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ХИМИЧЕСКАЯ ТЕХНОЛОГИЯ

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ОПРЕДЕЛЕНИЕ ПОТРЕБНОСТИ СОРТОВ ОЗИМОЙ ПШЕНИЦЫ В МИНЕРАЛЬНЫХ УДОБРЕНИЯХ НА ОСНОВЕ КЛАСТЕРНОГО АНАЛИЗА И ДЕНДРОГРАММ

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DETERMINATION OF THE NEED OF WINTER WHEAT VARIETIES FOR MINERAL FERTILIZERS BASED ON CLUSTER ANALYSIS AND DENDROGRAMS

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АННОТАЦИЯ

При оценке генотипов озимой пшеницы по уровню в кластере, выделенном на основе дендрограммы, сорта группировали по потребности в минеральных удобрениях, а потребность в минеральных удобрениях определяли по урожайности зерна. На этом основании сорт озимой пшеницы, т.е. накопление сухого вещества растений за вегетационный период, относительная оценка потребности в удобрениях по компонентам урожайности (длина колоса, количество колосков в колосе, количество зерен в колосе, масса зерно в колосе, масса 1000 зерен) и накопление сухого вещества растений. Установлено, что сорта озимой пшеницы различались по реакции на факторы внешней среды при их оценке методом кластеризации по разным агрономическим показателям.

ABSTRACT

When assessing winter wheat genotypes by level in a cluster identified on the basis of a dendrogram, varieties were grouped according to the need for mineral fertilizers, and the need for mineral fertilizers was determined by grain yield. On this basis, the variety of winter wheat, i.e. accumulation of plant dry matter during the growing season, relative assessment of the need for fertilizers by yield components (ear length, number of spikelets in an ear, number of grains in an ear, weight of grains in an ear, weight of 1000 grains) and accumulation of plant dry matter. It was established that winter wheat varieties differed in their response to environmental factors when assessed using the clustering method for various agronomic indicators.

Ключевые слова: сорта озимой пшеницы, нормы минеральных удобрений, динамика, кластер, компоненты урожая, уровня, потребность.

Keywords: winter wheat varieties, mineral fertilizer rates, dynamics, cluster, yield components, level, need.

Введение. Разработка системы применения минеральных и органических удобрений среди других агротехнических мероприятий имеет большое значение для получения более высокого и качественного урожая от сортов пшеницы в различных почвенно-климатических условиях Узбекистана.

Несмотря на разнообразие научных исследований, проводимых с озимой пшеницей, с этой культурой необходимо провести определенное количество новых исследований. Пока что для него характерно отсутствие научных исследований по данному вопросу. Один из них – определение потребности сортов озимой пшеницы в минеральных удобрениях и их степень.

Очень важно работать на основе региональной агротехники, т. е. разрабатывать технологии создания

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и выращивания сортов, подходящий для различных почвенно-климатических условий, а также иметь высокие качественные показатели, особенно размещение сортов на основе местные условия каждого региона.

Цель исследований - основными целями и задачами исследований являются определение оптимальных норм внесения минеральных удобрений и усвоения минеральных удобрений различными сортами озимой пшеницы на староорошаемых светло-сероземных почвах.

Методика. Изучено влияние различных норм минеральных удобрений ($N_0P_0K_0$; $N_{150}P_{105}K_{75}$; $N_{200}P_{140}K_{100}$ и $N_{250}P_{175}K_{125}$ кг/га) на разные сорта озимой пшеницы (Чиллаки и Купава) в условиях староорошаемых светло-сероземых почвах Наманганской области. Исследование было размещено в 16 вариантах, 4 повторах и 1 страте, площадь каждого блока составляла 224 м^2.

Во всех вариантах опыта полную норму N_{30}, РК-удобрений вносили перед посевом озимой пшеницы, остальной азот делили поровну на две части и вносили во время весеннего кущения и трубкования.

Эффективность норм минеральных удобрений у сортов озимой пшеницы исследовали в условиях полевого опыта. Опыт, фенологическое наблюдение, отбор проб почвы и растений проводили, согласно пособиям, «Методика полевых опытов» и «Методика государственного сорта испытаний сельскохозяйственных культур».

По агрохимическому методу проб почвы и растений «Методика агрохимических анализов почв и растений Средней Азии» определяли качественные показатели урожая зерна, пищевую ценность соломы по ТУ Уз 8-115-97 и «Практикум». в науке о растениях».

Полученные в результате экспериментов данные (биометрические показатели, скорость накопления растениями сухого вещества, компонентов урожая, урожайность зерна и соломы, их качественные показатели, кластерный статистический анализ потребности сортов пшеницы в минеральных удобрениях по большинству агрономических показателей) анализировались с использованием программ SAS 9.1 и SPSS 12.0.

Для кластеризации сортов озимой пшеницы использован метод построения горизонтальных древовидных диаграмм. В данном случае расстояние между сортами рассчитывали по методу Уорда (минимальной переменной) [6,7]:

$$D_{KL} = B_{KL} = \frac{||X_K - X_L||}{1/N_K + 1/N_L}$$

Если $d(x, y) = (1/2) \mid x - y \mid 2$, то формула запишется следующим образом:

$$D_{JM} = [((N_J + N_K) D_{JK} + (N_J + N_L) D_{JL} - N_J D_{KL})/(N_J + N_M)]$$

Метод Уорда эффективен по сравнению с другими методами и отличается от них тем, что расстояние между объектами рассчитывается на основе дисперсионного анализа (ANOVA). В этом методе создаются небольшие кластеры и минимизируется сумма квадратов (SS) для любых двух (гипотетических) кластеров.

Результаты исследований. На основании полученных агрономических показателей с помощью кластеризации в статистической программе SPSS 12.0 и метода минимальной дисперсии Уорда определили потребность сортов в минеральных удобрениях. Этот кластерный анализ (минимальный дисперсионный анализ Уорда) широко используется для определения устойчивости сортов риса, пшеницы и картофеля к засолению почвы и их группировки [1, 2, 3,4].

Поскольку агрономические показатели (урожайность зерна, сухое вещество, компоненты урожая) находятся в разных размерностях, то сначала, то есть до проведения кластерного анализа, эти данные были приведены к единой относительной единице измерения. Для этого были получены следующие коэффициенты путем деления среднего значения каждого показателя по сортам на свой контроль (например, по урожайности зерна, табл. 1).

Таблица 1.

Индексы потребности урожайности зерна в минеральных удобрениях при внесении удобрений озимой пшеницы в разных нормах

Сорты	2017			2020		
	$N_0P_0K_0$	$N_{150}P_{105}K_{75}$	$N_{250}P_{175}K_{125}$	$N_0P_0K_0$	$N_{150}P_{105}K_{75}$	$N_{250}P_{175}K_{125}$
Чиллаки	0,640	0,920	1,030	0,660	0,880	1,020
Купава	0,650	0,930	1,020	0,640	0,860	1,000
Деметра	0,430	0,750	1,030	0,640	0,860	1,010
Санзар-8	0,600	0,890	1,020	0,650	0,880	1,010

В качестве контроля при этом были взяты растения, у которых не отмечалось недостатка минеральных элементов питания, т. е. вариант, в котором применялся $N_{200}P_{140}K_{100}$ кг/га, и сорт Чиллаки, поглощавший наибольшее количество питательных веществ из почвы.

В результате статистического анализа была представлена 2- и 3-кластерная таблица, в которой сгруппированы сорта пшеницы (табл. 2).

Таблица 2.

Кластеризация сортов по методу Уарда

Сорты	3 кластер	2 кластер
Чиллаки	1	1
Купава	1	1
Деметра	2	1
Санзар-8	3	2

Выбор подходящего кластера производился на основе созданной дендрограммы (рис. 1), то есть сорта имеют близкую ориентацию внутри одной группы, и желательно, чтобы межкластеры отличались друг от друга, и определяли расстояние между кластерами, объединенными по обновленному масштабу (Rescaled Distance Cluster Joint).

