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CENTAUR: Smart Utilisation of Wastewater storage capacity to prevent flooding

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Abstract

This paper will describe and present results for a local flood risk reduction system which utilises existing in-network storage capacity to attenuate flow peaks. The storage capacity is mobilised through active flow control automatically regulated by an Artificial Intelligence system using local level monitoring.

The effects of climate change, population growth and urbanisation are putting increasing pressure on sewer and drainage networks both in the UK and overseas. The capacity of networks to cope with runoff at the required rate often falls short of requirements leading to localised floods and/or increased CSO spills to receiving waters. Smart Water/ Wastewater Network technologies have the potential to deliver improved service to customers and cost-effective performance improvements for the water industry.

CENTAUR aims to provide an innovative, cost effective, local autonomous data driven in-sewer flow control system whose operation will attenuate peaks and reduce the risk of surface water flooding. The system enables the capacity of existing infrastructure to be utilised more efficiently as a very economical alternative to capital-intensive solutions, for example building extra storage capacity. The system is also quick to implement with virtually no enabling works prior to installation.

CENTAUR comprises level monitors which relay data to an intelligent controller, which instructs a flow control device regulated by a novel and robust artificial intelligence routine based on Fuzzy Logic. The level monitors and intelligent controller are located locally and utilise real time data to provide effective real time control (RTC).

The CENTAUR Fuzzy Logic control algorithm was developed in Matlab. The Matlab RTC algorithm was linked to a SWMM hydro-dynamic model of a test network to prove its efficiency. Further rigorous testing was carried out by the University of Sheffield on the full-scale test facility designed to replicate field conditions. The CENTAUR system has been further developed and it is now implemented and fully functional in trial site in Coimbra, Portugal. Results of successful testing in the laboratory and the Coimbra field trial will be presented.

Introduction

Climate change is likely to result in more intense storms. Equally, increased urbanisation means increased volumes of runoff must be conveyed by the same downstream infrastructure to the wastewater treatment works. The response to these pressures has often been capital solutions such as storage tanks, or increased sewer size. These solutions are disruptive and have large associated costs.

CENTAUR controls flows and utilises untapped water network capacity through local autonomous Real Time Control (RTC) using Artificial Intelligence routines which act on water level data. The algorithm has been developed in a virtual environment, prior to being integrated with the complete CENTAUR system which has been further development in a laboratory facility at the University of Sheffield. The first field pilot system in Coimbra, Portugal became active in September 2017. Its first applications have been in the protection of hydraulic capacity related flooding sites. The "autonomous local control" paradigm introduced by CENTAUR is distinct from previous RTC paradigms by its decentralisation and autonomy.

CENTAUR Control system

A Fuzzy Logic control system has been developed with objective to control the FCD position in order to regulate level at the flooding location and minimise the risk of localised flooding. Control actions are based on relative levels upstream of the FCD and at the flooding location, making sure that control system does not cause additional flooding upstream while storing excess flow. The Fuzzy Logic control system needs to be robust and respond accordingly to changes in different flow patterns i.e. rainfall events and provide storage space responding to dynamic changes in the system. Interaction between a FCD and sewer network behaviour has been observed through level monitoring at key locations and lab testing and it has been built in into CENTAUR control system.

Fuzzy Logic (FL)

Fuzzy systems are based on linguistic descriptions of complex systems. They don't demand knowledge of mathematical modelling. Fuzzy systems allow the application of 'human language' to describe the problems and their 'fuzzy' solutions. This is achieved by using Membership Functions and a Rule Base, both developed based on an existing knowledge about system that can be presented as a set of IF-THEN sentences. Each membership function imitates a linguistic approach which is used to describe some condition in every day descriptive usage (high, low, etc.). The rule set is based on fuzzy reasoning which employs linguistic rules in the form of IF {condition} – THEN {action} statements. There is a relationship between membership functions and rule sets. The membership values control the degree to which each of the IF – THEN rules will contribute to the control decision.

FL is particularly suited to wastewater applications, where phenomena can be understood but where their behaviour are characterised by variability. FL algorithms can capture, for example, expert knowledge, the conclusions of laboratory and field experiments, and modelling outputs around a particular phenomenon, and cope with their variability.

In wastewater, FL has been used in: detection (e.g. blockage detection; state detection in anaerobic wastewater treatment (Murnleitner et al., 2002); CSO performance optimisation and management in near-real-time (Mounce et al., 2014)) and control applications (e.g. pump station control and optimisation of energy use (Ostojin et al., 2011); control of additives in treatment; control of an activated sludge plant; energy saving in the aeration process (Ferrer et al., 1998); in-line control of non-linear pH neutralization; optimisation of nitrogen removal and aeration energy consumption in wastewater treatment plants).

