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IntelliBike: a cycling infrastructure asset management system

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ABSTRACT

Research methods employed and pilot study data results for the authors' IntelliBike: an innovative instrumented bicycle that can be used to monitor the conditions of off-road cycling infrastructure in real-time, are presented. The IntelliBike is designed to look at all key variables which influence off-road cycling infrastructure quality. The IntelliBike instrumentation links global positioning data, real-time camera footage, vibration (ride-quality) data, and environmental (noise, light) data for each route being investigated; the IntelliBike is an asset management tool which will allow decision makers to make the most informed decisions relating to where best to spend allocated funds in order to best manage their existing infrastructure. The process aims to produce an asset management tool aimed at better targeted cycling infrastructure maintenance. Presently the bicycle is fitted with a camera, bicycle computer, sound meter, light meter, vibration logger, and net-book (data logger). Pilot test studies have facilitated the compilation of rider comfort perception data to determine the defect rating system to be developed which will allow surfaces to be categorized by quality level.

Keywords: Cycling, vibration, maintenance, off-road, management.

1 INTRODUCTION

The IntelliBike is an instrumented bicycle capable of monitoring the pertinent variables which influence cyclist comfort and off-road infrastructure quality. The IntelliBike is intended to depict digital moving images with defect and hazard recognition, the correlation of measured vibrations (on-bicycle) with surface running quality, the correlation of mapping of camera images onto positional and topographical data, and the related monitoring and analysis of environmental parameters. The research being conducted contributes to the development of knowledge and practice in relation to sustainable infrastructure development. Currently the UK's National Cycle Network comprises of 25,750 km of cycling and walking paths of which a large percentage is dedicated off-road infrastructure; this represents a significant civil engineering infrastructure asset that currently contributes to the provision of a sustainable transport mode option nationwide. Commuting and recreational cyclists have observed the often hazardous conditions on these paths. There are various simple, effective, measures that could be taken to improve the maintenance of such off-road paths, however, reliance on walk-over surveys and path users notifying the damage reporting sections of the relevant roads authorities is not tackling maintenance in a resource efficient manner. While these methods represent a reactive approach, the IntelliBike will be a preventative approach to management. The

City of Edinburgh Council signed up to the Charter of Brussels setting itself a target for 15% of journeys to work and places of education to be undertaken by bicycle by 2020 (*c.f.* national target of 10% across Scotland by the same date), this targeted increase in cycling extends throughout all of the UK so there is a real need to develop and enhance infrastructure. The IntelliBike project plan can be broken down as Figure 1 demonstrates.

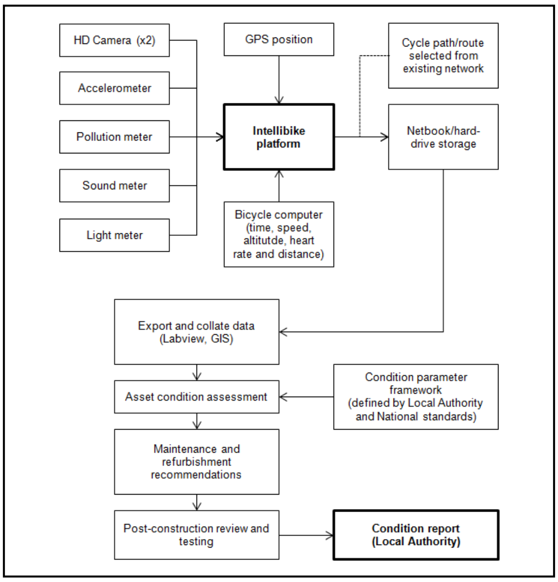

Figure 1. IntelliBike instrumentation and process flow diagram.