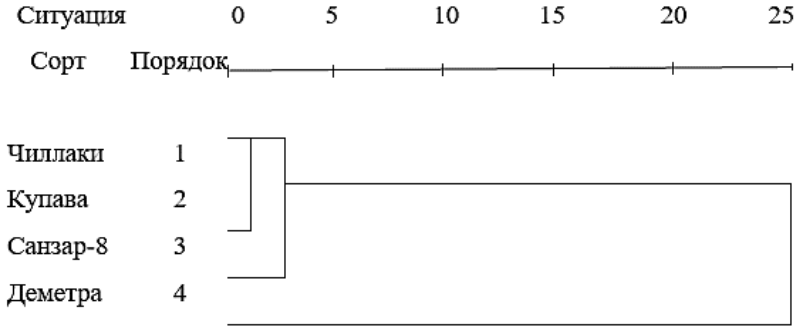

Рисунок 1. Дендрограмма с использованием метода Уорда (Dendrogram using Ward Method)

При оценке изучаемых генотипов мы основывали группировку (уровень) в кластере, выделенном на основе дендрограммы, а сорта озимой пшеницы классифицировали по их потребности в минеральных удобрениях. В результате во всех случаях сорта пшеницы были разделены на три кластера по всем агрономическим показателям, величина (уровень) каждой нормы удобрений суммировалась и определялась их сумма. При этом генотип с наименьшим баллом оценивался как требовательный к минеральным удобрениям (табл. 3).

Таблица 3.

Классификация сортов озимой пшеницы по потребности в минеральных удобрениях (Анализ минимальной дисперсии Уорда)

Сорты	Норма минеральных удобрений			∑	Группировка по потребности на минеральные удобрения
	$N_0P_0K_0$	$N_{150}P_{105}K_{75}$	$N_{250}P_{175}K_{125}$		
По урожайности зерна					
Чиллаки	1* (1) **	1 (1)	1 (1)	6	1
Купава	1 (2)	1 (2)	2 (2)	10	2
Деметра	2 (2)	2 (3)	3 (3)	15	3
Санзар-8	3 (3)	3 (1)	2 (3)	15	3
По компонентам урожая					
Чиллаки	1 (1)	1 (1)	1 (1)	6	1
Купава	2 (2)	2 (2)	2 (2)	12	2
Деметра	2 (2)	2 (2)	3 (1)	12	2
Санзар-8	3 (3)	3 (3)	1 (3)	16	3
По накоплению сухого вещества					
Чиллаки	1 (1)	1 (1)	1 (1)	6	1
Купава	2 (2)	2 (1)	2 (1)	10	2
Деметра	2 (2)	2 (2)	2 (2)	12	2
Санзар-8	3 (3)	3 (3)	3 (3)	18	3

По результатам статистического анализа, потребность в минеральных удобрениях по урожайности зерна озимой пшеницы высокая у сортов Чиллаки, Купава и Деметра находятся на промежуточном месте, что можно выразить следующим образом: Чиллаки>Купава>Деметра=Санзар-8. По накоплению сухого вещества растениями за вегетационный период первое место занимал сорт Чиллаки, промежуточное место - Купава, последнее - сорта Деметра и Санзар-8.

Относительная оценка потребности сортов в удобрениях по компонентам урожайности (длина колоса, количество колосков, количество зерен в колосе, масса зерна с колоса, масса 1000 зерен) аналогична накоплению растениями сухого вещества [1]. При оценке сортов методом кластеризации по разным агрономическим показателям их реакция на внешний фактор среды различна, это наблюдалось и в исследованиях El-Hendawy S.E., и др. [8].

Таким образом, оценить потребность сортов озимой пшеницы в минеральных удобрениях по большинству агрономических показателей (урожайность зерна, накопление сухого вещества растений, компоненты урожая) можно с помощью кластерного анализа. Потребность сортов пшеницы в минеральных удобрениях может быть различной в зависимости от различных агрономических показателей.

Выводы. При кластеризации озимой пшеницы по агротехническим показателям, таким как урожайность зерна, накопление сухого вещества растений и компоненты урожайности, сорт Чиллаки оказался очень требователен к минеральным удобрениям, а сорт Купава – требователен. Установлено, что сорт Санзар-8 менее требователен к минеральным удобрениям по всем показателям, а Деметра менее требователен при оценке урожайности зерна, растения требовательны к минеральным удобрениям при группировке по накоплению сухого вещества и компонентам урожайности.

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СИНТЕЗ ТРИАЦЕТИНА НА ОСНОВЕ МЕСТНОГО СЫРЬЯ

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SYNTHESIS OF TRIACETIN BASED ON LOCAL RAW MATERIALS

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АННОТАЦИЯ

Глицерин является побочным продуктом биодизеля, на его долюриходится около 10% по весу его производства. Избыточное количество глицерина является очень перспективным сырьем для преобразования в более ценный продукт. Одним из перспективных производных глицерина является триацетин, который производится путем ацетилирования глицерина. Синтез триацетина из глицерина с уксусной кислотой с использованием гомогенного кислотного катализатора был проведен в периодической реакции и был проанализирован с помощью газовой хроматографии. Параметры, которые были изменены, - это молярное соотношение глицерина к уксусной кислоте 1:3, 1:6 и 1:9 моль/моль, а время реакции составляет 30, 60 и 120 минут. Кроме того, количество используемого катализатора составляло молярное соотношение глицерина к серной кислоте 1:0,00, 1:0,02 и 1:0,04 моль/моль, а изменяемые температуры находились в диапазоне от 90 до 120 oC. После изменения параметров будет получен и изучен набор параметров, обеспечивающих максимальный выход триацетина. В ходе исследования эффективность производства триацетина была дополнительно улучшена путем определения оптимальных рабочих условий для процесса.

ABSTRACT

Glycerol is the by-product of biodiesel with about 10 wt% of its production. The excessive amount of glycerol is a very promising feedstock for converting into more valuable product. One of the prospective glycerol‟s derivatives is triacetin which produce by glycerol acetylation. Synthesis of triacetin from glycerol with acetic acid using homogeneous acid catalyst has been carried out in a batch reaction and was analyzed by gas chromatography. The parameters that were manipulated are glycerol to acetic molar ratio of 1:3, 1:6, and 1:9 mol/mol and the reaction times are 30, 60 and 120 minutes. Besides, the catalyst amount used were glycerol to sulphuric acid molar ratio of 1:0.00, 1:0.02 and 1:0.04 mol/mol and the temperatures being manipulated were between 90 to 120 oC. After manipulating among the parameters, a set of parameter that produce highest yield of triacetin will be obtained and studied. In the study, the triacetin production efficiency was further improved by determining the optimum operating condition for the process.

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Ключевые слова: глицерин, биодизеля, триацетин октаноповышающей, модификатор, эффективность модификатор.

Keywords: glycerol, biodiesel, Triasetin Octane booster, modifier, efficiency modifier.

В настоящее время при производстве биодизеля примерно 10% побочного продукта составляет глицерин. В результате образующийся в большом количестве глицерин является актуальным сырьем на сегодняшний день и в перспективе для преобразования в продукцию высокого качества.

Одна из основных задач на будущее по использованию избыточного глицерина — преобразование его в 1,2,3-триацетоксипропан, также известный как глицеринтриацетат, триацетин или триацетилглицерид. Триацетин в настоящее время является одним из высокоценных производных глицерина, и его можно получить путем ацетилирования глицерина

При использовании этого продукта в качестве добавки он предотвращает кристаллизацию биодизеля, которая может происходить из-за изменения температуры и вызывать засоры в двигателе. Помимо того, что триацетин является высокоценным соединением, он обладает способностью растворяться в биодизеле, что позволяет включать его в состав биотоплива. Кроме того, триацетин может использоваться в косметике, фармацевтике и в качестве добавки к топливу.

Синтез триацетина из глицерина представляет собой поэтапный процесс, осуществляемый с использованием уксусной кислоты в присутствии гомогенного катализатора, а анализ полученных продуктов проводился с помощью газовой хроматографии. Среди изменяемых параметров были молярные соотношения глицерина и уксусной кислоты — 1:3, 1:6 и 1:9 моль/моль, а также продолжительность реакции — 30, 60 и 120 минут. Кроме того, количество используемого катализатора выражалось через молярное соотношение глицерина и серной кислоты — 1:0.00, 1:0.02 и 1:0.04 моль/моль, а изменяемые температуры варьировались от 90 до 120 °C. После внесения изменений в параметры был определен и изучен набор условий, обеспечивающий максимальный выход триацетина.

