the quality of living reinventing the bed, which is the single piece of furniture where we spent majority of our life, creating the first smart bed ever conceived. It’s the first walk-in device capable to take care of our wellbeing and health completely contactless and effortless.

WE decided stand out from the crowded arena of sleep tech devices, because we believe we don’t need an additional device to track our sleep and health, but we can use the same products we are used to integrating smart technology inside.

WE decided, indeed, to innovate a mainstream industry such as the furniture and bedding industry creating the first open source platform for the bedding industry.

WE aim to highlight with this whitepaper the results of our first validation study conducted comparing our smart bed technology for tracking sleep to polysomnography.
We are all sleep consumers. 60 billions hours of sleep are consumed every day on average. Chronic sleep loss or sleep disorders may result in an annual costs of billions worldwide in health care expenses and in lost productivity.

Sleeping less than seven hours per day is associated with an increased risk of obesity, diabetes, high blood pressure, heart disease, stroke and mental distress. Lack of sleep is also a big problem at work. In fact, lack of sleep can lead to burnout and poor decision-making.

Figure 1: Costs of bad sleep.
The U.S. “sleep market” alone was worth an estimated $28.6 billion in 2017. For 2018, the market should grow by 3.3%. To 2023, 4.7% average annual growth is forecast.

Proper nutrition, sleep, and exercise are important pillars of health. However so far the importance of sleep has been underestimated.

Sleep well and live longer is not only a suggestion but also a certainty. To sleep well we have to know our sleep quality. PSG is the current gold standard for measuring sleep. This technique employs numerous collections of surface electrodes, each measuring physiologic parameters of sleep, including brain dynamics of electroencephalography (EEG), eye movements, muscle activity, heart physiology, and respiratory function. To achieve all this, individuals typically spend the night in a sleep laboratory—a controlled setting under the continued supervision of a sleep technician. Time series data are aggregated, processed, and visually examined or mathematically transformed in order to reveal insights about sleep-wake states and many aspects of physiology. We cannot evaluate every night in a sleep laboratory and on the other hand a single night in laboratory is not representative of physiological sleep. The sleep evaluated in our bedroom is closer to real life way to evaluate sleep. However PSG is expensive, obtrusive (requiring a patient to be hooked up to many devices through electrodes and other interfaces), measures sleep in an
unfamiliar and artificial environment, does not lend itself to longitudinal studies, and requires visual analysis and manual scoring/annotation by a trained expert for adequate data interpretation. The predictable state of immobility, relative to wakefulness, is a characteristic feature of sleep. Taking advantage of this distinctive feature of sleep, clinicians and researchers have attempted to measure the binary presence of sleep or waking states by measuring wrist movements. This approach supports large-scale, population-level sleep research by facilitating inexpensive, unobtrusive sleep measurement without disrupting sleep as PSG sometimes does, and enables measurement across a wide range of circumstances and locations. The resulting opportunity for high participation rates can enhance generalizability of results and also renders longitudinal and repeated measure designs more feasible. Wrist actigraphy, measurement of wrist movements to assess sleep or waking state, is accomplished through an accelerometer in a wrist worn device. However, limited validations exist relative to the gold standard of PSG. Since the traditional methods are intrusive, researchers have been studying unobtrusive approaches to assess mobility in bed by instrumenting the bed with sensors (i.e. conductive mats, pad with pressure sensors to determine movement onset times, pneumatics-based system, placed under the bed mattress, air-mattress with balancing tube method).

Figure 3: Examples of other sleep tech devices.
More recently we assisted to the proliferation of consumer smart devices to track sleep, mostly wearable and/or accessories you place under your sheets or pillow or close to your bed. We see a limit in using this approach to track sleep professionally and extensively due to the nature of such devices which force the contact with the user in most cases, turning the experience of sleep less comfortable and natural for the user. Furthermore, these devices usually present issues with battery life while they are used also during the day (i.e. smart watch, etc.) and have a life-time around one year in most cases, which limits the potential of data collecting for a longer period.
We’ve designed the smart bed as a cocoon for your personal entertainment, wellness and health. These are the three main levels on which the smart bed works.

![Image of HiCan, the first smart bed]

Particularly, in this paper we’ll focus about the sleep and health tracking function, explaining in the next paragraph how it works. However it’s interesting to note here that, thanks to the combination of the sleep tracking with the wellness and entertainment features, the smart bed can be programmed for smart functions such as:

1) “smart alarm”, meaning that the smart bed is going to wake you up in the right moment (when you are supposed to be in the light stage of sleep) and in the best way you want with light (ex. Blue) and/or audio-video and/or even mechanic stimulation, in order to guarantee a natural and regenerating awakening;

2) “smart fall-a-sleep”, meaning that you can design relaxing scenarios that help you to fall a sleep with audio and/or video contents, and when the bed will detect you are sleeping it will automatically turn off the entertainment system and/or any lights, returning the bed in the preferred sleeping position;

3) “anti-snoring”, meaning that the smart bed is able to help you stop snoring, adjusting your position during the night, moving your head up when it is detecting you are snoring;
Furthermore, we are working hard to turn our smart bed also a sleeping coach able to teach you how to improve the quality of your sleep. Our research has just started about how to integrate the use of Artificial Intelligence (AI) to automatically provide the user with meaningful feedbacks and insights on how to improve his/her own sleeping habits, and is still in progress to optimize the data and to improve the experience of the user.

