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enlEYEght

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Imagine Cup 2007, Embedded Development
Final Report

1. Executive Summary

When you think about education, one of the first things that comes to your mind is probably reading. Reading is the most frequently used ability we gain during our school years – first we learn to read, then we learn through reading. Moreover, its significance continues after completing education. In modern society it is hard to imagine a world without written documents. This makes a high quality of reading skills in today's society essential.

Specialists estimate that 15-20% of population have deficits in reading. The most discussed reading difficulty is dyslexia, also known as "word blindness" – it is a complex condition which impedes the reading learning process. People suffering from dyslexia find it much more difficult to assimilate any written text. According to International Dyslexia Association, one in eight people has deficits in reading (research indicates in Poland about 10% of primary school students are dyslexic *Bogdanowicz, 1998*). Although a lot of research into dyslexia has been done, its causes are still not fully understood. The most recent status of understanding dyslexia shows that dyslexia depends on individual differences in processing information by the brain.

If dyslexics are not limited by the process they endure, they could have higher than normal intelligence, and extraordinary creative abilities. Amongst that dyslexic population are scientific geniuses (Albert Einstein), remarkable artists (Andy Warhol), noble prize winners (Pierre Curie), actors (Tom Cruise), political leaders (Winston Churchill), musicians (John Lennon), inventors (Thomas Edison) etc. These are people who harnessed their extraordinary abilities.

Taking into consideration the commonness of the dyslexia, we designed **enlEYEght**, the first portable system providing:

- Early diagnosis of the reading disorder among children with an instant therapy advisory
- Teleconsultations with dyslexia specialists
- Researches on reading disorders on the global scale
- Latest technology reaching out to the problem as of yet unsuccessfully approached

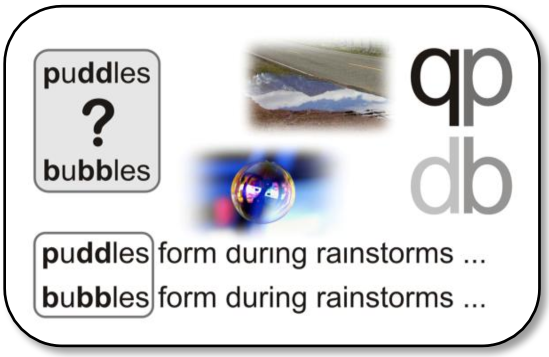


Figure 1. Words combination caused by wrong decoding of symmetric letters

Dyslexia

The basic problem with dyslexia is that it is hard to recognize it at early stage, when it can be treated in the most effective way. Difficulties with diagnosing reading deficits derive from physiological basics of reading process, which has two dimensions: decoding single words into isolated meanings and combining it into meaningful sentences and information. Decoding single words should be an automatic, preconscious process, whereas text comprehension always requires conscious attention. "Word blindness" disrupts word decoding, causing pupils to involve attention on this phase and leading to reduced comprehension – the mind does not have enough "free resources" to put pieces together. What is characteristic about dyslexic children is that they tend to be very intelligent, so they are able to hide their reading deficits at early stages of education. At this level they can predict words, which they do not manage to decode in an automatic manner, or even memorize the whole text, so that they seem to read it fluently. However, problems appear later, when the comprehension of the text being read becomes essential for learning – dyslexic children allocate so much attention to assembling letters into words, that they are not able to understand it. Therefore, pupils suffering from dyslexia are often unsuccessful at school, become unwilling to learn, sometimes even try to compensate for their low self-esteem by misbehavior. However, given appropriate help they could succeed.

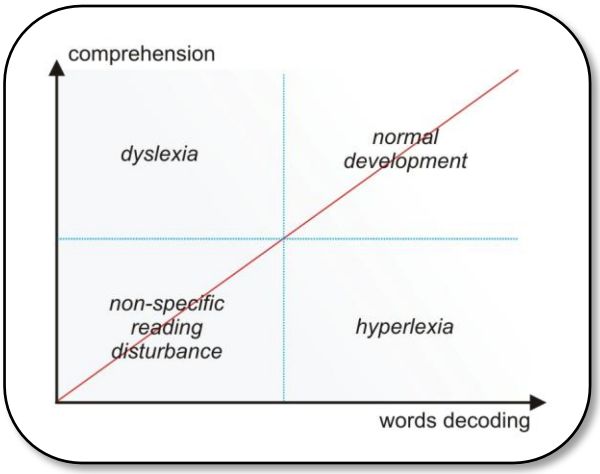


Figure 2. Two dimensions of reading phenomenon

How to measure the reading process?

Considering the structure of the reading process, recognizing reading disorders requires an objective method of measuring both earlier mentioned dimensions: ability to decode words and text comprehension (in accordance with principle: "You can't manage it if you can't measure it"). An innovative approach to the evaluation of reading capabilities, benefiting from latest achievements of cognitive sciences, was proposed by prof. Jan Ober, researcher at the Polish Academy of Sciences. It led to development of a set of lexical paper&pencil tests, called Pro-lexia, which enable to pinpoint the individual's reading ability on the surface shown in figure 2. Pro-lexia is successfully used in several tens specialized research centers, but access to them is limited for geographical and economical reasons.

Innovation

Imagine a world in which unfortunate children, impaired because of reading disorders, have free access to diagnostic facility at their place of habitation. Their dysfunction can be precisely diagnosed at an early stage and children can be given individualized, appropriate treatment. Imagine they have inexpensive and easy access to the best specialists in dyslexia from all over the world. If that vision became real, reading disorders occurrences would surely decrease and more people in the world could get access to education at a level appropriate to their talents and gifts.

This vision enlightened our group to provide the possibility for everybody to access a system allowing to diagnose reading disorders. Thanks to the knowledge and support of prof. Jan Ober we introduce **enlEYEght**, worldwide unique system. We extend the tried-and-tested Pro-lexia method by recording eye movements which are the absolute physiological measure of cognitive processes during reading. Prof. Ober provided us with the Jazz sensor, a non intrusive, inexpensive and easy to use eye movement measuring device. We have upgraded this device by adding a Bluetooth communication module, distance sensor and will integrated it with the Pocket PC and the eBox-2300 obtaining **enlEYEght** – the first portable dyslexia diagnosing system capable of precise reading ability assessment in the classroom environment and providing remote expertise even in rural area schools.

Figure 3. **enlEYEght** out of the box

We have ported the Pro-lexia tests to the Pocket PC device. Data collected by the sensor during examination provides information used to indicate which letter combinations and syllables caused problems, so that targeted methods to compensate disorders can be applied. **enlEYEght** gives an opportunity to make dyslexia screening checkups, now unavailable to vast majority of pupils, in the everyday life of every school. **enlEYEght** also includes a Reading Disorder Community Server (RDCS), where data fetched during the examination is sent, via a secure Internet connection established by eBox-2300, and where it is stored. RDCS should enable communication between teachers and dyslexia specialists, who can advise adequate treatment based on the analysis of available data. Additionally, carrying out dyslexia examination on a larger scale than ever before will create an opportunity for scientists to explain causes of reading disorder, which are yet uncertain, using the gathered information.

2. Market Overview

2.1. Project background


Figure 4. Focus group study in April 2007

Over the years dyslexia has been recognized by consecutive symptoms such as reading inaccuracy, pupil's frustration about school, poor self-esteem or even headaches while reading or studying. With such misleading signs, adequate diagnosis relied on parents' and teachers' intuition, whereas, according to Davis Dyslexia Association, teachers get little or no training in the area of learning disabilities. This situation resulted in poor efficacy of dyslexia diagnosing, which was recognized late or not at all. On the other hand there are many methods of treatment, provided in several professional facilities all over the world for those children who are fortunate enough to have their reading disorder diagnosed before it is too late for an intervention.

