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Final Presentation

System Identification of
Controlled Irrigation Channels
Introduction: Project Idea
Context

- Currently supply driven irrigation
  - Water wastage
  - Mismanagement
  - Shortage and flood

- Shift to demand driven (needs automation)
  - Maintaining a required water level
  - Better control
  - Gives way to further development, theft prevention etc.
Related and Past work

• Simulated canal and time/space solution using Saint Venant Equations – Hasan Nasir Thesis
• Canal gate automation module’s proof of concept – SSE 2012 SPROJ
• Water level sensor design and implementation – SSE 2012 SPROJ
• Initial experimentation at canal site – SSE 2012 SPROJ
• Robust/deployable water sensor module with GSM communication – CyPhyNets group/Zahoor Ahmad
Control action on canal

Introduction: Project Idea
Requirements for Automation

• **System ID**
  - Experimentation to collect data
  - Data manipulation and processing
  - System identification and verification through least-square estimation

• **Gate Automation**
  - Standalone gate automation module connectable to any common canal gate
  - Black box implementation with microcontroller based raising/closing by user
System Identification
System Identification is an optimization technique, used to generate a viable transfer function between informative input and output data. It is a combination of:

**Experiments**
- Sensor Network for Water Level
- Gate Position

**Data Manipulation**
- Interpolation for Missing Measurements
- Outlier Detection / Removal

**Processing and Optimization**
- Least Squares Estimation
- Model Validation
System ID: Experiments

- The experimental phase consists of collection of representative data points of overall behavior of canal under various inputs.

- Location:
  - KHAIRA Distributory
  - Length 87000 feet
  - Width 10 feet
  - Max height 4 feet
  - 3 Minors
  - Discharge 87 cusecs
Procedures:

- Sensors are placed at appropriate sites (usually at downstream bridges) along the length of canal.
- Sensors record the height of water in the channel and communicate, through GSM module, to a cell phone, or through GPRS to a server.
- At the Upstream, Gate is closed and then subsequently opened to model step input, while monitoring the gate position.
- The readings are recorded and then used as empirical output, in conjunction with the input, to perform System Identification.
System ID: Data Manipulation

Data Interpolation

- Sampling time: 10 sec
- Readings are transmitted through GSM module, introducing delays between successive messages.
- Data Interpolation to obtain a uniformly sampled data
- The original data is time-stamped and is adjusted for uniform sample time of 10 seconds
System ID: Modeling

Physical Modeling
– Builds models based on physical principles
– Provides physical insight, but are generally complex because perfect physical knowledge of a system is usually unknown.
– *St. Venant Equations* are used to describe flow of fluids in an open channel. These equations derive the model of fluid flow based on geometry of the channel, in terms of partial differential equations (PDEs)

\[
\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0
\]

\[
\frac{\partial Q}{\partial t} + \left(\frac{gA}{B} - \frac{Q^2}{A^2}\right) \frac{\partial A}{\partial x} + \frac{2Q}{A} \frac{\partial Q}{\partial x} + gAS_f - gA\bar{S} = 0
\]

- $A$ – cross sectional area of channel
- $B$ – width of the water surface
- $Q$ – flow discharge
- $g$ – gravity
- $S_f$ – friction slope (nonlinear function)
- $\bar{S}$ – mean bed slope
System ID: Modeling

- Models obtained by **system identification** are relatively easier to construct.
- Provide validity for only certain input signals and around certain operating points.
- In order to use System Identification methods, we must have informative (and representative) input and output data.
- Model of water with time delay (under free flow approximations):
  \[
  \frac{dV}{dt} = Q_i(t) - Q_o(t)
  \]
  \[
  V(t) \approx cy(t), \quad Q_i(t) \approx c_i h^{3/2}(t), \quad Q_o(t) \approx c_o(y(t) - p(t))^{3/2}
  \]
  \[
  \frac{dy}{dt} = \theta_1 h^{3/2}(t - \tau) + \theta_2(y(t) - p(t))^{3/2}
  \]
- For control applications we can obtain a discretized model:
  \[
  y_{k+1} = y_k + \theta_1 h_{k-\tau_k}^{3/2} + \theta_2(y_k - p_k)^{3/2}
  \]
System ID: Gate Modeling

Water Flow: Overshot Gate

\[ Q \approx \theta h^{3/2} \]