Figure 5: Screenshots of our App
Quality of sleep is an important attribute of an individual’s health state and its assessment is therefore a useful diagnostic feature. Changes in the patterns of motor activities during sleep can be a disease marker, or can reflect various abnormal physiological and medical conditions. Presently, there are no convenient, unobtrusive ways to assess quality of sleep outside of a clinic. This paper describes a system for unobtrusive detection of movement in bed that uses load cells installed at the corners of a bed: Smart Bed. The current sleep monitoring technologies have limitations such as inaccuracy, high maintenance, and lack of comfort. The Smart Bed Technology (hereinafter referred as “SBT”) developed by Hi-Interiors is based on the use of powerful and not intrusive system of load cells.

Our system ensures the maximal comfort utilizing a full contactless device to evaluate sleep quality and monitor main biometrics - such as weight, heart and respiration rate - on a daily basis effortless for the user, with access to an historical log.

The Hi-Interiors’ system allows non-contact, high accuracy monitoring of respiration and movement during sleep. To state its validity and accuracy, we conducted a study comparing the movement measured by the SBT with data from 10 full polysomnographic recordings (hereinafter referred as “PSG”) obtained by 2 subjects in 5 consecutive nights. The assessment of nocturnal sleep is traditionally performed using overnight PSG or actigraphy. PSG consists of continuous recordings of several physiological measures including brain waves (electroencephalography), electrical activity of muscles, eye movement (electrooculogram), breathing rate, blood pressure, blood oxygen saturation, and heart rhythm. It involves at least a full night’s stay in a sleep laboratory attended by properly trained technicians. Although PSG provides a detailed quantitative evaluation of sleep quality and it facilitates the diagnosis of many sleep-related disorders, it is highly disruptive to the patient and may not provide a representative sample of routine sleep patterns and movements during a person’s daily life.

The study demonstrates that SBT sensors are able to measure and detect small body movements during sleep, and overall deliver quality data comparable to polysomnography and better for specificity, sensitivity and accuracy than those obtained by means of sleep actigraphy. The study results show that the SBT is able to track sleep pattern with an average accuracy of 88% compared to the standard polysomnography or actigraphy. Provide accurate measurements across 10 datasets, totaling more than 80 hours of data.
Our research focuses on the unobtrusive assessment of movements in bed using data from load cells installed in the frame of the bed, which has a life-time of ten (10) years circa in average. We have developed a system that allows detection of body movement, i.e., identification of the time intervals when a movement in bed occurs.

In order to validate the accuracy of our SBT, a comparative study was conducted, comparing the SBT output with the physiological gold standard for sleep monitoring PSG and we compared the accuracy, sensitivity and specificity with data obtained by sleep actigraphy and polysomnography. We have related the identification of the modifications of the strength exercised on load cells to sleep phases so as identified from gold standard polysomnographic. The advantages deriving from this type of technology may be represented by long term sleep monitoring and a constant application of standards sleep hygiene through one “smart sleep coach” which may modulate the answers and suggestions on the basis of sleep data obtained in large populations.

Polysomnography (PSG), the gold standard for sleep study, is a multi-parametric test used in the study of sleep and as a diagnostic tool in sleep medicine. The test result is called a polysomnogram. The name is derived from Greek and Latin roots: the Greek “πολύς” (polus for “many, much”, indicating the high number of channels), the Latin “somnus” (“sleep”), and the Greek “γράφειν” (graphein, “to write”). PSG is a comprehensive recording of the biophysiological changes that occur during sleep. It is usually performed at night, when most people sleep. The PSG monitors many body functions, including:

1) Brain electrical activity (electroencephalogram, EEG),
2) eye movements (EOG),
3) muscle activity or skeletal muscle activation (EMG),
4) heart rhythm (ECG), during sleep.

