A Method for Precision Closed-loop Irrigation Using a Modified PID Control Algorithm

Martin S. Goodchild, Karl Kühn, Malcolm Jenkins, Kaz Burek & Andrew Dutton

Delta-T Devices, 130 Low Road, Burwell, Cambridge, CB25 OEJ, UK

Abstract: Closed-loop irrigation control has been demonstrated in grower trials to improve crop yields and resource usage. Managing water use by controlling irrigation in response to soil moisture changes to meet crop water demands is a popular approach but requires knowledge of closed-loop control practice. In theory, to obtain precise closed-loop control it is necessary to characterise every component in the control loop to derive the controller parameters, i.e. proportional, integral & derivative (PID) parameters in a classic PID controller. In practice this is often difficult to achieve. Empirical methods are employed to estimate the PID parameters by observing how the system performs under open-loop conditions. In this poster we present a modified PID controller, with a constrained integral function, which delivers excellent regulation of soil moisture by supplying the appropriate amount of water to meet the needs of the plant during the diurnal cycle. This system responds quickly to changes in environmental conditions, including rainfall events which can result in: controller windup, under-watering and plant stress conditions. The experimental work successfully demonstrates the functionality of a constrained integral PID controller that delivers robust and precise irrigation control.

Delta-T Devices

Applying the GP2 to precision irrigation applications

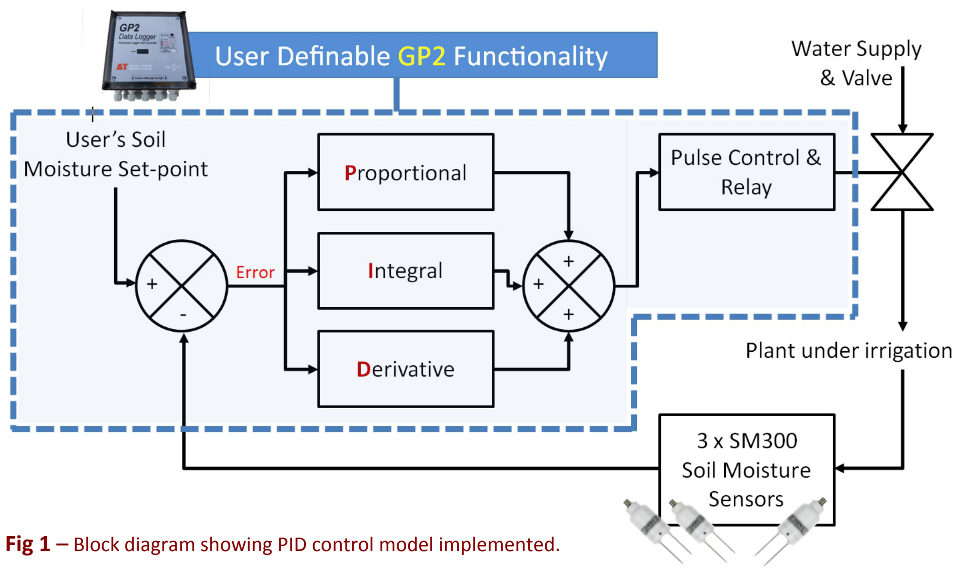

Fig 1 – Block diagram showing PID control model implemented.

- **Proportional**
  - Absolute (measurement) Error relative to the User's set-point
- **Integral**
  - sum of Errors over time,
  - reaches a 'steady-state' level that drives the irrigation flow
  - controller wind-up conditions (Romero et al.) addressed by applying constraints to the integral
- **Derivative**
  - responds to rapid changes in Error
  - used to offset transient high gain Proportional signals
- **Pulse Control & Relay**
  - takes the sum of weighted PID terms and converts it to a duty-cycle for an ON/OFF valve signal
  - pulse frequency or pulse width modulation methods

- **Proportional + (constrained) Integral + Derivative**
  - each contribution weighted by a coefficient: k_P, k_I & k_D respectively
  - typically aim for 'critical damping' by adjusting coefficients
  - usually difficult to do in theory, requires Laplace transfer functions etc.
  - Ziegler-Nichols often used in practice to start with then optimise