В результате исследований создание оптимальных условий для реакции стало одной из основных приоритетных задач, направленных на повышение эффективности получения триацетина. Оптимальные условия для производства триацетина были следующими: молярное соотношение глицерина и серной кислоты — 1:0.02 моль/моль, глицерина и уксусной кислоты — 1:9 моль/моль, время реакции — 60 минут, температура реакции — 105 °C.

В данном исследовании основная цель заключалась в определении оптимальных условий ацетилирования, при которых достигается максимальный выход триацетина при использовании серной кислоты (H_2SO_4) в качестве гомогенного катализатора. На начальном этапе исследования изучались следующие параметры: температура реакции (90 и 120 °C), время реакции (30–60 минут), соотношение глицерина и уксусной кислоты (1:3, 1:6 и 1:9), а также соотношение глицерина и серной кислоты (1:0.00, 1:0.02 и 1:0.04).

Материал и химические реагенты

Одним из основных реагентов, использованных в данном исследовании, является глицерин, который представляет собой бесцветную жидкость. Все химические вещества, использованные в ходе исследования, приведены в таблице 1.

Таблица 1.

Список химических веществ, использованных в ходе эксперимента

Вещества	Место происхождения	Цель использования
Глицерин	Flagma.uz	Растворитель для ацетилирования
Уксусная кислота	**All-kimyo**	растворитель при ацетилировании Asetillashda erituvchi
Серная кислота	**Glotr.uz**	Катализатор ацетилирования
Этанол	**Prom.uz**	Стандарт для анализа

Оборудование, использованное в данном исследовании, приведено в таблице 2. В таблице также указан поставщик оборудования.

Таблица 2.

Оборудование и его поставщик

Оборудование	Оборудование место производства
Газовая хроматография	Германия
Отопительная печь	Германия
Нагревательная печь	Германия
Роторный испаритель	Германия
Холодильный охладитель	Германия
Инфракрасная спектроскопия	Германия

Приготовление реагента и катализатора

Все химические вещества были приобретены в коммерческих целях и использовались без дополнительной очистки. 90% уксусная кислота была получена от All-kimyo (Узбекистан), 99,7% глицерин — от Flagma (Узбекистан), а 95,6% серная кислота — от Glotr.uz (Узбекистан). Этанол для газовой хроматографии (GC) с чистотой 96% уровня GC был приготовлен Prom.uz (Узбекистан).

Ацетилирование реакции

Синтез триацетина представляет собой процесс, протекающий в присутствии катализатора, в реакторе при атмосферном давлении и скорости перемешивания 290 об/мин, при температуре от 90 до 120 °C. Ранее для синтеза триацетина использовались различные гомогенные и гетерогенные катализаторы, однако по результатам наших наблюдений мы приняли решение выбрать серную кислоту в качестве наиболее подходящего гомогенного катализатора для данной реакции. мешалкой и термометром (рисунок 1). Глицерин и уксусная кислота непосредственно добавлялись в трехгорлую колбу вместе с серной кислотой в качестве катализатора. Реакция проводилась при перемешивании в течение 30–60 минут. Перемешивание в ходе реакции осуществлялось непрерывно с помощью магнитной мешалки.

После завершения реакции продукты с содержанием серной кислоты нейтрализовали в сосуде с добавлением гидроксида натрия в том же соотношении. После нейтрализации загрязненный катализатор удаляли с помощью устройства с рециркулируемой водной аспирацией (рисунок 2). В конечном этапе моноацетин, диацетин, триацетин, глицерин и непрореагировавшая уксусная кислота подвергались обработке на ротационном испарителе для удаления растворителя из продукта (рисунок 3).

Рисунок 1. Процесс синтеза триацетина

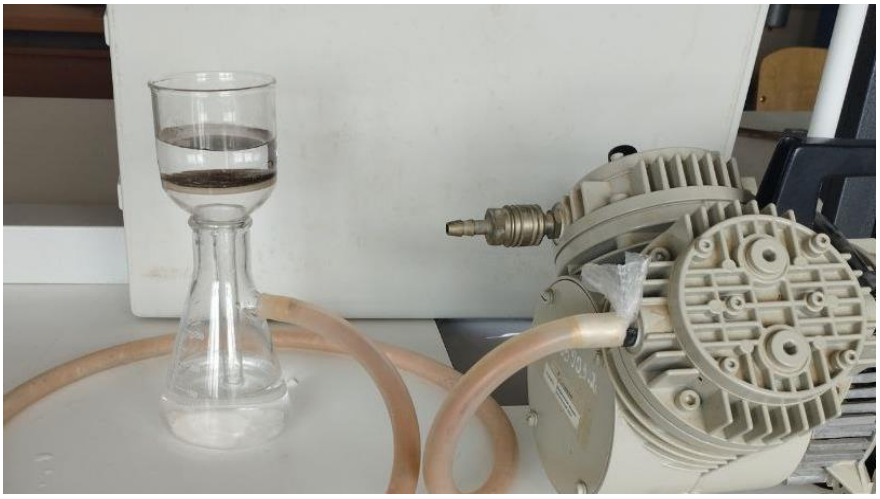

Рисунок 2. Процесс фильтрации

Рисунок 3. Ротационный испаритель

В данном исследовании наибольший выход триацетина составил 31,89%, и он был достигнут при молярном соотношении глицерина и серной кислоты 1:0,02, глицерина и уксусной кислоты 1:9, времени реакции 60 минут и температуре реакции 105°C. Полученный триацетин был проанализирован с помощью инфракрасной спектроскопии.

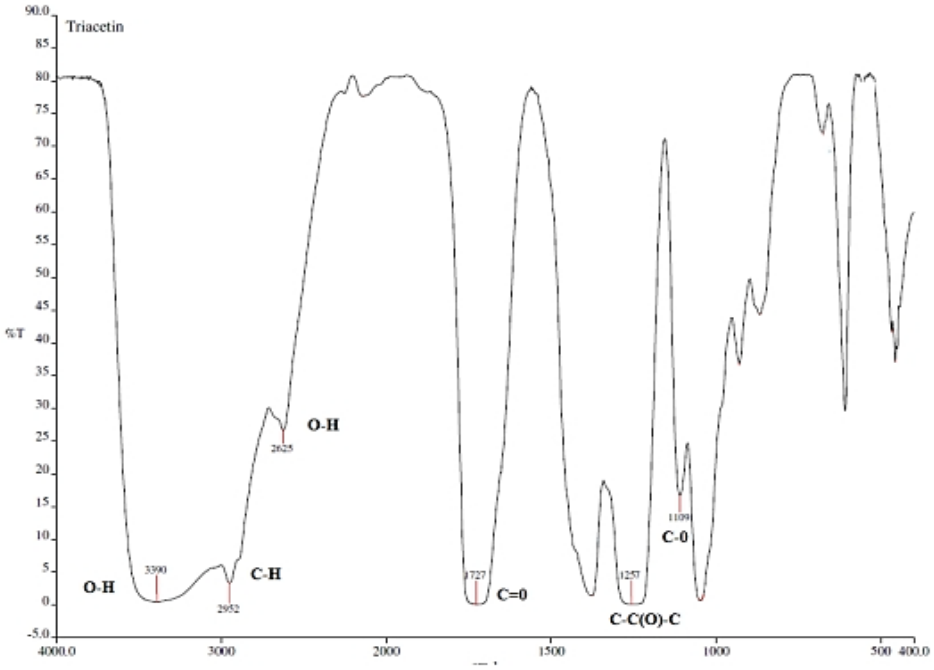

Рисунок 4. Анализ триацетина с помощью инфракрасной спектроскопии

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ОЧИСТКА ЭКСТРАКЦИОННОЙ ФОСФОРНОЙ КИСЛОТЫ ОРГАНИЧЕСКИМ РАСТВОРИТЕЛЕМ И ПОЛУЧЕНИЕ ВЫСОКОМАРОЧНЫХ ФОСФАТОВ АММОНИЯ

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PURIFICATION OF EXTRACTION PHOSPHORIC ACID WITH ORGANIC SOLVENT AND PRODUCTION OF HIGH QUALITY AMMONIUM PHOSPHATES

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АННОТАЦИЯ

Изучен процесс обессульфачивания экстракционной фосфорной кислоты (ЭФК) из фосфоритов Центральных Кызылкумов (16.5% P_2O_5; 1.11% MgO; 2.98% SO_3; 0.28% Fe_2O_3; 0.42% Al_2O_3; 0.99% F) с помощью карбоната кальция. При оптимальной норме осадителя (125%) степень удаления сульфатных ионов достигает 85,65%. Далее проведена глубокая очистка ЭФК от примесей (CaO, MgO, Fe_2O_3, Al_2O_3, SO_3 и F) с трехкратным избытком смесью 99.5 %-ного ацетона и 99 %-ного этилового спирта. При этом выпадавшие осадки содержат такие макроэлементы, как фосфор, кальций и магний и они рекомендуются для самостоятельного фосфорно-кальциево-магниевого (PCaMg) удобрения. На основе очищенной ЭФК получены образцы высокомарочных фосфатов аммония.