These parameters allow to recognize specific sleep stages of nonREM sleep (light sleep, stages N1 & N2 and deep sleep stage N3). Of particular interest further informations regarding sleep latency (time to sleep), sleep quality (ratio between total sleep time and time in bed (total sleep time plus wakefulness during sleep) *100, values higher than 90% represent good sleep quality), number of awakenings, wakefulness during sleep.
A sleep expert medical doctor should evaluate the entire night of PSG data. This evaluation is performed manually by comparing all the raw data in epochs of 30 seconds. Based on all parameters, the sleep specialist assign a sleep stage for every epoch (“non REM”, without rapid eyes movements, “REM” sleep, with rapid eyes movements and wakefulness) and creates what is called a hypnogram showing the different sleep stages as a function of time. This process is highly time consuming, costly, and leaves room for human error.
The study conducted at Hi-Interiors included two healthy subjects evaluated by PSG recordings obtained using PSG equipment monitoring their sleep for 5 consecutive nights (10 PSG recordings). Each subject was at the same time monitored by SBT sensors measuring movement throughout the night. The goal of the study was to validate the accuracy, sensitivity and specificity of the SBT while monitoring sleep compared with the gold standard PSG. The absolute values of the variations of the linear measurement of the force obtained from the individual load cells in intervals of 30 seconds synchronized with the sleep periods were calculated.

Figure 7: Correspondence between SBT & PSG, after ROC analysis in the first subject (5 nights). High value of both sensitivity (86,8%) and specificity (93,03%) were evident. Area under the curve (AUC)=0,93 level of significance p<0.0001.
The SBT sensors detect movements, sleep and wake when compared with PSG after the ROC curve analysis of differential. In order to quantify the accuracy of the SBT detection data from the PSG data was calculated for each data point during sleep. A data point occurs every second, and for all 10 test subjects this gives a total number of more than 280,000 seconds evaluated, or more than 80 hours. We evaluated the correspondence between SBT & PSG by ROC curve analysis. Sensitivity for sleep corresponds to the proportion of epochs PSG-scored as sleep epochs that are correctly classified as sleep by SBT. Specificity for sleep corresponds to the proportion of epochs PSG-scored as wake epochs that are correctly classified as wake epochs by SBT. A proportion defines accuracy: the total number of 30-sec epochs of sleep (defined by PSG) that were correctly classified by SBT, divided by the total number of events classified (either correct or incorrect). We obtained 86.8% sensitivity and 93.03% specificity in the first subject (5 nights) and 86.3% sensitivity and 84.8% specificity in the second one (5 nights).

The evaluation of all subjects (10 nights) showed high values of both sensitivity (85.3%) and specificity (88.3%).

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**Figure 8**: Correspondence between Hi-Can & PSG after ROC analysis in the second subject (5 nights). High value of both sensitivity (86.3%) and specificity (84.08%) were evident. Area under the curve (AUC)=0.907 level of significance p<0.0001.

**Figure 9**: Correspondence between Hi-Can & PSG after ROC analysis in all subjects (10 nights). High value of both sensitivity (85.3%) and specificity (88.3%), and accuracy (88%) were evident. Area under the curve (AUC)=0.92 level of significance p<0.0001.
The SBT system shows high values of sensitivity, specificity and accuracy when compared with polysomnography. In addition these results are appealing if we compare these data with those obtained by the main medical wrist actigraphy (Actiwatch Spectrum) where as compared with PSG, actigraphy is known to overestimate sleep and underestimate wake time. The specificity reported for actigraphy may range from 22% to 65% lower than SBT specificity (88.3%) and similar values of both accuracy and sensitivity.
We innovate a mainstream industry, so we definitely stand out from the crowded arena of sleep tech devices. In fact, we think we don’t need an additional device, but we need to use the bed that should track our sleep simply contactless and effortless for the user.

The SBT system allows non-contact, high accuracy monitoring of sleep as demonstrated by a polysomnographic study measuring accuracy, sensitivity, and specificity compared to gold standard polysomnography with data from 10 PSG recordings. Over the 80 hours of data analyzed, SBT showed accuracy for sleep measures of 88% compared to the PSG data for all 10 recordings. This pilot study shows that SBT sensors demonstrated high correspondence with polysomnographic data to detect sleep, wake and assess sleep quality. For this reason we envision the possibility of a potential consumer mass-market application of our SBT technology, creating a platform for smart beds and stimulating third parties to develop new software applications for this upcoming marketplace with aim to enhance the sleeping experience and help people take more conscious decision about how to improve their sleeping habits.

We also identify a big opportunity in the development of technologically advanced real time intervention solutions, according to an “Ambient Assisted Living” and “Ambient Intelligence” scheme, allow the redesign of living environments introducing a smart approach in order to guarantee and favor inclusion, safety, health, active aging and home care to enhance elderly people’s living conditions and promote their independence.

Finally, we believe that the sleeping patterns and biometrics collected in bed constantly for the useful life of the product, can represent a unique reliable dataset on which to study AI models, involving the scientific, pharmaceutical and medical community, to develop predictive algorithms able to detect in advance any chronic diseases directly and / or indirectly linked to sleep, promoting active prevention of such disorders and drugs free treatments.

We are just at the beginning of a health and wellness revolution!


5. https://blog.marketresearch.com/top-6-things-to-know-about-the-28-billion-sleep-market