A few formalized methods of reading disabilities recognition have been developed in the form of paper&pencil test. Despite their usefulness, they are still unpopular as they are providing only partial knowledge on dyslexia grounds. According to specialists, members of focus groups created by our team, such tests should be supported with eye movement analysis as an absolute measure of cognitive processes during reading. That would enable therapists to adjust treatment to the specificity of the subject's disorder.

2.2. Idea

An ideal system supporting dyslexia diagnosis should be broadly accessible (enabling every school child to be regularly monitored), based on the best already proven methods and increase the availability of the expertise which is nowadays limited to a few specialized facilities. Teachers, potential users of such a system, advised us to provide also a community web site as a place where knowledge and experience between teachers and experts could be easily exchanged. Commitment of our consultants enabled us to clarify the mission of the project to lay the groundwork to shape the **enlEYEght** system.

"Accessible information system enabling early diagnosis of reading problems and supporting effective therapy"

enlEYEght mission

2.2.1. Why Pro-lexia?

We chose the Pro-lexia method of reading skills evaluation because of its excellent reputation and effectiveness proven in several tens schools and diagnostic research centers. It provides a separate measure of individual's skills of word decoding and comprehension. This approach benefits from 25 years of experience of working with difficult cases of dyslexic children. In contrast to other available methods, Pro-lexia tests can be repeatedly conducted on the subject even the same day without affecting the results. The position on two dimensional space i.e. the efficiency of word decoding and text comprehension is so specific to the individual as their signature. Such a method is especially suitable for the monitoring of reading skills development, which is crucial while evaluating efficacy of the applied therapy.

2.2.2. Why eye movements?

In order to adjust the therapy to reading disorder specificity, knowledge about the reasons for disorder is a key issue. The most effective approach to this question bases on the analysis of eye movements. It provides complimentary information about which word, sentence or even sequence of characters caused difficulties to the examined person, explaining why reading them took more time. Eye movements help to determine whether the reading was fluent or some words had to be reread several times.

2.2.3. Why both together?

enlEYEght creates a bridge between science and practice. Taking advantage of modern technologies, this knowledge can be practically applied and help people on the global scale.

Pro-lexia supported with eye movements analysis provides a method of reading skills evaluation based on physiological measures. Combining of two proven approaches to gather the knowledge about reading process allows for thorough investigation of reasons causing the reading disorders. Based on such a method it is possible to suggest treatment adjusted to the specificity of reading disorder: dyslexia, hyperlexia and non-specific reading problems (figure 2).

We proposed to introduce so called treatment packages - instructions for teachers, parents and children on performing simple exercises, which, done on the regular bases by dyslexic children, should 'unlock' the development of reading skills. At this level each treatment package can be advised and applied without supervision of an expert.

2.3. System Overview

The mentioned methodology is used predominantly in several research centers. Its main limitation is the fact that it requires laboratory environment because of complex and expensive instrumentary.

Making it available for schools and accessible for every child required the development of a mobile, non-intrusive and self-calibrating sensor, recording eye movements, which would not limit the field of vision. Our initial idea of the system consisted of the sensor connected to the PocketPC mobile device. On the same device Pro-lexia tests were ported omitting imperfections of their paper&pencil equivalents. PocketPC was chosen as a more affordable alternative of a tablet PC, while both are equipped with a touch screen which will be used for the tests. This functionality of the **enlEYEght** project is realized by Portable Checkup Unit (**PCU**).

The process of dyslexia diagnosis can be supported by the expert system, based on the knowledge obtained from normative tables developed for the Pro-lexia method and from dedicated algorithms analyzing the characteristics of eye movement record. More specific diagnosis requires the opinion of an expert who can identify dyslexia causes and suggest appropriate therapy. To support remote consultation between a teacher and an expert we designed Reading Disorder Community Server (**RDCS**). On the server the history of subject's checkups is stored, which reflects long-term evaluation of individual's reading skills development. Moreover, as RDCS is instantiated in every country, it provides necessary statistics and global information about the status of reading skills among society.

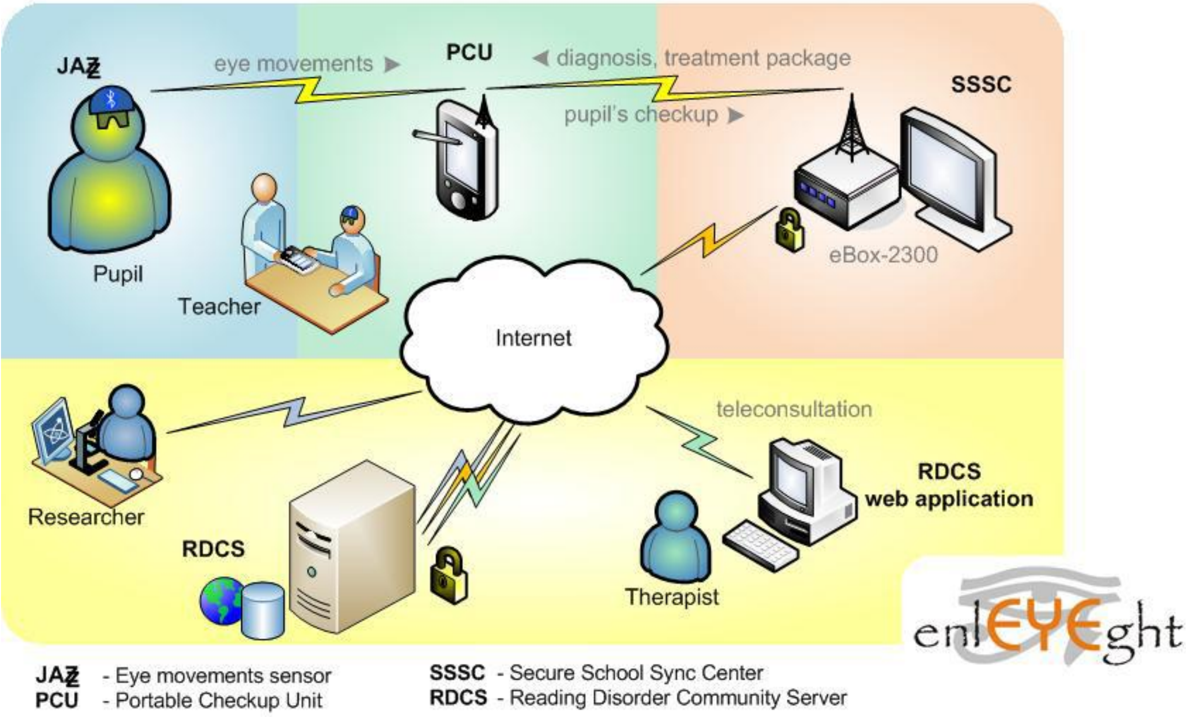


Figure 5. System concept

PCU is linked with RDCS via Secure School Sync Center (**SSSC**). It provides secure wireless connection between PCU and RDCS and integrates with a school students' database, simplifying administrative effort to put into register every new pupil coming to school. SSSC gathers statistics on dyslexia among school children and realizes functionality of the expert system used for preliminary diagnosis, as mentioned above. PCU can work independently (without connection to SSSC) and synchronize with RDCS via SSSC on demand.

All three subsystems together reduce the distance between specialized facilities and school children, providing an innovative and accessible information system enabling early diagnosis of reading problems and supporting effective therapy.

