# Mechatronics of the inspective robot 

Józef Giergiel, Krzysztof Kurc<br>Department of Applied Mechanics and Robotics, Rzeszow University of Technology j.giergiel@chello.pl, kkurc@poczta.onet.pl

Received (15 May 2006)
Revised (23 May 2006)
Accepted (15 June 2006)


#### Abstract

The abstract in this paper was presented the project and prototype of inspective robot, he was permitting on monitoring and the analysis of technical state of inside part of pipes. Kinematics and dynamics were determined, it main mechanical, electronic components were described as well as the chart of power was introduced.


Keywords: Construction, kinematics, dynamics, simulations, control system

## 1. Introduction

Modern inspective robots substitute for the person's in dangerous, unavailable places. To Permitting minimization of side effects, the breakdown and expenses of removing. The research of pipelines is a popular method of inspection of the existing pipeline from the interior as well as checks on the new pipeline. All over the world existing thousands of kilometers transferring media of the various kind of pipes which require periodic service. The paper can afford presenting of the concept of the robot of the inside being able to make an inspection of the pipe on the purpose.

Robot inspective to pipes it is a prototype of the device intended for applications of control pipelines about the circular section. A lot of solutions to this type of robots are existing already $[1,2,5,6,7]$ however the great majority has the ability to control only horizontal sections of pipes from them.

Problems are rising when many physical hindrances are making inspection difficult, they belong to them:

- bends and elbow about the angle $90^{\circ}$ - this of limitations to come most often,
- pipe under angle the bigger than $10^{\circ}$,
- valves with the reduced of transit opening, and the like.

Geometry of the robot is dependent on the diameter of the pipe in the first order, and next from hindrances the robot will meet which during work. The presented solution will permit for control of horizontal, vertical and curved pipelines, as well as surmount obstacles e.g. so how contraction in area pipes.

## 2. Construction of the robot

### 2.1. Guidelines constructional and maneuver robot

Elaboration of the construction of the robot permit to monitoring and the analysis of the technical state of internal parts of the various kind of pipes about the circular section. Tested pipes are able to be horizontal, vertical, about the radius of curvatures R .

The construction of the robot should be modular, what a chance of the quick change of the configuration will be, e.g. exchange of leading and driving arms of wheels in order using him for pipes about the bigger diameter

The robot will be consist from:

- of mobile platform,
- of control console.

Communication will be happening between the mobile platform but the control console of the wire what is conditioned on the kind of the tested pipe.

Table 1 Guidelines technical parameters of the robot

| Diameter of research pipes $\phi$ | Dependent from shins of wheels. <br> It is in the present configuration 140 for 155 mm. |
| :--- | :--- |
| Kind of research pipes | Arbitrary about the circular section |
| Position of research pipes | Arbitrary |
| Communication | Long distance cable |

The robot will be moving in simple and curved sections of pipes about the diameter $\phi$ and radius of curvatures R dependent from:

$$
\begin{equation*}
R \geq 1,5 \phi \tag{1}
\end{equation*}
$$

### 2.2. Prototype of the robot

The project of the robot was realized in the application Autodesc Inventor. The mobile platform are posing of two modules wheeled Figure 1 merged with the joint of Cardan whom the application is making possible overcoming of curvatures of pipelines.

First module "A" Figure 1, team of three wheeled modules arranged after the circumference are entering to his composition what directed towards $120^{\circ}$ along the pipe, and is located on his platform: the motor with the gear, the camera, lighting up and the like.

Second module "B" it is rotor Figure 1, consisting of three wheeled modules arranged after the circumference what $120^{\circ}$, of whom every of wheels is sloping to the axis of the pipe under the same angle.


Figure 1 Mobile platform
Motor with the gear rotating the rotor ( n - rotation of the rotor) he is propelling wheels of the rotor of whom is the axis pulled back from the axis of the pipe for the angle $\alpha$ Figure 2. Mobility of the whole platform was obtained through this deviation ( $V$ - speed of the robot).


Figure 2 Module ,,B" (rotor)
Accepted angle of the slant of wheels of rotors $\alpha$ is so small that he will assure self-locking of whole design what special importance has during the research of vertical sections of pipes. The robot is being fitted together and pairs from subassemblies which are merged kinematics classes V.

