TITLE	Draft specification for an automated inspection system for highway structures
PROJECT	Research into the development of automated bridge inspection systems
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DATE	15 January 2010
FILE	
REQUESTED BY	Project Steering Group

1   Introduction

This document describes the proposed requirements for an automated bridge inspection system, presented as a draft specification. The draft specification has been developed by TRL as part of a research project, sponsored by the DfT, into the development of automated bridge inspection systems. To help develop this specification there is a need to understand the types of inspections currently performed, and the uses of the data provided by these inspections. A consultation with engineers responsible for inspecting and maintaining bridges therefore explored exactly what information was recorded during existing inspections, and how this information was recorded, interpreted and used, and whether this met the needs of the engineers responsible for bridge maintenance. The research also considered, via consultations with survey equipment manufacturers and researchers, the progress that had already been made in the automation of bridge inspections, in order to determine what would be practical, meaningful and achievable using current technologies.

The consultation has suggested that an automated system to provide surveys of bridges which are comparable in detail and scope to those provided by standard Highways Agency General Inspections would be desirable. Such surveys would be more repeatable, objective and auditable than General Inspections, and may also be cheaper, quicker and safer. Note that the review of current practice has concentrated on highway bridges, and consequently the specification has, at this stage, been developed with highway bridges in mind. The research has not yet undertaken practical trials of the technologies that may be used to undertake these automated surveys. However, TRL was asked to provide an intermediate draft specification for an automated inspection system based on the findings of the project to date. This is presented in the following sections. The draft specification considers:

- Where the automated inspections fit within the existing regime of inspections
- Guidance on survey type selection (automated or manual)
- Suitable bridge types and environments for inspecting automatically
- The technical capabilities of the data collection and processing systems
- Information to be delivered to the end user
- Limitations of system use

NOTE: this is an aspirational DRAFT SPECIFICATION, which may change in light of trials which are planned to take place in spring 2010 as part of the research project.

2   Draft Specification

2.1   General requirements for the inspection system

2.1.1   Bridges maintained by the UK Highways Agency are currently inspected using a regime of different inspection types, at defined intervals. These inspections are defined in Volume 3, Section 1, Part 4 of the DMRB (BD 63/07) (Highways Agency, 2007), and include:

- **General Inspection**: to provide information on the physical condition of all visible elements on a highway structure.

- **Principal Inspection**: to provide information on the physical condition of all inspectable parts of a highway structure. A Principal Inspection is more comprehensive and provides more detailed information than a General Inspection

- **Special Inspection:** is to provide detailed information on a particular part, area or defect that is causing concern.

- **Inspection for Assessment**: to provide information required to undertake a structural assessment.

2.1.2   Annex A of this document provides further information on these inspections.

2.1.3   The minimum requirement for the automated inspection system is that it should be able to provide data that is comparable to that achievable using a standard General Inspection.

2.1.4   The inspection system will operate via the collection of high resolution images. These images will be presented for analysis using visualisation tools to enable the images to be presented 3-dimensionally on a virtual model. These visualisation tools would enable the assessor to view a realistic representation of the bridge such that a "general inspection" can be carried out on the presented data.

2.1.5   The method described above is referred to as an *automated system with manual analysis*, where the images are manually assessed to identify defects.

2.1.6   A more advanced inspection system, referred to as an *automated system with automated analysis*, would undertake automated processing of the images (via image processing software) to identify and report the defects typically identified in a General Inspection (or a subset of these defects, using manual analysis to identify any defects not identifiable by the automated analysis system.

2.1.7   Any system designed to achieve these objectives will have to satisfy technical requirements on image quality, location referencing of data, model creation, overlay and display, and processing.

2.1.8   Systems meeting these technical requirements should also meet practical requirements in terms of traffic management and access to the bridge.

2.1.9   This specification has been produced as an 'end-result' specification, rather than a technical specification. For this reason there are no details regarding how to achieve the required standards, or how the system should collect and process data.

2.1.10   Note that many elements of this specification cannot be completed until the completion of the research, and are presented in blue. Elements of this

specification which will not be completed without further research subsequent to the current project are shown in red.

2.2   Guidance to users

2.2.1   It is suggested that a section be provided to give advice to potential users (e.g. local authorities and Highways Agency) on the use of this technique. The advice could include

- Which types of structures could/should be surveyed automatically.
- How to select and use the most appropriate inspection system (e.g. a manual standard general inspection, or an automated inspection).
- Description of available systems.
- Guidance on interpreting the data delivered to the engineer.
- Other

It is envisaged that the development of much of this advice would be beyond the scope of the current research as it should reflect the recommended practice once we reach a stage close to implementation of automated systems, when much more experience will have been gained. It is recommended that the development of such advice be considered within any further research.

2.3   Technical specification for the data collection

Image collection

2.3.1   The inspection system will provide high resolution colour images of the visible elements of the structure.

2.3.2   The images should be sufficient to enable the identification of defects to a level of detail comparable to that achieved in a General Inspection. It is anticipated that this will require the images to

- Have a resolution of at least 1 millimetre per pixel of the structure surface.
- Be full colour (3 channels, at least 8 bits of information per channel).
- Be provided in a standard jpeg or bitmap format.

