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Design of Tracking Controllers for Medical Equipment Holders Using AHRS and MEMS Sensors

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***Abstract*—**There are various kinds of medical equipment which requires relatively accurate positional adjustments for successful treatment. However, patients tend to move without notice during a certain span of operations. Therefore, it is common practice that accompanying operators adjust the focus of the equipment. In this paper, tracking controllers for medical equipment are suggested to replace the operators. The tracking controllers use AHRS sensor information to recognize the movements of patients. Sensor fusion is applied to reducing the error magnitudes through linear Kalman filters. The image processing of optical markers is included to adjust the accumulation errors of gyroscope sensor data especially for yaw angles.

The tracking controller reduces the positional errors between the current focus of a device and the target position on the body of a patient. Since the sensing frequencies of AHRS sensors are very high compared to the physical movements, the control performance is satisfactory. The typical applications are, for example, ESWT or rTMS, which have the error ranges of a few centimeters.

***Keywords*—**AHRS, Sensor fusion, Tracking control, Position and posture.

I. INTRODUCTION

THE recent expansion of MEMS sensors has a tremendous impact on numerous applications. The typical merits are small scales, low-power consumption, and low prices. One of the prominent application areas is AHRS (Attitude and Heading Reference System) [1], which provides basic coordinate and directional information of a moving object [2]. The immediate adaptations can be found in small-scale unmanned flight vehicles, smart phones, body movement monitoring, robots and even toys to mention a few [3].

Many kinds of medical equipment require relatively high accuracy of positional adjustments for successful operations [4], [5]. However, it is not easy for patients to stay without any movement during the operations of medical equipment such as ESWT (Extracorporeal Shock Wave Therapy) or Rtms (repetitive Transcranial Magnetic Stimulation). Practically, accompanying operators are needed to adjust the focus of the equipment to compensate the patient’s movements [6]-[9].

In this paper, tracking controllers for the positioning holders of medical equipment are suggested to reduce the burden of the operators. The automatic tracking controllers use AHRS sensor information to recognize the movements of patients [10], [11]. One sensor module consists of one digital three-axis acceleration sensor LIS3LV02DQ, two gyroscope sensors of LPY530AL which has two-axis analog outputs, one e-compass Ami302 which has three-axis analog outputs, and a temperature sensor for sensor calibration [12]. The sensor module is directly connected to a main module for sensor data acquisition and transmission which has a microprocessor of MSP430F149, Bluetooth module and a power source.

Each sensor has a few noise characteristics. The angle data by an acceleration sensor have noise components due to dynamic movements. Also, yaw angles are difficult to measure due to perpendicularity with gravitational force. Gyroscope sensors need other information to measure angles due to integration errors. Temperature compensation is required as well. Electronic compass sensors have relatively low accuracy though they are easy to use. Sensor fusion is applied to reduce the error magnitudes through linear Kalman filters. Also, the image processing of an optical marker is applied to adjusting the accumulation errors of gyroscope sensor data especially for yaw angles.

The automatic tracking controller for medical equipment is installed at a standing holder to make the necessary positional and directional changes. It reduces the positional errors between the current focus of the equipment and the target position on the body of a patient. Since the sensing frequencies of AHRS sensors are very high compared to the physical movements of a patient, the tolerable control performance depends on the sensor data accuracy. The typical applications, for example, ESWT or rTMS, have error ranges of a few centimeters. The experimental results show satisfactory tracking performance with less than two degrees of angular errors for both of pan and tilt. The tracking control system for a

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medical equipment holder which includes the AHRS sensor module and the microprocessor and data transmission module is proposed in Section II. The sensor fusion and an optical marker with image processing for error reduction are described in Section III to obtain the required noise levels. The implementation and experimental results of the controller are described in section IV, which is followed by the conclusion in Section V.

II. TRACKING CONTROLLER DESIGN USING AHRS

In this paper, the design of an automatic tracking controller for the positioning holders of medical equipment is suggested. The purpose is to reduce the continuous focusing burden of the operators. The automatic tracking controllers use AHSR sensor information to recognize the movements of a target part on the body of a patient.