ABSTRACT

The process of desulfurization of extraction phosphoric acid (EPA) from phosphorites of Central Kyzylkum (16.5% P_2O_5; 1.11% MgO; 2.98% SO_3; 0.28% Fe_2O_3; 0.42% Al_2O_3; 0.99% F) using calcium carbonate has been studied. At the optimum precipitant rate (125%), the removal degree of sulfate ions reaches 85.65%. Further, the EPA was deeply purified from impurities (CaO, MgO, Fe_2O_3, Al_2O_3, SO_3 and F) with three times excess with a mixture of 99.5 % acetone and 99 % ethyl alcohol. The precipitates contain such macronutrients as phosphorus, calcium and magnesium and they are recommended for independent phosphorus-calcium-magnesium (PCaMg) fertilizer. Samples of high quality ammonium phosphate were obtained on the basis of purified EPA.

Ключевые слова: ЭФК, кальциевые минералы, обессульфачивание, гипсовый шлам, ацетон, этиловый спирт, очистка, осадок, очищенная фосфорная кислота, фосфаты аммония.

Keywords: EPC, calcium minerals, desulfurization, gypsum sludge, acetone, ethyl alcohol, purification, precipitate, purified phosphoric acid, ammonium phosphates.

Фосфорная кислота широко применяется во многих отраслях: медицине, машиностроении, пищевой промышленности, в качестве моющих средств, является катализатором в процессах дегидратирования, полимеризации, алкилирования углеводородов. Ортофосфорная кислота зарегистрирована в качестве пищевой добавки Е338. Применяется как регулятор кислотности в газированных напитках, например Кока-Кола [1].

В настоящее время АО «Ammofos-Maxam» в Узбекистане перерабатывает мытый обожженный концентрат со средним содержанием 26% P_2O_5 (МОК-26), получая из него дигидратным способом ЭФК состава 14-16% P_2O_5; 0.5-1.0% CaO; 0.3-0.8% MgO; 1.5-2.0 Fe_2O_3; 0.5-1.0% Al_2O_3 и 2-3 SO_3 и на её основе аммофос. Согласно TSh 6.6-09:2008 состав аммофоса: 46±1% $P_2O_{5усв.}$, 33-43% $P_2O_{5водн.}$, 11±1% N, 1.0% H_2O с прочностью гранул не менее 3.0 МПа. Однако продукт в воде полностью нерастворим ($P_2O_{5водн.}$: $P_2O_{5общ.}$ менее 80%), что объясняется загрязнением состава ЭФК с различными балластными примесями.

Поэтому необходима очистка ЭФК и получение высокомарочных фосфатов аммония, соответствующих по качеству мировому стандарту, то есть содержащих максимальное количество водорастворимого P_2O_5 и минимальные количества примесей.

В литературе имеются сведения о способах очистки ЭФК от одной или нескольких примесей с использованием различных методов – выпаривания [1,2], осаждения [3], нейтрализации аммиаком [4], ионообменная очистка [5], сорбционный способ с применением адсорбентов [6], а также экстракционная очистка органическими растворителями [7-10].

В ходе промышленной эксплуатации установки по очистке ЭФК, полученной сернокислотным разложением апатитового концентрата выявлено, что применяемый при очистке экстрагент – трибутилфосфат (ТБФ) загрязняется органическими веществами, в том числе гуминовыми кислотами, представляющими собой азотсодержащие, высокомолекулярные оксикарбоновые кислоты [11]. По мере загрязнения ТБФ ухудшаются гидродинамические условия в пульсационных колоннах, что приводит к снижению производительности и захлёбыванию аппаратов. В патенте предложен способ очистки ТБФ от смолистых веществ путем предварительной промывки экстрагента 10-15 %-ным щелочным раствором перед стадией экстракции при 50ºС. Дополнительная операция позволяет снизить не только потери экстрагента и улучшить гидродинамические показатели, но и утилизировать раствор фосфата натрия. Реализованный в промышленности процесс очистки фосфорной кислоты с ТБФ требует доочистки от фтора и остаточного ТБФ, которая осуществляется при концентрировании в условиях интенсивного тепломассообмена [12-13].

Однако высокая стоимость ТБФ технологический процесс делает малоэкономичным, к тому же его производство в Узбекистане нет. Поэтому целесообразно поиск наиболее доступных и дешёвых органических экстрагентов.

В наших условиях необходимо предусмотреть применение уксусной кислоты, ацетона и этилового спирта. Выбор данных экстрагентов диктуется тем, что уксусная кислота производится на АО «Navoiyazot» с мощностью 25 тыс. т в год. Ацетон выпускается

на этом же предприятии. А этиловый спирт производится во многих предприятиях республики. И главное, эти органические экстрагенты легко регенерируются и возвращаются в технологический цикл очистки, то есть используются многократно.

С целью определения оптимальных условий очистки ЭФК от сульфатных ионов лабораторные эксперименты проводили в широком диапазоне нормы осадителей (100-150% от стехиометрии для связывания H_2SO_4 в $CaSO_4$). В опытах исходная ЭФК загружалась в реактор с винтовой мешалкой и подвергалась подогреву в водяном термостате до 80ºС. Затем к ней постепенно дозировалось расчётное количество осадителя. При этом длительность обессульфачивания – 15 минут. По истечению времени содержимое реактора отстаивалось в течение 30 минут при 60-65ºС. Далее суспензию отделяли от осадка методом фильтрования на воронке Бюхнера, с использованием колбы Бунзена, при разряжении 0.65 мм рт. ст. через один слой фильтровальной бумаги «белая» лента, осадок промывали водой, затем ацетоном. После чего осадки высушивали при 80ºС.

Состав исходной и обессульфаченной ЭФК, а также осадка последнего определяли по методикам [14]. Определение содержания CaO и MgO осуществляли объемным комплексонометрическим методом: титрованием 0.05 н раствором трилона Б в присутствии индикаторов флуорексон и хром темно-синий. Определение содержания P_2O_5 проводили широко применяемым в анализе фосфатных руд и фосфорсодержащих удобрений – дифференциальным способом на приборе КФК-3 (λ=440 нм) в виде фосфорнованадиево-молибденового комплекса. Анализ на Al_2O_3 и Fe_2O_3 проводили согласно методике комплексонометрическим методом, SO_3^{2-}-ион весовы методом - осаждением в виде сульфата бария. Определение фтора проводилось потенциометрическим методом с помощью фторселективного электрода.

Следует отметить, что при найденной оптимальной норме – 125% с применением $CaCO_3$ коэффициент осаждения SO_3 достигает 85.65%. То есть в плане обессульфачивания фосфорной кислоты $CaCO_3$ дает наибольший эффект.

Этиловый спирт и ацетон обладают «средней» (78,39°С) и «низкой» (56,2°С) температурой кипения, т.е. не слишком высокой, как, например, у уксусной кислоты (118,2°С), что может затруднять отгонку растворителя. Это делает их применение для очистки ЭФК весьма перспективными.

