SCIENTIFIC PROBLEMS
OF MACHINES OPERATION
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Research results transformation in the process of innovation development illustrated by the example of automatic optical inspection

K e y w o r d s

Knowledge transformation, incremental innovation, automatic optical inspection, technology transfer.

S ł o w a k l u c z o w e

Transformacja wiedzy, innowacja przyrostowa, automatyczna optyczna inspekcja, transfer technologii.

S u m m a r y

The paper presents the chosen aspects of the innovative solutions that have been worked out within the Multi-Year Programme "Development of innovativeness systems of manufacturing and maintenance 2004-2008." Most of the tasks that were qualified for the programme concern incremental innovation. One task, as the example of a direct transformation of the scientific research into innovations for economy, is described. The discussion was concentrated on the implementation of the method of automatic optical inspection (AOI) for a quality inspection in production. The specific features of AOI methods were discussed in relation to an incremental innovation. The analysis enables the identification of the crucial factors influencing the successive stages of the innovation development and consequently determining project success. The final effect of the project realisation, namely quality changes in production as a result of the incremental innovation development and implementation, was presented.

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1. Introduction

A strong relationship between the innovation level and competitiveness of the economy increases the demand for the development of new solutions of great commercial potential. In the existing literature [1–4], one can find much research and analysis of innovation processes and initiatives taken in order to support the transfer of new products and technology into the economy. Nowadays, apparently, it is observed that the changes of the expectations connected with scientific achievement put higher and higher emphasis on the increase of research efficiency. Since scientific knowledge is essential to innovation and business development, science and R&D is forced to deliver the applicable research results that enable the development and commercialisation of truly innovative products. The knowledge transformation process into innovations is characterised by diversity, when this kind of innovation is considered. While breakthrough innovation needs the intensive engagement of science, the development of incremental innovation usually is supported by the adaptation of general models to particular application. Additionally, incremental innovation, because of its strong user orientation, has the great possibility to achieve market implementation in a short time.

Breakthrough innovation is the radical change that refers to radically new products. These products involve challenges that resulted from both technological and market uncertainty. Therefore, such innovation entails significant costs and high investment risk. Research conducted by Plamberg [5] proved that firm collaboration with universities opens up new opportunities to innovate, and the consequences are prolonged commercialisation and break-even times of innovations. However, a science-based innovation might be highly successful in the longer run due to accumulated monopoly assertion, once a significant market position is reached. Breakthrough innovations play an important role in competitive advantage through new products and also through new knowledge that contributes to the development of incremental innovations once the technological barriers are overcome. So breakthrough innovation increases innovative potential that results from new knowledge. This potential should be used for applications developing in different areas of the economy, since it heightens economic and social advantage, influences skill levels and contributes to the improvement of both firms and economic competitiveness. Thus, many initiations and activities are taken in order to increase knowledge implementation by innovations. Countries and regional governments establishing special programmes for applicable research results in dissemination and new technology put into practice [6–9]. From the literature [10-12], we can identify factors of success and failures. There are [13] also suggested the need for development the methods and instruments of supporting innovation. Some important issues related to research that results in commercialisation are presented in [14], especially the problem of barriers in knowledge transformation and technology transfer that are considered.

2. The method of the process of incremental innovation in the PW-004 Programme

The Multi-Year Programme “Development of innovativeness systems of manufacturing and maintenance 2004–2008” encompasses a wide range of problems. According to the general aims, the program includes both comprehensive methods for supporting the development of innovations and the direct transformation of scientific research into innovations for the economy. Most of the tasks that were qualified for the programme concern incremental innovation. One of the important assumptions of the programme was to create new applicable products with use of the innovative potential of knowledge accumulated in research results. In practice, incremental tasks were realised by individual research teams that were responsible for the achievement of a particular aim. The final effect of each particular task was usually a prototype of an applicable feature. The research tasks from the same area of science were conducted in the common structure of the package of tasks. However, the collaboration among package members was voluntary, without signing any agreement. Each research team operated independently and with individual responsibility. The development of application within PW-004 methods, especially the creation of the operating structure, is presented further on with the example of automatic optical inspection used for the incremental innovation development in quality control systems.