2 LITERATURE REVIEW

The IntelliBike team has been inspired by the real world need for good quality cycling infrastructure and by other groups and companies who have worked on similar projects to different degrees of success, a recent study found highlighted the fact that there is a demand for greater information relating to the transmitted road vibrations in cycling [1], with this need coupled with Cleland *et al* stating that the effect of surface texture and the effect of objects on bicycle stability are best measured with actual cyclists riding over the objects or textured surfaces [2] highlights the need for a device such as the IntelliBike. The recently developed Aeroflex bicycle is a device designed for mobile air quality monitoring [3], it is equipped with devices to monitor ultrafine particle number counts, particulate mass and black carbon concentrations, the data gathered is logged with its geographical location and time of sampling. While the author has found similar projects which look at some of the variables the IntelliBike looks at such as surface quality using accelerometers [4, 5, 6] or the cycling environment itself [7, 8], thus far no cycling infrastructure decision support tool to assist in the allocation of funds to maintenance has been found, especially so in the UK: the IntelliBike's linkage to asset management is novel.

A study by Oliver et al [9] aimed to assess the feasibility of combining GPS, GIS, and accelerometers to understand transport-related physical activity in adults, adults were fitted with GPS units and an accelerometer and used them for their daily commutes to and from their place of work, data was then extracted and in-putted into a GIS database, maps were generated that showed physical activity and travel speed, they found that loss of signal was a problem for some users, particularly in areas with tall buildings or dense foliage, this could prove to be a problem at some point as the IntelliBike will be surveying paths which will no doubt have overhanging foliage.

If an off-road cycle path is to be a success there are numerous design variables which must be considered in conjunction with the long term maintenance of the path. Variables to be considered include what type of cyclist will use the path and to what destinations must the path link, from there design options must be considered which include what surface type, path width, vegetation levels, path gradient, and lighting conditions to name but a few, with these variables the long term maintenance must be considered as problems will occur so designers must be conscious of this (the remote nature of some paths makes it difficult for councils to manage these paths adequately); it is these maintenance problems that the IntelliBike is targeted to assist with, allowing key decision makers to know where best to spend there some times small allocated funds.

As sound and light can both affect comfort when cycling the IntelliBike will monitor both for routes, Russell [10] highlighted the importance of lighting provision on commuter routes, school routes and where usage is sustained throughout the longer periods of darkness associated with the winter months. Furthermore, the provision of street lighting at locations where nuisance issues or anti-social behavior is frequently reported can help reduce these problems. Hence, the IntelliBike data collection includes the monitoring of luminescence (LUX) levels in association with geographical positioning data. The research method also includes the collection of data at night to assist in the provision of lighting safety audits as recommended by Transport Scotland [11].

Noise in busy urban cities is unavoidable, noise pollution effects quality of life and sleep it can also have adverse affects on health, a sounds unpleasantness depends on a group of variables which include loudness, frequency, and duration, the EU Environmental Noise Directive (END) aims to 'define a common approach intended to avoid, prevent or reduce on a prioritized basis the harmful effects, including annoyance, due to the exposure to environmental noise' [12], it also aims at providing a basis for developing EU measures to reduce noise emitted by major sources, the END requires member states to create strategic noise maps and to generate noise action plans [13], noise maps show noise environmental noise levels due to for example roads, the map are intended to ultimately help reduce noise levels at problem spots and to preserve quieter areas, noise maps are generated through computer modeling as the cost of directly measuring sound levels nationwide render it impractical, but it is unlikely that averaged levels will always reflect local levels which the IntelliBike is targeting.

The variables which the IntelliBike is examining are all important when considering the overall quality of a route. The most important variable is the surface of the path, this impacts user comfort the most. Asphalt is commonly the best option for cycle paths, problems can occur if not properly maintained, cracking can happen and pieces of the surface can tear away, but these are problems that can be avoided if properly maintained. Surfaces can suffer from a number of damaging effects, such as potholes, weathering, rutting, root damage, and cracking to name but a few, these effects can have hazardous results on a cyclist. Travelling with greater speed increases vibration levels when cycling over a defect and can possibly cause damage to the bicycle wheels or injure the cyclist. The surface is the most important factor a designer will have to consider when designing a path, this is the part of the path that directly comes into contact with the bicycle and thus the cyclist, if the surface is poor it will be uncomfortable to cycle on. Ideally the path will be smooth, the surface type will affect the aesthetic appearance of the path. When considering maintenance designers need to choose a surface type suitable for the route in question, the expected use and budget will affect the final choice. Routes that are expected to have a lot of use will benefit from a bound solid surface. When cycling there are many resistances the rider must overcome in order to be able to cycle forward, the point of pedaling is to exert a propulsive force against the ground, to maintain speed, the size of the force must be greater than the total force resisting the forward motion of the bicycle. Thus it is in the cyclist's interest that surfaces are kept to a good standard so as to not cause the cyclist to be uncomfortable [14].