## 3. Modeling of kinematics

Description kinematics robots we are giving equations kinematics, which to describe linear or angle parameters of movement of arbitrary points. In case of mobile robots wheeled we are analyzing the inverse task kinematics in whom we are to assume


Figure 3 Robot in front of putting together
something the path of the movement of the characteristic point of the robot and we are determining parameters of the movement [3, 4]. Parameters of the movement will be necessary to the analysis of the inverse task of dynamics.

### 3.1. Inverse task of kinematics

To the description of the movement of the inspection robot Figure 1, a model was accepted on Figure 4. Basic parts of this model it: motor with the gear transmission 1 , cogwheel of the motor 2 , cogwheel on the left part of the joint of Cardan 3, wheel arm 4, left part of the joint of Cardan 5, driven wheel 6 , right part of the joint of Cardan 7 , arm of wheels of the rotor 8 , driving wheel of the rotor 9 .

Analyzing the inverse task kinematics is betting that the point B will be moving after the given trajectory. He is also betting, that point A will be moving with the given value of the speed $\mathrm{V}_{A}$.

From the following system of equations:

$$
\begin{array}{r}
\dot{f}\left(x_{B}, y_{B}, z_{B}\right)=0 \\
\dot{y}_{B}=V_{A} \cos (\gamma-\delta / 2)-l_{1} \dot{\gamma} \sin \gamma \\
\dot{z}_{B}=V_{A} \sin (\gamma-\delta / 2)+l_{1} \dot{\gamma} \cos \gamma \\
\dot{y}_{F}=V_{A} \cos (\gamma-\delta / 2)+l_{2} \dot{\beta} \sin \beta \\
\dot{z}_{F}=V_{A} \sin (\gamma-\delta / 2)-l_{2} \dot{\beta} \cos \beta \\
\dot{\gamma}=\dot{\beta}+\dot{\delta} \\
\frac{V_{B} \pi}{60\left(l_{4}+r_{2}\right) t g \varphi}=\frac{z_{S} \dot{\alpha}}{z_{K} \cos \delta} \\
l_{5} \dot{\beta} \cos \beta-l_{2} \dot{\beta} \sin \beta=l_{5} \dot{\gamma} \cos \gamma+l_{1} \dot{\gamma} \sin \gamma \\
l_{5} \dot{\beta} \sin \beta+l_{2} \dot{\beta} \cos \beta=l_{5} \dot{\gamma} \sin \gamma-l_{1} \dot{\gamma} \cos \gamma
\end{array}
$$



Figure 4 Model inspective of robot with timetable of vectors of the speed
were determined as parameters of the movement are changing in the time.

### 3.2. Simulations of the inverse task kinematics of inspective robot

On the basis of the above-mentioned analysis take a computer simulation of the movement of the inspective robot, assuming that his point $B$ is moving after the trajectory shown on Figure 5a, moreover data were accepted:

$$
\begin{gathered}
l_{1}=A B=0.037[\mathrm{~m}] \quad l_{2}=A F=0.037[\mathrm{~m}] \quad l_{3}=F G=0.057[\mathrm{~m}] \\
l_{4}=B C=0.057[\mathrm{~m}] \quad l_{5}=B E=E F=0.3[\mathrm{~m}] \quad r_{1}=r_{2}=r=0.015[\mathrm{~m}]
\end{gathered}
$$

The simulation was carried out analyzing six characteristic periods of the movement of the robot:

- driving after the path horizontally - starting 1 Figure 5a when:

$$
V_{A}^{*}=\frac{V_{A}}{t_{r}}\left(t-t_{p}\right), t_{p} \leq t \leq t_{r}, \quad \gamma=0, \beta=0
$$

- movement determined 2 Figure 5 a when: $V_{A}=$ const,

$$
t_{r} \leq t \leq t_{1}, \quad \gamma=0, \quad \beta=0
$$

- driving after the circular path 3 Figure 5 a when: $V_{A}=$ const,

$$
t_{1} \leq t \leq t_{2}, \quad \gamma \neq 0, \beta \neq 0
$$

- departure from the arch 4 Figure 5a when:

$$
V_{A}=\text { const }, \quad t_{2} \leq t \leq t_{3}
$$

- driving after the path vertically 5 Figure 5 a when: $V_{A}=$ const,

$$
t_{3} \leq t \leq t_{4}, \quad \gamma=\beta=\frac{\pi}{2}
$$

- and braking 6 Figure 5a when:

$$
V_{A}^{*}=V_{A}-\frac{V_{A}}{t_{h}}\left(t-t_{4}\right), t_{4} \leq t \leq t_{S}, \quad \gamma=\beta=\frac{\pi}{2}
$$



Figure 5 Assumption path of the movement point B (a) and assumed course of the speed point A (b)

Route of the speed of the point A in the time from $\mathrm{t}_{P}$ for $\mathrm{t}_{S}$ were shown on Figure 5b. Calculations were realized with the taking into consideration of symbolic and numeric transformations of package Maple.

