# WILD BIRD FOR REAL-TIME ASSESSMENT OF HYDRO-HAZARDS AT BRIDGE STRUCTURES

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## ABSTRACT

Transportation assets represent a critical component of society's infrastructure systems. Flood-related hazards are considered one of the main climate change impacts on highway and railway infrastructure, threatening the functionality of transportation systems. Of such hazards, flood-induced scour is a primarily cause of bridge collapses worldwide and one of the most complex and challenging water flow and erosion phenomena, leading to structural instability and ultimately catastrophic failures. Evaluation of scour risk under severe flood events is a particularly challenging issue considering that depth of foundations is very difficult to evaluate in hydro-environment. Continual inspection, assessment and maintenance of bridges and other hydraulic structures under extreme flood events requires a multidisciplinary approach, including knowledge and appreciation of hydraulics, hydrology, structural engineering, geotechnics and infrastructure management. The large number of bridges under a single management unit also highlight the need for efficient management, information sharing and self-informing system for reliable and cost-effective flood and scour risk management.

BRIDGE SMS EU/FP7 project couples state-of-the art scientific expertise in multidisciplinary engineering sectors with industrial knowledge in infrastructure management. The project aims to deliver an intelligent decision support tool to efficiently manage and prevent flood-related structural failures. One of the project outcomes is the development of real-time monitoring platforms to remotely assess and mitigate impacts on civil infrastructure, focusing on flood and scour hazards. The developed instrumentation is interfaced with an open-source software that can offer a cost-effective and remote monitoring solution. The proposed monitoring system consists of the Weather Information Logging Device (WILD) which integrates a variety of sensors to provide rainfall, humidity and temperature data to assess the potential of flood hazards in the bridge site area. The monitoring system is complemented by the Bridge Information Recording Device (BIRD) which consists of instrumentation to monitor water level in river environment, scour effects at underwater bridge foundations and variations in the structural performance of both individual elements and the bridge as a whole during flood events. The developed WILD BIRD platform has the potential to deliver key information in real-time regarding the impact of water-related hazards at bridges and other hydraulic structures and provide a critical tool to efficiently manage hydro-infrastructure systems.

*Keywords*: flood risk; bridges; scour; water hazards; infrastructure; structural health monitoring; environmental monitoring.

## 1. INTRODUCTION

Hydro-hazards associated with extreme precipitation events pose a major threat for the resilience of civil infrastructure assets over watercourses. Of such hazards, scour is the most complicated process leading to destructive consequences of hydraulic structures. A result of being relatively complex process to identify, quantify and model is that scour and erosion actions are the main causes of bridge failures worldwide (Wardhana, 2003). Such issues are not confined to bridge infrastructure, as scour and erosion are also considered one of the main complications in the design and operation of offshore infrastructure (Michalis et al., 2013). Scour action has also been highlighted as highly disruptive and time critical vulnerability due to its destructive consequences on civil infrastructure systems (Highways Agency, 2009). Despite more resources being invested in protecting structures from hydro-hazards, damage due to scour action on infrastructure assets is expected to increase due to climate projections which indicate that the frequency of extreme flooding across Europe is anticipated to double by 2050 (Jongman et al., 2014).

The evaluation of scour action on structures is a critical issue taking into account the deterioration of infrastructure as well as the cost and technical issues arising from the rehabilitation and replacement of bridges (Michalis et al., 2012). However, current standard practices which rely on visual inspections utilising specialist divers cannot reveal actual bed level variations around the foundations of structures due to several issues associated mainly with the periodicity of inspections and safety considerations during major flood events (Michalis et al., 2015). Even though water and flow characteristics around bridge piers have been investigated both experimentally and numerically, there is still lack of a tool that can offer fast and reliable predictions (Valyrakis et al., 2015). Therefore, the implementation of a real-time system for monitoring vulnerable infrastructure systems is a highly attractive option.

