Smart-Bike as One of the Ways to Ensure Sustainable Mobility in Smart Cities

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Abstract. Ensuring sustainable urban mobility is based on the rational management of transportation system. This involves the infrastructure development and design of vehicles equipped with intelligent modules, which provide the control ability. The widespread use of environmentally friendly bicycles is constrained by a number of reasons. One of them is the absence of models designed for physically untrained people. This paper proposes the concept of the smart-bike control system, which was developed to help cyclist in the situations, when the values of his/her physical condition as well as parameters of environment are critical. Prototypes of the proposed system were tested in the laboratory environment.

Keywords: Sustainable mobility · Control system · Smart-bike · Sensors · Controllers

1 Introduction

The global trend of urbanization and population growth, which puts ever increasing pressure on the world's urban area, requires from the cities to develop a sustainable way of living. This sustainability is developed through environmental sustainable solutions combined with a full use of the possibilities, which are given by the digitalization of the society. This means enabling the technology to gather data, which can be used by the technology itself in order to adapt to the most sustainable and smart behaviour. Enabling the technology to communicate, to share the gathered data with people or other technologies, to borrow relevant data from elsewhere and to make the technology multi-functional - all of this provides solutions not only to one, but to multiple problems [1].

The Smart City concept can be defined as a model of the city development, which creates a surplus of resources through the use of information and communication technologies combined with sustainable and environmentally friendly multiple solutions. It emphasizes the need to improve the level of mobility and connectedness through collaboration and open source knowledge on all levels of the society [2].

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One of the main ways to create a Smart City is a Smart Transportation systems implementation, which is in line with the United Nations Sustainable Development Goals and the Transition to a Green Economy. As far as transport starts to be one of the main sources to produce air pollution, emissions of greenhouse gases, noise as well as one of the main reasons of the consumption of nonrestorable resources, household inconveniences caused, for example, by the neighborhood with a highway, etc. [3], the number of adherents of transition to a green economy is growing. They initiate the development of strategies and policy documents on sustainable development of the urban transportation systems.

Transition to a Smart Transport involves the development of appropriate infrastructure, which will ensure the rational management of transportation system, as well as the intellectualization of vehicles, which can provide a sustainable urban mobility.

2 Ensuring Sustainable Mobility in Smart Cities

2.1 Main Ways to Increase Sustainability of the City Transportation System

There are three main ways, using which cities can innovate to make transport more sustainable without increasing journey times:

- Better land use planning.
- Making existing transport modes more efficient.
- Moving towards sustainable transport.

Part of measures to ensure the transport sustainability is connected with planning for urban and suburban centers in accordance with the development, which is provided for a mixed fleet of vehicles and reasonable growth. Such principles of city development will help to reduce dependence on private vehicles and to ensure widespread use of public and non-motorized transport for short trips and for regular commuting into the city from the suburbs [4].

The UNEP report [5] states that, in order to achieve economic goals and objectives of sustainable transport development as well as integrated planning of this development and regulation system load, it is necessary to switch to fuels with lower carbon content and to implement a more extensive electrification of transport.

Safe public transport systems are considered often as an important tool to increase the safe of population mobility, especially, in urban areas suffering from growing traffic congestion. In many cities with high income, the policy to reduce the use of personal motor transport is particularly emphasized through investment in the development of public transport networks [6]. According to the Global Status Report on Road Safety 2015 [3], moving towards more sustainable modes of transport (such as cycling and public transport) has positive effects if associated road safety impacts have been well managed. These include increased physical activity, reduced emissions and noise levels, reduced congestion and more pleasant cities. Moreover, measures to promote safe public transport and non-motorized modes of transport are also in line with other global moves to fight obesity and to reduce noncommunicable diseases (such as heart disease, diabetes) [7].