Experiment #1 – testing the constrained integral PID controller

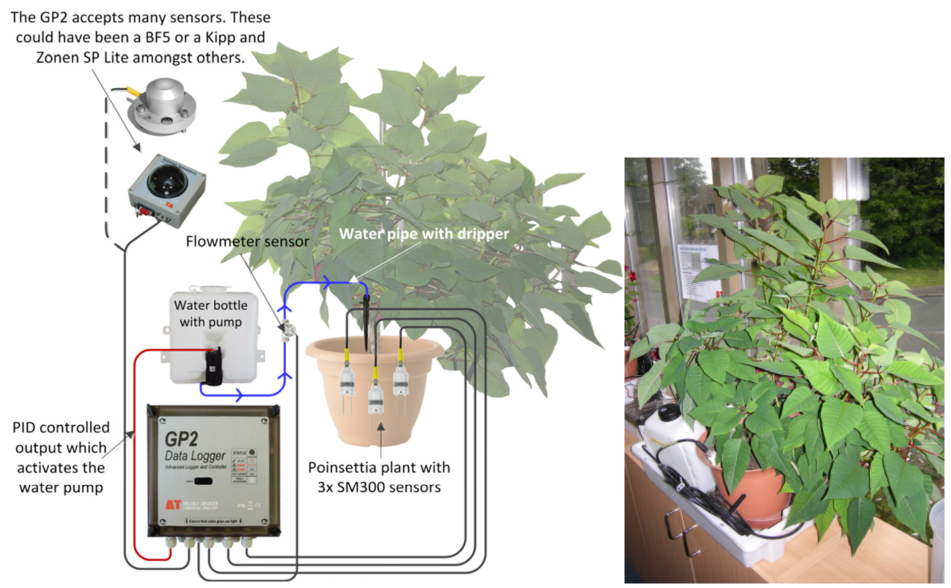

Fig. 2 – Diagram showing the setup of the equipment

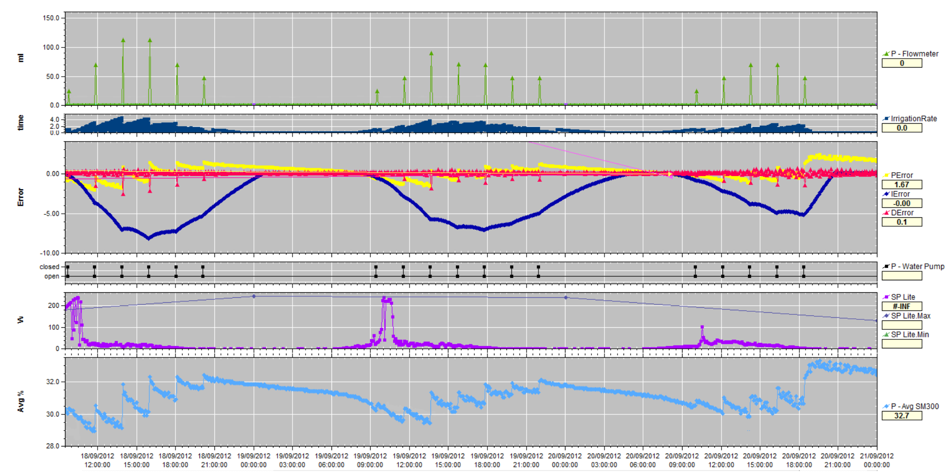

Fig. 3 – The data generated by the PID experiment.

Prior to the plant experiment we tested the PID controller using the GP2 simulator to confirm the implementation. Fig. 3 shows three days data from the Poinsettia plant with the controller responding to the water demands of the plant through the diurnal cycle. The proportional, constrained integral and derivative responses are also presented which result in prescriptive irrigation events occurring in line with the diurnal cycle whilst regulating soil moisture to 31%. Further tests illustrated the system was robust to rainfall events and recovered quickly from water supply interruptions. Using k_P = 2, k_I = 0.05 & k_D = 0 moisture was maintained at 31% ±1.5% with a 2 hour irrigation interval.