С этой точки зрения для очистки обессульфаченной ЭФК были приготовлены смеси из этилового спирта и ацетона при массовых соотношениях C_2H_5OH : CH_3COCH_3 от 1 : 0,35 до 1 : 3. При очистке обесульфаченной ЭФК выпадаемые осадки представлены солями (Ca, Mg)HPO_4, (Ca, Mg)SO_4, (Fe, Al)PO_4, (Ca, Mg)SiF_6 в кристаллическом и аморфном формах.

Приведены данные по коэффициенту осаждения различных компонентов из ЭФК. Из неё видно, что чем больше массовая доля ацетона в смеси, тем выше коэффициент осаждения компонентов. Так, если при C_2H_5OH : CH_3COCH_3 = 1 : 0,33 коэффициенты осаждения CaO; MgO; Fe_2O_3; Al_2O_3; SO_3 и F из обессульфаченной ЭФК составляют 92,29; 46,21; 92,19; 94,56; 78,59 и 58,25%, то при C_2H_5OH : CH_3COCH_3 = 1 : 3 эти значения достигают 97,56; 81,93; 99,18; 99,18; 94,94 и 62,74%. При этом потеря фосфора с осадками возрастает с 11,07 до 13,88% P_2O_5.

Осадки, содержащие 29,51-33,17% P_2O_5, 11,99-12,71% CaO, 6,75-10,74% MgO, 3,70-3,89% Fe_2O_3, 5,55-5,98% Al_2O_3, 5,91-6,52% SO_3 и 9,19-10,02% F цитратнорастворимы, и вполне приемлемы в качестве удобрения пролонгированного действия. Они могут быть представлены солями (Ca, Mg)HPO_4, (Ca, Mg)SO_4, (Fe, A1)PO_4, (Ca, Mg)SiF_6 в кристаллическом и аморфном формах.

Как сказано выше, что органические растворители, используемые в процессе очистки легко восстанавливаются и повторно используются для удаления примесных компонентов из свежей порции обессульфаченной ЭФК. Для этого смесь, состоящую из ацетона, этилового спирта и фосфорной кислоты подвергли к упариванию под вакуумом (0,65 мм.рт.ст.). В процессе выпарки сначала отгонялся ацетон (при 58°С), затем спирт (80°С) и далее вода. Они с помощью холодильника конденсировались, при этом регенерированный ацетон и этиловый спирт возвращаются в цикл очистки.

В табл. 1 приведён состав образцов очищенной ЭФК с концентрацией более 45% P_2O_5, после реэкстракции ацетона и спирта методом вакуумной выпарки.

Таблица 1.

Состав упаренной фосфорной кислоты после реэкстракции органических растворителей

Массовое соотношение C_2H_5OH : CH_3COCH_3	**Содержание компонентов, вес.%**						
	P_2O_5	**CaO**	**MgO**	**Fe_2O_3**	**Al_2O_3**	**SO_3**	**F**
1 : 0,33	45,30	0,21	1,57	0,08	0,07	0,24	0,43
1 : 0,5	45,32	0,19	1,38	0,07	0,06	0,18	0,42
1 : 1,26	45,35	0,17	0,98	0,07	0,06	0,11	0,39
1 : 2	45,42	0,15	0,61	0,06	0,05	0,09	0,35
1 : 3	45,63	0,14	0,53	0,05	0,04	0,07	0,32

Установлено, что при отгонке ацетона, этилового спирта и частично воды происходит дополнительное выпадение примесных компонентов, но и пятиокиси фосфора.

Хотя обеспечивается максимальное освобождение состава ЭФК от двух- и трёхзамещенных металлов, сульфатных и фторидных ионов. Однако, судя по содержанию фтора в концентрированной ЭФК следует провести процесс её отдувки горячим воздухом, паром или топочными газами.

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В любом случае, получение очищенной, к тому же концентрированной фосфорной кислоты на базе отложенной ЭФК вполне приемлема для производства водорастворимых фосфорсодержащих удобрений: фосфатов аммония либо жидких комплексных удобрений, пригодных для капельного орошения в тепличном хозяйстве.

Далее проведена аммонизация предварительной обессульфаченной, очищенной и упаренной ЭФК состава (вес.%): 35,16% P_2O_5, 0,028% CaO, 0,065% MgO, 0,059% Fe_2O_3, 0,024% $A1_2O_3$, 0,163% SO_3 и 0,84% F до pH = 5,5 и 8,5 с целью получения моно- (МАФ) и диаммонийфосфата (ДАФ), соответственно. Во избежание потери аммиака аммонизацию проводили при температуре ниже 70°С. Сушку и грануляцию фосфатной пульпы проводили при температуре 60°С. Грануляция пульпы была осуществлена методом окатывания.

Приведён состав и прочность МАФ и ДАФ. Результаты испытаний показали, что гранулы удобрений полностью растворяются в воде. МАФ имеет в своём составе (вес. %): N – 12,83; P_2O_5 – 61,10; CaO – 0,16; MgO – 0,19; Fe_2O_3 – 0,14; Al_2O_3 – 0,03; F – не более 1,0 с прочностью гранул 2,98 МПа. Продукт с такими показателями пользуется большим спросом. ДАФ содержит 19,26% N и 53,83% P_2O_5 и прочностью гранул 2,70 МПа. В нём 0,13% CaO; 0,17% MgO; 0,16% Fe_2O_3; 0,03% Al_2O_3 и не более 1,0% F.

Установлен солевой состав образцов фосфатов аммония. Рентгенографический анализ проводили на дифрактометре XRD-6100 (Shimadzu, пр-во Япония). Применяли CuK_α-излучение (β-фильтр, Ni, режим тока и напряжения трубки 30 mA, 30 kV) и постоянную скорость вращения детектора 4 град/мин, а угол сканирования изменялся от 4 до 80°. При снятии образцов применялась камера с вращением, где скорость вращения равна 30 об/мин. Расшифровка полученных рентгенограмм производилась с использованием база данных International Centre for Diffraction Data [15].

На дифрактограмме образца МАФ (рис. 1) четко проявляются дифракционные максимумы 5,303; 3,739; 3,066; 2,653; 3,368; 2,005; 1,773; 1,675; 1,600; 1,536; 1,471; 1,370; 1,329 А°, которые относятся к дигидроортофосфату аммония. В штрихдиаграмме появление полос 5,563; 5,035; 4,118; 3,41; 3,209А° свидетельствует об образовании в продукте гидрофосфата аммония (диаммонийфосфат).

В отличие от образца МАФ на штрихдиаграмме МАФ мы наблюдаем несколько иную картину (рис. 2). Здесь проявляются полосы гидрофосфата аммония, на что указывают дифракционные максимумы 5,60; 5,341; 5,066; 4,14; 4,01; 3,78; 3,374; 3,226; 3,145; 3,064; 2,81; 2,546; 2,475; 2,304; 2,08; 1,686А°.

Таким образом, фосфор в получаемых продукта – фосфатах аммония находится исключительно в водорастворимой форме. МАФ состоит из $NH_4H_2PO_4$ с некоторым количеством $(NH_4)_2HPO_4$. ДАФ содержит $(NH_4)_2HPO_4$ и частично $(NH_4)_3PO_4$ (рис. 3): $CaHPO_4{\cdot}2H_2O$ (7,635; 4,287; 3,768; 3,06; 2,54; 1,896Å), $CaHPO_4$ (3,38Å), $MgHPO_4$ (3,06Å), $AlPO_4$ (2,71Å), $FePO_4$ (8,63; 2,54Å), $(Fe,Mg)Al_2(PO_4)_2(OH)_2$ (6,146; 2,27Å), $(Al,Fe)PO_4{\cdot}2H_2O$ (4,87; 3,333; 2,675Å) и вследствие малой их растворимости переходят в осадок. А кальций связывается в виде $CaSO_4{\cdot}2H_2O$ (7,63; 4,287; 3,06; 2,87; 2,675Å) и CaF_2 (3,158Å).