Coverage

2.3.3   The inspection system will be capable of collecting images of all of the elements of the bridge that would typically be surveyed during a General Inspection

2.3.4   The following allowance is made for partial coverage.

- "Dummy data" such (for example blank images) will be provided from any area of the bridge that was not able to be surveyed, so that the analysis can unambiguously determine whether any part of the structure was not covered.
- The maximum allowance for uncovered components is 10% of the surface area of the structure.
- The following essential structural elements must be covered:

- Deck elements

- Load bearing sub-structure

- Durability elements

- Safety elements

- Other bridge elements

- Ancillary elements

- A complete list of "essential" structural elements to be determined in a later stage of this research project.

Location

2.3.5   The location referencing of the images shall be sufficient to enable the creation of a photorealistic model of the bridge which can be manipulated and inspected using the display system described in section 2.5.

2.3.6   As a minimum requirement the images shall be collected, and labelled, to enable the accurate location of any image in relation to any other image, to within ±5cm.

2.3.7   Suitable information shall be collected to enable the creation of a virtual 3-D model of the structure. Potential sources of this information include:

- Digitised design drawings of the structure (noting that all images would need to be collected so that they can be related to these design drawings).

- Measurements collected on site during the image collection, for example using laser surveying techniques.

2.3.8   The 3-D model should be dimensionally accurate to within ±10cm of the real bridge.

2.4   Practical Requirements for collecting the data

2.4.1   No special access equipment or traffic management arrangements shall be necessary for the automated inspection beyond what would normally be used for the performance of a standard manual General Inspection.

2.5   Technical specification for the data display and processing

3-D modelling and display

2.5.1   A suitable facility shall be provided to undertake any required processing of the images in order to prepare them for display on a 3-D model. This facility should be practical and efficient and require minimum human input.

2.5.2   A display system shall be provided to display the images 3-dimensionally on a virtual model. These visualisation tools would enable the assessor to view a realistic representation of the bridge. Manipulation tools for the visualisation system will include:

- The ability to remove the effects of parallax and perspective from any image, enabling it to be presented without distortion, whilst maintaining the

minimum resolution standard required.

- A formalised method for splitting the 3-D model into the discrete structural elements reported on during a General Inspection.

    - A list of other components to be determined in a later stage of this research project.

Systems with manual analysis

2.5.3　A system shall be provided such that manual analysis can be undertaken of the images in order to carry out "general inspection" on the presented image data.

2.5.4　Further detail on the requirements for the manual analysis system such as how the analysis should be undertaken and data recorded, to be determined in a later stage of this research project.

Systems with automated analysis

2.5.5　A processing system shall be provided that undertakes automatic analysis of the images to identify defects.

2.5.6　The defects identified shall fall within the set of defects identified in a General Inspection.

2.5.7　The automatic analysis system shall clearly list the defect types identified in a General Inspection that are not detected by the automatic analysis system, so that appropriate manual analyses can be undertaken to identify these missing defects.

2.5.8　The automatic analysis system shall have a level of accuracy such that each defect type that the system is able to identify is identified to a level of accuracy of:

    - False positive requirement

    - False negative requirement

To be partially determined in a later stage of this research project. However, it is felt that full definition of these requirements will draw on greater practical experience with systems (possibly after they have been developed further).

2.6　Deliverables

2.6.1　The following shall be delivered

- The images of the structure.

- The location data for each image.

- The data required to establish the 3D model.

- A 3D viewing system to view the above data.

- Software to enable manual analysis of the above data.

2.6.2　If required by the client, the results of the manual analysis.

2.6.3　If required by the client, the results of automated analyses of the images.

To enable transfer between display systems (e.g. if an LA wants to display

images collected using one contractors system in another contractors display software) it is proposed that specific formats be defined for the data. The current research will suggest how these might appear, but does not expect to define detailed file formats. For example the ability to produce output reports in a format compatible with current General Inspection report forms will be desirable.

2.7 Quality assurance and accreditation

2.7.1 Systems undertaking automated inspections of structures in England (UK?), shall be subject to a process of accreditation and quality assurance.

2.7.2 The accreditation regime will test the capability of the equipment in the areas of

- Image quality
- Locational accuracy
- Measurement of bridge 3D model
- Display systems
- Manual analysis processing systems
- Automated analysis processing systems
- Data delivery (formats etc).

The technical requirements for accreditation will need to be fully defined following greater experience with the systems. It is envisaged that developing the details of these requirements will be the subject of future research work.

2.7.3 It is also proposed that a QA regime be developed to help users draw confidence in the data provided by these systems.