2.2 Benefits of Using Bicycles as a Travel Mode and Examples of Their Implementation

Considering the fact, that the world community has set an objective to reduce the levels of greenhouse gases (first of all carbon dioxide) by 50% by 2050 [8], bicycles get an additional advantage, as this mode of transport does not produce CO_2 emissions. Furthermore, bicycling makes efficient use of roadway capacity and reduces congestion. The advantages of cycling include cheap infrastructure requirements and improvements of the public health. Bicycle pathways, lanes and parking require less space than their automobile counterparts. Cycling has direct health benefits: it is an aerobic exercise, which can minimize the risk of muscle and ligament injury, lower blood pressure and reduce the risk of heart disease [9]. Moreover, in urban areas, cycling can sometimes prove to be faster than other modes of transport and also allows cyclists to avoid traffic jams.

Thus, bicycling is a low-polluting and a low-cost transportation alternative and can be an important means to reach destinations, which are not serviced by transit [10]. But at the same time, cycling has a number of disadvantages, however, including a greater physical effort, the difficulty of carrying loads while cycling, being at the mercy of the weather, and, outside urban areas, travelling more slowly than motorized transport. Factors such as physical effort and speed also limit the distance, which a cyclist can travel [11].

Today, in some European cities – such as Amsterdam or Copenhagen – two-thirds of all road users are cyclists. In other words, it is perfectly feasible for a majority in a metropolis to ride a bike and not to travel by car. Not everybody can ride a bike every day, however, which is why the bike should not be seen as a competitor, but rather as complementary to public transport. Especially, on the way to and from work, there is a lot of potential: in London onle around 2.5% of all commutes to work are by bike, in Berlin it is 13%, in Munich – 15%, in Copenhagen and Amsterdam these numbers reach a whopping 36% and 37%, respectively.

Such a high percentage of trips to work or to education facilities by bicycles in Copenhagen is provided by the fact that the priority strategy of politicians is development of bicycles infrastructure as a way to create more friendly conditions to live in the city [12]. The so-called “carbon footprint” of Copenhagen is one of the smallest in the world (it is less than two tonnes per capita). But there is even more ambitious goal to become neutral on emissions has been set in its development strategy. To do this, there have been set very strict targets in order to follow energy efficiency standards, “green” construction and “green” energy. The city government approved the project of equipping bicycles with special sensors, which report on the level of pollution and traffic congestion in real time [13].

One of the most popular counter-argument about cycling are adverse climatic and natural conditions [14]. However, it is a matter of attitude and priority for cycle paths when clearing snow. It is confirmed by the example of Oulu, where there is a substantial proportion of people commute by bicycle, even when the temperature is below zero in deepest winter. This is ensured by 845 km of routes (4.3 m per inhabitant), 98% of which are maintained throughout winter because the main route maintenance prioritized over highways. Routes parallel to highways are separated with a green lane, which also serves as snow build-up space. There are underpasses in most busy crossings and it is possible to reach every place by bike using cycling routes [15].

Also, technology can be used not only to make better cars, but also better cycle paths, such as the proposed air-conditioned bike path in Qatar [16].

Introducing bicycle lanes is not enough to make a city attuned to cyclists' needs. Essential infrastructure in a city with the size and traffic volume of Moscow includes a strategy for secure parking lots and allows alternative ownership structures through a bike share system. Moscow decided to introduce various parking facilities appropriate for short-term and long-term parking and to introduce a bike sharing system similar to schemes in London, Barcelona and Paris [17]. To use such a system, person must register and receive a personalized card. In Barcelona, each one can rent a bike and leave it at any convenient point of the city, because there are bicycle parkings all over the major streets. An extensive network of bicycle paths and cycling facilities and services are also contributes to the development of this system [13].

Problem of the environmental pollution is a major issue in China with its notoriously poor air quality in large cities. Probably, this was the main reason of China's bicycle development [16]. In 2014 Lanzhou (Northwest China) was praised for integration Asia's second-largest bus rapid transit system with a bike share system (14,000 docks planned), bike parking, and greenways [18]. Bike share system is also implemented in such cities as Beijing, Zhuzhou, Shanghai, Wuhan and Hangzhou [19], where the popularity of this mode of transport is also provided by the widespread introduction of electric bicycles, which help physically untrained people to overcome steep climbs and long distances. That is why an increasing number of people choose non-motorized transport as a travel mode.