The continuous monitoring of water levels, alongside with rainfall and other environmental processes, can provide flood warnings and critical information required for the identification and prediction of water-related hazards to hydraulic structures (Rango and Shalaby 1998). A large number of commercially available weather monitoring solutions currently exists. Such solutions are often curtailed by price, requirements for technical setup, power demand and the number of environmental elements being monitored. While many types of sensors can be procured to measure a wide range of elements, it can take significant technical expertise to integrate all sensors with appropriate data-logging and telemetry modules, both for physical connections and the programming of such modules to record, store and transmit data at required intervals to a dedicated server.

This paper address such issues through the introduction of the BRIDGE SMS Monitoring System, a solution which has been developed to provide real-time monitoring of environmental and bridge conditions. The system will provide a significant advance for predicting hydro-hazards to bridge structures and deliver an important resource for a reliable bridge management system, especially in the context of an ageing bridge network in Europe (Znidaric et al., 2011). A description of the BRIDGE SMS monitoring system and objectives is provided in this regard. A novel approach for remotely monitoring of conditions is detailed through the development of a low-cost monitoring and data-logging device, which provides real-time data to the BRIDGE SMS platform using remote stations communicating through telemetry. The BRIDGE SMS solution aims to offer not only a method for monitoring, modelling and predicting hydro-hazards for bridge structures, but also a powerful, all-encompassing method for bridge maintenance management.

## 2. BRIDGE SMS MONITORING SYSTEM

Combined assessment of environmental processes (e.g. water level fluctuations, scour and sedimentation depth variations, rainfall, temperature, catchment characteristics, land coverage, soil type and soil moisture) are critical for reliable assessment of flood and scour hazards at infrastructure assets. Of great importance is therefore considered the development of real-time instrumentation to assess and predict water-related hazards and to monitor environmental processes at bridge structures.

BRIDGE SMS EU/FP7 project aims to couple state-of-the art scientific expertise in multidisciplinary engineering sectors with industrial knowledge in infrastructure management. This is assisted by the application of an integrated, low-cost, structural health monitoring systems aiming to provide real-time information about water level fluctuations in river environment, scour/sedimentation depth variations, precipitation and soil moisture information. Data from the aforementioned variables will provide critical input towards the development of an intelligent decision support tool to assess and efficiently manage bridge infrastructure. The proposed BRIDGE SMS monitoring platform for bridges over watercourses consist of two systems, the Weather Information Logging Device (WILD) which is deployed in the catchment area and the Bridge Information Recording Device (BIRD) installed at the target bridge site.

As part of an environmental monitoring station, there are four key modules which must be combined so as to provide real time monitoring, namely:

a. Sensors – It is required that each environmental element being monitored has the appropriate sensor to accurately monitor it. Such sensors range in price and accuracy, but for current monitoring stations sensors which conform to standards as established by legislation, the mechanisms are consistent, e.g. standards

  ISBN: 978-90-824846-2-5

established for monitoring rainfall using a tipping bucket mechanism with uniform volume requirements of the bucket size and the accuracy of the readings.

b. Data-logging – There exists stark contrast in available data-logging modules, in terms of number of sensor inputs available for logging, input types, programming requirements, reliability, cost and power consumption. While many cost effective solutions are available, such solutions are often not appropriate for remote monitoring in harsh environments nor are the connecting and programming requirements for integrating the sensors user-friendly.

c. Telemetry – As with the data-logging module, a diverse range of telemetry units exists, which can be used with remote environmental monitoring stations, in terms of cost, reliability, programming, power consumption and connection to data-logging module.

d. Power Supply – When individual modules are integrated, the power demands for the entire station can be such that a connection to the mains power is required or a significant renewable source that is capable of satisfying the power needs for real-time monitoring. Significant cost and expertise is therefore required to ensure that the power requirements of the station are met and that the connections to the sensors, data-loggers and telemetry modules are established correctly.

The newly developed WILD system integrates all four required modules with a variety of sensors providing real-time rainfall, soil moisture, humidity and temperature data, which is subsequently utilised to monitor the catchment conditions and assess the potential of flood hazards in the general bridge site area. The information recorded from the WILD system is used as input data for hydrological modelling and now-casting resulting to flow hydrographs at the bridge including flow rates and water level information.

