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Automatic Control of Human Rate and Blood Pressure Using Tilt Abend Mechanism

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ABSTRACT

Prolonged bed rest has significant negative impacts on the human body, particularly on the cardiovascular system. To overcome adverse effects and enhance functional recovery in bedridden patients, the goal is to mobilize patients as early as possible while controlling and stabilizing their cardiovascular system. The potential clinical applications of active control for pharmacology in general, and anesthesia and critical care unit medicine in particular, are clearly apparent. In this paper, we used a robotic tilt table that allows early mobilization by modulating body inclination and automated leg movement to control the cardiovascular variables heart rate (HR) or systolic or diastolic blood pressures (sBP, dBP). The design and use of a control system is often done with a simulation model of a plant, but the time-variant and nonlinear nature of the cardiovascular system and subject-specific responses to external stimulimakes the modeling and identification challenging. Instead, we implemented an intelligent self-learning fuzzy controller that does not need any prior knowledge about the plant.

1. INTRODUCTION

Acute respiratory failure due to infection, trauma, and major surgery is one of the most common problems encountered in intensive care units (ICU) and mechanical ventilation is the mainstay of supportive therapy for such patients. In particular, mechanical ventilation of a patient with respiratory failure is a critical life-saving procedure performed in the intensive care unit.

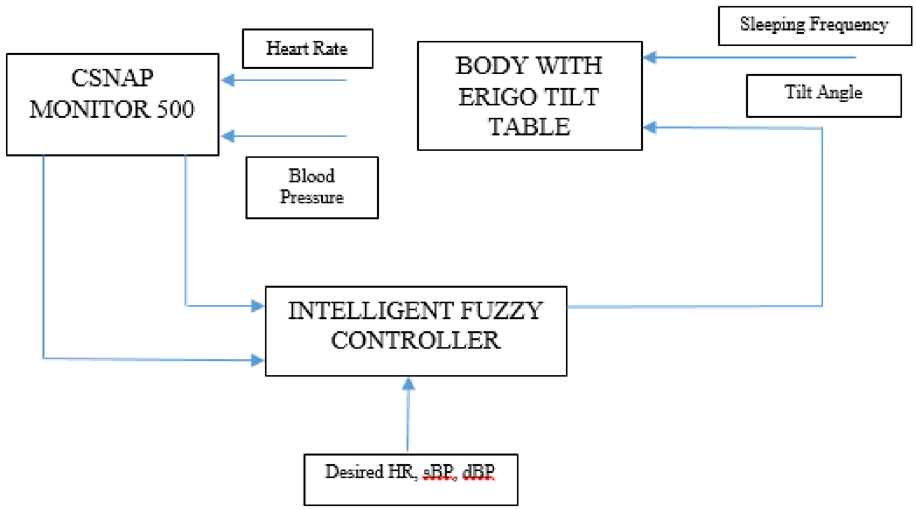

Fig.1. Evaluation of the controller with tilt angle as input, HR, sBP or dBP as output, and stepping as disturbing factor.

However, mechanical ventilation is physically uncomfortable due to the noxious interface between the ventilator and patient, and mechanical ventilation evokes substantial anxiety on the part of the patient. Long-term bed rest negatively affects the cardiovascular, respiratory, musculoskeletal, and neuropsychological systems of these patients and can postpone recovery. To mobilize the patients safely, their cardiovascular parameters have to be considered carefully. Control of these parameters is important to enable early mobilization while avoiding any further adverse effects e.g., decompensation due to fatigue or falling during mobilization. Here, our objective is to design an intelligent rehabilitation bed that allows automatic mobilization of bedridden patients while controlling and stabilizing their cardiovascular system. This will allow patients to get in a vertical position (stand and walk) while reducing risks of side effects, such as dizziness or syncope. It is expected that such a rehabilitation approach reduces secondary complications, personnel effort, and patient time in bed. As an initial prototype, we use a robotic tilt table that allows early mobilization through modulating body inclination and automated leg movement. These external mechanical stimuli are used in a closed-loop framework not only to provide early mobilization but also to control cardiovascular parameters, i.e., Heart rate (HR) and blood pressure (BP).

