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Application of financial analysis techniques to vital sign data: A novel method of trend interpretation in the intensive care unit

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ABSTRACT

*Modern critical care medicine is based on flow of information. This information requires significant amount of interpretation to become clinically valuable. Despite the wealth of data in the modern intensive care units (ICU), intensivists often rely on fragmentary information. In an attempt to improve data trending utilization, application of financial analysis (**FA**) methods to vital sign data samples was examined. Two randomly chosen vital sign datasets of patients who spent at least 30 days in the ICU were retrospectively reviewed. Hourly vital sign data was retrieved and recorded for each patient. Variables tracked included systolic blood pressure for patient #1 and heart rate for patient #2. These variables were then entered into specialized **FA** software and subjected to computer-based processing. Trends in the recorded data were examined using (1) the **Stochastic Oscillator (SO)**, (2) the **Moving Average Convergence-Divergence** (**MACD**) tool, (3) **Price Envelope (PE)** analysis and (4) **Moving Average** analysis. Both blood pressure and heart rate analyses demonstrated that vital sign data could be successfully trended using **FA** techniques. Not only was the vital sign data easy to read and interpret when formatted in financial-like fashion, but some trends that were not apparent on gross inspection of the numeric data were clearly demonstrated upon **FA**. Much like with financial patterns, trends noted within vital sign data appeared to be more significant when more than one indicator identified them, utilizing the concept of a **confirmatory variable**. Vital sign data, much like financial data, were subject to trend reversals. Such reversals in vital sign data appeared to follow rules similar to those followed by financial vehicles and markets. This report demonstrates that vital sign data can be subjected to the same manipulations as financial market data. Furthermore, **FA** tools appear to provide the interpreter of the data with means to define, confirm, and possibly predict trends and trend reversals.*

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Modern critical care medicine, like most of our fast-paced world, is based on flow of information. Every conceivable device in the modern ICU provides the intensivist with some kind of information, including vital signs, various pressures, intravenous infusion rates, respiratory parameters, etc. The ever-present information requires significant amount of interpretation before it attains some kind of therapeutically meaningful character. The ICUs have not capitalized on the huge amount of streaming data. Unlike the financial market specialists, intensivists still rely only on fragmentary data and trends often limited to a glimpse at the data from the most recent 24-hour period or shift. An examination of trending methods not previously used in medicine was conducted in an attempt to improve on the current state of data utilization in the ICU. Namely, trending techniques commonly used by financial market professionals were applied to vital sign data.

Technical indicators have long been used in analyzing past trends and in attempting to predict future events. It is well established that nearly all variables in biology are non-stationarily stochastic.[1] Numerous complicated approaches have been used in the past in order to describe trending of vital signs.[1,2] Fourier spectral analysis has been shown to work well for strictly periodic or stationary random time functions.[1] A stochastic exponential dispersion model was shown to describe regional organ blood flow in an animal model.[2]

Financial indicators are used to signal potential trend reversals in the financial markets, and when used with other variables (such as company earnings, sector earnings, or stock market 'sentiment') can contribute to the global decision-making regarding a purchase or a sale of a given security. Some of the most commonly used economic indicators include moving average convergence-divergence (**MACD**) and the stochastic oscillator (**SO**).[3,4]

The advantage of the indicators used in this study is that, while the Fourier spectral analysis and other such analyses are extremely complex, the indicators used in this report can be understood with only a rudimentary knowledge of mathematics.

It was hypothesized that use of **MACD**, **SO**, and **PE** can effectively demonstrate trends in vital sign data, and open a possibility that these indicators could be used in conjunction with clinical findings to improve global patient care and clinical decision making. The goal of this study is not to create or propose new indicators. Instead, this report simply aims to use existing and proven methods of financial data 'trending' in a novel way.

Vital sign data were obtained retrospectively from two randomly selected, anonymized, ICU vital sign charts. Vital sign data was recorded in hourly intervals, over a period of weeks. These vital sign data were transformed into the open-high-low-close (**OHLC**) format used in stock analysis. In order for this format to be used, the hourly-collected data had to be arranged into 4-hour **epochs**. For each **epoch**, the opening value (the first value in the **epoch**), the high and low values, as well as the closing value (the last value in the **epoch**) were ascertained over a 4-hour period. Data were then entered sequentially for each epoch into MetaStock™ (Equis International, Salt Lake City, UT, USA) financial analysis software. Once the data were entered, a graphical interpretation, much like a stock price graph, emerged. Data analysis included observational inspection of the stock-like charts, which were examined for presence or absence of variability and/or trends.

