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Research Article

Motion Control and Implementation for an AC Servomotor System

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Recommended by Igor Kotenko

This paper presents a study on trajectory tracking problem for an AC synchronous servomotor. A mathematical model for the system including AC synchronous servomotor, gearbox, and a load is developed to examine the systems dynamic behavior. The system is controlled by a traditional PID (proportional + integral + derivative) controller. The required values for the controller settings are found experimentally. Different motion profiles are designed, and trapezoidal ones are implemented. Thus, the experimental validation of the model is achieved using the experimental setup. The simulation and experimental results are presented. The tracking performance of an AC servomotor system is illustrated with proposed PID controller.

1. INTRODUCTION

Electric motors can be classified by their functions as servomotors, gear motors, and so forth, and by their electrical configurations as DC (direct current) and AC (alternating current) motors. A further classification can be made as single phase and polyphase with synchronous and induction motors in terms of their operating principles for AC motors, and PM (permanent magnet) and shunt DC motors for DC's. Although DC motors are preferred dominantly in the variable speed applications, increasing use of AC motors can be seen prior to improvements in solid state components. Servomotor is a motor used for position or speed control in closed-loop control systems. The requirement from a servomotor is to turn over a wide range of speeds and also to perform position and speed instructions given. DC and AC servomotors are seen in applications by considering their machine structure in general. When the requirement is low power and variable speed, AC servomotors are the ones preferred in control systems. They certainly introduce a brushless structure and offer no maintenance [1–4]. Applications of AC servomotors can be seen in conveying technology, printing, wood processing, textile industry, plastics industry, food and packaging industry, packaging and filling plants, and machine tools. Two types of AC servomotors are available as squirrel cage asynchronous and permanent magnet synchronous.

In the field of control of mechanical linkages and robots, research works are mostly found on DC motors. Limited number of studies are found in the literature about AC servomotor motion control and tracking characteristics, since AC servomotor technology is respectively new. AC servomotors applied in some research articles are overviewed herein. Gross [5] has described a study on simulation and dynamic performances of electrical machines; the transformer, the DC machine, the polyphase induction machine, the polyphase synchronous machine, and the single phase induction machine with an electric machine simulation program. Viitanen et al. [6] in his work presented an environment to model and simulate mechatronical devices; electrical motors (AC and DC), electronics, fluid power and control, and mechanical systems. Morimoto et al. [7] have described a study on a high-performance servo drive system and characteristics of a salient pole permanent magnet motor. Lessmeier et al. [8] compared the performances of AC servo drives using synchronous and asynchronous motors. A mathematical model is given with the control scheme and supported by experimental results. Tzou [9] achieved robust control of an AC induction servomotor for a motion-control system. Friedrich and Kant [10] have given a comparative study between two permanent magnet AC machines by using numerical simulation and also experimentally. Simulations were included for a two-joint rigid robot directly driven by induction motors. Jiang and Holtz [11] have worked on high dynamic speed sensorless AC drives. Experimental verification was achieved with an induction motor. On-line mode parameter tuning was applied to eliminate the steady-state error. Vukosavic and

Stojic [12] have dealt with the problem of mechanical resonance in a system of comprising a permanent magnet synchronous servomotor and a load with experimental verification. Goldfarb and Sirithanapipat [13] have given a study on the performance of PD controlled servo systems. Simulations were carried on the measure of tracking. Safak and Turkay [14] studied universal motor dynamics. A mathematical model was presented with simulation results. An experimental implementation was included. In a motion control and implementation, Guerrero-Ramírez and Tang [15] performed motion control of robots by induction motors to track the given trajectory by proposing a current controller. Wang et al. [16] developed a complete PM AC servomotor model. A neural network self-tuning PI control scheme is implemented. Experimental results are presented with simulations in that study.

This paper discusses dynamic behavior and practical implementation on AC synchronous servomotor. A permanent magnet synchronous AC servomotor with a fitted resolver is applied in this study. Resolver is considered as a rotary transformer producing an output signal which is a function of the rotor position. Mathematical model of the system is developed by including motor, gearbox, and an inertia disk representing the load. An experimental arrangement is built up, and characteristically different motion profiles are implemented to examine the positioning performance of the system for potential industrial applications. AC synchronous servomotor is incorporated with a PID controller. Simulation model and experimental results are presented herein to form a base for similar studies. The study is verified experimentally.