2.3 Ways to Increase the Attractiveness of Cycling

In conjunction with the foregoing, the population will prefer the cycling as a mode of transport in a case if there is a considerable advantage of its usage. The results of the population preferences research (Table 1) show that the number of people who choose bicycle as a mode of transport can be increased by the expansion of non-motorized model line-up and the integration of its infrastructure into the city road network system. What is more, cycling facilities and services should be developed. These steps, on the one hand, will help to enhance the attractiveness of bicycles for different groups of population and, on the other hand, will make roads safer and more secure particularly for non-motorized road users who are the most vulnerable.

In simplified form, ways to increase the attractiveness of non-motorized transport are shown on the Fig. 1.

Table 1. The results of the sampling survey of population.

Indicator	Students	Workers	Retiree	Other category	TOTAL
number of respondents	624	299	16	14	953
number of trips to work or education by public transport	313	109	-	-	422
number of trips to work or education by bicycles	50	7	-	-	57
number of trips to work or education by cars	163	133	-	-	296
number of trips to work or education by foot	98	50	-	-	148
number of bikes in the personal property	313	86	2	6	407
the number of drivers who are ready to transfer to bicycles, if there are:					
bikeways	127	56	0	0	183
bicycles parkings	129	46	0	0	175
bike hire system	75	28	0	0	103
the possibility to take the bike in buses or trams	76	21	0	0	97
E-bikes	78	22	0	0	100

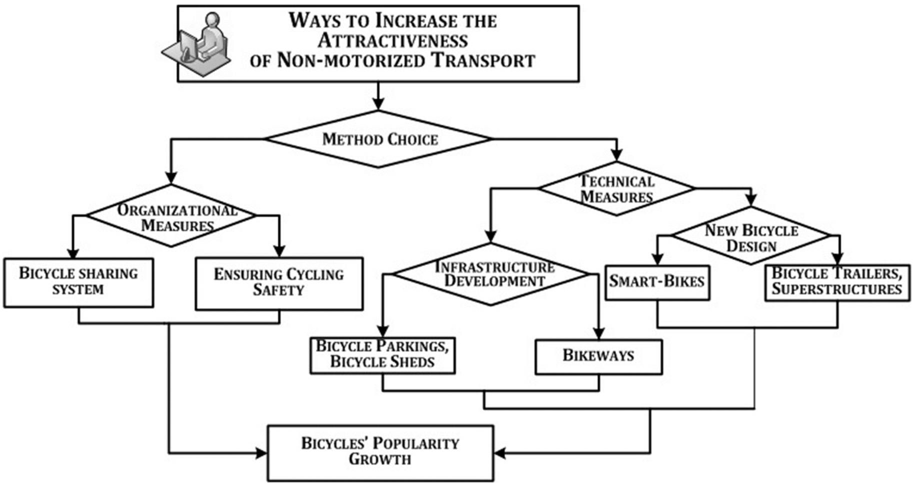

Fig. 1. Measures to implement for moving towards non-motorized modes of transport.

The case of Copenhagen proved that the attractiveness of cycling may be increased by the expansion of bicycles model line-up for different population groups and different use cases. In Copenhagen it is possible to rent not only conventional bikes, but also such models as [20]:

1. The Velomobile: it protects against wind, rain and drizzle; it is the best suited for long distances over 20 km and runs well on wide bicycle lanes outside the city; and also several users would cycle more in the rain if they had a similar cycle.
2. The Cargobike: it is good to transport children and to carry things and products; it is the best suited for short distances below 10 km.
3. The Recumbent: it is comfortable and good to ride on, especially, in headwind; it lends itself well to long distances over 20 km.