При этом состав высушенного осадка выглядит таким образом: 40,55% P_2O_5, 8,47% CaO, 3,91% MgO, 6,52% Al_2O_3, 4,95% Fe_2O_3 и 2,49% SO_3 и может использоваться в качестве концентрированного фосфорсодержащего удобрения пролонгированного действия. При этом 10,41% пятиокиси фосфора от общего содержания в исходном кислоте связываются в виде солей (рис. 3): $CaHPO_4{\cdot}2H_2O$ (7,635; 4,287; 3,768; 3,06; 2,54; 1,896Å), $CaHPO_4$ (3,38Å), $MgHPO_4$ (3,06Å), $AlPO_4$ (2,71Å), $FePO_4$ (8,63; 2,54Å), $(Fe,Mg)Al_2(PO_4)_2(OH)_2$ (6,146; 2,27Å), $(Al,Fe)PO_4{\cdot}2H_2O$ (4,87; 3,333; 2,675Å) и вследствие малой их растворимости переходят в осадок. А кальций связывается в виде $CaSO_4{\cdot}2H_2O$ (7,63; 4,287; 3,06; 2,87; 2,675Å) и CaF_2 (3,158Å).

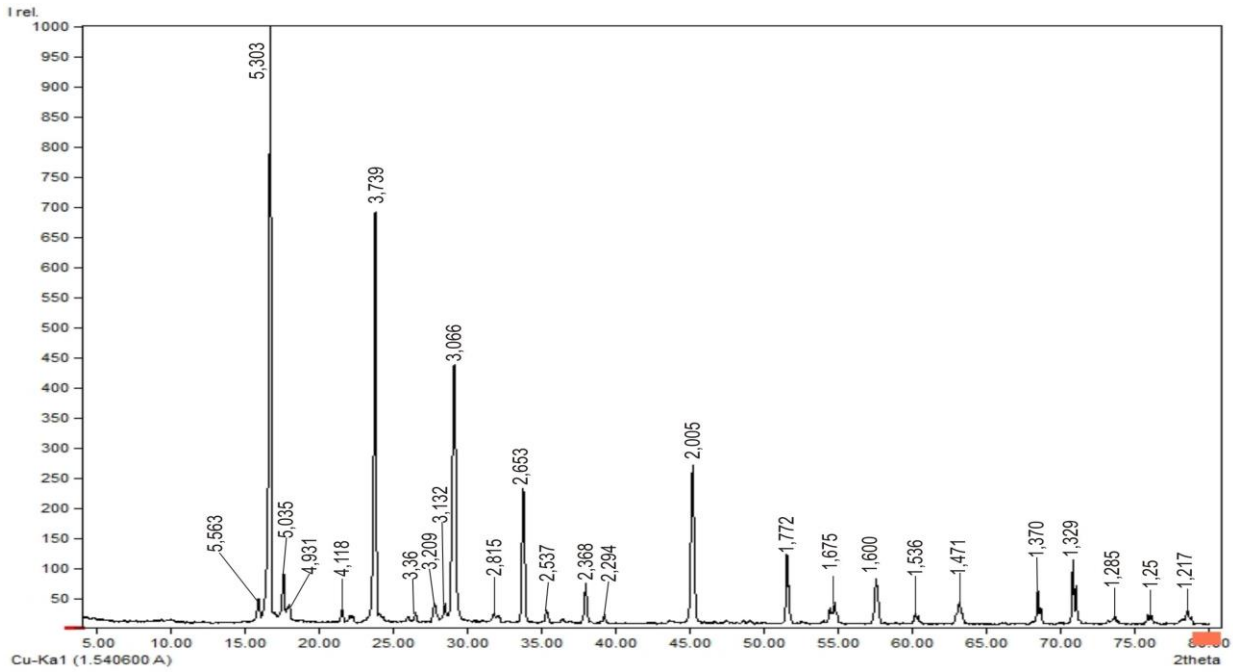

Рисунок 1. Рентгенограмма образца моноаммонийфосфата

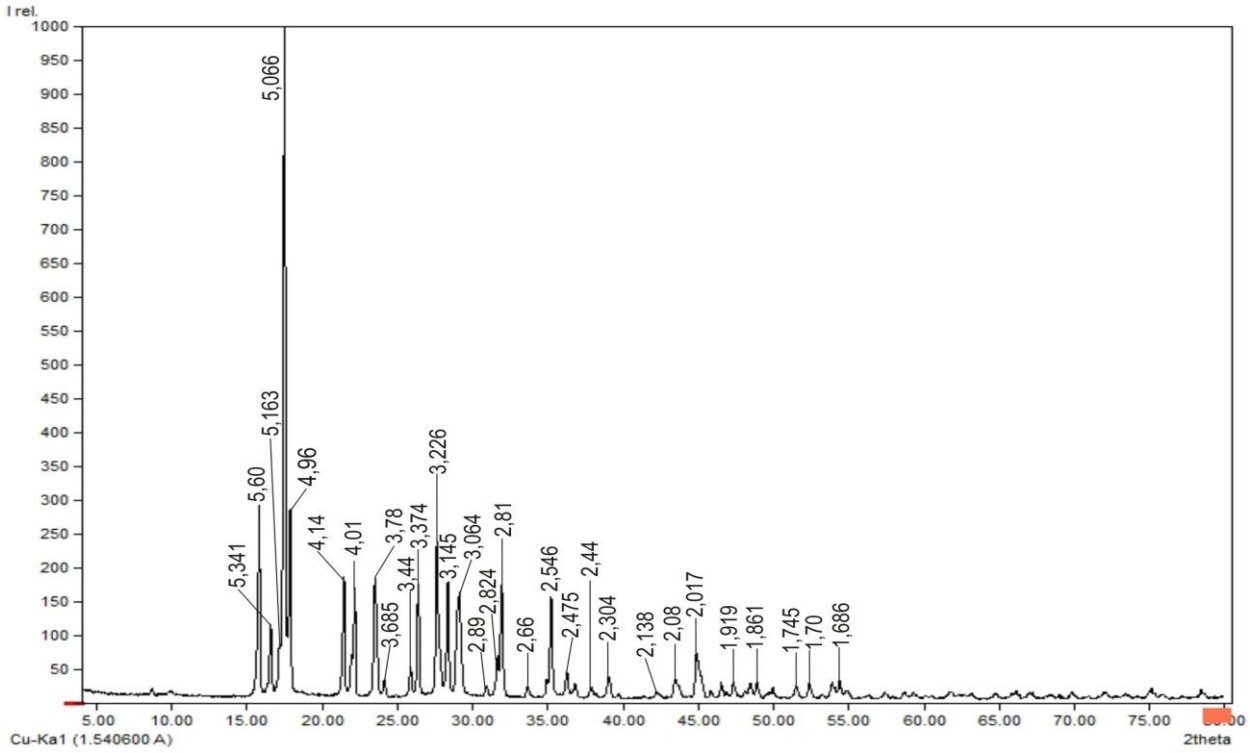

Рисунок 2. Рентгенограмма образца диаммонийфосфата

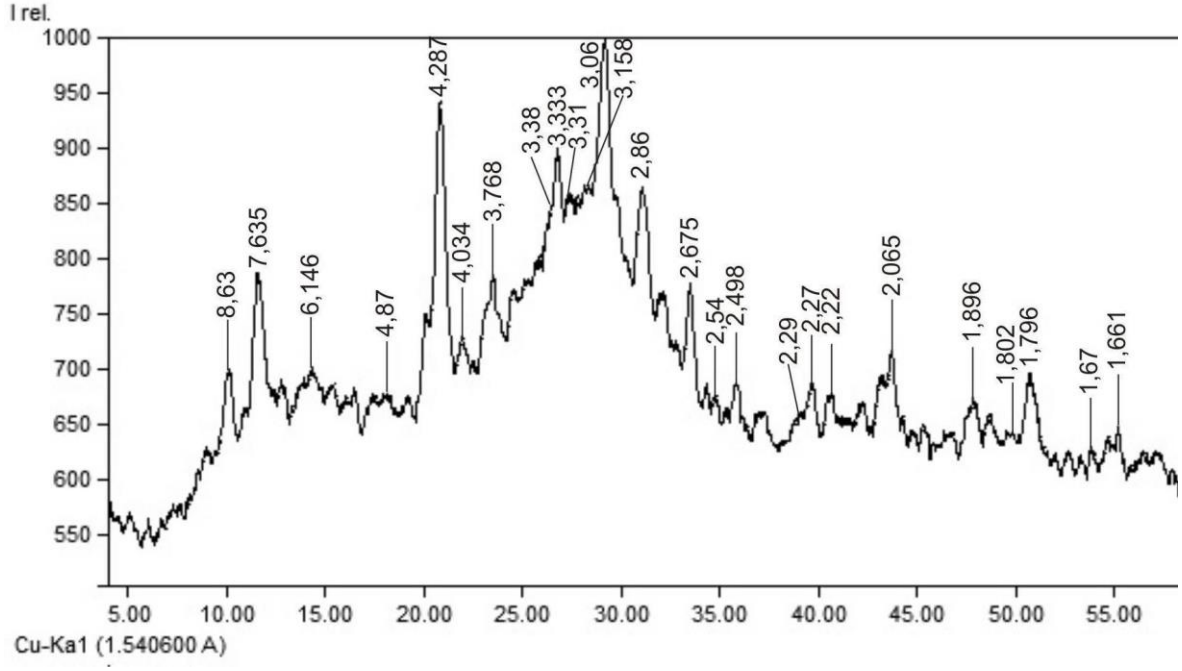

Рисунок 3. Рентгенограмма осадка при H_3PO_4 : (C_2H_5OH : CH_3COCH_3)= 1 : 0,33, τ – 30 минут; t – 25℃