A. *AHRS Sensor Module*

One sensor module consists of one digital three-axis acceleration sensor LIS3LV02DQ, two gyroscope sensors of LPY530AL which has two-axis analog outputs, one e-compass Ami302 which has three-axis analog outputs, and a temperature sensor for sensor calibration. The sensor module is directly connected to a main module for sensor data acquisition and transmission.

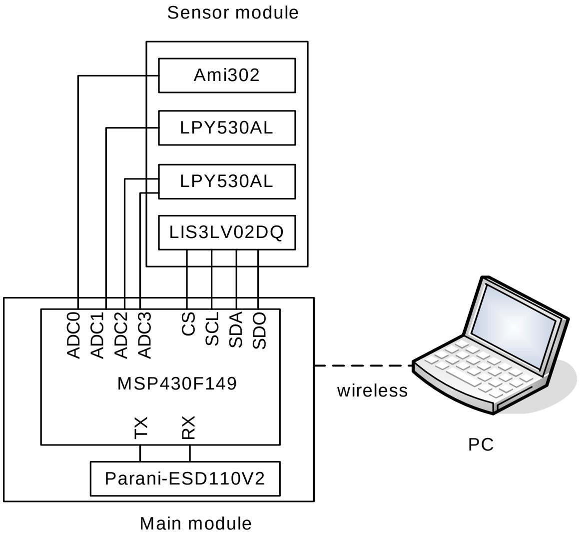
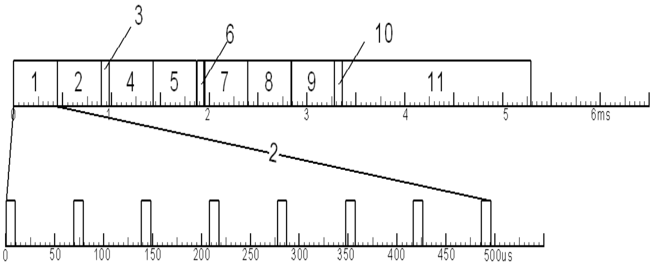


Fig. 1 Typical AHRS data acquisition system

B. *Data Acquisition and Transmission*

The main module, which has a microprocessor of MSP430F149, Bluetooth module for data transmission to a server and a power source, is designed to provide interface of a few AHRS sensor modules.

Fig. 2 shows the time allocation for sensor data acquisition. One sampling time of ADC of the MCU is 60μ sec. as shown in the lower part. Eight samples are averaged to make one measurement to reduce sensing errors. Analog sensor outputs are sampled using MCU's ADC. Digital sensor outputs are transmitted by SPI.



1: X-axis of e-compass 480 μsec.
2: X-axis of gyroscope 480 μsec.
3: X-axis of accelerometer 139μsec.
4: Y-axis of e-compass 480 μsec.
5: Y-axis of gyroscope 480 μsec.
6: Y-axis of accelerometer 139μsec.
7: Z-axis of e-compass 480 μsec.
8: Temperature sensor 480 μsec.
9: Z-axis of gyroscope 480 μsec.
10: Z-axis of accelerometer 139μsec.
11: Data transmission 1,900 μsec.

Fig. 2 Time allocation for sensor data acquisition

Fig. 3 shows the sensor data structure. Sensor data are stored temporarily at the internal memory of MCU before transmission. Data are transmitted by MCU's UART through a BlueTooth module.

1	2	3	4	5	6	7	8	9	10	11	12	13
F	F	0	0	MX H	MX L	MY H	MY L	MZ H	MZ L	GX H	GX L	GY H
14	15	16	17	18	19	20	21	22	23	24	25	26
GY L	GZ H	GZ L	AX H	AX L	AY H	AY L	AZ H	AZ L	P H	P L	T H	T L

1-2: Header
3-4: Number of sensor module
5-10: e-compass data
11-16: gyroscope data
17-22: accelerometer data
23-24: potentiometer data
25-26: Temperature sensor data

Fig. 3 Sensor data structure

III. SENSOR ERROR REDUCTION

The sensor fusion and an optical marker with image processing for error reduction are applied to reducing error magnitudes.

A. *Linear Kalman Filters*

Each sensor of AHRS has a few noise characteristics. The angle data obtained by an acceleration sensor have noise components due to dynamic movements. Also, yaw angles are difficult to measure due to perpendicularity with gravitational force. Gyroscope sensors need other information to measure angles due to integration errors. Besides, temperature compensation is required. Electronic compass sensors have relatively low accuracy though they are easy to use. Sensor fusion is applied to reducing the error magnitudes through linear Kalman filters [13].