3 THE BICYCLE

3.1 Evolution of the IntelliBike

The IntelliBike project started as a walk over survey which essentially was the IntelliBike without the bicycle; the walk over survey was developed to find which variables influenced off-road infrastructure the most, the survey was conducted from October 2010 to January 2011, and enabled the author to find the most pertinent variables, with the walk over survey and literature review the authors decided the bicycle would examine surface quality, vegetation levels, signage quality, path widths, light levels, and sound levels, and potentially investigating air quality as a future study. The walk over survey was conducted over 50km of Edinburgh's off-road paths and provided an initial holistic study of the defects that would be encountered.

3.2 Bicycle and Equipment

The IntelliBike prototype bicycle is a TREK 2012 6000 19.5”, it is a robust off-road bicycle that has the ability to lock its front suspension. This feature is useful as lots of cyclists use bicycles without suspension, as the authors are developing a universal vibration rating system to take into account all path users the bicycle must not dampen the excitations caused by defects. Currently the bicycle is fitted with two HD camcorder’s, a vibration logger, a bicycle computer, a sound meter, a light meter, and a net-book for data logging purposes, Table 1 lists the equipment and specifications as well as key parameters which the device measures. The sound meter, light meter, and vibration logger all record on a one second logging cycle. They are connected to the data-logger and data is constantly being logged in real-time to assist with data synchronization. The bicycle computer and cameras log data to their own internal memory.

Figure 2 shows where each device is fitted, the front facing camera, bicycle computer, light meter, and sound meter are all connected to the handlebars; the downward facing camera is fitted to the front fork; the vibration logger is connected to the seat stay, which allows vibration experienced when sitting to be logged; the data-logger is contained within the waterproof box fitted to the rear bicycle rack.

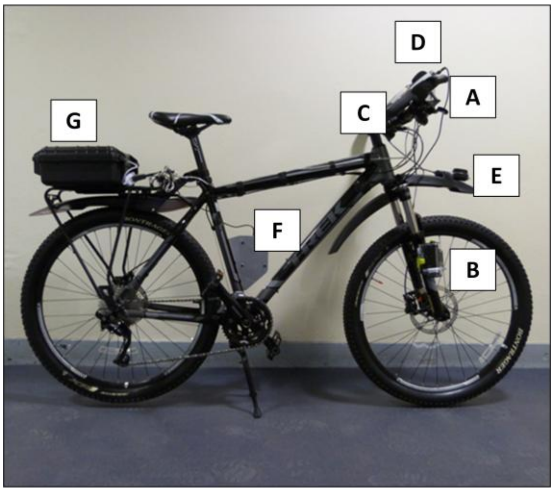

Figure 2. IntelliBike instrumentation positioning.

Table 1. Equipment specifications

Device	Name	Specifications	Parameters
Camera 1 (A)	GoPro Camera HD Hero2 Outdoor Edition	**Resolution:** 1080p: 1920×1080 – 30FPS **Weight:** 95g **Dimensions:** 42 mm x 60 mm x 30 mm	Path width, vegetation levels, signage quality, surface defects.
Camera 2 (B)	Contour Plus 2	**Resolution:** 1080p: 1920x1080 – 30FP **Weight:** 156 g **Dimensions:** 34 mm x 98 mm x 60 mm	Surface type
Bicycle computer (C)	Garmin Edge 800 Touch-screen GPS Bike Computer	**Features:** High-sensitivity GPS receiver, stays locked on while under tree. Water-proof to IPX7 standards **Weight:** 98 g **Dimensions:** 51 mm x 93 mm x 25 mm	Latitude, longitude, altitude, speed.
Sound meter (D)	ATP Precision logging sound level meter ASL-8851	**Frequency range:** 31.5 Hz to 8 KHz **Range:** 30 – 130 dB **Resolution:** 0.1 dB **Weight:** 350 g **Dimensions:** 278 mm x 76 mm x 50 mm	Sound level
Light meter (E)	ATP LX-8809A SB Data-logging light meter	**Lux measuring ranges:** 0 to 400, 4000, 40000, 400000 Lux **Weight** 390 g **Dimensions:** 230 mm x 80 mm x 50 mm	Light level
Vibration logger (F)	Madge Tech Shock 101	**Sample rates:** 1.953ms/512 Hz **Range:** ±5 g **Calibrated accuracy:** ±0.2 g **Acceleration resolution:** 0.001 g **Real-time recording:** 1 second or slower reading rate **Reading rate:** 64Hz to 5 minutes for shock **Dimensions:**89mm x 112mm x 26mm **Weight:** 340 g	Surface quality
Data logger (G)	Acer Aspire One D270 10.1 inch Net-book	**Processer:** 1.6 GHz **Ram size:** 2 GB **Hard-drive:** 500 GB **Screen size:** 10.1 inches **Weight:** 3.5 kg **Dimensions:**618 mm x 394 mm x 90 mm	-