4. The Electric-assist Long John: it is good to carry cargo and children; it motivates to cycle more and drive less; it is fast, practical, fun and effortless to get around within the city.
5. The Electric Bicycle: it is fun and different to drive on; the electric slide is a good help, especially uphill and against wind.

Bicycle infrastructure planning should include the creation of bike parkings, bike sheds and bikeways as well as it should be taken into account the terrain and the structure of population, who want to use the bike to get around the city. Despite a fast growing literature on the bike lanes design [21–24], the problem of terrain identification and topographic conditions modeling is still actual. The most common method of bicycle wayfinding is the shortest path method.

As far as bicycle routing is not always possible to avoid hilly terrain, bike-lifts and electric drives creation can solve the problem of overcoming steep climbs. In contrast to the electric scooter or motorcycle, e-bike may be driven by pedals. At this time electric drive is off and accumulator is charging.

E-bikes are generally different from ordinary bicycle because of three additional components presence such as an electric motor, a storage battery and a battery controller. Despite of electric drive presence, electric bike is used approximately the same as an ordinary bicycle and in most countries does not require a presence of the driving license or license plate. Electric bicycle is suitable as a vehicle for a wide range of people with the different level of abilities, as it is easy to dose physical training. There is a number of disadvantages of electric bicycle, which makes it difficult to use. They are following: significant weight (from 20 to 50 kg or more) and the corresponding inertia; lack of power reserve on the drive (rarely more than 25–50 km); long battery charging (usually at least 2–6 h); short service life of lead-acid and lithium-ion storage batteries; the high cost of the final product and its use compared with an ordinary bicycle cost and use (from 2 to 10 times).

3 Smart-Bikes: One of the Ways to Ensure Sustainable Mobility

One of the ways to ensure sustainable mobility in Smart Cities is to combine the possibilities of bicycles and electric transport.

3.1 Idea of the Smart-Bike Control Realization

Electric bicycles are controlled by cycling computer (controller), which is supposed: to supply amperage from the battery to the electric motor in accordance with the user's settings; to show residual battery charge on the indicator; to determine the rotation/stop of pedals; to limit the maximum speed of the bicycle movement in order to save energy; to keep constant speed (cruise control); to charge the battery while braking.

At the same time, there is a variety of velosimulators, which are belong to the group of cardiovascular machines equipped to control the physical condition of a user. Also the main indicator to diagnose critical state is a pulse rate. As far as the parameters of the bicycle motion are influenced by both condition of the cyclist and the parameters of the environment, the rational management should be based on monitoring, analysis as well as taking into account all these factors.

Today there are two types of systems, which are used to analyze bicycle's characteristics and motion parameters. They are:

- Cycling computers – electronic devices to measure the speed and daily run of bicycle as well as such additional parameters as average speed, travel time, full speed, transmission (for multi-speed bikes), running time, temperature, atmosphere pressure, cadence (pedal rotation frequency), etc.
- Smart phones applications – applications, which duplicate functionality of cycling computer, except the ability to monitor the transmission and cadence, use built-in phone sensors such as GPS, accelerometer, barometer.

To implement the smart-bike control idea, it is necessary to design a system, which combines cycling computer, motorized wheel (it is the type of a driving wheel: complicated mechanism, which combines the wheel itself, electric motor, power gear and braking system) and velosimulator to control the physical condition of a user. Sensors readings are transmitted into the controller for the further analysis. In critical cases (when the physical cyclist's condition is bad) the system sends the request to turn on the electric drive and after receiving the confirmation from user electric drive control is transferred to the controller.

Thus, if to equip the bicycle with the universal module, which includes a pulse sensor, a controller and other components that are shown on the Fig. 2, and to manage it in accordance with the selected program installed on smartphone, it will help to increase the attractiveness of cycling among untrained population.