3. AOI methods in the creation of incremental innovations

Automatic optical inspection methods enable measurement without direct contact with an object. These methods have been known for many years; however, due to significant technological limitations and application difficulties, their usage in industry was slight. With the development of optical technologies, particularly lighting methods, and computer methods of data acquisition and processing that were implemented in image analysing systems, the breakthrough knowledge enables the increase the application of AIO methods in a wide area of industry. As a result of software development, the main barrier of image analysis was overcome. This was the reason for the renewed interest in the application of such methods as incremental innovation in many areas of the economy, e.g.: bar code identification systems, image recognition, surface topography measurement, control systems, dimensions estimation, motion control, etc. National output in the area is not large and practically limited only to simple systems. However, the extremely high potential for the application of optical systems is connected with the diversity and abundance of innovations, and it needed R&D to pay special attention and take an interest in order to take advantage of market opportunity.

One of the PW-004 Programme's major aims was the development of methods supporting a quality in production that encompassed, among others things, issues of the optical inspection of multi-parameters optical as a model for the application of incremental innovations. As the result of the project's qualification, the task package of product inspection and defect identification was included in the programme. Each task has a specified effect that was an incremental innovation. Four research teams from scientific units, namely, Institute for Sustainable Technologies - National Research Institute, Tele & Radio Research Institute, Wroclaw University of Technology, and Institute of Applied Optics, were joined into the structure, established for package realisation. Within the scope of the planned innovations of the package were vision methods and systems for quality inspection of plastic products in application for parts of spectacles and of metal products in application for bearing rollers and in application for cylindrical parts [15]. Fig. 1 presents the structure organised for the creation of incremental innovations with the use of automatic optical inspection that constitute the tasks package in the PW-004 programme. Also presented is the example of application (defect inspection of bearing rollers) and the scheme of the element observation method.

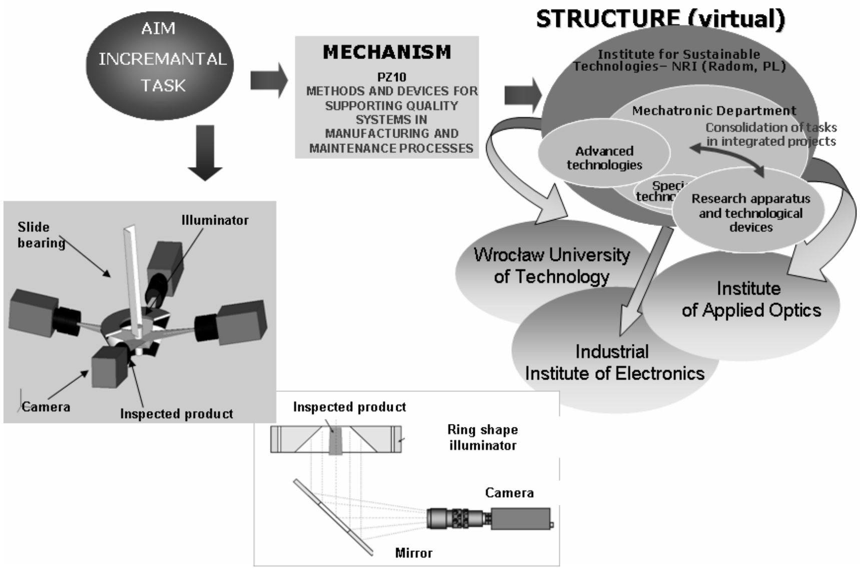

Fig. 1. Structure for incremental innovations realization with tnę use ofAOI methods
Rys. 1. Struktura operacyjna realizująca innowacje przyrostowe z zastosowaniem metod AOI

As the common structure for tasks package was organised, the synergy effects of scientific and research potential appeared. Each team was working on individual aims; however, common working shops and seminars monitoring the tasks of package realisation enabled the exchange of knowledge and experience and the sharing problem solving and new idea creation.

4. Incremental innovation development – knowledge transformation

The aims required, aside from existing knowledge of optical inspection, new research on the image acquisition methods, adopted to the defect detection in particular applications. In the scope of model application, there were identified and catalogued the defects for chosen products that appeared during production. On the basis of scientific knowledge and the results obtained in experimental tests, the factors that were important for the selection of lighting methods were specified as follows:

– Those connected with the inspected object: shape, unevenness, surface roughness, microstructure, surface colour, reflection coefficient, light dispersion and transmission of material, optical properties;
– Those connected with the inspection environment (illumination);
– Those connected with camera parameters (sensor size, spectral sensitivity); and,
– Those connected with the process of inspection (stable or moving parts during inspection, blur effect).