2.4. User Scenario

The main user of **enlEYEght** is the teacher or school psychologist, supervising a group of pupils. Working with the system starts by preparing on SSSC a list of children for future examination. The next day, the teacher equipped with PCU visits a classroom, where screening checkups on planned list of children are to be conducted. Every pupil from a class solves in a few minutes two simple tests, during which eye movements are measured using the Jazz sensor. Results of the test are presented immediately to the teacher on the PCU screen, indicating whether individual's reading capabilities are appropriate to their age. If test result indicates reading disorder, the teacher marks the results as requiring thorough diagnosis. The teacher sends the gathered data, temporarily stored on PCU, to SSSC. There the data is analyzed by expert system algorithms, which identify reading disorder reasons and match an adequate treatment package for each individual requiring further diagnosing. SSSC saves every change in personal checkup record on RDCS.

After two months, a control checkup is conducted. Its results are compared with the ones saved in individual's file. If the advised treatment package did not lead to improvement, the teacher may request consultation with an expert via RDCS teleconsultation module. RDCS forwards it to a chosen therapist, who diagnoses the possible reasons for which proposed standard therapy appeared not to be effective. Then feedback information with a description of the more specific therapy for the dyslexic child is sent to the teacher. The teacher is allowed to browse the pupil's profile including previous checkups with a consultation transcript via RDCS web application. It enables also to assess current individual's reading skills in comparison to other pupils from the same age group. Access to such statistics is available to every user of RDCS.

2.5. Target

- **School children** between 8 to 12 years old (potentially dyslexic) – main beneficiaries of **enlEYEght** services.
- **Teachers / school psychologists** – the group of users responsible for conducting checkups and operating PCU with Jazz.
- **Therapists** – the group of users in charge for remote diagnosis of pupils' reading disorders on the grounds of provided checkup data.

- **Scientists** – indirect beneficiaries of the system. They have access to reports, summaries and statistics concerning dyslexia among children of various age with diverse social backgrounds.

2.6. Customers

Public: In most of countries schools are subsided from governmental or local governmental budget. Thus, our customer is a representative of the government, responsible for educational issues (e.g. the Minister of Education). As **enlEYEght** helps to increase reading quality among children, and at times gathers data about dyslexia for scientific purposes in a larger scale than ever before, it can also be subsided from education grants (e.g. EU grants for school development and science, Wallace Foundation Grants etc.)

Non-public: In the private sector our customers are private schools, financing a dyslexia diagnosing system from the school budget increasing the level of education among pupils and positively influencing the school's reputation. Last but not least, customers who might be interested in buying **enlEYEght** system are private psychological counseling services which could extend their offer with a dyslexia diagnosing service.

2.7. Market requirements

To summarize the requirements that **enlEYEght** should meet to provide real business value, we propose a list of the following quality factors:

Requirements		enlEYEght
The method of diagnosing dyslexia should base on the best proven approaches.	☑	Pro-lexia supported by eye movement analysis provides the best diagnosis methodology. Implementation of tests on PCU has been already proven in beta tests with pupils.
The system should be accessible for every school child.	☑	**enlEYEght** uses inexpensive hardware components providing every school a complete advanced dyslexia diagnostic tool.
Administration and maintenance of a system in a school should require minimal effort.	☑	A school has to administer PCU with Jazz, both self configuring, and SSSC requiring simple installation.
The system should meet highest safety and security standards.	☑	Safety**:** Jazz sensor provides galvanic isolation preventing from electronic shock. Security**:** Personal data are encrypted during transmission over open networks and stored in a secure database. In local networks access is limited by an authorization policy (meets HIPAA requirements)
User friendliness and usability should be thoroughly investigated in every part of the project.	☑	Wire free system. Interfaces designed considering advices of future users. Checkups on PCU can be conducted everywhere - without connection with SSSC (later synchronization required).

Table 1. Market requirements

2.8. Financial analysis

The final product offered to customers consists of a Portable Checkup Unit (PCU), the Secure School Sync Center (SSSC) and the Jazz sensor. This set of devices supplied with software enables to conduct checkups, diagnose reading disorder and store the results in the database on the Reading Disorder Community Server (RDCS) (see figure 5).

We simulated how the project could be manufactured economically by a company, and prepared a business plan for six years (see table 3). It is worth mentioning that **enlEYEght** is an innovative project, covering a market gap, since now not having any competition. The simulation is realistic – we intentionally assume having shares in market at the level of only 10% after six years to show that even in a pessimistic scenario the project is cost-effective. Our strategy assumes building credibility among customers during the first two years of bringing our product to the market, and a constant rise in customers' number in the following four years.

The customer is charged for purchasing the product and for the access to its services in two ways: once – at the beginning of using the system, and every year – for the access to RDCS server, teleconsultations, administrative costs and external licenses. To make the system more affordable for the customer, we decided to reduce the initial price, and partly subside provided devices. Remaining expenses will be covered by the customer in the following two years after installation in a yearly charge. Such an approach has been proven by many successful businesses (e.g. mobile phones sector).

We calculated average costs per one school child to make the real cost of the system for each beneficiary evident. Assuming that each school child is tested 3 times a year, the cost per one checkup amounted to about 1$ - as little as a can of coke. In contrast, nowadays such test, if available, costs about 50$. The annual cost of the system per school, including consultation costs, administrative costs and access to RDCS services is about 1700$. It is about ten times lower than employing another school staff member. According to the business plan, our project requires about 100 000 $ from a venture capital or a business angel at the beginning. Expected return of investment is about 500 000 $ after six years.

The total cost of the system was divided into categories: design, RDCS, devices per each installation and variable costs.

Design – cost of research, design and development of software and hardware components of the final product. The software development cost has been calculated basing on function points effort estimation. This method was elaborated by Allan Albrecht and figures out the complexity of the project. Each function point requires the implementation in approximately 40 lines of code in object oriented programming language. Use of modern software development tools and technologies (MS Visual Studio 2005 and .NET Platform) can reduce this value by 30%. The total number of lines of code is translated into effort expressed in person-months using COCOMO II method for Post - Architecture model. The total estimated cost includes also hardware design, development and prototype production costs.

Function points calculation	CM (complexity multiplier)	0,65
	UT (unadjusted total)	1030
	IF (influence factors)	46
	CM + IF	1,11
	FP = UT x (CM + IF)	1143
Software size estimation	LOC/FP (lines of code per function point)	40
	Average LOC generated by software development tools	30%
	Total LOC	20579
Effort estimation (person-months)	Software design & development	40,4
	Hardware design & development	6
	Total PM	46,4
Cost estimation	Total PM x average monthly salary	46,4 x 1449$ = 67 212$
	Prototype cost	500$
	Total cost	**67 712$**

Table 2. Software & hardware development effort estimation based on Function Points & COCOMO II

Server – cost of hardware and software licenses.

Devices per installation – cost of devices required to provide an environment for application. It consists of licenses for used technologies and hardware costs. Jazz sensor price is a retail price, which could be several times lower in the massive production, but we do not consider this fact in our simulation.

Variable costs – collocation fee (paid annually) and total cost of teleconsultation with specialists in dyslexia.