2. EXPERIMENTAL SYSTEM

The experimental system consists of a 1.5 kW permanent magnet synchronous AC servomotor fed from an inverter operated at 190 Hz frequency and its matching servo drive, a gearbox with 5.665 : 1 reduction ratio, a fitted resolver, and a constant load. The experimental verification is performed using the setup. The hardware configuration of the experimental AC servomotor system is presented in Figure 1. Motor-driver data is given in Table 1.

A motion-control card [18] manufactured by Performance Motion Devices Inc. (PMD-MC) 1401 series DB1000 PC motion-control card is chosen as an interface. The control card provides a 4-axis control with incremental quadrature encoder input. The software needed is provided by the manufacturing company. Motor-control system configuration is achieved by using a 68-pin connector to dual 34-pin header converter cable.

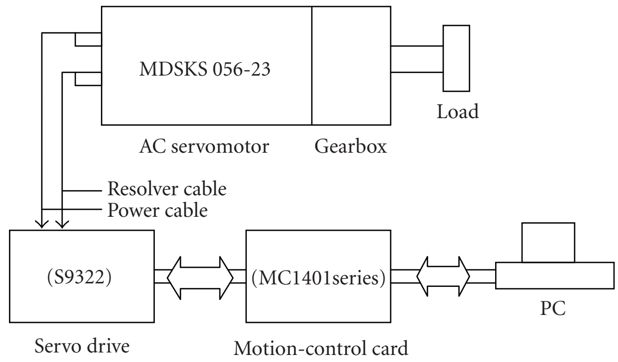

Figure 1: Configuration of system hardware.

Table 1: AC servomotor-driver data [17].

Drive type-9322	
Motor power	$P = 0.75$ kW
Motor output current, 8 kHz	$I = 2.5$ A
Output power	$P = 1.7$ kVA
Terminal voltage	$V = 320$–528 V
Weight	$m = 3.5$ kg
Motor type-MDSKS 056-23, 190	
Motor weight	$m = 5.3$ kg
Speed	$n = 3800$ rpm
Torque	$T = 2.8$ Nm
Power	$P = 1.1$ kW
Voltage	$V = 330$ V
Current	$I = 2.3$ A
Maximum torque	$T_{\max} = 11.6$ Nm
Maximum current	$I_{\max} = 10$ A
Frequency	$f = 190$ Hz
Moment of inertia	$J_m = 1.2\ \text{kg}\cdot\text{cm}^2$

3. AC SERVOMOTOR DYNAMICS

The model of the system consists of a motor coupled to a gearbox and an inertial load rigidly fixed to output shaft. Friction is taken as negligible throughout the analysis. The relations for stator and rotor windings and dynamic torque analysis for the permanent magnet AC synchronous machine can be described by the following nonlinear differential equations [7, 19, 20]:

$$R_R I_R + L_R \frac{dI_R}{dt} + L_o \frac{d}{dt}\left(I_s e^{-j\theta_m}\right) = V_R, \quad (1)$$

$$R_s I_s + L_s \frac{dI_s}{dt} + L_o \frac{d}{dt}\left(I_R e^{j\theta_m}\right) = V_s, \quad (2)$$

$$\left(J_m + J_g + \frac{1}{N^2} J_l\right) \frac{d^2\theta_m}{dt^2} + c\frac{d\theta_m}{dt} = K_1 V_s - K_2 \frac{d\theta_m}{dt}. \quad (3)$$

The following symbols are used in the above equations:

(i) R_S, R_R: stator and rotor resistances (Ω),
(ii) L_S, L_R, L_o: stator, rotor, and mutual inductances (mH),
(iii) K_1, K_2: motor constants (Nm/V, Nms/rad),
(iv) V_s: control field voltage in stator,
(v) c: damping resistance of the load (Nms/rad),
(vi) θ_m: angular position of the motor (rad),
(vii) θ_{mR}: reference angular position of the motor (rad),
(viii) $\dot{\theta}_m$: angular velocity of the motor (rad/s),
(ix) $\ddot{\theta}_m$: angular acceleration of the motor (rad/s^2),

(x) J_m, J_g, J_l: moment of inertias of the motor, gearbox, and load,

(xi) N: reduction ratio between motor and load (5.666 : 1),

and K_1 and K_2 are calculated from the following relationships:

(i) K_1 = stall torque/rated voltage (Nm/V),

(ii) K_2 = stall torque/no-load speed at rated voltage (Nms/rad).