4 PILOT STUDIES

4.1 Route One Pilot Study

To test the data acquisition process of the IntelliBike the author conducted a set of pilot study cycles in Edinburgh. A route in Edinburgh (Lat/Long 55.944261,-3.230218 to 55.968254,-3.239401) was chosen that was to serve as the test-bed for the bicycle and its devices. The route itself is a converted railway line and is two miles long. A diverse path relating to quality level was chosen as it allowed the IntelliBike to experience a broad range of defects; the route surface is completely made up of asphalt. Vibration levels can be significantly influenced by different riding preferences such as hand positioning and posture, thus while testing the bicycle the user had to be conscious of this and remain in reasonably constant riding position. The posture of the cyclist, speed at which the cyclist is travelling, pedal motion, and gear levels can all affect the vibrations being monitored by the bicycle, as can tire pressure which can dampen vibration levels. As can be seen from Figures 3, 4, & 5 the bicycle is capable of monitoring vibration, light, and sound levels. Figure 3 shows the vibration levels captured by the bicycle and as can be seen peak vibrations can be linked to defects along the route, with the development of the comfort perception study discussed in Section 4.2 comfort levels will be categorised to different gravitational levels.

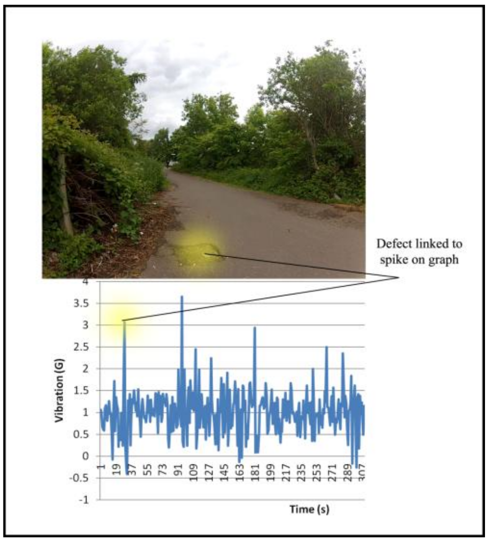

Figure 3. Example defect vibration detection.

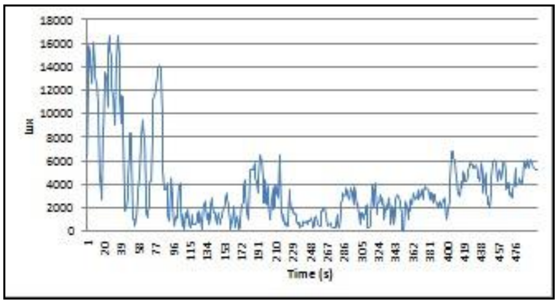

Figure 4. Light levels (Lux)

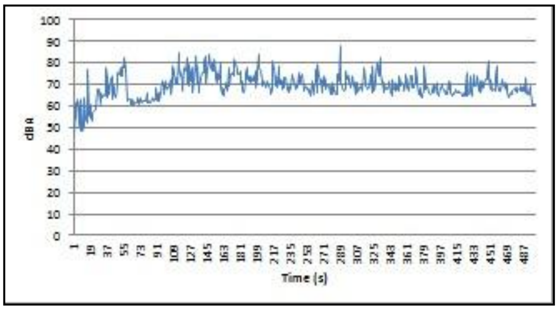

Figure 5. Sound levels (dB(A))

As can be seen from Figures 4 and 5 the light meter records lux levels and the sound meter records in the dB(A) sound scale. In Figure 4 at roughly 85 seconds it can be seen that the light level dramatically falls, this is because of the dense foliage on the path.