The CENTAUR control algorithm uses water level data provided by a sensing network as input data and makes decisions based on this data to adjust the FCD position.

System Overview

The CENTAUR system has two key elements, the Flow Control Device (FCD) which controls flows and the Local Monitoring and Control System (LMCS) which monitors water levels and issues commands to the FCD. CENTAUR has been developed so that it can usually be installed with minimal civil engineering works. The system has been engineered to achieve a high level of reliability in terms of communication links, power and sensor data. The technology uses fuzzy logic algorithm to adapt to prevailing conditions and the changing situation. The FCD technology is purpose-designed for the application and for easy deployment. The dashboard provides visibility of the data and system status. Although the dashboard isn't necessary for the operation of the system, it introduces convenience features.

Figure 1: Modular Arrangement of CENTAUR (beta version)

Laboratory and field testing of CENTAUR

Following the virtual testing process which was used in the initial development of the FL algorithm as presented at the 2016 UDG conference (Shepherd et al, 2016), the LMCS and control algorithm have been tested on a laboratory system at the University of Sheffield. After testing in the laboratory, the first CENTAUR pilot has been installed in Coimbra, Portugal.

Laboratory testing

The laboratory facility, shown in Figure 2, has been constructed specifically to test the CENTAUR system. The facility is designed to be effectively full scale, it consists of a 30 m long pipe, 0.2 m in diameter with four, 1.5 m high and 1 m in diameter, manholes. Clean water is pumped into the facility at up to 50 l/s. The facility is fitted with the same LMCS used in field installations.

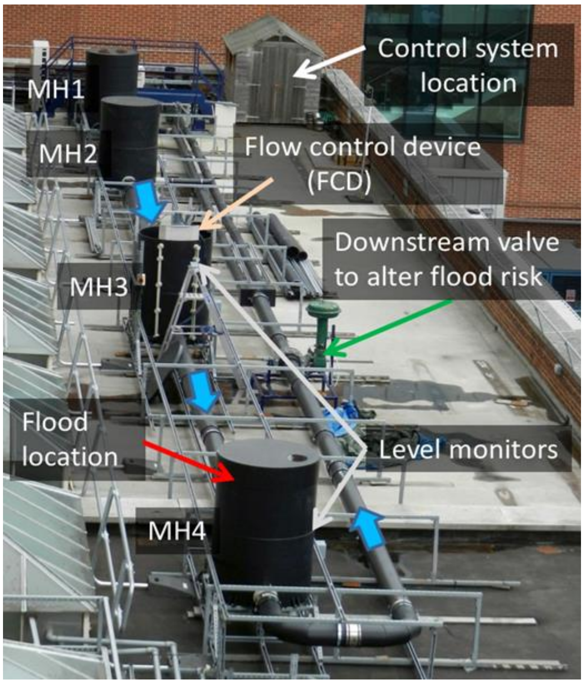

Figure 2: Laboratory facility, University of Sheffield

The laboratory testing has allowed both the LMCS and the control algorithm to be tested and refined in a controlled and repeatable environment. Figure 3 presents an example test result, showing that the system has reduced the peak water level at the downstream location by around 15 cm (red line) and stored the excess water upstream of the flow control device (blue line) by changing the position of the flow control device (black line). Figure 4 shows the repeatability of the CENTAUR system by re-running an identical test three times. The only significant difference here is that in Test 150 the FCD re-opens slightly more quickly after the 30 minute mark, this in turn means that water drains more quickly from upstream of the FCD. This difference in FCD re-opening is a function of the 'fuzzy' nature of the control system meaning that control signals vary according to the input data, here the input data results in a larger opening command.