3.1. Controller settings

Three-mode control referred to PID (proportianal + integral + derivative) control is incorporated with the system to eliminate tracking errors. The PID tuning parameters are found by applying Ziegler-Nichols (ZN) amplitude decay response of the closed-loop system with proportional gain. The gain is increased until the system becomes critically stable. K_{cr} corresponds to this gain. Then the period of oscillation is taken as T_{cr}. So controller tuning is performed by experimental settings of the three parameters for PID controller [2, 4, 21]. PID tuning parameters are calculated as $K_p = 0.6K_{cr}$, $T_i = 0.5T_{cr}$, and $T_d = 0.12T_{cr}$. Several iterations are required in the model to obtain the desired system behavior.

PID controller is described as

$$V_s = K_p e(t) + K_v \frac{d}{dt} e(t) + K_i \int_0^t e(t)dt, \tag{4}$$

where K_p, K_v, and K_i represent the proportional, derivative, and integral gains, respectively.

In the equation, gains are referred to as $K_v = K_p T_d$ and $K_i = K_p/T_i$. $e(t)$ is the error given by

$$e(t) = \theta_{m_R} - \theta_m \tag{5}$$

and V_s in (2) is the PID controller output.

3.2. Simulation results

The performance characteristics of AC servomotor control system is studied initially by using test input signals like step and ramp input. Having obtained critically damped responses, motion profiles involving trapezoidal character are then implemented.

Two trapezoidal motion profiles called as trapezoidal motion I and II are applied. Trapezoidal profile I has an initial constant velocity period followed by a dwell period and then followed by a constant velocity period in reverse direction as shown in Figure 2(a). This is an easy profile to implement as a reference motion. Here, trapezoidal profile I consisting of 3 segments is performed in 4.16 seconds. Initially motor is rotated to 2π radians in 1.1 seconds, kept its angular position the same for 1.95 seconds, finally, slowed down to zero radians in 1.1 seconds.

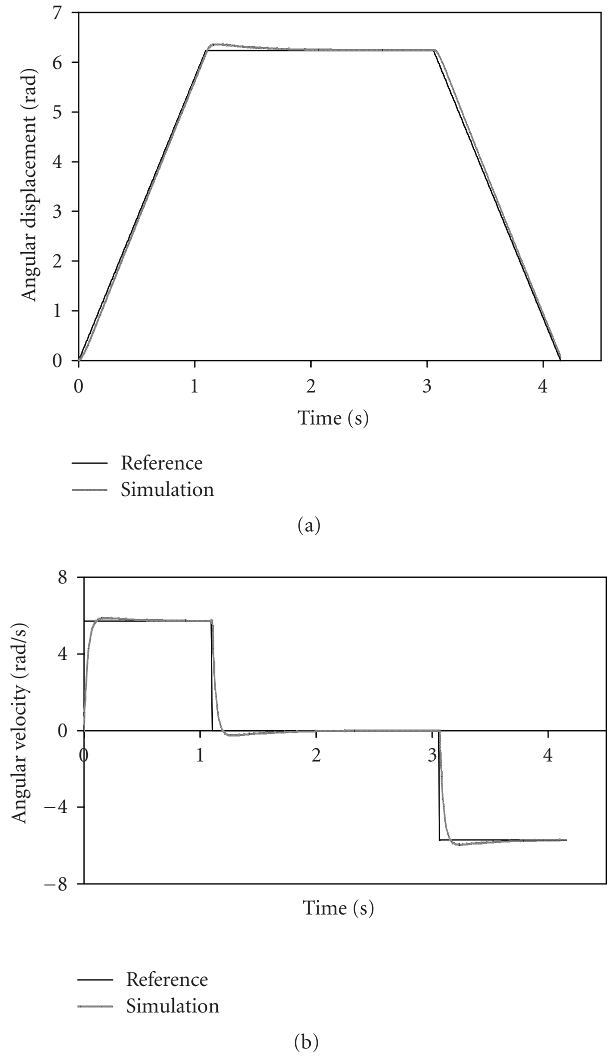

Figure 2: Simulation results for trapezoidal motion I.