Table 3. Business simulation

Total number of schools in Poland	13200

Design	
software and hardware design total cost	**$67 712**

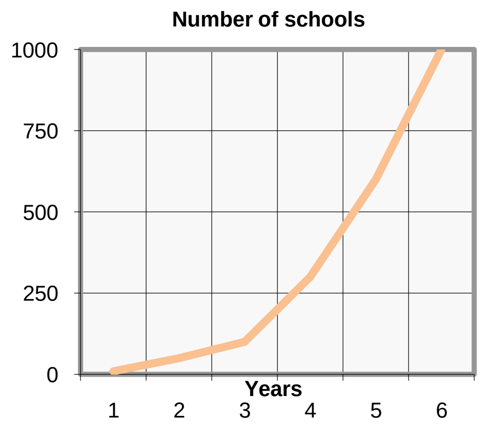
Server	
RDSC hardware	$3 000
MS Windows 2003 Server	$952
MS SQL Server 2005	$3 223
Total	**$7 175**

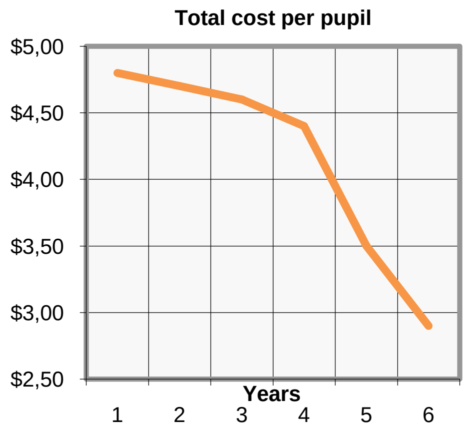
Cost per installation	
PocketPC	$439
eBOX + WiFi adapter	$280
Jazz sensor	$2 437
external licenses	$219
Instalation & configuration	$100
Total	**$3 526**

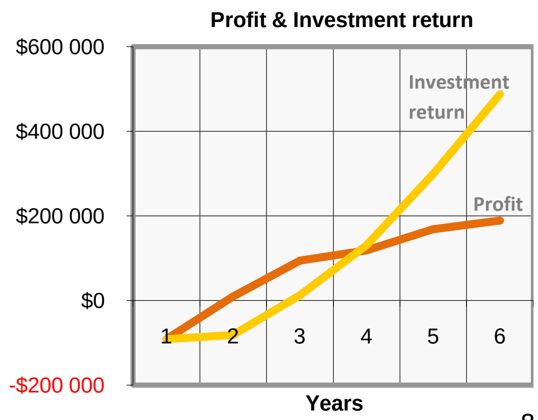
Additional cost (yearly)	
Collocation price	$2 000
Total	**$2 000**

Variables	
Consultation cost	$20,00
Pupils per school	600
Examined children rate	50%
Dyslexic children rate	20%
Consulted children rate	3%
Maximal schools no. per server	350
Maximal schools no. per employ	50
Average marketing costs to get one customer	$100
Employee costs per year	$15 384

	Year	1	2	3	4	5	6
Impact	Number of schools	10	50	100	300	600	1000
	Number of pupils	6000	30000	60000	180000	360000	600000
	No. of examined pupils	3000	15000	30000	90000	180000	300000
	No. of dyslexic pupils	600	3000	6000	18000	36000	60000
	No. of consulted pupils	90	450	900	2700	5400	9000
System costs	System cost / pupil	$4,50	$4,40	$4,30	$4,10	$3,20	$2,60
	Initial cost / school	**$1 000,00**	**$1 000,00**	**$1 000,00**	**$1 000,00**	**$1 000,00**	**$1 000,00**
	Initial cost / pupil	$1,67	$1,67	$1,67	$1,67	$1,67	$1,67
	Annually consultation cost / school	$180,00	$180,00	$180,00	$180,00	$180,00	$180,00
	Annually system cost / school	$2 700,00	$2 640,00	$2 580,00	$2 460,00	$1 920,00	$1 560,00
	Total cost / school	$2 880,00	$2 820,00	$2 760,00	$2 640,00	$2 100,00	$1 740,00
	Total cost / pupil	**$4,80**	**$4,70**	**$4,60**	**$4,40**	**$3,50**	**$2,90**
	Number of servers	1	1	1	1	2	3
	Number of employees	1	1	2	6	12	20
Investment	Costs	$113 954	$152 068	$196 335	$761 340	$1 177 186	$1 603 857
	Marketing & employees costs	$16 384	$19 384	$35 769	$112 307	$214 615	$347 692
	Total outcome	$130 339	$171 452	$232 104	$873 648	$1 391 802	$1 951 549
	Income	$38 800	$181 000	$326 000	$992 000	$1 560 000	$2 140 000
	Profit	-$91 539	$9 547	$93 895	$118 351	$168 197	$188 450
	Investment return	-$91 539	-$81 992	$11 904	$130 255	$298 453	$486 904







3. Technical Overview

3.1. Reading phenomenon

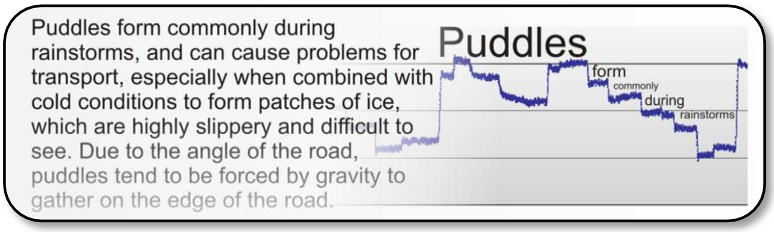


Figure 6. Reading process

When a person reads, they move their eyes along the line of text. We do not realize the fact that the eye movement is not fluent, but is a sequence of rapid 'jumps' - so called saccades. Each saccade is followed by a stop lasting several milliseconds – the eye fixation. It was proven that the process of recognizing letters and acquiring whole word happens after each saccade during the eye fixation. Thus, when a person cannot understand a letter or a word, they go back and read the word again. These returns are called the regressive saccades. Analyzing characteristics of the recorded eye movement, such as the mentioned saccades, the eye fixations and the regressive saccades, provides extensive knowledge about the reading process.

3.2. System structure

3.2.1. Jazz

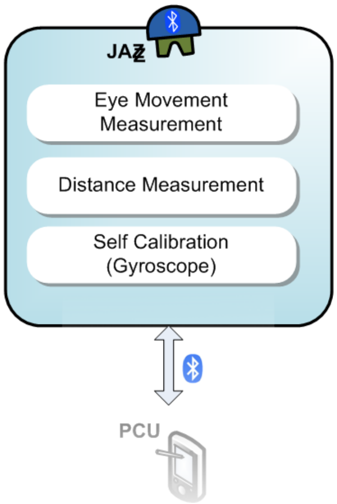


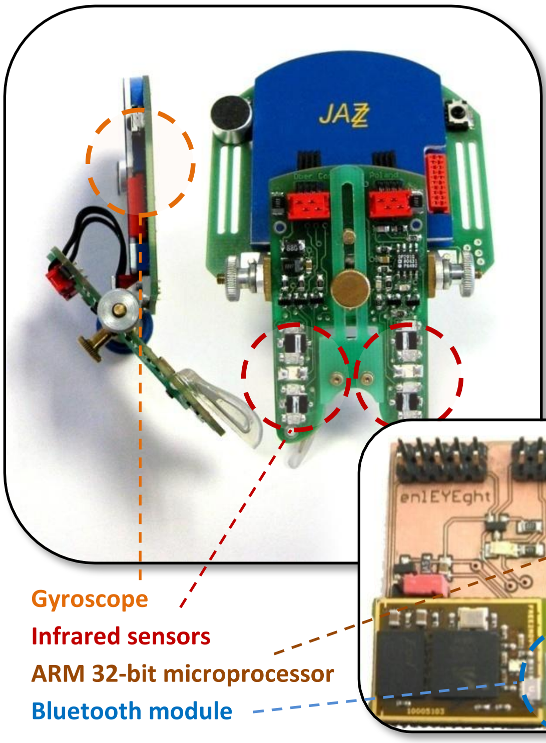
Figure 7. Jazz module

Jazz sensor, thanks to the use of infrared, provides a non-invasive method to measure the position of the eyeball and constitutes the source of input data. The device consists of the central unit and wireless extension. It communicates with the PCU (on which data is stored) via Bluetooth connection (at the frequency of 2.4 GHz). The Jazz is conveniently equipped with a gyroscope, which allows for a self-calibration, not depending on a position of person's head.