- \(Q\): Water Flow
- \(h\): Head over gate
- \(\theta\): Unknown discharge coefficient

\(h\) is computed from measurements of gate position \(p\) and upstream water level \(y\)

Water Flow: Undershot Gate

\[ Q \approx \theta p \sqrt{y_u - y_d} \]

- \(Q\): Water Flow
- \(y_u\): Upstream Water Level, before gate
- \(y_d\): Downstream Water Level, after gate
- \(p\): Opening under the gate
- \(\theta\): Unknown discharge coefficient
System ID: Least Squares Estimation

- **Linear Regression Model**
  \[ \hat{y}(\theta) = \theta_1 \phi_1(x) + \theta_2 \phi_2(x) + \cdots + \theta_n \phi_n(x) = \phi^T(x)\theta \]
  \[ \phi = [\phi_1, \phi_2, \ldots, \phi_n]^T - \text{known functions, regressors} \]
  \[ \theta = [\theta_1, \theta_2, \ldots, \theta_n]^T - \text{unknown parameters} \]

- **Model Errors**
  \[ \varepsilon_i(\theta) = y_i - \hat{y}_i(\theta) = y_i - \phi^T(x_i)\theta \]

- **Minimizing the Cost Function**
  \[ V(\theta) = \frac{1}{2} \sum_{i=1}^{N} \varepsilon_i^2(\theta) \]
  \[ \hat{\theta} = \left( \sum_{i=1}^{N} \phi(x_i)\phi(x_i)^T \right)^{-1} \left( \sum_{i=1}^{N} \phi(x_i)y_i \right) \]
**System ID:** Irrigation Channels

Model for Irrigation Channel:

\[
y_2[k+1] = y_2[k] + \theta_1 p[k-\tau_k] \sqrt{y_u - y_d[k-\tau_k]} + \theta_2 (y_2[k] - p_2[k])^{3/2}
\]

where \( y_u \) is assumed to be constant and \( p_2[k] \) is always taken to be 0.

Assuming:

\[
y[k+1] = y_2[k+1] - y_2[k]
\]

\[
\phi[k+1] = [p[k-\tau_k] \sqrt{y_u - y_d[k-\tau_k]} \ y_2[k]^{3/2}]^T
\]

\[
\theta = [\theta_1 \ \theta_2]^T
\]

Then

\[
y[k] = \phi^T[k] \theta
\]
System ID: Experiment
**Experimental Setup**

- Upstream Gate was closed and then opened
- The water level was measured at 50m, 350m and 550m, every 10s.
- The corresponding data was processed and interpolated to obtain a uniformly sampled and synchronized set.

**Estimation Process**

- The linear regression model was attempted to fit the observed response at 350m and 550m sensors.
- As mentioned earlier, $y_u$ was assumed to be constant and $p_2[k]$ was taken to be zero to model an ‘always opened – hypothetical – downstream gate’.
- In addition, $y_d[k]$ was taken to be the values of 50m sensor.
- The response delay were inspected from the raw data, which came out be approximately 50s, 200s and 350s for the 50m, 350m and 550m sensors respectively.
- Using the above conditions, the response for the sensors at 350m and 550m was estimated
System ID: Least Squares Estimation

Least Square Estimation at 350m: $\theta = [0.0160 - 0.3271] \times 10^{-3}$

- **Gate Height**

Least Square Estimation at 350m: $\theta = [0.0160 - 0.3271] \times 10^{-3}$

- **Estimated Water Level**
- **Actual Water Level**
System ID: Least Squares Estimation

Least Square Estimation at 550m: \( y = (0.0152 - 0.2737) \times 10^{-3} \)

- **Gate Height**
- **Estimated Water Level**
- **Actual Water Level**
System ID: Least Squares Estimation

• Results
  – For 350m the estimated parameters were:
    • \( \theta = [0.0160 -0.3271] \times 10^{-3} \)
  – For 550m the estimated parameters were:
    • \( \theta = [0.0152 -0.2737] \times 10^{-3} \)

• The estimated parameter values make sense from a physical point of view.
  – \( \theta_1 \) is positive. It is associated with the inflow of water
  – \( \theta_2 \) is negative. It is associated with the outflow of water
  – \( \theta_2 \) has a greater magnitude than \( \theta_1 \) because there exists no hydraulic structure at the downstream sensor position, and there is always an outflow at the hypothetical downstream end.
**System ID: Model Validation**