Trapezoidal profile II has an initial constant velocity followed by a dwell, a higher constant velocity followed by another dwell, a higher constant velocity with a longer dwell period, and finally at the highest constant velocity of all in reverse direction as shown in Figure 3(a). Trapezoidal profile II involving 7 segments is performed in 6.8 seconds in this study. Servomotor is rotated to 2π radians in 1 second, kept its position the same (dwell) for 1 second, increased to 4π radians in 0.5 second, kept at 4π radians (dwell) for some time as 1.5 seconds, later increased to 6π radians to 0.4 second, kept the same angular position (dwell) for 1.6 seconds, and finally decreased its position to zero radians in 0.8 second.

The computer simulation employs a fourth order Runge-Kutta (RK) integration algorithm to integrate (1), (2), and

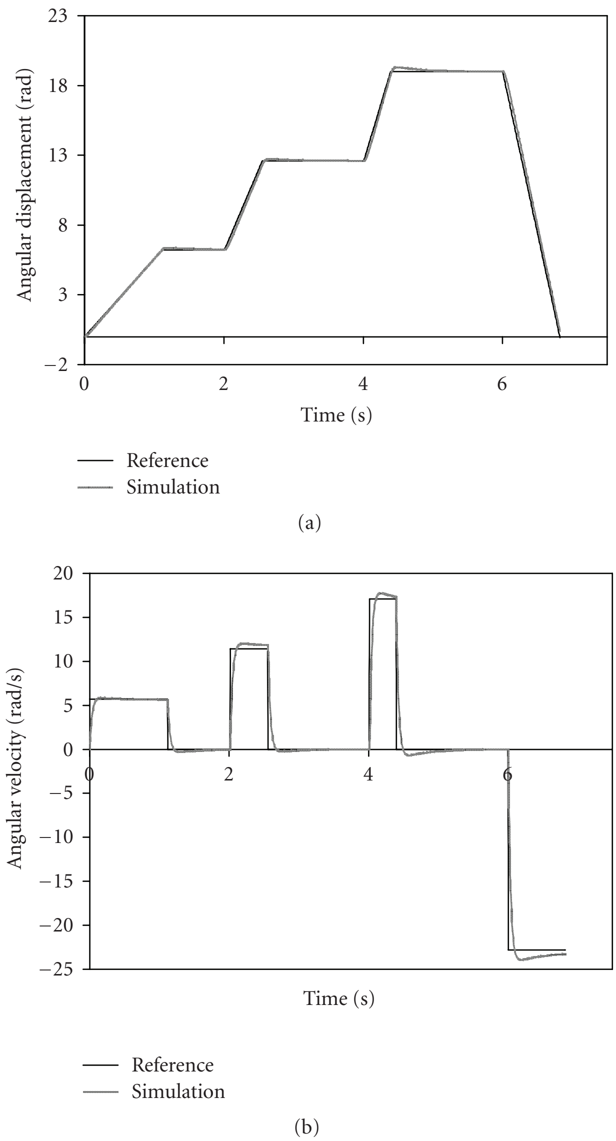

FIGURE 3: Simulation results for trapezoidal motion II.

(3) and solving them numerically. The method is self-starting. Several function evaluations are required at every integration step. The fourth-order RK method needs four function evaluations per integration step. The dynamic equation of the system (3) is of second order. State space representation of the system gives four state equations to be solved. Initial conditions are needed to solve the differential equations. The state variables are defined for angular displacement and velocity of the motor. The angular acceleration of the motor are then derived from combination of these state variables for the system.

The simulation input contains the electrical properties of the motor, the mechanical properties of the gearbox, the load, the controller setting values, and the initial conditions for the system. The time between two discrete observations, Δt is selected as 8 milliseconds. The total response times are taken as 4.16 seconds and 6.8 seconds for trapezoidal motion I and II, respectively. A large number of computer simulations are available by changing PID controller gains while keeping the system parameters and the initial conditions the same. So by numerical integration, the angular velocity and displacement of the motor can be obtained from the angular acceleration. The simulation output includes the stator current, the rotor current, the motor angular displacement, velocity, and acceleration as functions of time.