This module is also equipped with ultra sound/infrared distance meter. It is used to measure the distance between the pupil's head and the surface of a screen, on which tests are displayed. The distance is calculated according to the time that is needed to travel from the PCU to the sensor. Real time recording of this distance allows to analyze the pupil's position during the test.

The battery-powered system and wireless connection make the device mobile and easy to install (no extra cables are required). As safety is an important factor in our project, we have used galvanic isolation and low voltage, so as to eliminate the threat of an electric shock. The location of the elements does not limit the subjects' field of vision even if wearing glasses. Also, taking user friendliness into account, our system is light and weighs approximately 120g. The device is powered by 2 AA (R6) batteries (together 3V). This voltage is transferred to the high-efficiency step-up, where it is converted to 3.3V, and supplies power to the unit.

The data gathered from the sensors is processed by 32 bit ARM microprocessor, from Luminary Micro. This chip, apart from the high-speed data processing, is also low power consuming. The system is under constant control and if the battery level goes down, the DC-DC converter notifies the processor, which lights up the red LED. Similarly, the status of the Bluetooth connection can be seen on two blue LEDs. Apart from the mentioned elements, we have also used a low power consumption Bluetooth module, which enables 10 hours of continuous use. The main task of the microprocessor is fast communication between data-gathering sensors and the Bluetooth module, which transmits the data to the PCU. The speed of the transmission is 115.200 b/s. The elements of which Jazz is made are lead free and pass ecological norms.



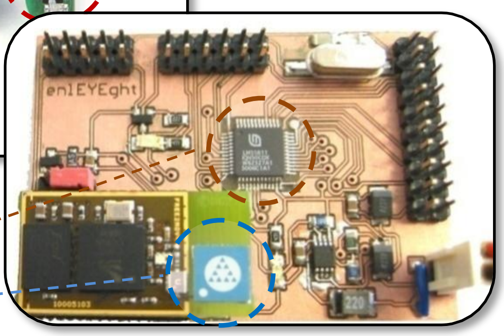


Figure 8. Jazz sensor with communication module

3.2.2. Portable Checkup Unit (PCU)

PCU - Pocket PC based device with dedicated software - is **enlEYEght**'s self-contained system for test conducting and management of registered pupils. It enables the teacher to add new pupils to database or edit existing pupils information. The messaging module lets the teacher request consultation and receive experts answers without using desktop PC. However, besides these helpful modules, PCU's main functionality is the checkup conducting. During the test, text is displayed on PCU screen. While test subject divides text by tapping on the screen in selected places, PCU is responsible for recording the data from the Jazz sensor and storing the subject's actions in a file, which subsequently will be used for the eye movements visualization and analysis.

enlEYEght system is designed to be used in schools on the global scale, so PCU supports multilingualism. This feature is based on XML files. It enables fast and easy language adding and editing. Currently PCU provides support for English and Polish language.

Our aim was to ensure that checkups could be conducted even if connection with the rest of the system was unavailable. Therefore PCU implements the cache module, which is responsible for saving checkup results locally, until it will be possible to send it to SSSC. Moreover, the sent files are not removed immediately from PCU cache – they remain there as long as there is free space for new files. This way, if recent checkup is to be viewed on PCU, it probably will be available instantly, without downloading.

The cache module is based on MS SQL CE database. The other solution we have considered, involved creating special XML file for storing information. We rejected this option, as it would not provide protection of personal pupils' data at level comparable with SQL CE password protected database. Besides it would require DOM for XML parsing, which is too memory-consuming.

To ensure no unauthorized person will view the data stored on PCU, teachers' profiles are also kept an in encrypted SQL database. On application startup, authentication is required to prevent the data stored on PCU from being accessed if Pocket PC would be stolen or lost.

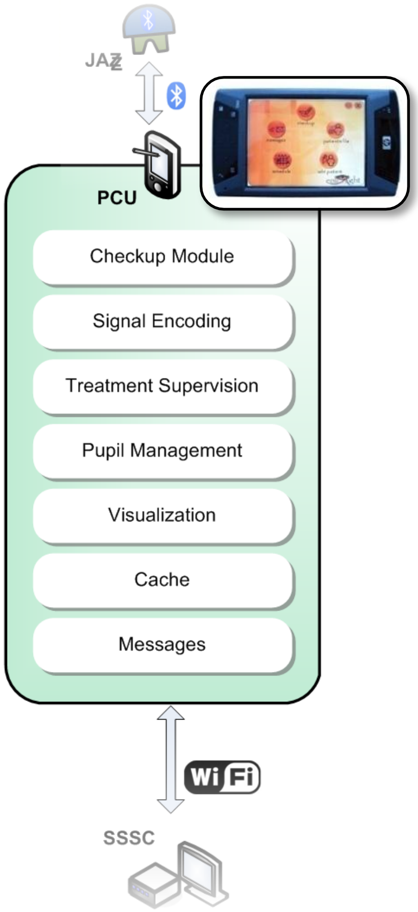


Figure 9. PCU module

3.2.3 Secure School Sync Center (SSSC)

Secure School Sync Center is the heart of the **enlEYEght** system in the school. It collects and analyzes data acquired during tests on PCU. A built-in expert rule system tries to identify the possible causes of reading disorders and match them with an appropriate therapy package. Through a secure SSL connection, SSSC maintains a connection with RDCS web service, to store the data on the remote server.

The SSSC has a full list of pupils in the school. Pupils' profiles can be added in three ways – on PCU, on SSSC – an easier alternative, since the teacher can use a keyboard and a high-resolution screen, or by importing profiles from an existing school database (the system currently supports importing the data in CSV format).

SSSC allows a teacher to schedule tests with certain pupils or classes at chosen dates. When the selected date comes, PCU automatically downloads all the needed data from SSSC (e.g. pupil's previous test results) and reminds of the scheduled checkups.

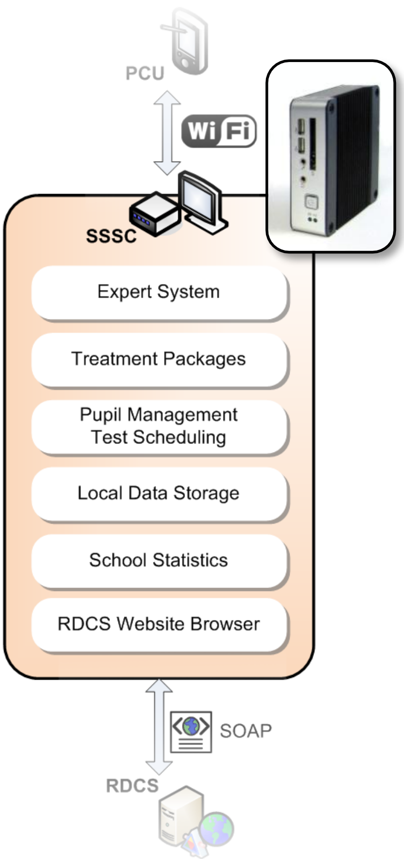


Figure 10. SSSC module

Communication between PCU and SSSC is based on TCP sockets. We designed a simple, yet sufficient protocol for exchanging data. Alternatively, we have considered running a web service on SSSC available from PCU. However, since we send a lot of binary data, XML serialization would produce too much overhead in processing time on PCU.