In the scope of task package, all planned effects were determined by solving problems common for each particular innovations, including the quality of images that is crucial to detection and the identification of defects. Image quality strongly depends on an illumination system. It can also be disturb by instability during the feeding of the parts to the area of inspection. One of the most important problems of the optical inspection of moving objects is image blur, which causes the reduction of resolution and limits the recognition and identification of defects. The limitation and elimination of a blur effect is possible when the time of image acquisition is adequately short; however, the illumination intensity needs to increase.

Even though there are many general solutions and much literature in that area and we had an experienced research team, with each development of incremental innovation, knowledge completion is needed in the way of experimental research. Some problems needed to be solve in order to achieve the planned effects, for example, those connected with defect identification and analysis methods, the description of objects properties under the inspection, hardware structure and technological problems, etc.

The development of methods, which enable comprehensive and highly efficient quality inspection in project analysing, have been determined by experimental research that supported specific information for each planned application concerning product properties and predominant types of defects. As the result of the conducted work, the research stand was developed that enabled experimental verification of operating modules while optical inspection was simulated. The example of the experimental setup for the inspection of falling bearing rollers is shown in Fig. 2. The verification of mechatronic modules was conducted, taking into consideration the stability of part feeding, process efficiency, the setup of sensors, etc. Also, the same problems of illumination of inspected parts had to be solved. In the scope of verification experiments, the research results were analysed as the knowledge basis of subsequent changes and development of the solution took place. During the final phase of the project, all of the teams were working together in order to verify each innovative application. This way of working enabled the exchange of remarks and took advantage of new experience achieved during project realisation.

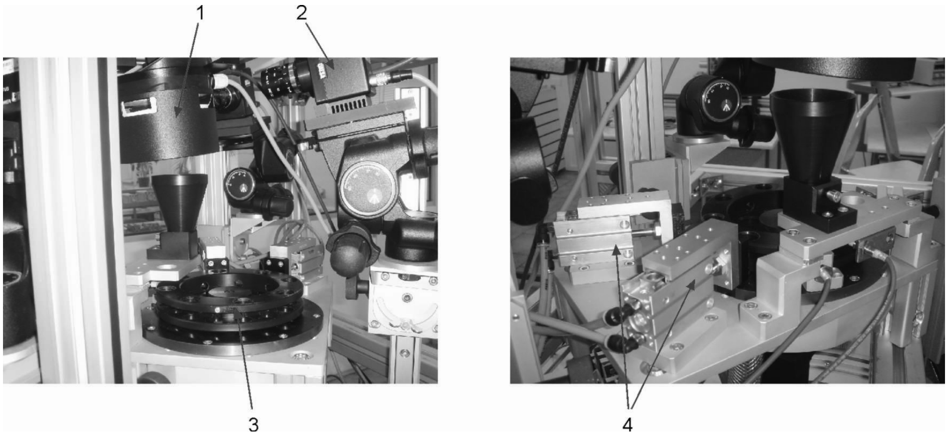

Fig. 2. Experimental setup of the optical inspection system:
1 – illumination setup with the LED ring-lighting, 2 – CCD camera, 3 – rotary feeder,
4 – pneumatic actuators in the selecting module [15]'
Rys. 2. Fotografie modułu odbierania i sortowania wałeczków zamontowany w systemie optycznej inspekcji: l – oświetlacz LED, 2 –kamera CCD, 3 – tarcza podajnika karuzelowego, 4 – siłowniki w układzie wyrzutu wałeczków

The results of the verification research were used for the knowledge base creation that encompasses the following:

– The module structure for automatic optical inspection systems;
– The new model solution of part feeding and sorting adjusted to industrial conditions of work;
– Assembly and running procedures for the optical inspection modular systems; and,
– The maintenance and service procedure for optical inspection systems.

As the result of systems verification, both the high effectiveness and productivity of developed multi-parameter algorithms and the possibility of their adaptation in analogical application were proved. The developed methods and systems of optical inspection are distinguish by the following:

– The possibility to inspect a number of defects on-line, during one inspection cycle;
– High inspection productivity that enables the application in a manufacturing line at a high rate; and,
– The flexibility of hardware and software that enables the reconfiguration and application of the system due to the user's specific needs.

However, it should to be underlined that, while system success was achieved in the laboratory, it is only a premise for subsequent research in the direction of industrial application. This kind of research should be conducted in industrial conditions in order to adopt system to work in a real environment that usually strongly influences the developed system, often as a critical factor for correct system operation. So, in the case of industrial applications of developed systems, the adaptations for real industrial conditions were needed.