2. ROBOTIC TILT TABLE AND MEASUREMENT EQUIPMENT

The rehabilitation tilt table Erigo (Hocoma AG, Volketswil, Switzerland) is a robotic tilt table enhanced with a motor-driven stepping device. The inclination angle α of the table can be continuously adapted between 0° and 75°. Passive leg movement is provided by two leg drives with a constant adjustable speed between 0 and 80 steps/min (maximum stepping frequency of $f$max . Step = 1.33 Hz) and equal periods of extension and flexion phases.

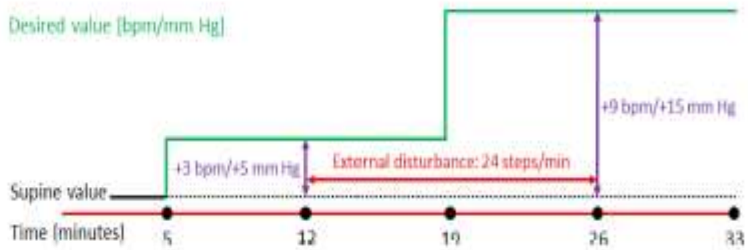

Fig.2. Exprimental protocol

For the continuous noninvasive measurement of biosignals), a CNAP monitor. The monitor requires a short initial calibration for each subject (about 2 min), and uses an arm and a finger cuff to measure the BP signal. The raw BP signal was extracted from the monitor in terms of an analog signal with the rate of 100 Hz and via a galvanic separation fed into an input card of the bed PC. The BP wave signal was buffered online. The peaks of the signal were detected and averaged, allowing real-time values of sBP and dBP to be computed. Moreover, heart period was obtained by averaging the time length between successive dBP peaks in order to calculate the real-time HR value.

3. SUBJECTS AND EXPERIMENTS PROTOCOL

The controller was evaluated in six healthy subjects (age ± standard deviation (SD)): 27.7 ± 2.05 years; height: 182.2 ± 7.9 cm; weight 83.2 ± 12.1 kg; body mass index (BMI) 25.4 ± 5.3). The participants had no known cardiovascular. Informed consent was obtained from all subjects.

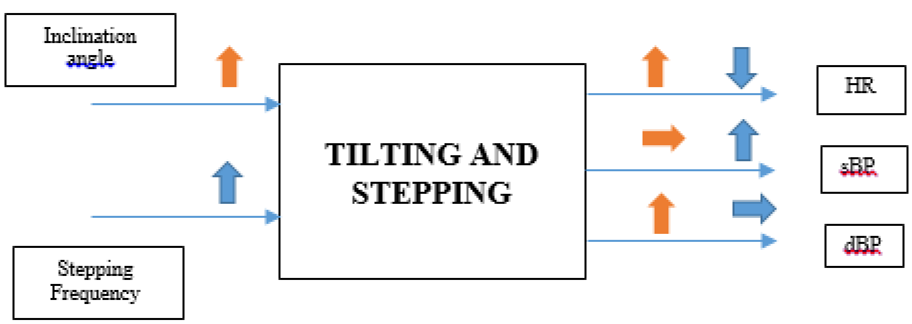

Fig.3. General steady-state response of cardiovascular parameters to passive tilting and stepping.

For each subject, three experiments of HR, sBP, and dBP control were done. Each experiment took 33 min. Since a stabilized steady-state response of the cardiovascular system at a sustained position can be reached in about 5 min [13], each experiment started with a 5 min initial measurement in the supine position, followed by four 7-min blocks where the controller had to keep the HR or each BP signal at predefined values by providing the appropriate inclination angle. To evaluate the performance of the controller and detect potential limitations of the system, appropriate, predefined desired values had to be chosen. To calculate the appropriate desired values and to obtain an approximate value for the steady-state response, the cardiovascular parameter was averaged during the last minute of the initial 5 min supine position phase. Then, we assigned the set points: For the HR control experiment, 3 beats/min for the first two 7-min blocks, and 9 beats/min for the second two blocks, were added to the calculated steady-state supine values . For BP experiments, 5 and 15 mmHg, respectively, were added to the calculated steady-state supine values. The goal from choosing relatively lower set point values in the first two 7-min blocks was to evaluate the performance of the controller and its robustness with respect to external disturbance. For the second two blocks, higher values were assigned to find potential limitations of the system.