On Figure 6. presented how chosen parameters of the movement of the robot are changing during the analysed movement.

On Figure 6a presented how a speed is being changed during the analysed movement selected of point A. On Figure 6c presented paths of the movement of characteristic points B and F. On Figure 6d presented how the corner and the angular velocity are changing during the movement of the inspective robot on the shaft of the motor $\alpha$, $\dot{\alpha}$. On Figure $6 \mathrm{e}, \mathrm{f}$ presented angle of rotation modular ,, $\mathrm{A} "-\beta$, and angle of rotation modular ,, $\mathrm{B} "-\gamma$.

Analyzing shown characteristics on Figure 6. they observed that beginning of the path of the movement of the point F and namely the coordinate $\mathrm{y}_{F}$ is equal zero, however of point B the coordinate $\mathrm{y}_{B}$ is equal to the distance $\mathrm{l}_{1}+\mathrm{l}_{2}$. Yes how they assumed trajectory of the movement of the point B Figure 6 b how and of remaining points of the robot dependent on the profile of the pipe and this connection is simple horizontal of elbow and simple vertical. Trajectory of the movement of the point F of the robot to following behind trajectory of the movement of the point B taking


Figure 6 Route of characteristic parameters of the movement of the robot
into consideration lengths 11,12 , and presented angles (Figure 6 e , Figure 6 f ) $\gamma$ and $\beta$. Figure 6.d presented angle of rotation and angular velocity on the shaft of the motor. For better illustrating and the comparison from angle of rotation angular velocity were increased twenty times Figure 6d. To follow angular velocity Figure 6 d we are watching three characteristic intervals: accelerate, movement at the speed insignificant variable during drive through elbow arch and braking.

Computer simulation of the inverse task kinematics, will make the solution to the inverse task of dynamics which we will receive information about the driving moment of the motor from possible.

## 4. Modeling of dynamics

In case of the description of the movement of mobile robots they are interesting us chiefly inverse task kinematics and dynamics [3, 4]. Analyzing issues of dynamics of mobile robots, we are looking for relationships between the movement of the setup, and with reasons which are causing this movement, that is of operating force. This dependence is resulting from dynamic equations of the movement. It is possible to apply various methods known in mechanics which possible arranging of dynamic equations of the movement.

### 4.1. Inverse task of dynamics of inspective robot

To determining the driving moment equations was utilized Lagrange'a II of kind in the neoconservative field. To counts of the robot (Figure 7a) [1, 2] a replacement
model was accepted shown on Figure 7b, where: 1- leading wheels, 2 - wheel arms, motor, camera and strengthening sheet metal, 3 - left part of the joint of Cardan with cogwheel, 4 - right part of the joint of Cardan with arms of driving wheels, 5 - driving wheels, $\dot{\alpha}$ - angular velocity on the shaft of the motor, $\dot{\alpha}_{1}$ - angular velocity leading wheel $1, \dot{\alpha}_{L}$ - angular velocity of left part of the joint of Cardan, $\dot{\alpha}_{P}$ - angular velocity of right part of the joint of Cardan, $\dot{\alpha}_{5}$ - angular velocity driving wheel 5 .


Figure 7 Inspective robot (a), substitute model of the robot (b)

The movement of the model was characterized using equations Lagrange'a II of kind. Determining kinetic energy of the robot which work is an amount of energy of kinetic each members to use Figure 7b.

$$
\begin{gather*}
E=E_{1}+E_{2}+E_{3}+E_{4}+E_{5}  \tag{3}\\
E=3\left(\frac{1}{2} m_{1} V_{G}^{2}+\frac{1}{2} I_{G x} \dot{\alpha}_{1}^{2}\right)+\frac{1}{2} m_{2} V_{F}^{2}+\frac{1}{2} m_{3} V_{F}^{2} \\
+\frac{1}{2} I_{F z} \dot{\alpha}_{L}^{2}+\frac{1}{2} m_{4} V_{B}^{2}+\frac{1}{2} I_{B z} \dot{\alpha}_{P}^{2}+3\left(\frac{1}{2} m_{5} V_{C}^{2}+\frac{1}{2} I_{C z} \dot{\alpha}_{5}^{2}\right) \tag{4}
\end{gather*}
$$