- Simulation of Model

- Average Squared Prediction Error

\[
\frac{1}{N - \tau_k - 1} \sum_{k=\tau_k+2}^{N} \varepsilon^2(k, \hat{\theta})
\]

- Comparison of predicted water level with the measured one
System ID: Model Validation

Model Validation at 350m ($\theta = [0.0180 - 0.3271] \times 10^{-3}$)

- Gate Height
- Water Level at 350m

Model Validation at 350m ($\theta = [0.0180 - 0.3271] \times 10^{-3}$), Mean Square Error = 0.0162 m$^2$
System ID: Model Validation

Model Validation at 550m \( \theta = (0.0152 - 0.2737 \times 10^{-3}) \)

- Gate Height
- Water Level at 550m

Model Validation at 550m \( \theta = (0.0152 - 0.2737 \times 10^{-3}) \), Mean Square Error = 0.0014 m²

- Predicted Water Level
- Actual Water Level
Gate Automation Module
Gate Automation Module: Motivation

• Currently manual control
  – Time inefficient
  – Leads to supply driven network
  – Requires more manpower in the operation

• Motivation for automation
  – Vital for controller implementation
  – Efficient
  – Better control
Gate Automation Module: Objectives

- “Plug and play” black box / stand alone unit
- Operable on any general canal gate
- Single phase power supply
- Allow manual control on site
- Records gate height (opening and closing)
Gate Automation Module: Components

- Motor
- Driving unit of motor:
  - Rectifier
  - Bidirectional control using Magnetic Relays
  - Back-EMF protection
- Height measuring unit using:
  - proximity sensor
- Microcontroller
- User Interface
  - LCD Display
  - Keypad
- Gears
Components: Motor

• DC Motor:
  – Why?
  – Easy availability of single phase AC supply
  – Higher torque than single phase AC motor
  – Special drive not needed

• Motor Chosen (After extensive survey online and at Branderth road, Lahore):
  – Simple DC motor
  – RPM: 3000
  – Operational Voltage: 180V
  – Power: 2 hp = ~1.5 kW
Components: Rectifier and Bidirectional Control

- Rectifier
  - Full bridge
  - 220V AC (input) to DC (output)
- Bidirectional Control
  - H bridge using Magnetic Relays
  - Surge Protection from Back-EMF using power diodes
  - Controlled using uC and switching relays through opto-couplers
Components: Rectifier and Bidirectional Control PCB Layout
Components: Proximity Sensor

Height Measurement
- Initial calibration set using microcontroller (User Input)
- Rotation sensing using proximity sensor
- Detect height of gate using no of rotations of motor
- Display height on LCD
Components: Microcontroller, LCD, Keypad and Gears

- Atmega-16 chosen for gate module operation
  - Controls switching of relays to open or close the gate
  - Calculates gate height using proximity sensor as input
  - Provides user interface on site (LCD and Keypad)
- 20x4 Character LCD for gate height
- 4x4 Keypad for user interface
  - Calibration of initial height of gate
  - Manual Bi-direction control of motor
- Gears
  - Increase torque
Components: Microcontroller
PCB Layout
Gate Automation Module: Cost

- Rectifier and Bi-directional Control (Total): ~ Rs. 3000
  - Magnetic Contactors (x2): 700x2: Rs 1400
  - Power Diodes (x6): 50x6 = Rs 300
  - Switching Relays (x4): 150x4 = Rs 600
- Motor ~ Rs. 15000
- Microcontroller ~ Rs. 750
- Proximity Sensor: ~ Rs. 1200
- LCD Display: ~ Rs. 600
- Outer Box: ~ Rs. 5000
Gate Automation
Module Demo
Deliverables and Future Work
Deliverables

• Start integrating the motor drive circuitry and DC motor - Done
• Start assembling the Gate Automation Module - Done
• More rigorous system identification – testing plant stability under various canal conditions - Done
• Actual experimentation using at least 3 sensors on canal site and performing system ID - Done
• Design and testing of software based controller and implementing various kinds of control action - Left as future work
More Exploration in the area

- From the varying bed width considerations – shape irregularity in canal and its effect on plant transfer function
- Sediment Transport Modeling and its effect

- Mathematically model Sediment Transport
- Effect of this as a function of canal geometry/parameters
- Effect/Change in plant transfer function
- Effect on controller design and parameters
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Questions and Answers
References