Servomotor-driver data used in simulation are summarized in Table 1. The following system parameters are already known or measured:

$$J_g = 0.01\,\text{kg}\cdot\text{m}^2, \qquad J_l = 2.06\times10^{-3}\,\text{kg}\cdot\text{m}^2,$$
$$K_1 = 8.43\times10^{-3}\,\text{Nm/V}, \qquad K_2 = 7.03\times10^{-3}\,\text{Nms/rad},$$
$$L_s = L_R = 15\,\text{mH}, \qquad R_S = R_R = 3\,\Omega. \tag{6}$$

The computer simulation is used to investigate steady-state operation and dynamic characteristics of AC servomotor used. Classical PI/PD/PID controller options were included in software prepared. When the simulation results are obtained, controller tuning under the full mechanical load is achieved, the performance is considered as acceptable. The final values for controller settings are taken as $K_p = 100$, $K_V = 40$, and $K_i = 10$, respectively. These settings are initially found from tuning carried on experimentally, and supported by the mathematical model. It is already possible to run simulation with different controller gain settings or observe the effect of each controller action separately on system dynamics. By altering PID controller settings many times, nearly a damped system behavior is observed and presented here. Since motor friction torques and other losses (gearbox, etc.) in the system are neglected, higher controller tuning values are applied for the simulation.

Simulated responses are presented in Figures 2(a) and 2(b) for trapezoidal motion I, and in Figures 3(a) and 3(b) for trapezoidal motion II as angular displacements and velocities of the servomotor, respectively. Since motor angular velocities are referred to as constant profile, motor angular accelerations are not given.

4. EXPERIMENTAL RESULTS

Motion-control program menu allows us to perform trapezoidal move, also to stop an existing move. A trapezoidal motion is performed by editing the axis number, destination position, maximum velocity, acceleration, and starting velocity as required. When the command is executed, the motion parameters are being sent, and the motion is performed. The program has an ability to record and observe the motor motion graphically. While collecting the data, the total time interval in axis position data is to be selected in seconds. The time interval between data points to be captured is then selected in milliseconds. Here it is taken as 8 milliseconds, and the PID controller is designed to give zero steady-state error for a step input when there is no load.

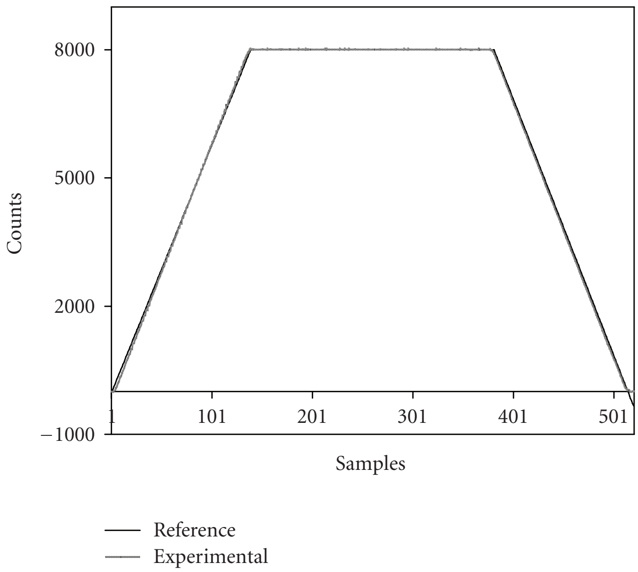

Figure 4: Experimental results for trapezoidal motion I.

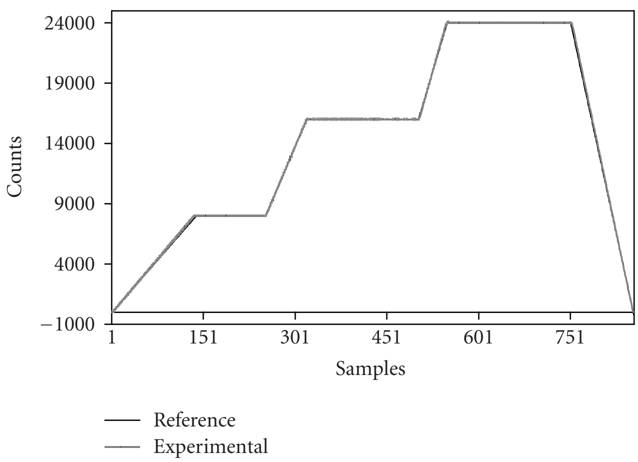

Figure 5: Experimental results for trapezoidal motion II.