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A definitive trend was defined as the **MACD** indicator above the 'trigger line'. Stochastic oscillator is a 'lagging indicator' and was used to confirm a trend reversal. Envelopes were added as a second confirmatory trending tool. In addition, two moving averages were used. Ordinary stock market parameters of 'oversold' and 'overbought' were used with respect to **SA**. The 'oversold' state represented a potential trend reversal on the low side, while the 'overbought' state represented a potential trend reversal on the high side. Detailed description of stock trending methods follows below.

Three 'public-domain' indicators used mainly in stock and bond market analysis were utilized. The first one, called **moving average convergence-divergence** (**MACD**), developed by Gerald Appel in 1980, signals overbought and oversold conditions. [5] **MACD** indicator is created by calculating the difference between two exponential moving averages. A third exponential moving average is plotted on top of the **MACD** as a trigger line to provide 'buy' and 'sell' signals. One of the popular trading strategies using **MACD**s is crossovers. Generally, when the **MACD** crosses above the trigger line, a buy signal is flagged. When the **MACD** crosses below the trigger line, a sell signal is indicated. **MACD** is especially valuable when used in conjunction with another indicator such as the **SO**. The most popular formula for the 'standard' **MACD** is the difference between a security's 26-day and 12-day exponential moving averages.

Stochastic oscillator is technical indicator, developed by George Lane in the early 1960's, compares a security's closing price with its price range for a given time period.[6] Lane observed that when a stock is rising, it tends to close near the high of the time period and a falling stock closes near its low. In an attempt to rationally quantify this empirical dynamic, he constructed a formulaic process by which a stochastic or "educated guess" as to the direction of an instrument's price could be applied. The **SO** is displayed as two lines. The main line is called %K and is calculated using the high, low, and closing data. The second line, called %D, is a moving average of %K. The formula for %K is as follows:

$$\%K = 100[(C - L5_{close})/(H5 - L5)]$$

Where C is the most recent closing value, L5 is the lowest low for the last 5 trading periods, and H5 is highest high for the same five trading periods. %D is a smoothed version of the %K line. Usually, three periods are used. The %D formula is as follows:

$$\%D = 100 \text{ X } (H3/L3)$$

Where H3 = the 3 period sum of (C - L5) and L3 is the 3 period sum of (H5 - L5).

The **SO** is plotted on a chart with values ranging from 0 to 100 for a specified time frame. As with moving averages, the sensitivity increases with shorter time spans. Readings above 80 are strong and indicate that the trend is nearing highs. Readings below 20 are also strong and indicate that the trend is nearing lows. It is possible to modify the SO calculation in order to 'smooth out' some of the volatility in the indicator. It may be that the slow stochastic provides more accurate signals and is easier to interpret.

Trading bands are lines plotted in and around the price structure to form an 'envelope.' It is the action of the variable under investigation near the edges of the envelope that is of particular interest. One of the earliest references to trading envelopes comes from financial market technical guide, *The Profit Magic of Stock Transaction Timing* by J. M. Hurst.[7] The idea of trading envelopes was advanced further in the 1970's by a common practice of shifting the trading bands by a fixed percentage amount above and below the price of the security.

The mathematical procedure of trading envelope creation is simple. It consists of plotting the moving average (MAV) for the particular security, followed by calculation of the upper and lower bands.[8] The upper band (UB) is calculated by adding a fixed percentage (%F) of value to the MAV (UB = MAV + MAV x %F). The lower band (LB) is calculated similarly by subtracting a fixed percentage (%F) of value from the MAV (LB = MAV – MAV x %F). The MAV, UB, and LB are then plotted. The number of **epochs** over which the MAV is averaged, as well as the %F value, are subject to preference of the person analyzing the data.

Figures 1 and **2** (page 16) show the graphical representation of vital sign data, with the various trends indicated by **FA** software indicators. As one can see, these graphs are no different from ordinary stock price charts processed with the same **FA** software (**Figures 3** and **4**, page 16). In fact, nearly identical reversal patterns are seen in both types of graphs, and temporal patterns that would be difficult to detect by examining purely numerical representation of vital sign data clearly emerge.

Blood pressure and heart rate data can be successfully trended using the **SO**, **MACD**, and **PE** indicators. Similar analyses using data from intracranial pressure monitoring and bladder pressure monitoring have been performed by the author, with equally satisfying results.

CONCLUSIONS

Indicators used by the author provide a new way of describing and interpreting vital sign data. As expected, when a trend was present, indicators tended to demonstrate it well. When no trend was present, the indicators tended to 'wonder around' until the next trend was identified. It may be that further research on the use of these indicators could result in better patient management and perhaps even improved patient outcomes though better vital sign trending analysis. Minimizing the subjective component of patient data interpretation and maximizing the objective component may provide us with a better way of assessing patients and, when correlated with clinical data, may provide useful adjunctive confirmatory or possibly even predictive value.