Data gathered from PCU is sent further to RDCS. This is done by invoking web methods exposed by the web service available on RDCS. The connection is secured by the SSL protocol and requires authentication.

Before sending to RDCS, tests are compressed with a ZIP algorithm. It provides 50-60% ratio, so the final size of an average test that is sent over the Internet is reduced from about 500 KB to less than 250KB. Still, sending a lot of tests consumes bandwidth. To balance the network load, SSSC can be configured to upload the data during the connection idle time, e.g. at night.

Hardware

As a hardware platform for this functionality we chose e-Box 2300, which is several times cheaper than the standard PC while being much easier in installation, administration and management

For our system, we have built and installed a custom Windows CE image, choosing the elements according to the specific needs of SSSC subsystem. Its main parts are:

- **Networking** – TCP protocol
- **USB NDIS Client** - for SSSC is equipped with a U.S. Robotics USB wireless adapter to enable communication with PCU
- **MS .NET Compact Framework 2.0** – since the code is written in C#
- **SOAP Client, DCOM** – to enable communication with RDCS Web Service
- **Firewall** – you cannot be too careful when connecting to the Internet.
- **SQL Server CE** - SSSC uses a database to store the local data

3.2.4 RDCS

RDCS is a part of a system, where the data gathered from the Portable Checkup Units are stored. It is also a community server, where teachers and scientists can register their profile and exchange knowledge, consult dyslexia cases or browse statistics on commonness of dyslexia among the society. Each subject tested on PCU has his or her history of checkups stored on RDCS server which enables the teacher to evaluate reading skills development even if a pupil changed a school. RDCS provides also services available for other users, who would like to take advantage of the knowledge gathered on the server.

Because of large amount of data processed by the server, database efficiency is crucial. RDCS core is MS Windows 2003 Server with MS SQL Server 2005.

Number of schools	10	50	100	300
Estimated number of users	30	150	300	900
Data storage space required	23 GB	113 GB	225 GB	675 GB
Estimated no. of hits per day	3 000	15 000	30 000	90 000
Estimated traffic per day	0,1 GB	0,6 GB	1,2 GB	3,6 GB

Table 4. RDCS storage space and data transfer analysis

Data storage per one school (**DSPS**):

DSPS = **PN** x **TN** x **CDS**

PN – number of examined pupils – for a typical school PN = 300

TN – number of tests per pupil (during all school years) – TN = 3 tests/year x 5 years

CDS – checkup data size. The checkup consists of two tests, each requiring after compression on average 250 KB of a storage space. CDS = 2 x 250 KB

According to the estimation presented above, one server machine can store the data and respond to queries from about 300-400 schools. To serve more schools, a clusterization and a service broking is required. The RDCS cluster will be instantiated per each country and will store the data needed to be exposed to the other countries' Reading Disorder Community Servers in a separate distributed database (e.g. statistics and rules discovered in data mining process).

Record of a single test stored on RDCS consists of a binary data, acquired from the Jazz sensor and encoded by a PCU module, and XML transcript of actions made by a tested subject during the checkup. After automatic diagnosis done by the expert system on SSSC, both the diagnosis and the proposed therapy are also stored in the database. All the gathered data are processed later by SQL Server 2005 Analysis Services to identify rules which therapy package was the most effective for a certain diagnosis. This knowledge is utilized by an expert system on SSSC.

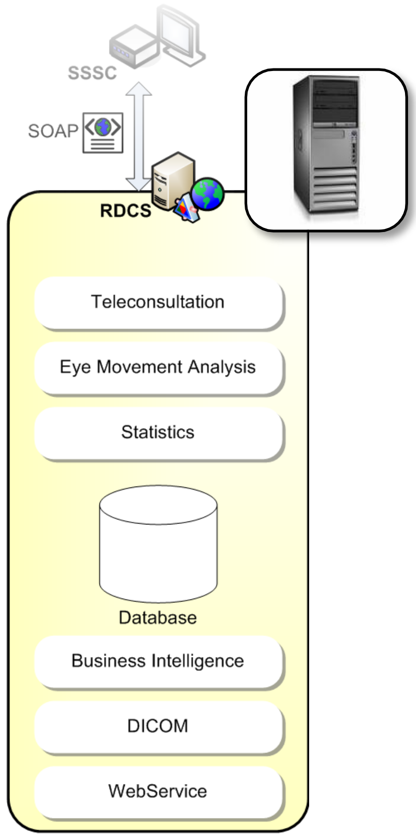


Figure 11. RDCS module

An important part of the RDCS server is a web application enabling teachers and therapist to communicate with each other, crossing the distance between school and specialized dyslexia research centers. Main functionality of the application is visualization of tests results. It enables specialist to measure length and timing of saccades, fixations and regressive saccades and identify reading disorder grounds. Visualization is an important part of the teleconsultation module, which allows teachers to take advantage of an expertise available in a remote localization. For the best user experience, we chose an ASP .NET web technology supported by Silverlight extensions, necessary for visualizing the complex eye movements signal in a web browser. To support the signal analysis, the dedicated algorithm of automatic tagging signal characteristics was developed. The Silverlight web application supports multilingualism.

RDCS provides also an access to general information about dyslexia among society (in various age groups), generating appropriate statistics on demand. This functionality, as well as the description of the therapy packages advised for a specific reading disorder, are available even to not registered users.

RDCS serves its functions to software modules installed on SSSC via web services and web application running on IIS v 6.0. There was a necessity to use Web Services Enhancement 3.0 for MS .NET, to provide optimization for a large binary data transmission via the W3C SOAP Message Transmission Optimization Mechanism. For security reasons, web service communication between SSSC and RDCS is encrypted using Secure Socket Layer technology and requires software authentication. Access to personal data via RDCS Silverlight web application is also authorized. As an add-on, we considered implementing the DICOM protocol service, enabling research centers to access the anonymous data stored in RDCS database for scientific purposes. Service oriented architecture of RDCS provides scalability and flexibility, without the detriment to the security.

3.3. Checkup procedure

To begin checkup, the teacher puts PCU on the tray, opposite to the pupil being examined. The Jazz sensor is attached to the pupil's forehead and turned on. The teacher enters information about the pupil being investigated and launches the checkup procedure.

The checkup consist of two phases:

- **chain-words**: subject has to decode two words written one after another, without any space, into single meaningful words
- **chain-sentences**: subject has to separate semantically unconnected sentences, which are written without any punctuation marks

PCU application loads a file containing words and sentences for a specified language and chooses a random test version from available sets.

The subject is performing the test by tapping the locations where the separation lines should take place. In the case of mistakes, individual can overdraw the misplaced separation mark. Every single action is recorded, with detailed information about time and place on the screen where it took place. Additionally some events, like the time when next page of text was shown, are recorded automatically. During the whole checkup, PCU receives data from the Jazz via Bluetooth, verifies it and stores for further, offline, analyses.

The important feature is an on-line compression of the Jazz signal. Size of the raw data is about 3-5 MB, depending on the test duration, and is inconvenient to send it via local network, not mentioning the Internet. In order to solve this problem, we have developed an algorithm decreasing the file size to acceptable amount. To achieve this, we detect consequent samples, which values do not differ significantly and replace them by an average value with information for how long does it last. Such a mechanism is similar to a key frame "trick" used in audio or video compression algorithms. The encoding of a signal leads to significant reduction in size of transferred data, which is decreased at least 4 times, to about 1MB per checkup (500 KB per each test).