Introducing dependence kinematics kinetic energy of the robot was written
down:

$$
\begin{array}{r}
E=\frac{z_{S}^{2} \dot{\alpha}^{2}}{z_{K}^{2}}\left[\frac{1800\left(l_{4}+r\right)^{2} t g^{2} \varphi}{\pi^{2}}\left(3 m_{1}+\frac{3 I_{G x}}{r^{2}}+m_{2}+m_{3}+m_{4}\right)+\right. \\
\left.\frac{3}{2} l_{4}^{2} \cos ^{2} \varphi\left(\frac{I_{C z}}{r^{2}}+m_{5}\right)+\frac{1}{2}\left(I_{F z}+I_{B z}\right)\right] \tag{5}
\end{array}
$$



Figure 8 Model of the robot with put strength during transport upwards (a) and down (b)

The right side i.e. generalized force during drive of the robot upwards and down were determined from the amount of work of prepared each elements Figure 8a,b:

$$
\begin{equation*}
Q \delta \alpha=\sum_{i=1}^{5} \delta L^{(i)}=\delta L^{(1)}+\delta L^{(2)}+\delta L^{(3)}+\delta L^{(4)}+\delta L^{(5)} \tag{6}
\end{equation*}
$$

$Q \delta \alpha=3\left(-N_{1} f_{1}-G_{1} r\right) \delta \alpha_{1}-G_{2} \delta r_{F}-G_{3} \delta r_{F}-G_{4} \delta r_{B}+\left(-3 N_{2} f_{2}-3 G_{5} r+\operatorname{Pr}\right) \delta \alpha_{5}$
Introducing forces dependences and relationships between vectors of the virtual shift and virtual circulation but virtual circulation received on the shaft of the
motor strength generalized the one:

$$
\begin{array}{r}
Q=\left(-180 z_{S} N_{1} f_{1} \operatorname{tg\varphi }\left(l_{4}+r\right) \mp 180 z_{S} G_{1} r \operatorname{tg} \varphi\left(l_{4}+r\right) \mp\right. \\
60 z_{S} G_{2} r \operatorname{tg\varphi }\left(l_{4}+r\right) \mp 60 z_{S} G_{3} r t g \varphi\left(l_{4}+r\right) \\
\mp 60 z_{S} G_{4} r t g \varphi\left(l_{4}+r\right) \mp 3 z_{S} G_{5} l_{4} r \pi \cos \varphi  \tag{8}\\
\left.-3 z_{S} N_{2} f_{2} l_{4} \pi \cos \varphi+M_{S} z_{K} r \pi \cos ^{2} \varphi\right) / z_{K} \pi r
\end{array}
$$

In dependence (8) in marking $\mp$ sign "-" appears during driving upwards, whereas " + " down.

After executing necessary mathematical operations in Maple resulting from equalization Lagrange'a II of kind, a moment was determined on the shaft of the engine during transport of the robot upwards and down (9) is:

$$
\begin{align*}
& M_{S}=\left[\begin{array}{l}
\frac{\left(3 m_{1} l_{4}^{2}+m_{2} l_{4}^{2}+m_{4} l_{4}^{2}+m_{3} l_{4}^{2}+3 I_{G x}\right) 3600 z_{S}^{2} \ddot{\alpha}}{z_{K}^{2} \pi^{2} \cos ^{2} \varphi} \\
+\frac{\left(m_{3}+m_{4}+m_{2}+3 m_{1}\right) 3600 z_{S}^{2} r^{2} \ddot{\alpha}}{z_{K}^{2} \pi^{2} \cos ^{2} \varphi}+\frac{21600 I_{G x} l_{4} z_{S}^{2} \ddot{\alpha}}{z_{K}^{2} \pi^{2} r \cos ^{2} \varphi} \\
+\frac{\left(m_{2}+m_{3}+m_{4}+3 m_{1}\right) 7200 z_{S}^{2} r l_{4} \ddot{\alpha}}{z_{K}^{2} \pi^{2} \cos (\varphi)^{2}}+\frac{10800 I_{G x} x_{4}^{2} z_{S}^{2} \ddot{\alpha}}{z_{K}^{2} \pi^{2} r^{2} \cos (\varphi)^{2}}
\end{array}\right] \tan ^{2} \varphi \\
& +\left[\begin{array}{c}
\frac{180 z_{S} N_{1} f_{1} l_{4}}{z_{K} \pi \cos ^{2} \varphi^{\varphi}}+\frac{60 z_{S} r\left( \pm G_{4} \pm G_{3} \pm 3 G_{1} \pm G_{2}\right)}{z_{K} \pi \cos ^{2} \varphi} \\
+\frac{60 z_{S}\left( \pm G_{4} l_{4} \pm 3 G_{1} l_{4} \pm G_{2} l_{4}+3 N_{1} f_{1} \pm G_{3} l_{4}\right)}{z_{K} \pi \cos ^{2} \varphi}
\end{array}\right] \tan \varphi \quad \pm \frac{3 z_{S} G_{5} l_{4}}{z_{K} \cos \varphi}  \tag{9}\\
& \quad+\frac{3 I_{C z} l_{4}^{2} z_{S}^{2} \ddot{\alpha}}{z_{K}^{2} r^{2}}+\frac{\left(I_{F z z}+I_{B z}+3 m_{5} l_{4}^{2} \cos ^{2} \varphi\right) z_{S}^{2} \ddot{\alpha}}{z_{K}^{2} \cos ^{2} \varphi}+\frac{3 z_{S} N_{2} f_{2} l_{4}}{z_{K} r \cos \varphi}
\end{align*}
$$

In dependence (9) in marking $\pm$ sign " + " appears during driving upwards, whereas "-" down.

Applying for symbols: $\mathrm{m}_{1}, \mathrm{~m}_{2}, \mathrm{~m}_{3}, \mathrm{~m}_{4}, \mathrm{~m}_{5}$, these are masseses of suitable parts. $\mathrm{I}_{B z}, \mathrm{I}_{C z}, \mathrm{I}_{F z}, \mathrm{I}_{G x}$ are mass moments determined of suitable parts with respect to suitable axes. $\mathrm{N}_{1}, \mathrm{~N}_{2}$ are strength of pressure of wheels, $\mathrm{f}_{1}, \mathrm{f}_{2}$ are friction factor of rolling suitable wheels, $\mathrm{M}_{S}$ driving moment, $\mathrm{l}_{4}$ it is the suitable distance resulting from geometry of the setup, $r$ is the radius of wheels.
4.2. Simulations of the inverse task of dynamics of the inspective robot

On the basis Of equalization received (9) was conducted a computer simulation in the MATLAB/SIMULINK package. Coefficient in equalization determining geometric measurements, masses and moments of inertia meet to the designed inspection robot in the Cathedral of Mechanics and Robotics on the University of Technology in Rzeszow.

Masseses of each elements of the robot were read in physical parameters available in the Autodesk Inventor application (Figure 9). Mass moments of inertia with respect to each axes were also necessary for the simulation. These data were also read in parameters of physical designed parts (Figure 9.).

Forces of pressure were determined experimentally by ratios of the springiness of springs and measuring their deformation. Resisting force by arms were measured experimentally. Data from the simulation are following:
$m_{1}=0,012 \mathrm{~kg} ; m_{2}=0,328 \mathrm{~kg} ; m_{3}=0,075 \mathrm{~kg} ; m_{4}=0,05 \mathrm{~kg} ; m_{5}=0,045 \mathrm{~kg} ;$ $I_{B z}=0,000034692 \mathrm{kgm}^{2} ; I_{C z}=0,000001971 \mathrm{kgm}^{2} ; I_{F z}=0,000018807 \mathrm{kgm}^{2} ;$ $I_{G x}=0,000000599 \mathrm{kgm}^{2} ; f_{1}=0,0015 \mathrm{~m} ; f_{2}=0,003 \mathrm{~m} ; N_{1}=4,4 N ; \mathrm{N}_{2}=6,1 N$.


Figure 9 Physical parameters of the right part joint of Cardan along with arms of driving wheels

The following figure is presenting the flowchart which a simulation was made according to.