The new knowledge and experiences in inspection with the use of vision methods obtained during the realisation of research works were applied in the next phase of incremental innovation development and application. The new concept of a mechatronic system for inspection of the face surface of bearing rollers was worked out. Unlike the method of inspection of falling rollers, in the new method the bearing roller is held in a stable position during vision inspection. The high quality images of the inspected surface and measurement resolution of about 50 microns were obtained this way. Similarly, the research presented the above experimental setup and was developed to study the identified defects and flaws on the metal surface under variable conditions, including illumination, kinematics, and impurities. It was important that the team investigated a real production line of bearing rollers and studied the process of part feeding and identified the critical factors in the line. The mechanical impurities, condensates, protective liquid, vibration and lighting changes can disturb the process of image acquisition and influence negatively the quality inspection. The conditions in the line were defined as very difficult. The developed advanced optical inspection system enables full automation of parts inspection in mass production, fulfilling the high requirements of inspection accuracy and process effectiveness. The innovative solutions were applied in the developed system, e.g. Intranet and Internet communication enabling the cooperation within a quality management system and a telemonitoring service. The system's software includes the catalogue of defects, a calibration and diagnostic module, and also the module for the analysis of inspection data and statistical classification.

The success of the development was dependent on the implementation of the system in the manufacturing line and exploitation tests that faced the staff's mistrust and the managers' requirements.

5. Verification of incremental innovation – technology transfer

Most innovative solutions for industrial application need collaboration of the research team with the potential user as soon as research work is started, often in the phase of aim specification and parameter assumption. Thanks to cooperation in the early stage of the project, knowledge and experience could be exchange. Additionally, interpersonal relationships were created that were very helpful in subsequent stages of the project realisation and final application. When an innovative technological device or system is put into practice that often support new quality and knowledge, psychological barriers, especially of lower skilled workers but also of managers, appear. Frequently, overcoming the barrier is as important as technical and organisational problem solving. As a characteristic example, the application process of quality inspection system was analysed with the use of automatic optical inspection conducted in a factory producing the bearing rollers. Both increasing market competitiveness and customers demands determined the necessity concerning the application of new solutions in the area of product quality improvement. Because of the Multiyear Programme, PW-004 potential and the research teams' experience in the area of optical inspection, the collaboration, in order to develop innovative quality control system, was established.

In the stage of experimental research and the development of the system model of the following issues that are crucial for project success [16-20] were investigated:

- Methods of planned level achievements of the defect detection,
- Issues of the structure modularization,
- The possibility of modification,
- The inspection system integration with the production line,
- Keeping the effectiveness of the production line when the inspection system is applied,
- Ensuring the simple system operation, and
- Minimising of setup and service time.

The synchronisation and parallel execution of tasks were used to achieve a high inspection speed.

The application process can be divided into stages determined by the technical advancement of the device, its distinctness in comparison with previous solutions, technical problems usually accompanying such a venture, and psychological factors (Tab.1). During the first system application, many problems appeared. In the stage of prototype development, there were a lot of unknowns determined mainly by the users-to-be lack of knowledge, and concerns with system parameters that guarantee work efficiency partly by intuition. Finally, only technological line tests and early stages of work make it possible to establish all the essential system parameters. The subsequent application took advantage of the present state of knowledge, and many of technical and organisational obstacles disappeared. Another problem of prototype development that met all maintenance demands was access to a real manufacturing line. Such activity needs some research and additional tests in the stage of prototype design and construction in order to minimise risk of the innovative venture. However, it involves costs, often not accepted in project's budget.

Table 1. Application stages and problems occurring
Tabela 1. Etapy wdrożenia i związane z nimi problemy

Stage	Main works	Critical problems	Efficiency in the problem solving
Final stage of designing Validation and verification of the prototype system during the experimental tests	Limitation of the solution to crucial features that enable method verification	Lack of user's knowledge of required system parameters	ca. 50%
Preliminary agreement	Determination of the system parameters		ca. 90%
Running and tests of the system in the manufacture under simulated conditions of work	Identification of defects and the creation of defects catalogue. Verification of the system parameters	Influence of impurities on the inspection process. Subsequent specification of system parameters	ca. 90%
Set up of the system and in-line tests			
Technical acceptation of the system and hand over to user	Formal technical acceptance and agreement on improving the system	-	-
Improving the system during exploitation	Improving the hardware and software Classification of detected new defects not yet identified	Identification of new defects that have to be inspected by the system	100%

As the result of the analysis of both the application process and the stages of AOI system improvement, we conclude that the technical level of the developing system increased in the way of steps (Fig. 3). While initial stages of project realisation ended, a great quality changes ensued. These stages also cost the most. Subsequent stages of improving the prototype in the area of hardware and software decrease consequently and are characterised by small changes of quality and definitely lower costs.