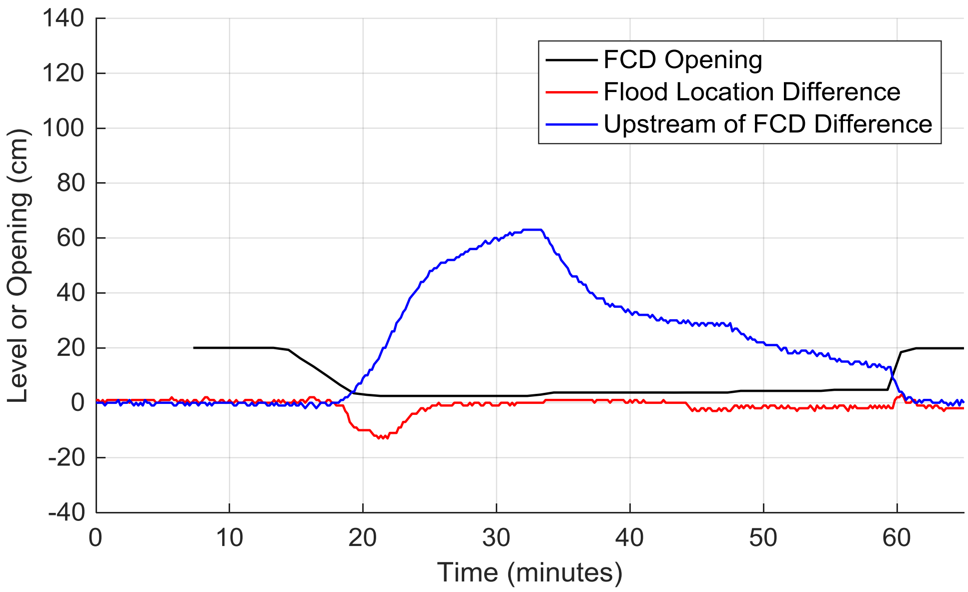

Figure 3: CENTAUR laboratory test showing system impact.

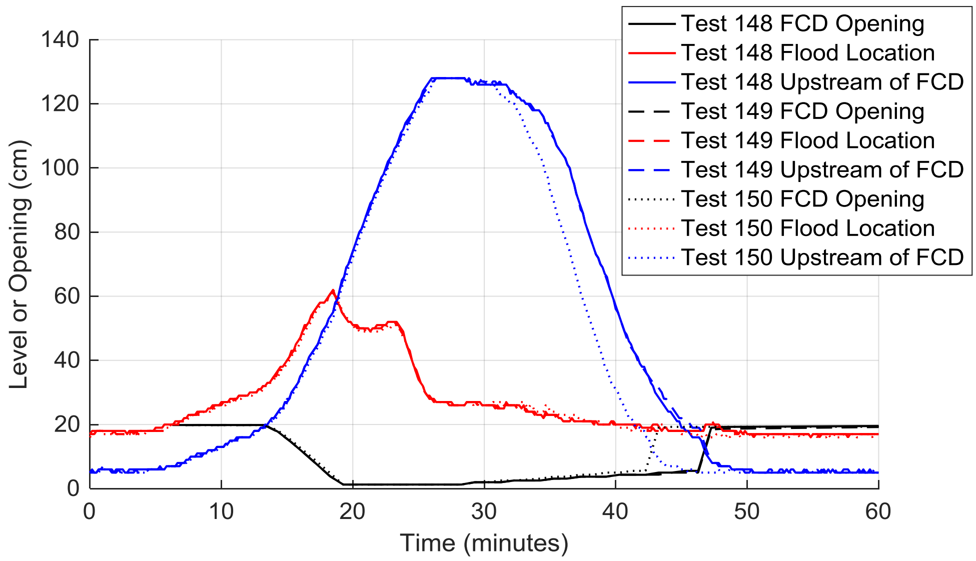

Figure 4: CENTAUR laboratory tests showing repeatability of CENTAUR system.

CENTAUR installation in Coimbra

For the first field installation, the city of Coimbra has been selected. Coimbra is a medium size city in the centre of Portugal that has suffered several urban floods in recent years. The most affected zone is the downtown area (Figure 5, right), where important services and tourist attractions are located. This zone is covered by the "Zona Central" urban drainage catchment, which has a total area of approximately 1.5 km^2 . The catchment is predominantly urban with a 34.8 km piped network, 29 km of which is combined conduits, 4.6 km of foul and 1.2 km of storm water. The time of concentration of the catchment is estimated to be around 45 minutes.