Figure 10 Flowchart of the inverse task of dynamics
In the Figure 11 was presented angular parameters of motor $\alpha, \dot{\alpha}, \ddot{\alpha}$ determined from inverse task of kinematics of the robot. For the same angular parameters of motor were made driving moment of motor $M_{S}$ during transport of the robot
upwards and down Figure 12a and Figure 12b.


Figure 11 Angle parameters of the motor


Figure 12 Driving moment of the motor during transport robot upwards (a) and down (b)

Comparing obtained diagrams (Figure 12a and Figure 12b) the driving moment of the motor is gaining maximum however the value is feeling when speeding up and braking, but these are the moment which is lasting the short moment of the time, the moment called this starting torque. Transport after the simple segment upwards at the constant speed (Figure 8a and Figure 12a) is occasioned must be the bigger driving moment than during transport moment down, it is caused with it that we are defeating all gravities force coming from each members of the robot additionally. The inverse situation is during transport after the simple segment down (Figure 8b and Figure 12b) at the constant speed that is the driving moment is smaller which it is possible to explain that to gravity force of elements of the robot are favourable to the direction of the motion.

## 5. Construction inspective robot into a pipes

With main materials which an construct robot remained from these are aluminium and ABS (kopolimer-akrylonitryl-butadien-styren).

### 5.1. Selection of the drive and measuring setups

An engine of the direct current with the cogged gear of the Micro company motors was applied to the prototype of the robot as the actor. The direction of revolutions changed by reversing polarity of power supply of circulation.

Table 2 Technical parameters motor with the gear

| Voltage | 12 V |
| :--- | :--- |
| Transmission of the gear | $15: 1$ |
| Consumption of current no load | 140 mA |
| Consumption of current no load with load | 680 mA max |
| Range of temperatures | -20 do $+60^{\circ} \mathrm{C}$ |
| Mass | 190 g |
| Revolving speed no load | $440 \mathrm{obr} / \mathrm{min}$ |
| Revolving speed with max. load | $300 \mathrm{obr} / \mathrm{min}$ |

A color camera was applied to the check and the inspection of internal parts of pipelines as the measuring setup, equipped with the 3.6 mm lens as a default about the corner of the $67^{\circ}$ view, with the chance of the exchange for the lens about the longer or shorter focal length, and the same the change of the corner and fields of view.

|  | Number <br> of line | 250 TVL |
| :--- | :--- | :--- |
| Objective | 3.6 mm F 2.0 |  |
|  | Sensitivity | 1.51 x |
| Power | DC $12 / 0.1 \mathrm{~A}$. |  |
|  | Dimension | $24 \times 24 \times 27$ |

Figure 13 Camera along with technical parameters

The image from the camera be displayed on the monitor of the notebook and the any TV is possible.

### 5.2. Schema of power supply

Power supply of the robot is realize from the control console with a package of accumulators (nickel- hydrogen) about voltage 12 V everyone. All devices of the
robot are powered from these batteries. During time-consuming check in the area to usage the car battery connected to specially clamps of the control console is possible. Aforementioned voltage supplying all devices of the robot with including the main engine through the bridge setup discussed below.


Figure 14 System power
The voltage for diodes of lighting is reduced to the value of 3 V .These diodes are merged parallel which he is guaranteeing us to light up even, when one of them damages himself.

### 5.3. Control system

The control of the robot is realized from the control console. Steering signals are transferred with the wire linking the console to the robot because in case of the examination of metal pipes use wireless is not possible. The fact that the robot is growing lighter is the plus of such a solution (relieved of batteries), however a negative effect of the one is a pulled wire limiting far-away inspection of pipes.

In the first phase of the project was used a Handy Board driver designed by Massachusetts Institute of Technology for steering the robot. However this microcontroller mainly wasn't meet expectations with efficiency voltage-current.

Of faults enumerated higher from the reason, referring with control of the robot through microcontroller Handyboard, was executed driver on the base of the bridge system containing two pairs of transistors steering circulation of the drive engine with enclosing keys.

Depending on the chosen position of the P switch (1 or 3) Figure 15, we are choosing other direction of the movement of the robot or stopping work position 2 [1].

### 5.4. Description of mechanical parts

A constructed robot is the reflection of the project realized in the constructional part of the robot in the Autodesk Inventor application. Element linking both parts


Figure 15 Ideological schema of the driver
mechanical work (module A and B) - the joint of Cardan was executed from the ABS material, which tolerated for the springy deformation of side parts for it, in order to introduce the crutch inside. It wasn't necessary thanks to it to ream bigger openings in Cardan side parts and after putting the crutch on for introducing sleeve and of securities.