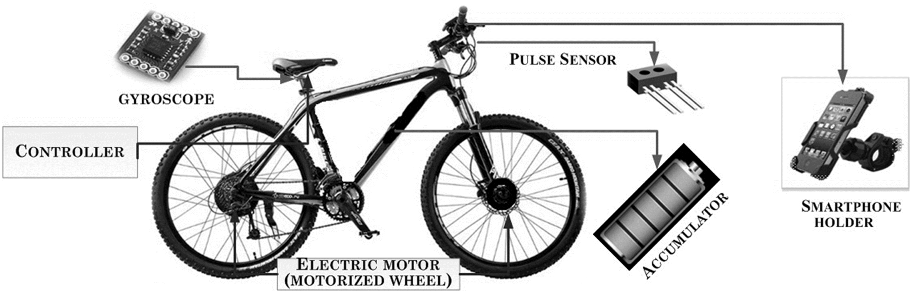

Fig. 2. The elements, which are included in the developed module.

3.2 Functional Requirements for the Control System

Existed sensors and controllers can be used to implement the concept of smart-bike. To determine the condition of the cyclist and to monitor travel times, the following devices are required:

- means of cyclist identification – to set his physical characteristics in the rest condition;
- pulse sensor – to determine heart rate;
- timer – to determine the travel time, setting training modes.

To measure the parameters of the bicycle will be required:

- gyroscope/accelerometer – to determine the position of the bicycle in the area;
- speedometer – to determine the travel speed;

– sensor of used chain sprockets;
– GPS sensor – to determine position and route setting.

Module, which determines the weather conditions on the route and transmits it to a smartphone, is required to establish parameters of the environment.

While designing bicycle control system it should be taken into account that the control system is completely autonomous, and the interference from the cyclist is impossible, so it may be unsafe for the rider. That is why the principle of feedbacks between control system and person should be implemented with the help of notifications. In this way, the possibility of accidents in electric drive, which could cause bicycle false alarm, will be excluded.

3.3 Algorithm of Smart-Bike Control System

Bicycle movement is provided by the cyclist, who sets the driving speed and the movement direction. It means that cyclist manages the process of cycling. But at the same time, cycling parameters depend on environmental conditions (including the terrain characteristics), natural conditions, time of the day and physical conditions of cyclist. In short, cycling parameters depend on everything, which affects the possibility of bicycle movement. If we consider the “bicycle” system, its functioning is provided by the interaction between such subsystems as “external environment” – “infrastructure” – “bicycle” – “cyclist”. To ensure the traffic safety, it is necessary to establish a control system, which implements the interaction between subsystems for rational functioning of the system.

While designing bicycle control system, the list of monitored events and the system’s responses was made (Table 2).

There is a data analysis algorithm of the smart-bike control system on the Fig. 3.

Table 2. List of the bicycle control system’s events.

№	Event	Response
1	Cyclist’s pulse > optimal heart rate (OTP)	Display of overcoming the training threshold, offer to turn on the electric drive
2	Road gradient > 15° (uphill)	Display of the warning of an uphill, offer to turn on the electric drive
3	Cyclist’s pulse > OTP + 50	Display of excessive overcoming the training threshold, offer to stop for the rest or to continue motion completely on electric drive
4	Road gradient < –15° (downhill)	Display of the warning of a downhill, electric drive’s switching-off, accumulator charging
5	Non-stop travelling during more than 1 h	Display of the need to have a rest, offer to stop for the rest or to turn on the electric drive
6	Non-stop travelling during more than 2 h	Display of excessive overcoming the training threshold, offer to stop for the rest or to continue motion completely on electric drive
7	Travel speed < 15 km/h during 15 s	Display of the offer to turn on the electric drive