4. RESULTS

The average of absolute mean error for HR over all the four set points was below 2 beats/min for each subject . The total absolute mean error was greater for sBP compared to dBP, whereas the error SDs (i.e., short-term dynamics) did not differ significantly. We calculated the average of absolute mean errors in HR and BP, and their corresponding SDs among the subjects. It depicts the controller performance in one of the subjects where the filtered value shows how successful the controller was in reaching the desired values. In the first two 7-min blocks, the set points were chosen to show the performance of the controller and its robustness with respect to external disturbances. During these set points for HR, sBP, and dBP, an average absolute error of 1.17 beats/min, 2.44 mmHg, and 0.85 mmHg were observed, respectively. Considering performance evaluation in all the four blocks, average absolute errors for HR, sBP, and dBP were 1.11 beats/min, 5.1 mmHg, and 2.69 mmHg, respectively.
In the present study, the first two set points were chosen such that they show the accuracy and robustness of the proposed controller, and the second two set points were chosen to show the limitations of the system and borders of the reachable values when trying to affect cardiovascular parameters through applied external stimuli. Hence, the control of variables generally seems to be more difficult in the last two set points. HR could be controlled accurately in all the four set points, and the errors were generally below 2.5

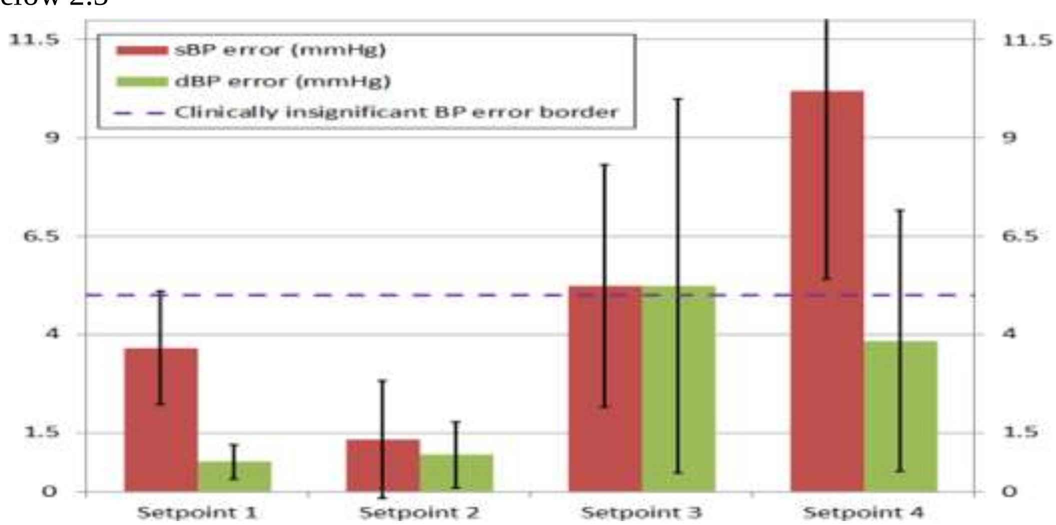

Fig.4. Mean absolute errors of sBP and dBP (solid columns) and corresponding SDs (black lines) among six healthy subjects.

beats/min (i.e., clinically insignificant error border). dBP could be controlled accurately only during the first two set points, and the errors during these two set points were generally below 5 mmHg (clinically insignificant error border). In contrast to dBP, the sBP could hardly be elevated to 5 mmHg with tilting alone (without stepping). Successful control was only observed in the second 7-min block with an average absolute error of 1.32 mmHg, and an increase of +5 mmHg with respect to the supine value when stepping was added. The comparison of "set point 1 and set point 2 together," and "set point 3 and set point 4 together" reveals that the controller reaches the desired values of sBP only when the stepper is active.

CONCLUSION

Control of cardiovascular parameters is governed by autonomic nervous system and, in particular, baroreflex regulation. Impairment of this internal controller causes orthostatic intolerance and is prevalent among bedridden patients. Due to the involved risks, this makes the patients mobilization cumbersome. Augmentation of the impaired internal controller by using an external controller providing suitable external stimuli type and intensity might impede associated risks such as sudden drop of sBP and consequence syncope during mobilization in patients. The goal of this project is to mobilize bedridden patients very early while controlling the cardiopulmonary function through external mechanical and electrical stimuli. As an initial step, this paper proposes an online self-adapting SISO fuzzy controller for HR, sBP, and dBP control through inclination and learning without detailed knowledge about the human body. The experimental results show successful results for HR and dBP control, while sBP could only be regulated within small ranges; adding stepping increased the reachable set of sBP.

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