Figure 16 Constructed inspective robot
On the "A" module Figure 1, Figure 16 and Figure 17 they are specified such elements like the engine, the camera, diodes lighting up and cogwheels are specified.

The installed setup is executing the video along with the lighting system two basic tasks. He is being utilized for navigation in the pipe and to visual inspection

Figure 18 work is presenting the landscape inside the vertical section of the executed pipe from PLEXIGLAS whom, we are able to watch the method exactly thanks to of moving work. Adjusting the robot to the diameter of the pipe and moving in the vertical trend they are ensuring set springs.

Control console the one: the driver, the set of batteries, the main switch, the switch of the camera, the switch of the lighting system, the joystick (manipulator


Figure 17 Sight of the robot from the page of the camera


Figure 18 Robot put in the pipe
with the stable central position). It is possible from the camera of the robot to display the image at the usage of the TV or graphical card on the TV receiver or the monitor of the computer.


Figure 19 Control console of robot

## 6. Testing of the robot

The examination of the robot was carried out utilizing the designed path of the movement of the Figure 20 robot for this purpose specially.


Figure 20 Position of examinations of the robot
Simple elements and vertical pipes were connected to elbow about the radius of the R curvature $=300 \mathrm{~mm}$ in accordance to assuming. Inside diameter of the pipe from PLEXIGLASU it is 144 mm , however inside internal elbow is 150 mm . The robot has to during transport adjust itself to these diameters defeating the obstacle about the shape of the ring with 3 mm thick of side. However it isn't max since the design is tolerating in turns in the $140 \div 155 \mathrm{~mm}$ interval. Increasing the length of arms of driving wheels and comperes it is possible to control pipes about the bigger diameter. In accordance to assuming with Figure 20 observations confirmed
inclination angle the wheels of rotors $\alpha$ is so small, that it guarantee self-locking of whole design, this has special importance during the inspection of vertical sections of pipes.

## 7. Summary

In the article was presented an approach for mechatronics designing and the construction of the executed prototype of the mobile inspective robot. From the analysis kinematics and of dynamics data have been drawn out from the suitable selection of the power transmission system and the precise preparation of the design.

The construction of the robot is simple and modular, what a quick change of the configuration is possible, e.g. exchange of leading and driving arms of wheels in order using him for pipes about the bigger diameter. The presented solution is permitting for control of horizontal, vertical and curved pipelines, as well as for adjusting oneself to variables of diameters of the pipe

The conceptive phase is the presented robot and he has one primary object - to take people's place under unfriendly or unavailable environments. Two basic tasks is executed through the installed setup video along with the lighting system. He is used for navigation in the pipe and to visual inspection.

Is being predicted joining conditioned wireless transmission at more far-away work, because a majority of controlled pipes is non-metallic pipes which he is possible for transmission radio waves and is making it possible to get rid of the linking wire and the same limitations range. The miniature applied camera on the miniature manipulator enable to more exact control of curves pipes. Equipment of the robot with the global system of the specification of the position (GPS) and the LCD installing in the control console, it enable to locate faults in the pipe or create the map of the pipeline.

Demand for inspective robots is growing bigger. A constructed prototype of the robot is the solution intended for purposes didactic-scientific and application. It is also the proposal for manufacturers with subject matter of inspection robots.

## References

[1] Giergiel J., Kurc K.: Robot inspekcyjny do przewodów rurowych, PAK nr. 11, Warszawa (2004).
[2] Giergiel J., Kurc K.: Podstawy robotyki i mechatroniki. Czȩść 2. Wprowadzenie do mechatroniki, Kraków (2004).
[3] Giergiel J., Hendzel Z., Żylski W.: Kinematyka, dynamika i sterowanie mobilnych robotów kotowych $w$ ujȩciu mechatronicznym, Monografie, Wydz. IMiR, AGH Kraków (2000).
[4] Giergiel M. J., Hendzel Z., Żylski W.: Modelowanie $i$ i sterowanie mobilnych robotów kotowych, PWN, Warszawa (2002).
[5] http://www.everestvit.com/crawlers/index.html
[6] http://www.ulb.ac.be/scmero/robotics.html\#pipe
[7] http://www.inuktun.com/purchasing/default.asp