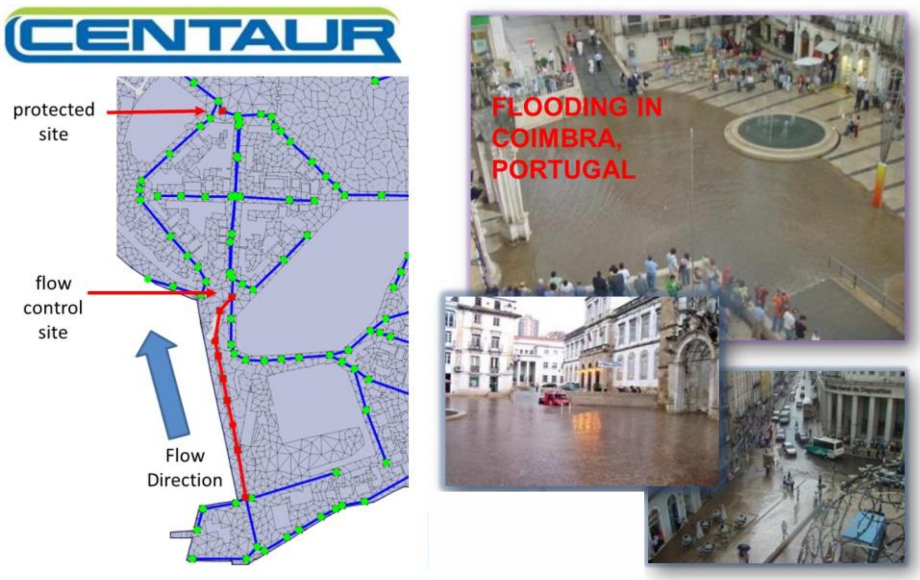

Figure 5: CENTAUR installation site (left). Flooding in Coimbra (right).

The site selected for the installation of the CENTAUR system is on Av. Júlio Henriques, this site has a length of large diameter pipe which provides a suitable potential storage volume. Installation of the FCD on Av. Júlio Henriques will reduce flows in the downstream part of the system, with the target protected site in Praça Republica. Figure 5 (left) shows the location of the storage on Av. Júlio Henriques in red and the protected site for this pilot installation.

CENTAUR Control algorithm in Coimbra

The pilot system has been set up to ensure that it activates regularly during the pilot testing period which will last for up to one year, hence rather than reducing flooding which may only occur once every two years, water levels within the sewer are being controlled.

The control algorithm parameters have been set so that the system aims to control flows from regularly occurring (sub-monthly) rainfall events. The CENTAUR system parameters are site specific and relate to the objective of the CENTAUR system. In the results presented here, the control objective is to keep the water levels at the downstream protected site below 0.3 m, which is a parameter defined in the control algorithm.

Results and Discussion

Three rainfall events have been captured in Coimbra in October 2017, one high intensity and two lower intensity but longer duration. Water levels recorded at the protected location (blue) and upstream of the FCD (red) can be seen on a screenshot from the CENTAUR online dashboard (Figure 6). All three events triggered the FL control and FCD movements can be seen in Figure 7.

Analysis has been carried out for the 17th October event and is shown in Figure 8. Here it can be seen that the level at the protected location stays below the control objective (solid lines). It can also be seen that the modelling carried out provides a good match to the observed data (dashed lines). Further analysis (not shown) indicates that at a location downstream of the FCD, peak water levels are reduced by 28% during this rainfall event, compared to a model simulation without the CENTAUR system.

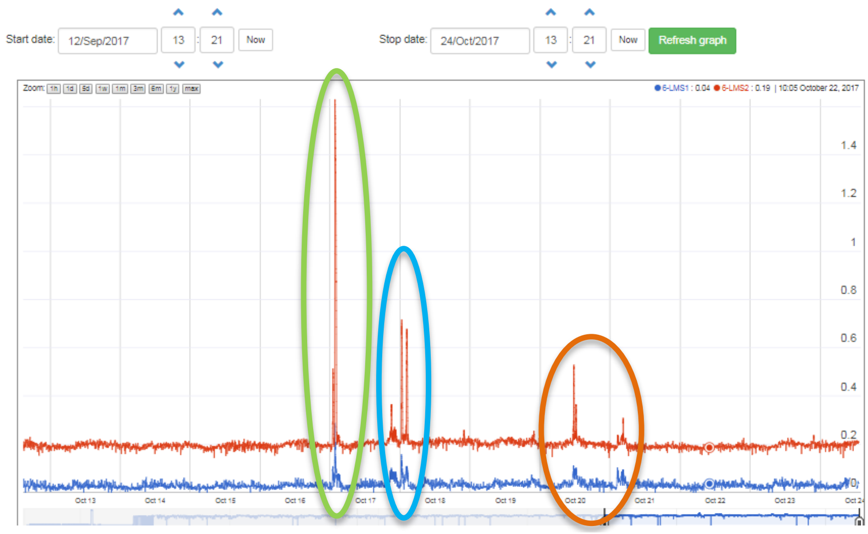

Figure 6: Rainfall events in Coimbra 17th October (green), 18th October (blue) and 20th October (orange).