Получение очищенной, к тому же концентрированной фосфорной кислоты на базе отложенной ЭФК вполне приемлема для производства водорастворимых фосфорсодержащих удобрений: фосфатов аммония либо жидких комплексных удобрений, пригодных для капельного орошения в тепличном хозяйстве (в том числе, в садах, ягодниках, виноградниках и под другие культуры).

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CONTROLLER FOR INDOOR 4-WHEEL CAMERA-CONTROLLED OMNI ROBOT

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КОНТРОЛЛЕР ДЛЯ КОМНАТНОГО 4-КОЛЕСНОГО ОМНИ-РОБОТА, УПРАВЛЯЕМОГО КАМЕРОЙ

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ABSTRACT

The aim of this article is to design solutions and built a control system for a transportation robot using omni wheels guided by a camera. The robotic design solution incorporates four omni-wheels, enabling smooth and flexible movement in multiple directions on flat surfaces. The camera navigation solution is a combination of the object detection algorithm YOLOv8 with the object assignment algorithm ByteTrack to build an autonomous system for the robot to follow the person. The test results show that the robot follows the person relatively accurately, moves without jerking, and does not lose the object it is following when the object moves quickly. This configuration makes the robot well-suited for indoor environments such as restaurants, hospitals, and similar settings.

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АННОТАЦИЯ

Целью данной статьи является разработка решений и создание системы управления для транспортного робота, использующего омни-колес и управляемого камерой. В конструкцию робота включены четыре омни-колеса, которые обеспечивают плавное и гибкое движение в различных направлениях по ровным поверхностям. Навигация с помощью камеры представляет собой комбинацию алгоритма обнаружения объектов YOLOv8 с алгоритмом присвоения объектов ByteTrack для создания автономной системы, позволяющей роботу следовать за человеком. Результаты испытаний показывают, что робот следует за человеком относительно точно, движется без рывков и не теряет объект, за которым он следует, даже если объект движется быстро. Эта конфигурация делает робота подходящим для использования в помещениях, таких как рестораны, больницы и аналогичные места.

Keywords: 4-wheel omni robot, object detection and tracking, YOLOv8; ByteTrack, ROS.
Ключевые слова: 4-х колесный омни-робот, обнаружение и отслеживание объектов, YOLOv8, ByteTrack, ROS.

1. Introduction

Indoor transportation robots are being increasingly widely utilized across in many fields thanks to their ability to optimize processes and reduce labor costs. Some applications of transportation robots in residential, hospital, and warehouse environments include: logistics (robots help carry items such as clothing, necessities, and other goods from one room to another); support for the disabled and the elderly (robots can deliver drinks, medicine or daily necessities to those in need, promoting greater independence); transfer of medical supplies (robots quickly transport medicine, surgical instruments or medical records between different areas in the hospital); reconnaissance and patrol (robots can be equipped with sensors and cameras to perform reconnaissance and patrol missions, providing security information in the factory and residential areas they are responsible for).

Currently, in the world, numerous organizations and individuals worldwide have conducted research on indoor transportation robots using advanced image processing technologies [1-6]. In Vietnam, many universities and research groups have published made significant contributions to this field, publishing a variety of research papers, typically: a group of scientists from the Faculty of Aerospace Engineering/ Le Quy Don Technical University have researched and successfully manufactured a medical transportation robot system to serve in infectious disease isolation areas [7-8]; A group of scientists from Hanoi University of Science and Technology has successfully researched and manufactured an autonomous robot for transportation in factories [9]; a research group from Phenikaa University has successfully designed and manufactured a transportation robot using renewable energy sources [10].

Despite the positive outcomes achieved such as: the ability to self-propell, avoid dynamic and static obstacles in an available map; the ability to detect, identify and track objects; the ability to move flexibly and smoothly, ... there are still, several issues that need to be addressed. The stability and reliability of the entire system remain low, the robot often loses its position, has problems leading to low reliability when put into operation in practice. The underlying cause of these limitations is temporal, as at present, navigation system based on sensors such as IMU, Lidar, and encoders is not yet stable and reliable, leading to the control system built on this idea not operating stably and with low efficiency.

In addition, guided by camera has a lot of potential for development, such as improving stability, continuity, efficiency and responsiveness to be able to develop into practical applications on robots [11].

Based on the evaluation of both domestic and international research, the authors propose a research direction focused on developing a controller for an omni-wheeled transportation robot guided by a camera. The aim is to verify and assess the effectiveness of object detection and tracking algorithms on an actual omni-wheeled mobile robot.

Based on the evaluation and analysis of the advantages and disadvantages of the transportation robot design in previous studies, as well as considering the goal of enhancing the robot's mobility, the authors have established the following design criteria:

- The 4-wheel omni robot can operate smoothly in indoor environments under normal temperature and humidity conditions.
- The real environment surface is not too rough, not slippery.
- Maximum moving speed is equivalent to indoor walking speed 0.6 m/s.
- Weight 10kg and load bearing 15kg.
- Expected dimensions 50*50*100 cm.

2. Kinematic model of 4-wheel omni robot

The robot model is a 4-wheel omni type arranged at an angle of 90^o to each other as shown in Figure 1.

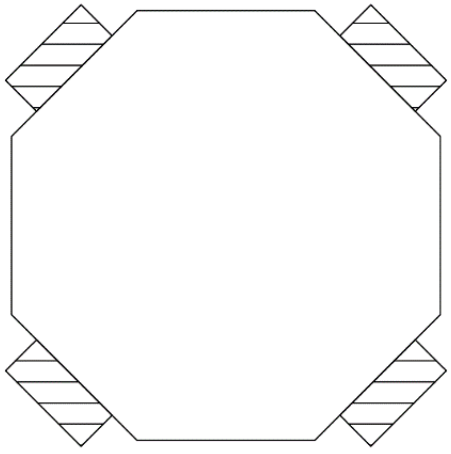

Figure 1. Model of omni 4-wheel autonomous robot

Let $X=\begin{bmatrix} x & y & \theta \end{bmatrix}^T$ be the coordinate vector of the robot in the global coordinate system, $\dot{\mathbf{X}}_R = \begin{bmatrix} \dot{x}_R & \dot{y}_R & \omega_R \end{bmatrix}^T$ be the velocity vector of the robot in the coordinate system attached to the robot center P.