When the checkup is complete, PCU shows a results screen, which summarizes subject's answers and the time needed to complete the test. It also points the results on the two-dimensional surface of reading phenomenon, giving the first evaluation of overall pupil's reading ability. It also instantly qualifies subject to one of four groups: normal reading, dyslexia, hyperlexia or non-specific reading disorders. Moreover, based upon the school statistics downloaded from SSSC, index comparing the subject's reading abilities with other registered pupils is shown. If the evaluation indicates low reading skills, teacher can immediately start diagnosis process. In the results visualization, the test text is displayed above the diagram showing the eye movements. We have developed algorithm, which tries to match lines of text with the received signal.

Figure 13. Checkup procedure

3.4. Diagnosing system

After the qualification for further diagnosis on PCU, the second phase is conducted by an expert system located on SSSC. It bases its decisions on two factors - predefined inference rules and accuracy of previous decisions. Decision rules are grouped into two sets. First of them helps the system to diagnose possible grounds of reading disorder. The second one, matches appropriate therapy and exercises (called treatment packages) to the previously estimated diagnosis. These rules sets are defined by specialists and therapists, based on their knowledge and experience. At this level, the system can propose treatment for the most common reading disorders, without involving experts.

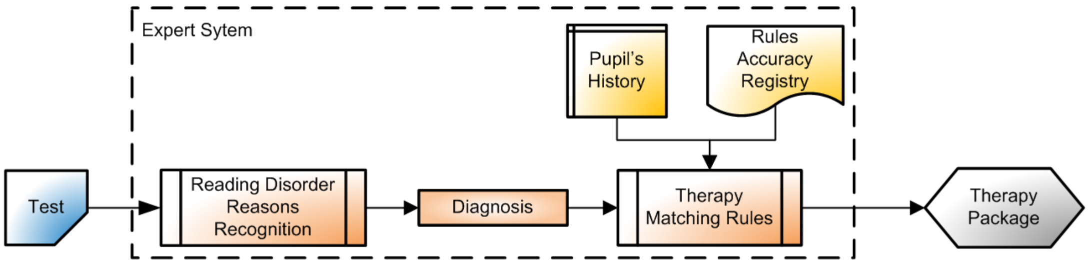


Figure 14. Expert system diagram

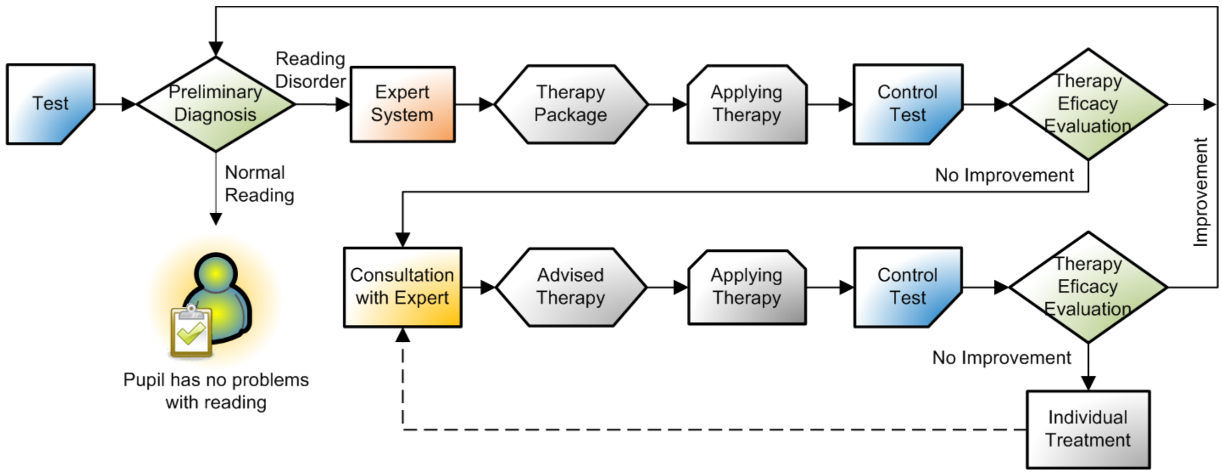


Figure 15. Diagnosing process

The rule modules for the expert system are implemented as DLL plug-ins, which are synchronized with the RDCS. As new knowledge is gained from researches, rules can be added or modified on the server, and the libraries on SSSC would be seamlessly updated.

Each decision made by the expert system is evaluated by conducting control tests during the therapy. If results are indicating expected development, the rules that lead to advising this therapy are graded high, as correct ones. If not - the rules are marked as not working in this case and a scientist should be consulted to determine further steps. In this case, system can extend its knowledge basing on efficacy of therapies advised for specific diagnosis.

When the therapy does not bring expected results, a consultation with a specialist is needed, for which RDCS teleconsultation module is used. After accepting a consultation request, therapist can browse the individual's checkup file and get to know about previously applied therapy packages. Additionally, after analyzing eye movements signal, they should be able to give a more precise diagnosis and advice profiled therapy. If this therapy doesn't bring any development, the subject is invited for an individual treatment program.

3.5. Performance requirements

Power consumption	Two AA batteries enable Jazz to work constantly 10 hours (single checkup lasts about 10 minutes). Power supply for PocketPC is supplied via specially designed tray, stabilizing PCU during the test.
Scalability	Distributed network of servers for storing global data. Usage of up to 5 PCUs in single school is possible
Bandwidth requirements	To reduce amount of data being sent via local networks and the Internet, we apply signal encoding and compression
Mobility	Checkups can be conducted at any place at school, as PCU's cache module stores checkup data until synchronization with SSSC is possible.

Table 5. Performance requirements

3.6. Security

As **enlEYEght** system requires storing and transmitting the personal pupils' and teachers' data, we have emphasized security issues at both design and implementation stage. Every system component, Pocket PC, E-box and web server, stores personal data in secure way, taking advantage of encrypted databases – MS SQL CE and MS SQL Server. While designing **enlEYEght**'s communication model, we met the HIPAA standard. The HIPAA recommends using encrypted, secure connection while transmitting over open network and unencrypted connection while communicating within local network with authorized access. **enlEYEght** meets the standard by sending data via the Internet using SSL connection. In local school networks we use the WPA algorithm and mandatory user authentication both on PCU and SSSC. We have analyzed a possibility to encrypt the communication between PCU and SSSC by our own encryption standard, but the level of security given by the methods listed above is more appropriate for this application.

3.7. Tests

In order to ensure the highest quality of our product, we have applied various tests after each stage of the project's development. To test each component separately, we used NUnit, a Framework supporting unit tests for .NET platform. Next stage of tests included laboratory tests, focusing on the checkup procedure and communication between **enlEYEght**'s modules. During this phase we have confirmed reliable data transfer and solved some minor problems with connection between PCU and the Jazz. After completing laboratory tests, we carried out experiments in cooperation with primary school number 44 in Poznań. Thanks to the kindness of teachers and parents, we were able to check in real world environment how our system works. These final tests proved feasibility of our solutions, however they also showed some minor issues with checkup procedure.

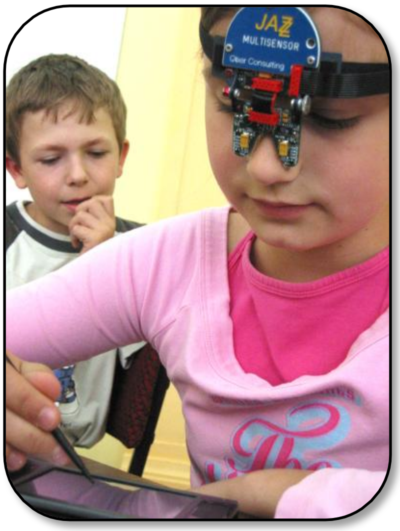


Figure 16. User test

4. Team overview

Our team had to challenge several trade-offs before **enlEYEght** was divided into subsystems and met all the mission goals. We discussed each alternative in the team and consulted trouble spots with specialists to choose the best option. The design of the components is based on the spiral model. Each increment was a functionally more complete and efficient version compared to the previous ones. This approach allowed for early prototyping, providing us with an indication of the main characteristics and limitations of the system functionality.