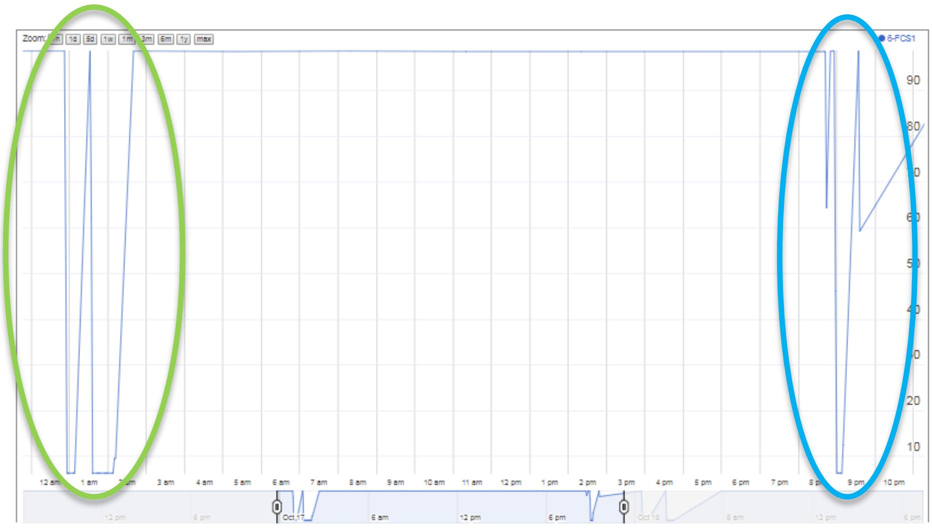

Figure 7: Rainfall event on 17th October (green) and 18th October (blue) event; position of the FL controlled FCD.

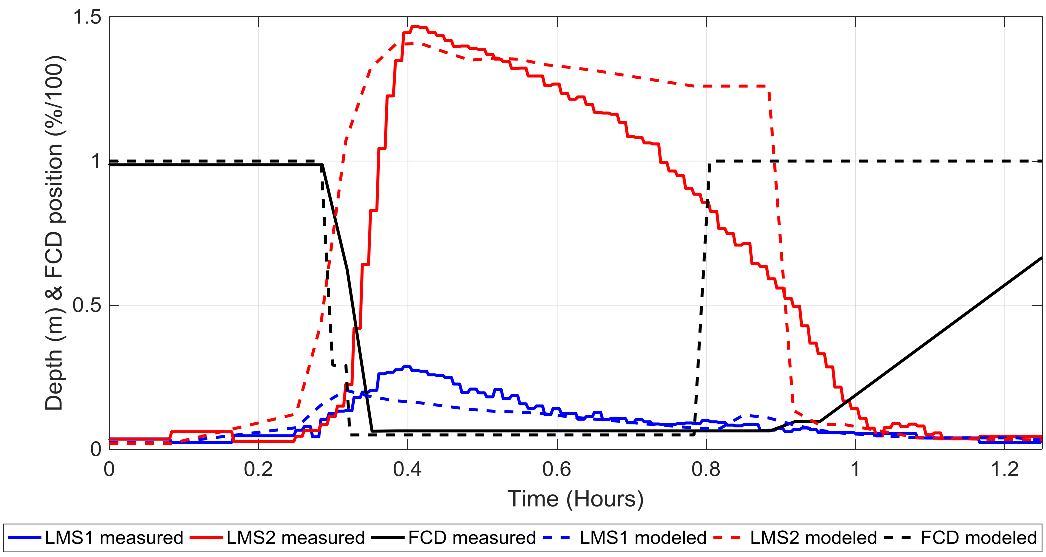

Figure 8: Comparison of measured and modelled data of CENTAUR system operation on 17th October.

Conclusions and next steps

The paper shows the successful use of the CENTAUR Artificial intelligence based RTC system used for flood protection. The system has been tested in a laboratory facility at the University of Sheffield and is currently undergoing testing in a live wastewater network in Coimbra, Portugal.

Benefits of the Fuzzy Logic driven flow control device to reduce water depths in the laboratory facility and in the Coimbra field trial have been shown to meet expectations.

A further field trial site has been selected in Toulouse, France. Installation of the CENTAUR system in Toulouse will commence in the near future.

Further Information

Additional information on the CENTAUR project is available at www.shef.ac.uk/centaur.

Acknowledgements

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