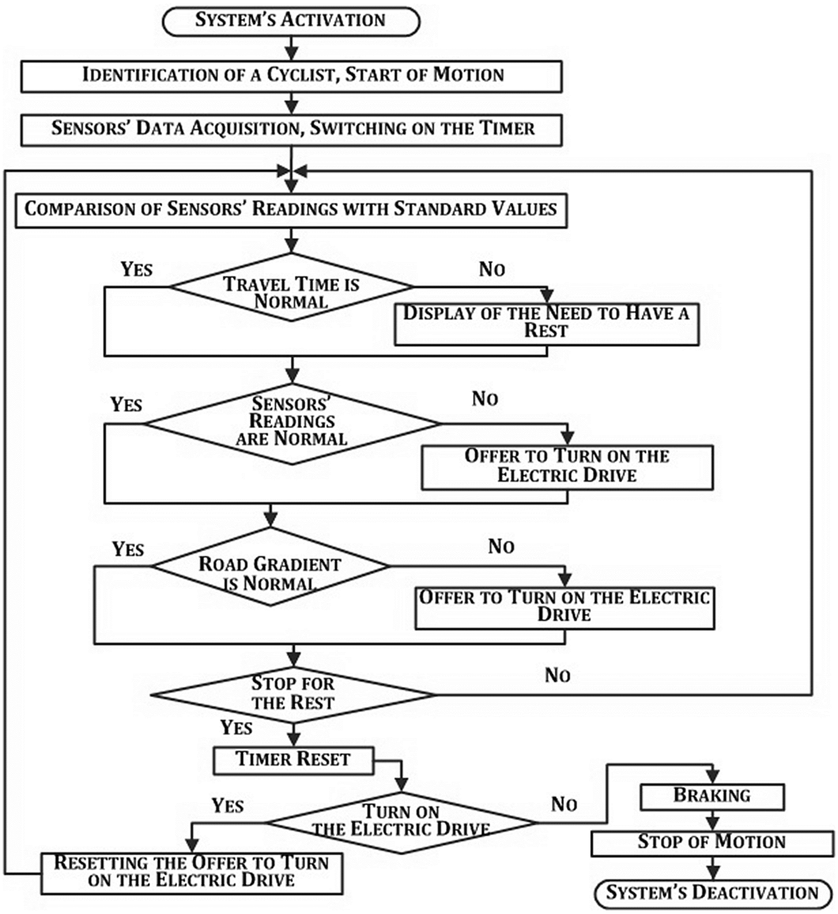

Fig. 3. Data analysis algorithm.

The Table 3 shows one of the system's operation scenarios. If cyclist's pulse value is higher than OTP and the movement speed is less than average speed that is usual for this person, the screen displays an offer to turn on the electric drive. When the pulse value and the speed become normal, the electric drive switches off.

Table 3. An example of the script «Turn on the Electric Drive».

Step	Event	Action
1	The value of the pulse exceeded OTP, movement speed is less than 15 km/h	User's condition data collecting (pulse, weight, height, location tracking, etc.) Comparison of these indicators with the "reference" values for a particular cyclist. Display of overcoming the training threshold. Offer to turn on the electric drive
2	Heart rate decrease	Electric drive's switching-off, resetting the display of overcoming the training threshold

To determine the cyclist's optimal heart rate (OTP) the formula (1) may be used:

$$OTP = (220 - A - PRC) \cdot K + PRC. \tag{1}$$

where OTP – optimal training pulse;
PRC – pulse in the rest condition;
A – cyclist's age;
K – coefficient which varies depending on the cyclist's preparation level: K = 0.6 for the freshman, K = 0.65 for a man of medium-level training, K = 0.7 for well-trained person.

Thus, the developed system analyzes sensors' readings and, if values of cyclist, bicycle and environment parameters are not normal, it warns the cyclist about the critical case as well as offers solutions for these problems.

3.4 Implementation of the System and Test Results

Conceptual scheme of interaction between modules of the developed system is shown on the Fig. 4.