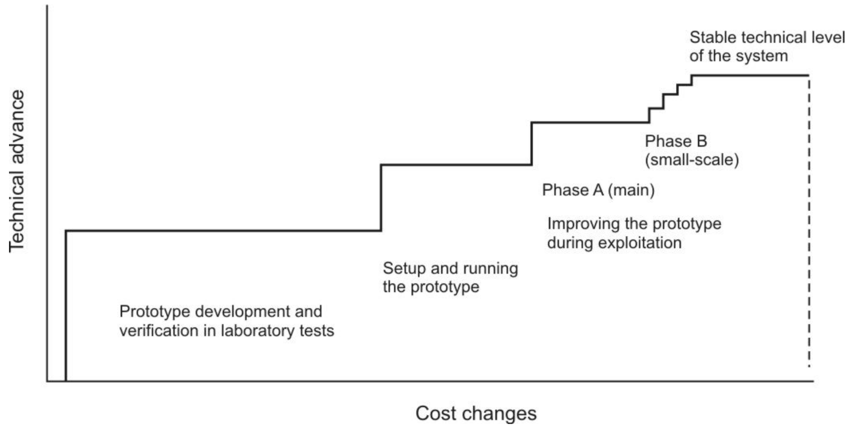

Fig. 3. Scheme of technical level and cost changes during AOI system development
Rys. 3. Schemat zmian poziomu technicznego i kosztów w czasie opracowywania systemu AOI

The initial stages of an innovative system for industrial application need high organisational and technical involvement. Additionally, emotional engagement of common workers and partly supervisors appear that frequently is connected with fear of their own status once the new system is applied. In the case of the described example, consequent to system improvement and work stability, these kinds of emotions and fears decreased and technical maintenance staff skills increased (Fig.4).

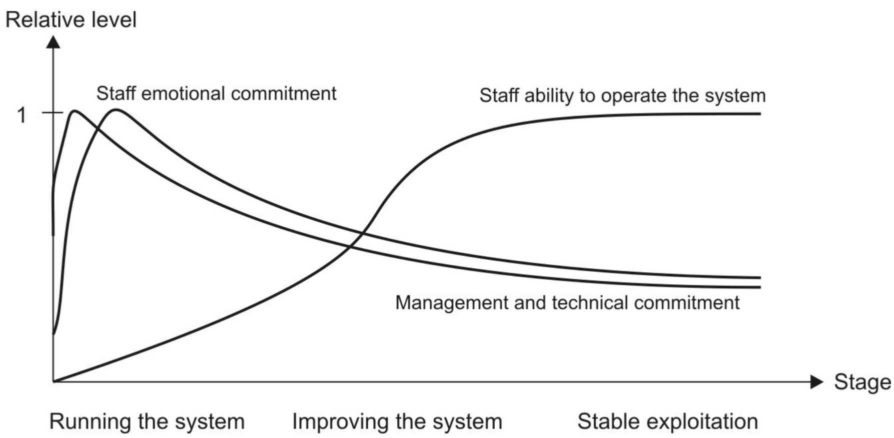

Fig.4. The staff attitude in relation to the development stage of the AOI system
Rys. 4. Zmiany podejścia obsługi do nowego systemu w czasie jego wdrażania

While a new system is activated with staff participation, the new skills are achieved, and correct and precise work is achieved in the maintenance stability stage. However, when a new worker for system operation is employed, he or she should learn the skills needed for the advanced system. Therefore, such innovations, in addition to technical problem solving, need adequate professional in-service training in the scope of system maintenance, because it can be crucial for the stability of system operation and consequent production efficiency.

As the project went, the increasing experience of the team proved that the AOI system operators have to get knowledge from the area of using computers and the knowledge of optic-electronic phenomenon and illumination techniques. Incorrect system calibration may consequently cause critical maladjustment and the lost of the system's crucial functions. Therefore, the system designer has the new challenge of system protection development in order to prevent or limit operations that decrease the system efficiency. Presently developing AOI systems have not had real auto-diagnostic and auto-calibrating functions.

The changes of the share of manual inspection when automatic optical inspection is under application are shown in Fig 5. The presented characteristic was practically proved in the AOI system's industrial application.