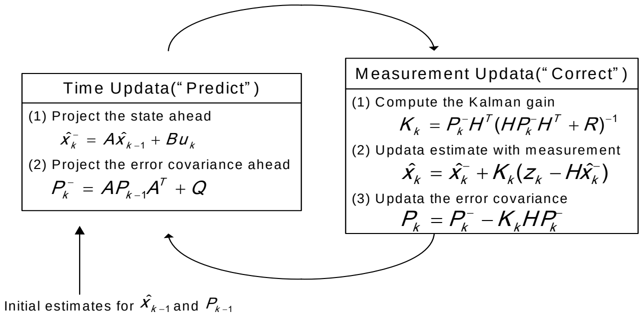
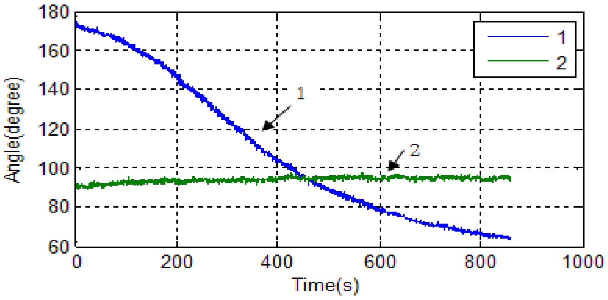


Fig. 4 Procedures of Linear Kalman Filter

B. Temperature Compensation

Sensor outputs have a severe influence due to environment temperature changes. Therefore, a temperature sensor is necessary on the sensor module. All sensor data are compensated on a server after data transmission based on the standard temperature database of each sensor. Fig. 5 shows the typical compensation of an e-compass.



1: raw sensor data   2: Temperature corrected data

Fig. 5 Temperature correction of e-compass sensor data

C. Error Reduction Using Image Processing

The image processing of an optical marker is applied to adjusting the accumulation errors of gyroscope sensor data especially for yaw angles. A small piece of a plate on which a set of optical markers are displayed is positioned near the sensor module. The length ratios of markers reveal all the angular information of the body on which the plate is positioned.

However, the image processing on a server requires tremendous amount of time compared to the sensor data acquisition time. Therefore, one reliable angular value by the image processing can be used as a true value for the correction of sensor data.

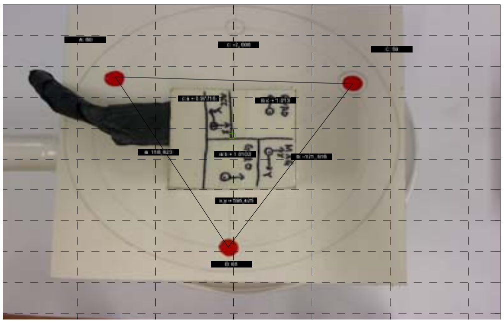


Fig. 6 A set of optical markers

The marker images are obtained by a Logitech Pro9000 web-cam using 1,280X 1,024 pixels. The image processing by Matlab R2008a requires the computation time of about 0.19sec., which is about fifteen times of the sensor data acquisition. Consequently, one error correction is possible every fifteen sensor data.

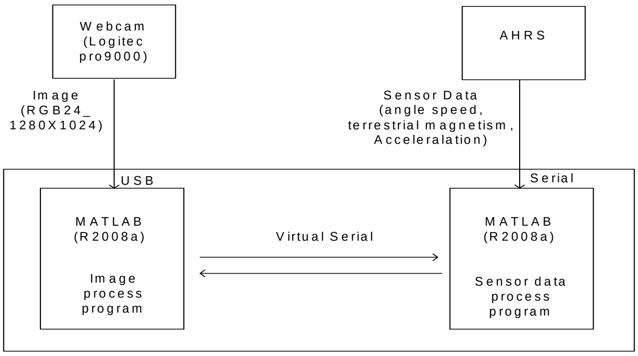
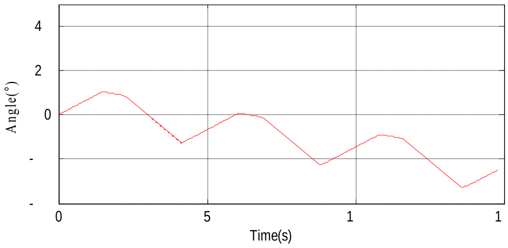
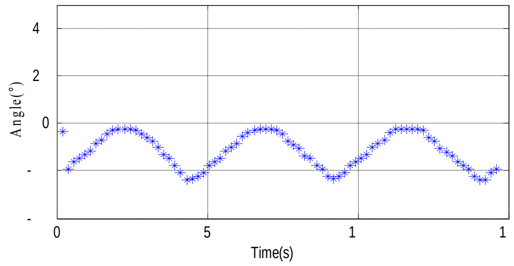