As the bicycle is fitted with numerous devices synchronization has been problematic, as the vibration logger, light meter, and sound meter all record direct to the net-book the authors are considering developing a program which will simultaneously start and stop the three devices, the bicycle computer and two cameras will still record independently.

4.2 Comfort Perception Study

Coupled with the development of the IntelliBike process and application the authors are currently developing a rating system for comfort levels from different users experience relating to the vibrations the bicycle experiences, the comfort perception study will allow the rating system to be a universal comfort quantifier bringing together the opinions of many people. The system will bring the opinions of a stratified sample of students and staff at Edinburgh Napier University with differing levels of cycling experience. Three short routes have been chosen which will serve as the test-bed for the study, the cyclist will rate on a scale of 1-5 (Excellent – Poor) there experience on the routes on a second by second basis, from the feedback recorded the data will be mapped for each user onto the routes and the IntelliBike will adapt its vibration levels for each second to the overall rating system for comfort developed by the study. The rider comfort perception study will employ the optimal scaling of categorical data in the statistical analysis of the results. This is currently being undertaken and will be the subject of future work.

5 ASSET MANAGEMENT

Encouraging more people to cycle is a priority of all local councils, making cycling more accessible improves congestion, air quality and promotes a healthy lifestyle, which means cycling infrastructure and off-road paths should be of higher priority for local authorities. In order that local authorities learn of the quality of their cycle paths the IntelliBike will present the overall quality of cycle paths and facilitate decisions regarding where to best spend maintenance budgets and how to best manage their assets, as the IntelliBike is the tool to find the quality the authors are currently working on developing a piece of presentation software which will allow the data gathered by the IntelliBike to be presented in a user friendly manner so that someone of limited experience with the IntelliBike will be able to so what is good, what is bad, and where they should spend allocated funds; essentially using the IntelliBike as an asset management tool for off-road cycling infrastructure. Figure 6 displays an early stage draft of the possible user interface for the software, as can be seen variable rating has been color coordinated for quality levels, since the data being gathered is tagged with its geographical location (latitude and longitude) users will be able to see exactly where each variable being rated is located.

6 CONCLUSIONS

At the IntelliBike's current stage of development, the author's are now confident in the process and that the bicycle will be capable of providing a practical solution to cycle path infrastructure asset management monitoring.

The pilot study unearthed a lot of new questions for the authors such as synchronization problems, but the authors are confident problems such as these will be overcome.

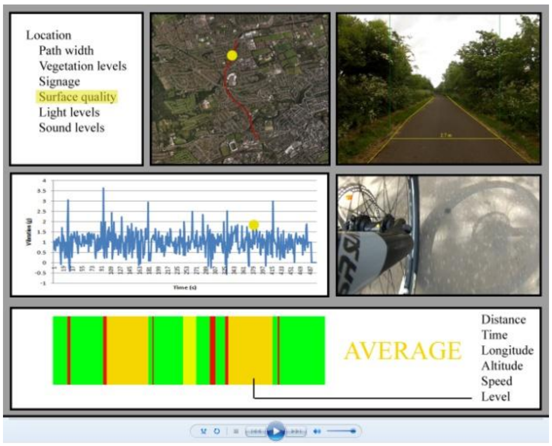

Figure 6. Mockup of potential presentation medium.

7 FUTURE WORK

As the initial pilot study has been completed and the authors are assured that the concept is workable the authors intend to further develop the IntelliBike refining the synchronization of the devices and developing the full presentation medium, the user perception study will be taken even further incorporating more users' opinions. Eventually the authors would like to incorporate air quality sensors onto the IntelliBike to create to create an even more overall encompassing device for asset management and environmental factors.

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