The experimental AC servomotor system is operated under loaded and unloaded cases. Figures 4 and 5 represent the experimental results of trapezoidal motion I and II responses when the system is coupled to a fixed load. The variables are scaled as digital counts and number of samples in experimental results. Trapezoidal motion I is taken as 520 samples, referring to 4.16 seconds overall. Trapezoidal motion II is taken as 854 samples covering 6.8 seconds all. The output tracks the reference well. Actually, the best tracking performance is achieved when PID controller gains are tuned. Experimental controller tuning values are found as $K_p = 20$, $K_V = 12$, and $K_i = 3$, respectively.

5. CONCLUSION

A mathematical model of a permanent magnet AC synchronous servomotor coupled to a gearbox and load has been developed. A traditional PID controller is applied, and tuning of controller is carried on experimentally. Good tracking performance is also obtained in experimental results. Controller tuning parameters are altered during experiments and simulation. Simulation results are taken in ideal running conditions free from losses and friction effects. Steady-state accuracy during simulation is certainly improved by altering PID controller gains up to a required point. Here AC synchronous servomotor is studied in detail for tracking problems and characteristics. AC system considered here can be applied as a drive system for coming studies easing the use of AC servomotors. AC servo systems are certainly recommended when maintenance free and variable speed intelligent applications are needed. Advanced control techniques can also be applied to improve tracking performance for coming studies.

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The scope for artificial intelligence, neuroscience, and systems biology is extremely wide. The motivation of this special issue is to create a bird-eye view on areas and challenges where these fields overlap in their defining ambitions and where these fields may benefit from a synergetic mutual exchange of ideas. The rationale behind this special issue is that a multidisciplinary approach in modern artificial intelligence, neuroscience, and systems biology is essential and that progress in these fields requires a multitude of views and contributions from a wide spectrum of contributors. This special issue, therefore, aims to create a centre of gravity pulling together researchers and industry practitioners from a variety of areas and backgrounds to share results of current research and development and to discuss existing and emerging theoretical and applied problems in artificial intelligence, neuroscience, and systems biology transporting them beyond the event horizon of their individual domains.

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The fuzzy technique for clean energy, solar and wind energy, is the most readily available source of energy, and one of the important sources of the renewable energy, because it is nonpolluting and, therefore, helps in lessening the greenhouse effect. The benefits arising from the utilization of solar and wind energy systems can be categorized into two sections: energy saving and the decrease of environmental pollution. The clean energy saving benefits come from the reduction in electricity consumption and from using any conventional energy supplier, which can avoid the expenditure of fuel supply. The other main benefit of the renewable energy is the decrease of environmental pollution, which can be achieved by the reduction of emissions due to the usage of electricity and conventional power stations. Electricity production using solar and wind energy is of the main research areas at present in the field of renewable energies, the significant price fluctuations are seen for the fossil fuel in one hand, and the trend toward privatization that dominates the power markets these days in the other hand, will drive the demand for solar technologies in the near term. The process of solar distillation is used worldwide for arid communities that do not have access to potable water. Also some solar technologies provide other benefits beside power generation, that is, fresh water (using desalination techniques).

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Special Issue on
Machine Learning Paradigms for Modeling Spatial and Temporal Information in Multimedia Data Mining

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Multimedia data mining and knowledge discovery is a fast emerging interdisciplinary applied research area. There is tremendous potential for effective use of multimedia data mining (MDM) through *intelligent* analysis. Diverse application areas are increasingly relying on multimedia understanding systems. Advances in multimedia understanding are related directly to advances in signal processing, computer vision, machine learning, pattern recognition, multimedia databases, and smart sensors.

The main mission of this special issue is to identify state-of-the-art machine learning paradigms that are particularly powerful and effective for modeling and combining temporal and spatial media cues such as audio, visual, and face information and for accomplishing tasks of multimedia data mining and knowledge discovery. These models should be able to bridge the gap between low-level audiovisual features which require signal processing and high-level semantics. Original contributions, not currently under review or accepted by another journal, are solicited in relevant areas including (but not limited to) the following:

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- Dimension reduction and unsupervised data clustering for multimedia content analysis tasks
- Mining methods and algorithms (classification, regression, clustering, probabilistic modelling), as well as association analysis
- Machine learning paradigms that perform spatial and temporal data mining
- Machine learning paradigms that allow for an effective learning of hidden patterns
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