The recording time intervals are very important for reliable assessment of water hazards, therefore the real-time rainfall data with 15-minutes time intervals from the rain gauges deployed at the catchment is used as the main input for the hydrological model in the proposed system.

The soil moisture data is then used to determine the appropriate hydrological model set-up, which consists of either (a) dry catchment conditions, (b) medium catchment conditions or (c) saturated catchment conditions. Air temperature and relative humidity information is used for evaporation calculation within the hydrological model. The output from the hydrological model is a now-cast flow hydrograph, discharge Q(t) with a lag time up to 24 hours. Q(t) is correlated to water levels H(t) using an existing rating curve (Q-H) and to the flow velocity v(t) using existing discharge-flow velocity curve (Q-v).

Alongside the WILD device is the BIRD, which is employed for real-time monitoring of the effects of water-related hazards on the structural performance at the bridge structure. BIRD consists of instrumentation to monitor flow conditions, water level, scour effects at underwater foundations (Ds) and variations in the structural performance of both individual elements and the bridge structure during flood events. WILD BIRD systems complement each other, e.g. water level monitoring information can be used for verification of now-casting hydrographs obtained from the hydrological modelling but also to provide an accurate real-time information of water fluctuations at the bridge site. Water levels and flow rates are correlated to the flow velocity which also provide the basis for the prediction of scour depth calculation. Scour depth calculations usually provide overestimated predictions (Ghorbani, 2007), therefore real-time data of scour depth variations will be valuable information to assess and improve the existing scour depth empirical models. The flow chart of the data flow and modelling procedure towards a reliable decision support tool are shown in Figure 1.