Fig. 7 Schematic diagram for data processing

Fig. 8 (a) shows the drifting errors of gyroscope angle data due to accumulation errors, and Fig. 8(b) is the results of error elimination by the compensation based on angle values from the image processing of optical markers.



(a) Angle data by integration of gyroscope values

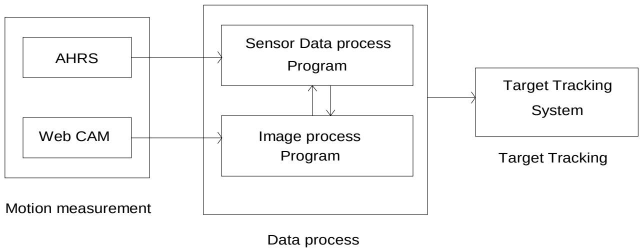


(b) Error elimination using image processing

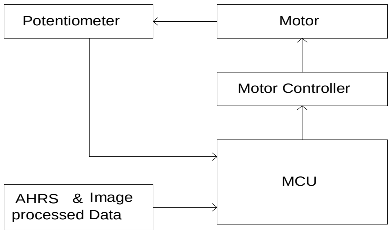
Fig. 8 Elimination of accumulation errors

IV. TRACKING CONTROLLER OF HOLDERS

The automatic tracking controller for medical equipment is installed at a standing holder to provide the necessary positional and directional changes. It reduces the positional errors between the current focus of the equipment and the target position on the body of a patient. Since the sensing frequencies of AHRS sensors are very high compared to the physical movements of a patient, the satisfactory control performance depends on the sensor data accuracy.



(a) Overall tracking controller system



(b) Pan/Tilt controller

Fig. 9 Tracking controller of equipment holders

The proto-type experimental tracking controller is implemented using a Pan/Tilt drive SPT-2500 by Samsung Techwin Co. to show the feasibility. It is operated by synchronous motors and has a maximum load of 4.5Kg.