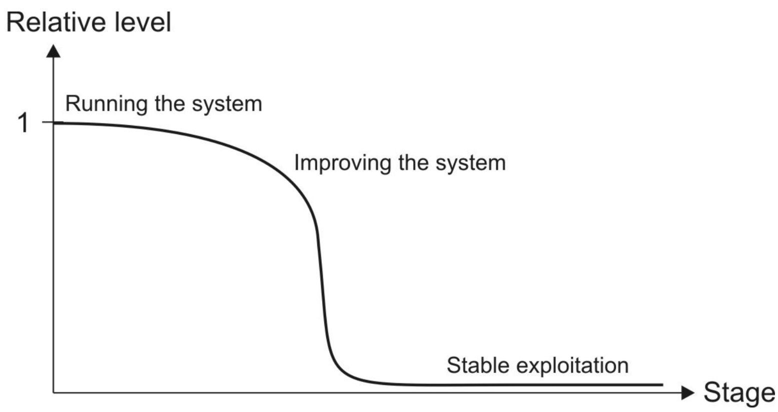

Fig. 5. Human participation in the inspection process in relation to the development stage of the AOI system
Rys. 5. Zmiany udziału manualnej kontroli pracowaników w relacji do etapów wdrożenia systemu AOI

Once the automatic optical inspection system was implemented (Fig 6), the human visual inspection of bearing rollers were practically eliminated.

Decreasing human inspection was especially at its height in the stage of system improving and reliability verification that were conducted by the inspection staff and company management. The most important argument that convinced staff of the new inspection system was examples of defect detected by the system that were unnoticed by a human controller.

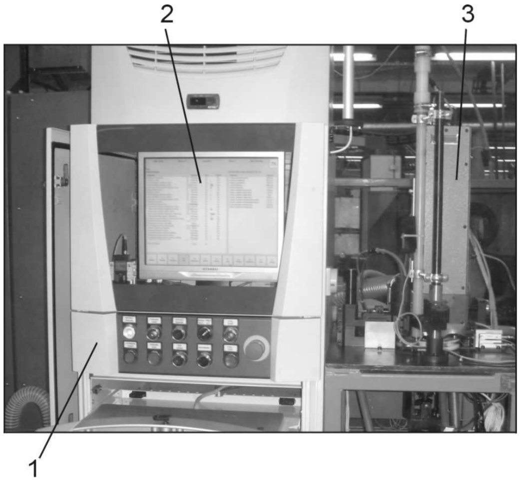

Fig. 6. AOI system implemented in the manufacturing line of bearing rollers:
1 – operator interface, 2 – monitor displaying inspection results, 3 – vision module
Rys. 6. System AOI wdrożony w linii produkcyjnej wałeczków łożysk tocznych
1 – interfejs operatora, 2 – monitor wyświetlający wyniki kontroli, 3 – moduł wizyjny

6. Conclusion

The system verification under industry condition and collaboration with enterprise staff increased research team experience significantly in the area of automatic optical inspection put into practice. As the system was adapting to work in the production line, the new possibilities of the AOI method use were identified that can support product quality inspection systems. Therefore, new challenges appeared, bringing new innovations generated in the area of higher quality metal surfaces of specified products – foreheads of bearing running elements and slip surfaces of anti-friction bearings.

The incremental innovations developed in the scope of PW-004 made use of the innovative potential of optical inspection methods united with illuminate systems and computer image analysis methods. Additionally, the possibilities both of new applications and development directions were identified. As the project results incremental innovation were implemented in industry and new knowledge in the area of AOI methods transfer into practice was generated, it gave rise to the potential advantage of innovation.

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Transformacja wyników badań naukowych w procesie rozwoju innowacji ilustrowana przykładem automatycznej optycznej inspekcji

S t r e s z c z e n i e

W artykule przedstawiono aspekty związane z aplikacją rozwiązania innowacyjnego opracowanego w ramach Programu Wieloletniego „Doskonalenie systemów innowacyjności w produkcji i eksploatacji w latach 2004–2008". Większość zadań zakwalifikowanych do realizacji w ramach programu obejmowała opracowanie innowacji przyrostowej. W artykule przedstawiono efekty jednego z tych zadań jako przykład bezpośredniej transformacji wyników badań naukowych do gospodarki. Przeprowadzono dyskusję zastosowania metod automatycznej optycznej inspekcji (AOI) w systemach kontroli jakości w produkcji. Przeprowadzone badania umożliwiły identyfikację kluczowych czynników oddziałujących na kolejne etapy procesu rozwoju innowacji i w konsekwencji warunkujących sukces projektu. Przedstawiono jakościowe zmiany w procesie produkcji wyrobów w efekcie wdrożenia innowacji przyrostowej.

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