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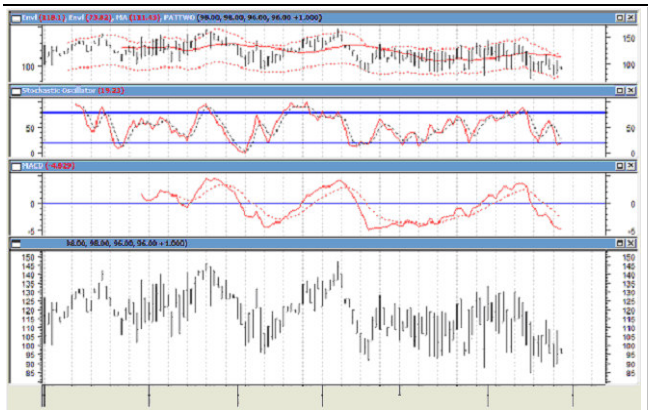


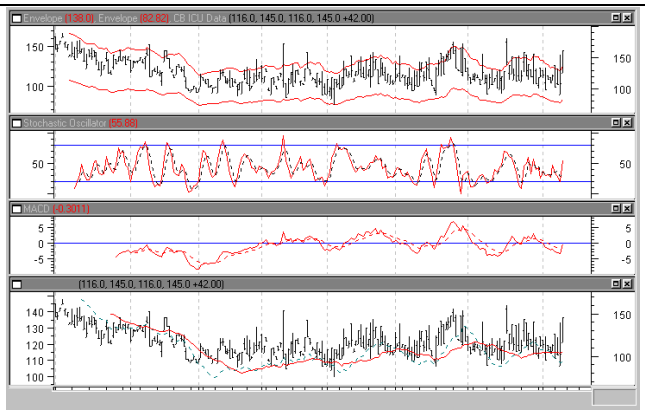
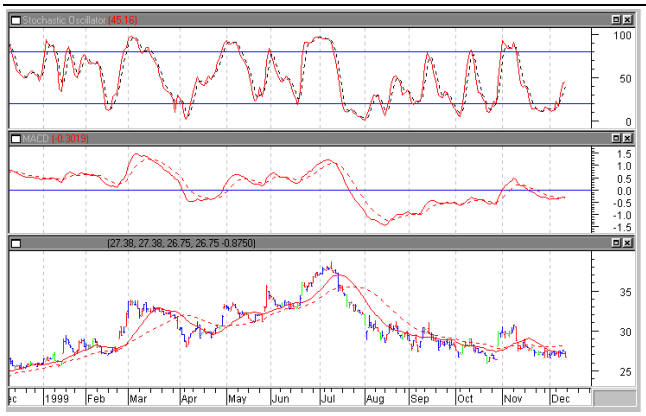


Figure 1 (left upper). Heart rate data shown in the format of a stock chart. The lower field shows heart rate movements in the open-high-low-close (**OHLC**) format grouped in 4-hour intervals (each bar). Above the bar graph are, from bottom to top: moving average convergence-divergence (**MACD**), stochastic indicator (**SO**), and envelope indicators (uppermost).

Figure 2 (right upper). Blood pressure data shown in the format of a stock chart. The lower field shows systolic blood pressure movements in the open-high-low-close (**OHLC**) format grouped in 4-hour intervals (each bar). Above the bar graph are, from bottom to top: moving average convergence-divergence (**MACD**), stochastic indicator (**SO**), and envelope indicators (uppermost).



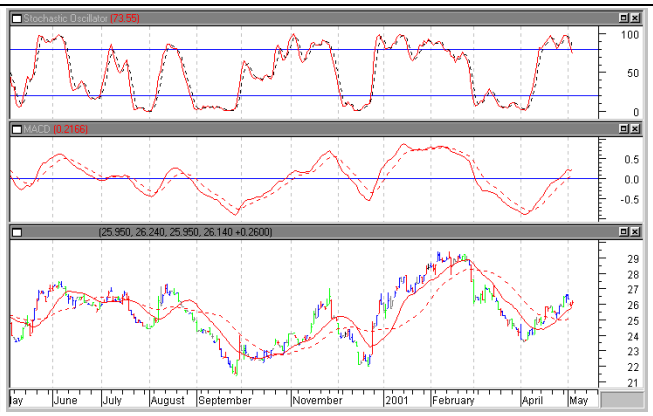


Figure 3 (left lower) and **Figure 4** (right lower). Examples of actual stock charts. The bottom field shows stock price movements in the open-high-low-close (**OHLC**) format grouped in daily intervals (each bar). Above the price movement bars are, from bottom to top: moving average convergence-divergence (**MACD**) and stochastic oscillator (**SO**). Included with the price movement bars are envelope indicators (solid and dashed lines overlying stock price bars in the bottom field).