Experiment #2 – scaling up, 32 strawberry plants in coir

This arrangement consisted of drip irrigation of 4 coir bags (Botanicoir) with 8 plants and 4 drippers per bag. Substrate moisture was measured in each bag using an SM300 soil moisture sensor. A moisture set point of 55% was used with the average moisture from the SM300 sensors, the irrigation interval was 2 hours. As with the poinsettia, setting k_s = 2 provided improved performance, achieving moisture control of 55% ±4%. Solar radiation data was recorded with a BF5 along with irrigation water volume (in litres) with a flow meter. Coir moisture and solar radiation measurements were taken every 10 minutes. The experimental arrangement and moisture data over a 7 week growing period is shown below in Fig 4.

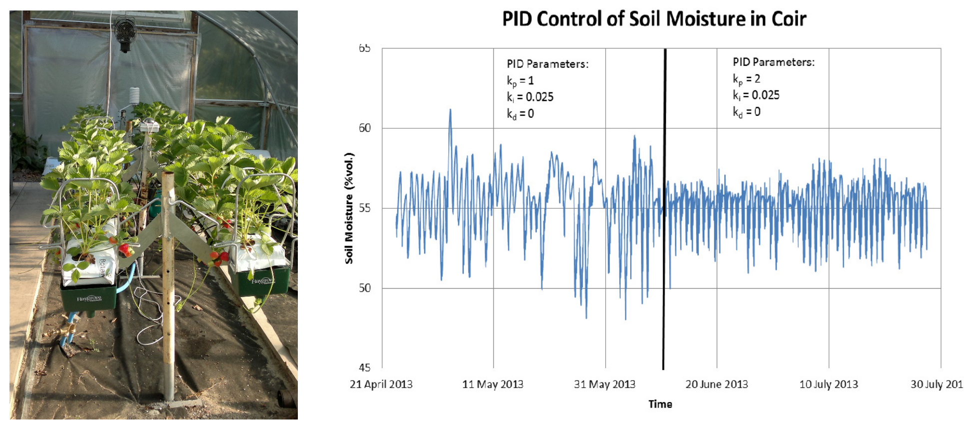

Fig. 4 – The strawberry plants in coir experiment.

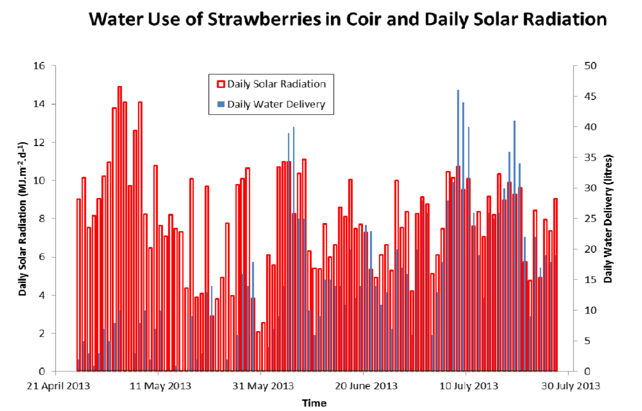

Fig. 5 – Showing the relationship between daily water delivery and daily solar radiation over the same period as in Fig. 4

Conclusions

These experiments demonstrate the effectiveness of a constrained integral PID controller for precision irrigation. Substrate moisture, daily solar radiation and water use data shows that the PID controller responds quickly to changes in environmental conditions and the diurnal cycle whilst delivering robust and prescriptive irrigation over a wide range of solar radiation levels. The coir substrate strawberry growing trial illustrates that this controller technology can automatically deliver the right amount of water when the plant needs it.

References:

- M. S. Goodchild et al., 2015, 'A method for Precision Closed-loop Irrigation Using a Modified PID Control Algorithm', Sensors & Transducers, Vol. 188, Issue 5, pp. 61 - 68
- R. Romero et al., 2012, 'Research on automatic irrigation control: State of the art and recent results', Agricultural Water Management, Vol. 114, pp 59-66
- Ziegler J. B., Nichols N. B., 1942, Optimum settings for automatic controllers, Trans ASME, Vol. 64, 759-768

Visit our website: www.delta-t.co.uk