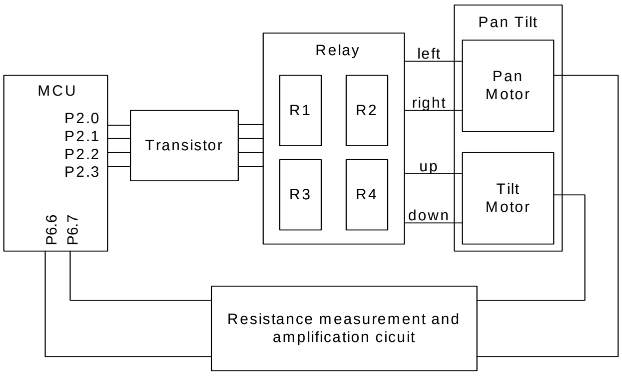


Fig. 10 Driving circuit for Pan/Tilt SPT-2500

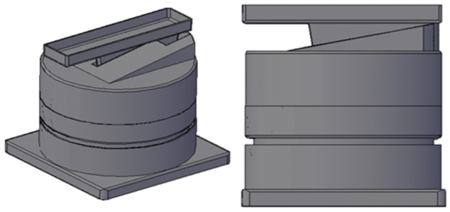
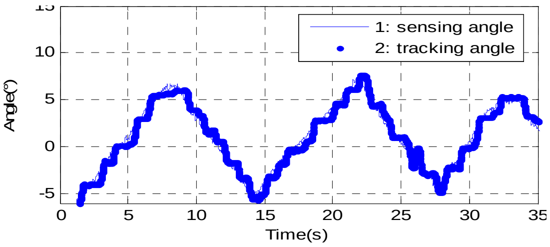
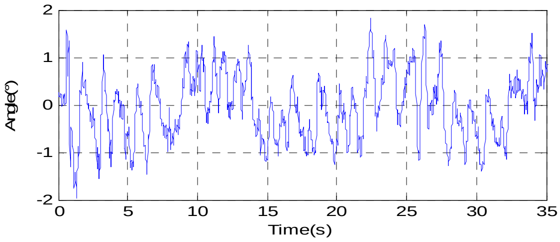


Fig. 11 Pan/Tilt drive SPT-2500

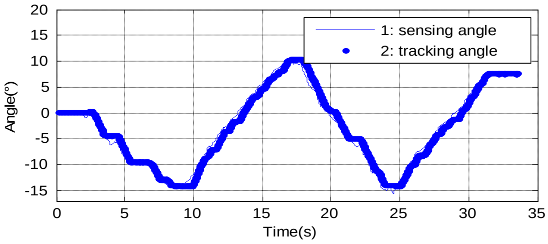


(a) Tracking results for Tilt angles

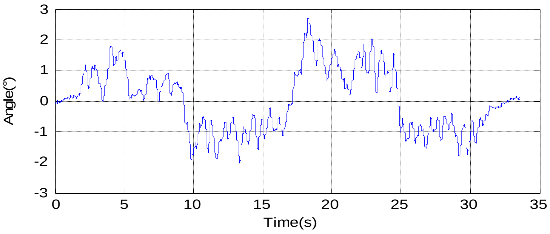


(b) Magnified Tilt errors

Fig. 12 Experimental tracking results for Tilt angles



(a) Tracking results of Pan angles



(b) Magnified Pan errors

Fig. 13 Experimental tracking results for Pan angles

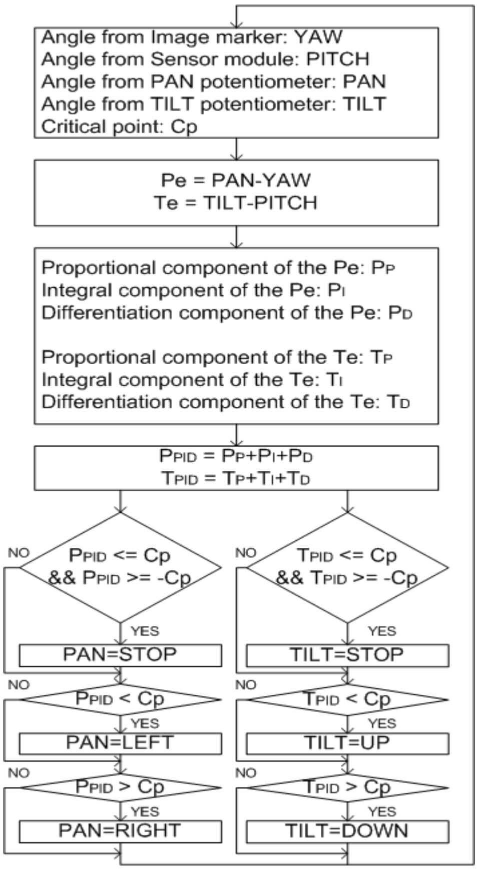


Fig. 14 Overall flowchart for Pan/Tilt operation

The typical applications, for example, ESWT or rTMS, have error ranges of a few centimeters. The experimental results show satisfactory tracking performance with less than two degrees of angular errors for both of pan and tilt.

V. CONCLUSION

In this paper, the design of automatic tracking controllers for the positioning holders of medical equipment is suggested to reduce the burden of the operators. The tracking controllers use AHRS sensor information to recognize the movements of a target on the body of a patient. The tracking controller for medical equipment is installed at a standing holder to provide the necessary positional and directional changes. It reduces the positional errors between the current focus of the equipment and the target position when a patient is moving. Since the sensing frequencies of AHRS sensors are very high compared to the physical movements of a patient, the satisfactory control performance can be obtained. The experimental results show sufficing tracking performance with less than two degrees of angular errors for both of pan and tilt.

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