Thanks to Microsoft's Solutions Framework, we adjusted methodology to specific characteristic of our project. **enlEYEght** project has been divided into five phases: envisioning, planning, building, stabilizing and testing phase. Each phase involves future customers, users and specialists to deliver system's business value. First two of them were conducted by sharing vision of every team member. Following three are based on empowering each team member to take responsibility for management, design and development of certain system module, according to their skills and experience.

We established highly collaborative and self-managing team, consisting of four motivated, willing to learn peers knowing well their roles in the project and enjoying it.

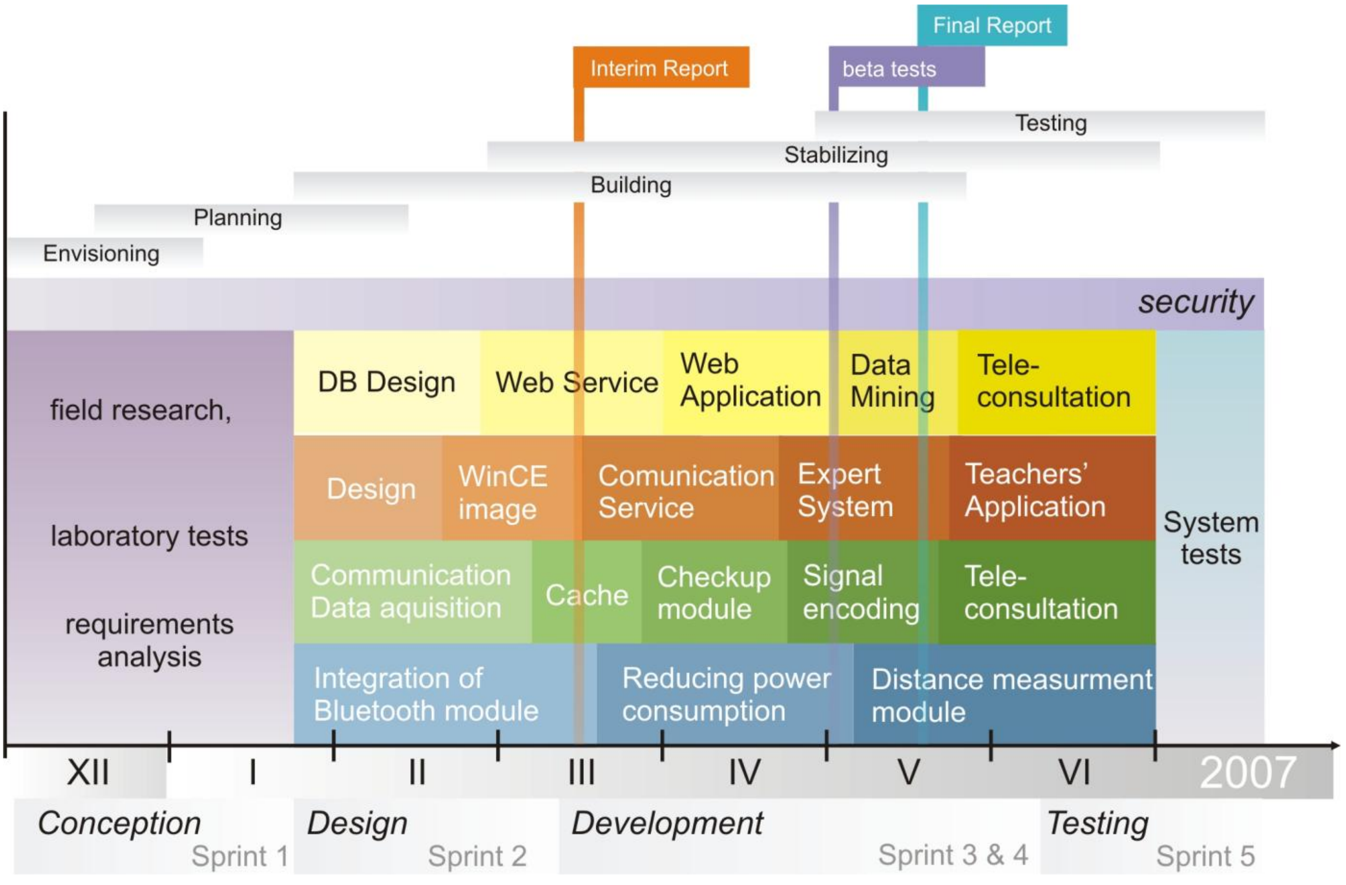


Figure 17. Teamwork

Mikołaj RDCS	environment analysis, requirements analysis, software development (**RDCS**)
Jakub SSSC	system architecture, software development (**SSSC**)
Piotr K. PCU	quality control, testing, software development (**PCU**)
Piotr Ś. Hardware	hardware design & development (**Jazz**)




Taking advantage of modern software development tools and ready-to-use components of .NET Platform, we could build our application in a relatively short period of time. Agile organization of our teamwork appeared to be more suitable for the project than more formalized methods.

According to MSF suggestion, in our teamwork much attention is paid to open communication between team members. We have introduced regular team meetings every week, organized voice conferences and shared documents via the project server. This approach enables each team member to know thoroughly the project and fully commit their knowledge and ideas.

5. Summary

enlEYEght provides worldwide unique system. Our solution is the first one which addresses reading disorder problem in complete way. We depend on solid methods, which were developed during years of scientific research and checked in work with children. Thus we can be sure of **enlEYEght**'s usefulness and efficiency.

We have used the latest achievements in cognitive sciences by developing dedicated software and hardware constituting **enlEYEght** – a perfect tool for early discovery of reading disorders at an early stage, when they can be effectively treated. The design and implementation of the system has been performed with the highest carefulness, with consideration of every detail. We have created complex architecture , including eye movements sensor, Pocket PC, eBox-2300 and server, which is essential for the realization and deployment of **enlEYEght**. User-friendly, intuitive interface enables teacher to easily conduct regular checkups, which provide detailed information about pupils' reading ability. **enlEYEght** provides also feedback, when problems are detected, in the form of treatment packages – sets of instructions and exercises, which should improve student's reading skill. It is crucial for the therapy process, that the pupil with its parents and the teacher follow given guidelines and exercise schedule. Pupils can exercise at school - under teacher's supervisory or at home - using print-outs. The third way is when the exercises are provided by the RDCS web application and a child solves them on the PC at home – we consider this functionality for future research and implementation.

From the economical point of view, **enlEYEght** creates totally new service in the market. Improving pupils' reading ability is primary schools' most important goal, so it is expected, that concern in our solution would be high in public and non-public education sector. The product we offer, is affordable and provides high quality software and hardware. We have reached out customer's needs in terms of system performance, interface ergonomics, security and safety. Our service quality will be constantly improved, as increase of number of recorded checkups will enhance diagnosis accuracy and treatment efficiency.

Impact, which **enlEYEght** will have on children education, is not to be neglected. Popularization of detailed reading ability checkups, now available only in several specialized centers, will result in overall increase in reading quality, one of the most important abilities in modern information-oriented society. Moreover data fetched during regular school check-ups will provide priceless information for researchers capable of discovering dyslexia causes and inventing more effective methods of detecting, treating or maybe even preventing reading disorders. **enlEYEght** is a huge step forward towards the world where **technology enables a better education for all**.