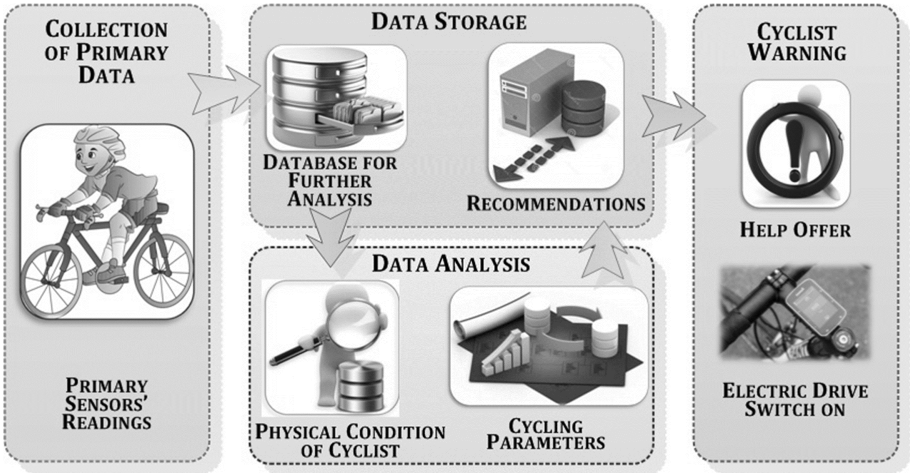

Fig. 4. Conceptual model of interactions between system's modules.

Primary data collection is realized using MPU6050 digital sensors and Pulse Sensor (plug-and-play heart-rate sensor for Arduino). These sensors being located on the steering wheel, on the frame and wheels as well as on cyclist are connected to the Arduino board via the I2C protocol. The motor-wheel MXUS XF39-30H is controlled by Arduino board. Connection to the smartphone is realized via the Bluetooth wireless connection. Sensors' readings are transmitted to the smartphone and then they come into the Microsoft SQL Server database for storage and processing. An example of the control realization scheme is shown on the Fig. 5.

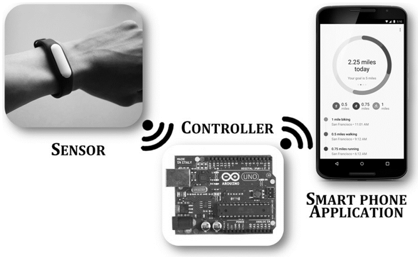

Fig. 5. Control realization scheme.

The application for smartphones, which was developed with the help of Android Studio in Java, allows to manage the sensor system according to the above-described algorithm and taking into account the state of the external environment as well as the cyclist itself.

The prototype of the developed system was tested in laboratory conditions. The results of tests confirmed that even physically weak category of people can use a bike equipped with the developed system as a mode of transport. Moreover, the widespread introduction of bicycles with such system allows to improve the road safety by avoiding accidents, which are related to fatigue or to a sharp deterioration of cyclists' physical appearance.

4 Conclusion

Despite the obvious advantages of using bicycles for short distances, there are still a lot of obstacles to the widespread use of the bicycles as an alternative travel mode. Some of these problems can be solved by use of smart-bikes with adaptive electric drive, which turns on when it's necessary. Since the intellectual smart-bike control system uses sensors' readings of the cyclist's physical condition and of the environmental parameters for decision-making, it will help even physically untrained people to overcome steep climbs and long distances without overload. The development of bicycles infrastructure and its integration into the public transport system will contribute to use of bicycle and public transport.

Moving towards non-motorized modes of transport is one of the key elements to ensure the sustainable urban mobility. Moreover, the experience of developed countries shows that this clean and efficient kind of transportation contributes also to the development of economy. Besides that, the health and longevity are also benefits from cycling. As it is seen in Denmark, the cycling benefits are seven times greater than the cost of accidents, in money value the total health impact is worth 230 million Euro.