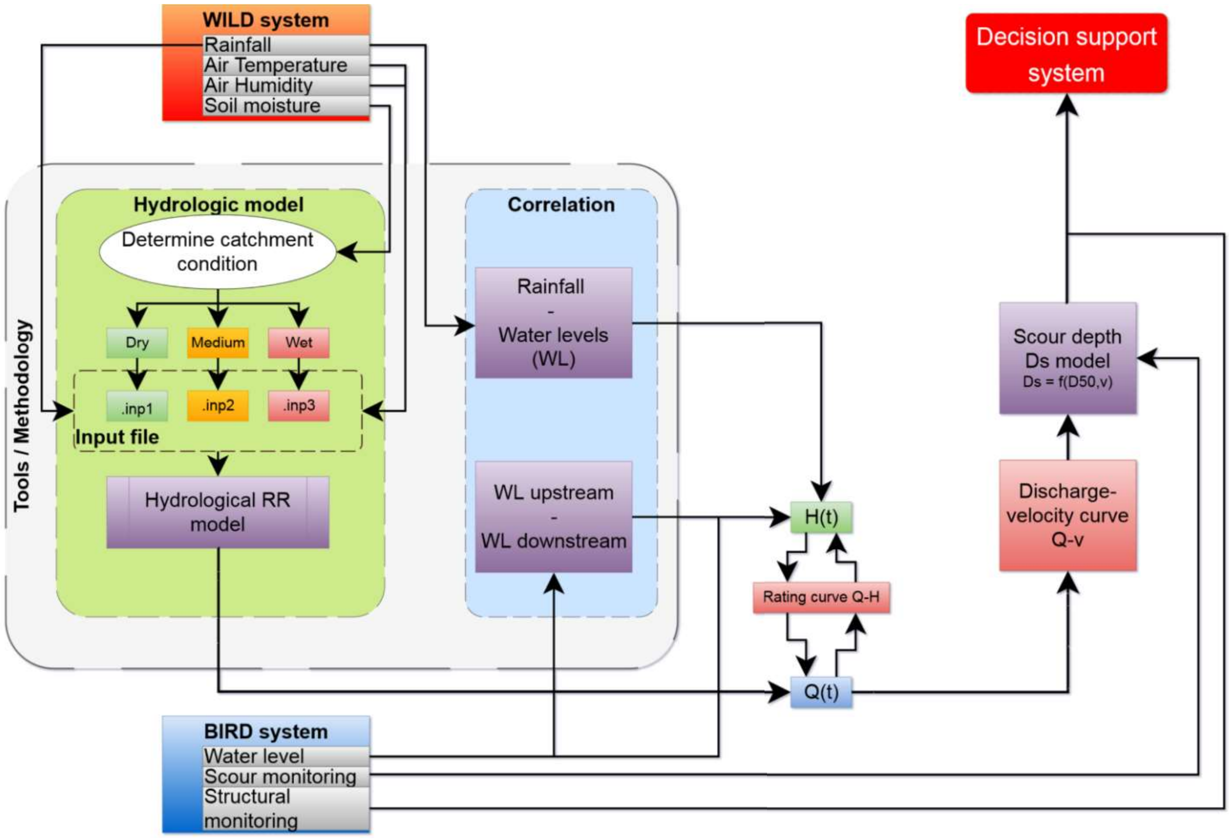


Figure 1. Flow chart of WILD BIRD systems which are employed to provide real-time environmental and structural input data and assess the potential of flood hazards in the catchment and bridge site areas.

## 3. WILD BIRD DATA LOGGING

The WILD BIRD systems are based on Arduino, an open-source electronics platform which encompasses microcontroller-based kits for building digital devices and interactive objects that can communicate and control physical devices.

The WILD system consists of various electronic components that were acquired considering the longevity and durability of each part. The housing for the WILD system has been produced by 3D printing using ABS plastic which provides practicality and durability in harsh environmental conditions. Figure 2 presents the various parts that assembled to provide a low-cost remote monitoring solution to assess environmental processes.

Figure 2. Housing (dimensions: 131 x 158 x 70 mm), external and internal components of WILD BIRD systems.

The device can host different types of sensors for various measurements. There are currently four sensors combined with the prototype device, two sensors (temperature and humidity) are internally stationed inside the device, while two more sensors (soil moisture and rainfall) are externally connected to the device. Additional sensors are planned to be added into the data logger in the new prototype iteration which is planned to be applied in the field.

The data logger itself can operate on different power sources, however, special consideration was paid to downsize the power consumption to 3.6 W which enables the system to be connected to off-the-shelf solar panels. The device has also been designed to operate on rechargeable batteries which can provide up to 5 days of auxiliary power when the primary power source is not active. A SIM module is used to transfer data gathered from the sensors and stored on an SD card. The WILD is using 2G/3G/4G data connection with the telecom operator / internet provider. The data are also stored

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inside the SD card in case of a communication failure of the internet provider and are programmed to be transmitted once the connection has been restored.

Two physical servers (a primary and a secondary one) are also allocated for data acquisition from the WILD device. In case the primary server is not accessible, then the data is transmitted to the backup server ensuring the data flow continuity. In case both servers are not reachable, then the data can be acquired from the SD card inside the WILD. The SD card has capacity to store from 2 to 20 years of data acquired from afore-mentioned sensors.

The data from the sensors is monitored continually by the device and subsequently stored by the system on the SD card, as presented in Figure 3. The data which has then been collected since the last data transmission is subsequently transmitted using the telemetry module of the device. As a precautionary safeguard, a protocol has been introduced so as to ensure that when transmission is unavailable or interrupted, the device will recognise a failure to transmit and will resend the data along with the intermediate data acquired by the device at the next transmission time. This ensures that all data will be obtained by the buffer server and protect against data disruptions. A further safety measure, as previously discussed, is the addition to the system of a backup buffer server to protect against any disruption to the primary server. The design of the system therefore offers an optimised monitoring system, while providing significant safety measures to ensure that the BRIDGE SMS system will be continuously in operation and provide information about the health of structures during critical events (e.g. flash floods).