3 Issues arising from the above

The above draft specification has been produced to illustrate some of the features of an automated system and identify areas where research is still required. We envisage that the current research project will provide answers to some of the outstanding questions, such as:

- Which types of structures could/should be surveyed automatically?
- What systems are available?
- How do they operate?
- What are the image requirements (resolution, colour, format)?
- Which parts of the bridge should be included in an automated survey?
- How should the data be presented?
- How should a manual analysis of automatic inspection images be undertaken and data recorded?
- What is the requirement for reporting false positives?

- What is the requirement for reporting false negatives?

- In what format should the output data, reports and models be available?

- How might automated systems be accredited and checked?

However, it is anticipated that, at the completion of the current DfT funded research into the development of automated bridge inspection systems, there will still be a number of outstanding issues. These will include:

- There may be a need to stimulate the development of commercially available systems by promotion of the technique and further practical demonstrations in the "real world" of bridge management.
- The specification for the collection and processing is quite "broad". Some areas will need further investigation and potential developers may need further guidance and assistance to help them target their developments.
- Identification and definitions of data formats will be required to enable delivery of data that can be practically used by engineers across display systems.
- Detailed testing of potential systems or specifications on a representative set of bridges will not yet have been undertaken.
- There is little understanding of the potential capability of fully automated analysis systems and there is great risk of them being oversold to users, who later find little confidence in the results. There is a need for assessment, control and expectation management.
- Quality Assurance, Accreditation or Correlation processes will be required to assess system compliance against the specification and help engineers have confidence when commissioning surveys.
- Guidance will be required for those who might wish to commission surveys to help them select systems, help them understand how the regime fits within their current processes, and help them interpret the survey data.

ANNEX A – Current Inspections

There are five different levels of inspection defined in Part 4 of the DMRB (BD 63/07)

General Inspection

- "The purpose of a General Inspection is to provide information on the physical condition of all visible elements on a highway structure." (Highways Agency, 2007).

- General inspections are performed without any special access equipment or traffic management arrangements and thus can only report on what can be seen from relatively accessible parts of the structure.

- Before performing a general inspection the inspectors should review the structure records, including previous inspections in order to familiarise themselves with the likely conditions when they arrive on site, and to highlight any areas which may require special attention.

- General Inspections must be performed every 2 years on every structure covered by the guidance and must, as a minimum, report the location, severity, extent and type of any defects.

- Part 2 of the Highways Agency Network Management Manual (Highways Agency, 2006) explains the defect reporting system used in England for General Inspections. This is summarised below in Table 1:

Table 1: Meanings of Severity and Extent codes for reporting defects in General Inspections

Extent	A	No significant defect
	B	Slight; not more than 5% of length or area affected
	C	Moderate; 5% – 20% affected
	D	Extensive; more than 20% affected
Severity	1	No significant defect
	2	Minor defects of a non-urgent nature
	3	Defects which shall be included for attention within the next annual maintenance programme
	4	Severe defects where urgent attention is required

- These severity and extent combinations provide a very versatile and informative framework with which the condition of a structure, or part of a structure can be assessed. The ability to report the severity and extent separately is very helpful for later interpretation of reports, and should be maintained in an automated system.

Principal Inspection

- "The purpose of a Principal Inspection is to provide information on the physical condition of all inspectable parts of a highway structure. A Principal Inspection is more comprehensive and provides more detailed information than a General Inspection." (Highways Agency, 2007).

- Principal Inspections enable the inspector to get close access to all parts of the structure, enabling the inspector to touch the structure and look at it from a variety of angles and directions when determining the condition of bridge elements.

- The execution of a Principal Inspection is usually performed with access equipment, traffic management and a selection of relatively simple tools such as binoculars, or hammers to test for delamination.

- As with the General Inspections, the inspector is required to familiarise themselves with the previous notes on the structure and its condition before visiting the site.

- Principal Inspections must happen for every structure every 6 years, unless special circumstances dictate that this interval can be altered.

- Principal Inspections are required to include as a minimum the details from a General Inspection as well as more detailed drawings and/or photographs to show the extent and severity of defects.

- Principal Inspections must also include comments on any significant changes which have occurred to the condition of the bridge since the last inspection, and any information regarding required maintenance or additional testing.

Special Inspection

- "The purpose of a Special Inspection is to provide detailed information on a particular part, area or defect that is causing concern, or inspection which is beyond the requirements of the General/Principal Inspection regime." (Highways Agency, 2007).

- There is no such thing as a standard Special Inspection as each one is tailored to the needs of the particular structure or element being inspected.

- Special Inspections are carried out when a need is identified.

- Special Inspections should provide detailed information on the parts of the bridge inspected, including photos and/or sketches. As in Principal Inspections, any significant changes to the condition of the element must be reported, along with details of any testing undertaken as part of the Special Inspection, and what the test results mean. The report should also include any recommendations for further testing, monitoring or maintenance.

Inspection for assessment

- "The purpose of an Inspection for Assessment is to provide information required to undertake a structural assessment. BD21/01 (DMRB 3.4.3) (Highways Agency, 2001) provides guidance on undertaking an inspection for assessment and recommends that these are done in conjunction with a Principal Inspection." (Highways Agency, 2007).