References

1. GREEN CAPACITY. http://greencapacity.ru/ru/information/smart-cities
2. Smart cities Preliminary Report (2014). http://www.iso.org/iso/smart_cities_report-jtc1.pdf

3. Global status report on road safety (2015). http://www.who.int/violence_injury_prevention/road_safety_status/2015/GSRRS2015_Summary_EN_final.pdf
4. Share the Road: Investment in Walking and Cycling Road Infrastructure. http://www.unep.org/Transport/sharetheroad/PDF/str_GlobalReport2010.pdf
5. Global “green” new deal. Policy Brief. http://www.unep.org/pdf/GGND_Final_Report.pdf
6. Makarova, I., Khabibullin, R., Belyaev, E., Mavrin, V.: Increase of city transport system management efficiency with application of modeling methods and data intellectual analysis. In: Sładkowski, A., Pamuła, W. (eds.) Intelligent Transportation Systems – Problems and Perspectives. Studies in Systems, Decision and Control, vol. 32, pp. 37–80. Springer, Warsaw (2015)
7. Global Report on Human Settlements. http://unhabitat.org/books/planning-and-design-for-sustainable-urban-mobility-global-report-on-human-settlements-2013/
8. Share the Road Programme. http://www.unep.org/Transport/sharetheroad/
9. Tsenkova, S., Mahalek, D.: The impact of planning policies on bicycle-transit integration in Calgary. Urban Plann. Transp. Res. Open Access J. **2**, 126–146 (2014)
10. Handy, S., Xing, Y.: Factors correlated with bicycle commuting: a study in six small US cities. Int. J. Sustain. Transp. **5**, 91–110 (2011)
11. Heinen, E., Wee, B., Maat, K.: Commuting by bicycle: an overview of the literature. Transp. Rev. **30**, 59–96 (2010)
12. Bredal, F.: The case of Copenhagen. In: Changing Urban Traffic and the Role of Bicycles: Russian and International Experiences, pp. 24 – 28. Friedrich-Ebert-Stiftung, Moscow (2014)
13. Smart City. http://city-smart.ru/info/125.html
14. Ernits, E., Pruunsild, R., Antov, D.: Links between road accidents and winter road conditions. Transport **4**(4), 2681–2703 (2015)
15. Tahkola, P.: The case of Oulu. In: Changing Urban Traffic and the Role of Bicycles: Russian and International Experiences, pp. 2943. Friedrich-Ebert-Stiftung, Moscow (2014)
16. Appenzeller, M.: Cycling – past, present and future. In: Changing Urban Traffic and the Role of Bicycles: Russian and International Experiences, pp. 11–18. Friedrich-Ebert-Stiftung, Moscow (2014)
17. Mityaev, A.: The case of Moscow. In: Changing Urban Traffic and the Role of Bicycles: Russian and International Experiences, pp. 72–79. Friedrich-Ebert-Stiftung, Moscow (2014)
18. 4 Cities Developing The World’s Best Sustainable Transport Systems. http://www.fastcoexist.com/3025399/4-cities-developing-the-worlds-best-sustainable-transport-systems
19. Zhang, L., Zhang, J., Duan, Z., Bryde, D.: Sustainable bike-sharing systems: characteristics and commonalities across cases in urban China. J. Cleaner Prod. **97**, 124–133 (2015)
20. Bicycle innovation lab. http://www.bicycleinnovationlab.dk/activities/data-popular-bikes?show=lgg
21. Parkin, J., Rotheram, J.: Design speeds and acceleration characteristics of bicycle traffic for use in planning, design and appraisal. Transp. Policy **17**, 335–341 (2010)
22. Larsen, J., Patterson, Z., El-Geneidy, A.: Build it. But where? The use of geographic information systems in identifying locations for new cycling infrastructure. Int. J. Sustain. Transp. **7**, 299–317 (2013)
23. Forsyth, A., Krizek, K.: Urban design: is there a distinctive view from the bicycle? J. Urban Des. **16**, 531–549 (2011)
24. Rybarczyk, G.: Simulating bicycle wayfinding mechanisms in an urban environment. Urban, Plann. Transp. Res. Open Access J. **2**, 89–104 (2014)