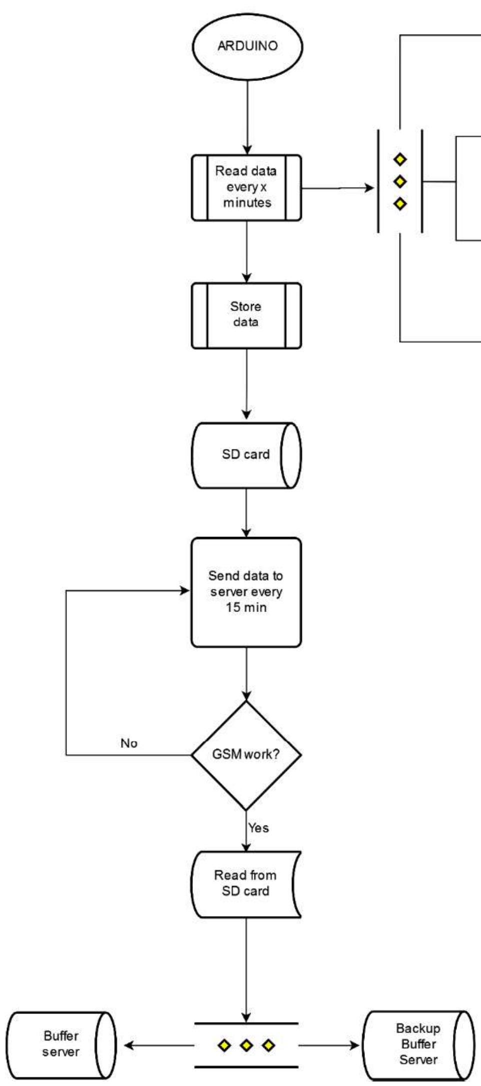
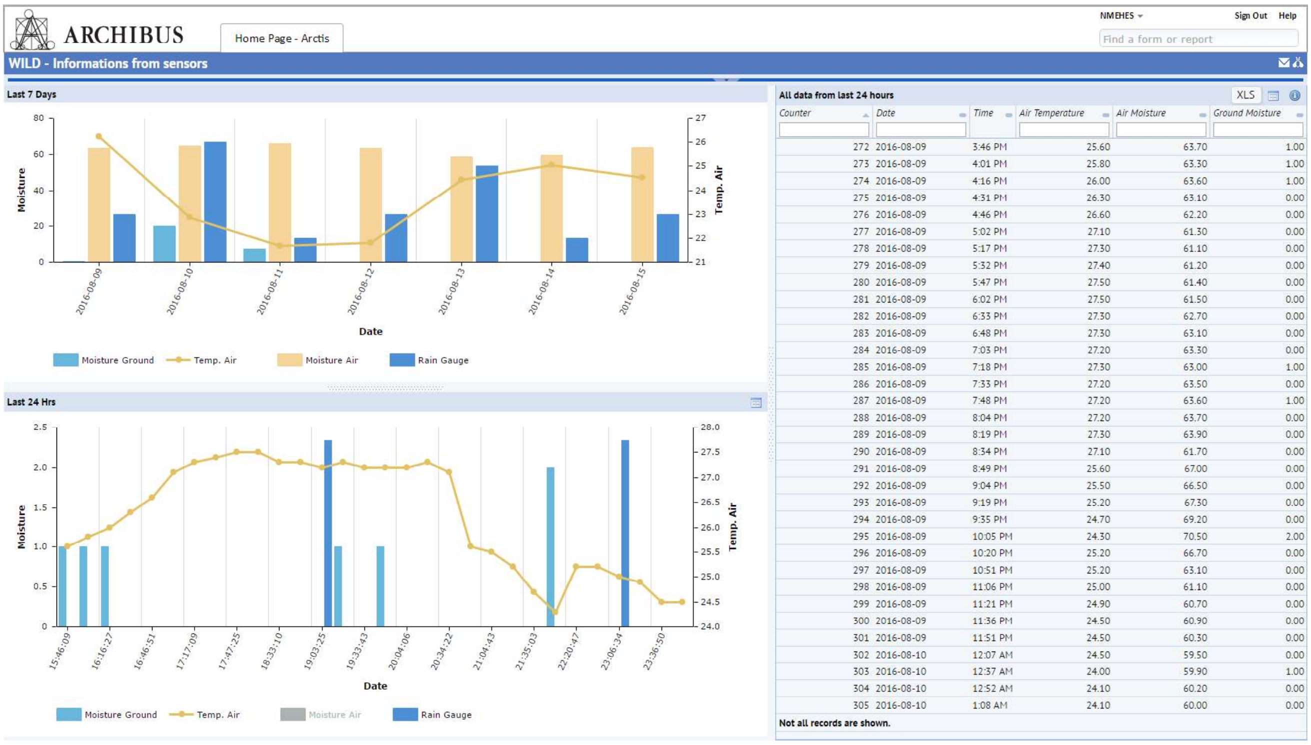



Figure 3. Data logging diagram of WILD device showing the flow and procedures for storage and real-time data transmission.

The data from sensors, transmitted through the SIM module, is optimized to save capacity and enable fast transmission while is categorized and grouped when acquired on the server. Data being obtained from the WILD device includes rainfall, temperature, air and soil moisture content. Furthermore, once the data is acquired inside the database and accommodated in the predefined tables, the ARCHIBUS platform has been employed to visualise the data and present graphically trends and graphs of the data historically, in real-time and in various time frames (see Figure 4). The advantage of such a platform allows for the comparison of data from a single device or from an entire network. The WILD device can therefore be employed for a number of auxiliary applications, such as flood-warnings or agricultural notifications, alongside its primary purpose of providing accurate, real-time information for detecting hydro-hazards at bridge structures.




| Counter | Date | Time | Air Temperature | Air Moisture | Ground Moisture |
|---|---|---|---|---|---|
| 272 | 2016-08-09 | 3:46 PM | 25.60 | 63.70 | 1.00 |
| 273 | 2016-08-09 | 4:01 PM | 25.80 | 63.30 | 1.00 |
| 274 | 2016-08-09 | 4:16 PM | 26.00 | 63.60 | 1.00 |
| 275 | 2016-08-09 | 4:31 PM | 26.30 | 63.10 | 0.00 |
| 276 | 2016-08-09 | 4:46 PM | 26.60 | 62.20 | 0.00 |
| 277 | 2016-08-09 | 5:02 PM | 27.10 | 61.30 | 0.00 |
| 278 | 2016-08-09 | 5:17 PM | 27.30 | 61.10 | 0.00 |
| 279 | 2016-08-09 | 5:32 PM | 27.40 | 61.20 | 0.00 |
| 280 | 2016-08-09 | 5:47 PM | 27.50 | 61.40 | 0.00 |
| 281 | 2016-08-09 | 6:02 PM | 27.50 | 61.50 | 0.00 |
| 282 | 2016-08-09 | 6:33 PM | 27.30 | 62.70 | 0.00 |
| 283 | 2016-08-09 | 6:48 PM | 27.30 | 63.10 | 0.00 |
| 284 | 2016-08-09 | 7:03 PM | 27.20 | 63.30 | 0.00 |
| 285 | 2016-08-09 | 7:18 PM | 27.30 | 63.00 | 1.00 |
| 286 | 2016-08-09 | 7:33 PM | 27.20 | 63.50 | 0.00 |
| 287 | 2016-08-09 | 7:48 PM | 27.20 | 63.60 | 1.00 |
| 288 | 2016-08-09 | 8:04 PM | 27.20 | 63.70 | 0.00 |
| 289 | 2016-08-09 | 8:19 PM | 27.30 | 63.90 | 0.00 |
| 290 | 2016-08-09 | 8:34 PM | 27.10 | 61.70 | 0.00 |
| 291 | 2016-08-09 | 8:49 PM | 25.60 | 67.00 | 0.00 |
| 292 | 2016-08-09 | 9:04 PM | 25.50 | 66.50 | 0.00 |
| 293 | 2016-08-09 | 9:19 PM | 25.20 | 67.30 | 0.00 |
| 294 | 2016-08-09 | 9:35 PM | 24.70 | 69.20 | 0.00 |
| 295 | 2016-08-09 | 10:05 PM | 24.30 | 70.50 | 2.00 |
| 296 | 2016-08-09 | 10:20 PM | 25.20 | 66.70 | 0.00 |
| 297 | 2016-08-09 | 10:51 PM | 25.20 | 63.10 | 0.00 |
| 298 | 2016-08-09 | 11:06 PM | 25.00 | 61.10 | 0.00 |
| 299 | 2016-08-09 | 11:21 PM | 24.90 | 60.70 | 0.00 |
| 300 | 2016-08-09 | 11:36 PM | 24.50 | 60.90 | 0.00 |
| 301 | 2016-08-09 | 11:51 PM | 24.50 | 60.30 | 0.00 |
| 302 | 2016-08-10 | 12:07 AM | 24.50 | 59.50 | 0.00 |
| 303 | 2016-08-10 | 12:37 AM | 24.00 | 59.90 | 1.00 |
| 304 | 2016-08-10 | 12:52 AM | 24.10 | 60.20 | 0.00 |
| 305 | 2016-08-10 | 1:08 AM | 24.10 | 60.00 | 0.00 |

Figure 4. Real-time data, consisting of air temperature, air moisture and soil moisture, acquired from the prototype WILD system on the server. The graphic visualisation of the obtained data is provided by the ARCHIBUS platform.

While a wide range of sensors and solutions for real-time monitoring of environmental events currently exists, a major issue with establishing such remote monitoring stations is the task to ensure that all four key modules, as identified in Section 2, can be integrated successfully. This is especially of great value when sourcing the modules from different companies, which result to issues of compatibility and increasing costs. The WILD BIRD systems aim to provide a cost-effective telemetry and data logging option with low power requirements, while also being compatible with various sensor technologies. The production and assembly cost of a device is expected to be at the range of 10% to 15% compared to the existing commercially available data-logging and telemetry options.

## 4. CONCLUSIONS

The high intensity of extreme weather events is anticipated to increase during the next years making flood risk assessment a particular challenging issue. The evaluation of the effects of hydro-hazards on aging civil infrastructure, and particularly on bridge structures, is therefore considered of great importance taking into account that underwater foundations are very difficult to evaluate due to lack of reliable real-time bridge and weather monitoring systems.

BRIDGE SMS EU/FP7 project aims to deliver an intelligent decision support tool to remotely assess and mitigate the effects of future civil infrastructure challenges, focusing on flood and scour hazards. This investigation presented the concept and development of a real-time monitoring platform, which interfaced with various sensors can provide important information that will potentially lead to cost-effective, efficient management and prevention of flood-related structural failures. The WILD platform will provide critical weather and environmental data (e.g. rainfall, soil moisture, humidity) that will be fed into a decision support tool for improved hydrological modelling and prediction of flood hazards in the catchment area. The BIRD system will deliver information (e.g. water level, scour and sedimentation data) about the condition of the bridge structure and the effects of flood events on its individual structural elements. The characteristics of the WILD BIRD systems are adjusted, so as to easily integrate various sensing devices, lower the power consumption, and with an extensible software can also be used by experienced and non-experienced users to visualise the obtained data and graphically present trends in real-time and in various time frames.

The WILD BIRD platform has the potential to deliver key information regarding the impact of water-related hazards at hydraulic structures in real-time and provide a critical tool to efficiently manage civil infrastructure. Future research entails

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the application of the proposed system to six pilot bridges in Cork County (Ireland) to monitor weather and hydro-processes in river environment and assess their influence on structural elements.

## ACKNOWLEDGMENTS

The authors wish to acknowledge the support of the European Commission, through the Marie-Curie IAPP project BRIDGE SMS – "Intelligent Bridge Assessment Maintenance and Management System" (BRIDGE SMS) (FP7-People-2013-IAPP- 612517).

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