Considering the geometric relationship in Fig. 2, we can determine the expression for the relationship between velocity in the local coordinate system compared to the global coordinate system:

$$\dot{\mathbf{X}}_R = R(\theta).\dot{\mathbf{X}} \quad (1)$$

With rotation matrix:

$$R(\theta) = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 \\ -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

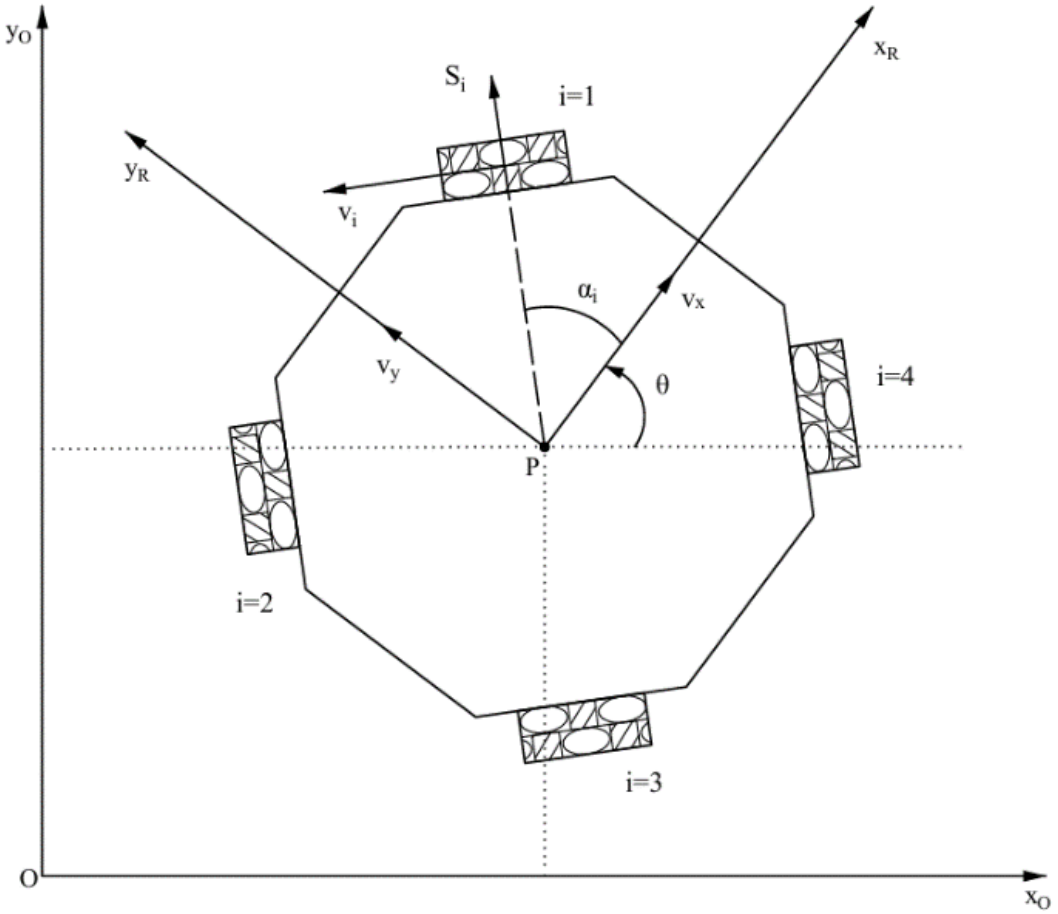

Figure 2. Global and local coordinate systems of the robot

The general kinematic model of an omni wheel is shown in Figure 3. The rotation center is located at A. The position of A attached to the robot local coordinate system is described using polar coordinates through the distance from A to P and the deviation angle α, the rotation axis of the wheel makes an angle β with PA. The wheel motion is represented by the rotation angle over time.

Here, define some parameters as follows:

- φ - rotation angle of wheel around axis.
- r - radius of wheels.
- γ - deviation angle between the wheel plane and the rotation axis of the rollers.
- l - distance from wheel center to robot rotation center.

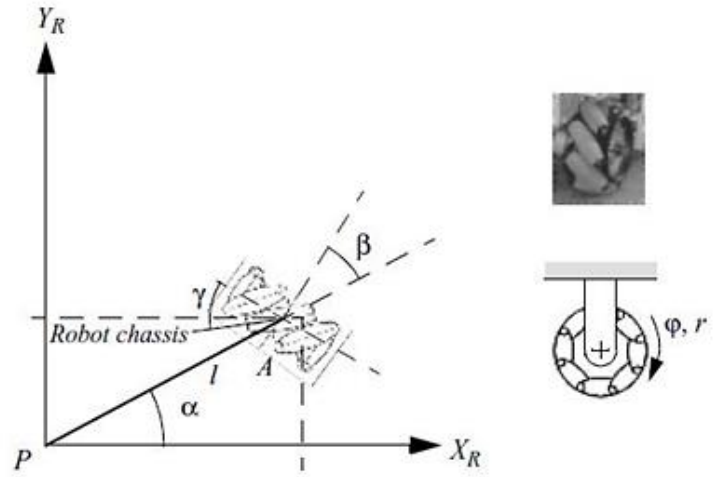

Figure 3. General kinematic model for an omni wheel

The rolling constraint of the wheel is represented by the equation:

$$\left[\sin(\alpha+\beta+\gamma) \quad -\cos(\alpha+\beta+\gamma) \quad -l\cos(\beta+\gamma)\right].R(\theta).\dot{\mathbf{X}} - r.\dot{\varphi}.\cos\gamma = 0 \tag{2}$$

The no-slip constraint of the wheel is expressed as follows:

$$\left[\cos(\alpha+\beta+\gamma) \quad \sin(\alpha+\beta+\gamma) \quad l.\sin(\beta+\gamma)\right].R(\theta).\dot{\mathbf{X}} - r.\dot{\varphi}.\sin\gamma - r_{sw}.\dot{\varphi}_{sw} = 0 \tag{3}$$

With the omni-wheel configuration selected for the robot model at a specific angle $\gamma = 0$, the wheel motion and the roller motion are independent of each other. As a result, the non-slip kinematic constraint equations do not contribute to the construction of the robot's kinematic model. Therefore, the four constraint equations for the 4 wheels are obtained as follows:

$$\begin{aligned}
&\left[\sin(\alpha_1+\beta_1+\gamma_1) - \cos(\alpha_1+\beta_1+\gamma_1) - l_1\cos(\beta_1+\gamma_1)\right].R(\theta).\dot{\mathbf{X}} - r.\dot{\varphi}_1.\cos\gamma_1 = 0\\
&\left[\sin(\alpha_2+\beta_2+\gamma_2) - \cos(\alpha_2+\beta_2+\gamma_2) - l_2\cos(\beta_2+\gamma_2)\right].R(\theta).\dot{\mathbf{X}} - r.\dot{\varphi}_2.\cos\gamma_2 = 0\\
&\left[\sin(\alpha_3+\beta_3+\gamma_3) - \cos(\alpha_3+\beta_3+\gamma_3) - l_3\cos(\beta_3+\gamma_3)\right].R(\theta).\dot{\mathbf{X}} - r.\dot{\varphi}_3.\cos\gamma_3 = 0\\
&\left[\sin(\alpha_4+\beta_4+\gamma_4) - \cos(\alpha_4+\beta_4+\gamma_4) - l_4\cos(\beta_4+\gamma_4)\right].R(\theta).\dot{\mathbf{X}} - r.\dot{\varphi}_4.\cos\gamma_4 = 0
\end{aligned} \tag{4}$$

In there:

- α_i, β_i and γ_i (rad) is the omni 4 wheel mount angle;
- l_i (m) is the distance between center O to each wheel;
- r (m) is the radius of each wheel;
- $\dot{\varphi}_i$ (rad/s) is the angular velocity of each wheel.

By substituting equation (1) into equation (4) and performing a series of transformation steps, the resulting equation is obtained as follows:

$$\begin{bmatrix}\omega_1\\ \omega_2\\ \omega_3\\ \omega_4\end{bmatrix} = \frac{1}{r}\begin{bmatrix}
\frac{\sin(\alpha_1+\beta_1+\gamma_1)}{\cos\gamma_1} & \frac{-\cos(\alpha_1+\beta_1+\gamma_1)}{\cos\gamma_1} & \frac{-l_1\cos(\beta_1+\gamma_1)}{\cos\gamma_1}\\
\frac{\sin(\alpha_2+\beta_2+\gamma_2)}{\cos\gamma_2} & \frac{-\cos(\alpha_2+\beta_2+\gamma_2)}{\cos\gamma_2} & \frac{-l_2\cos(\beta_2+\gamma_2)}{\cos\gamma_2}\\
\frac{\sin(\alpha_3+\beta_3+\gamma_3)}{\cos\gamma_3} & \frac{-\cos(\alpha_3+\beta_3+\gamma_3)}{\cos\gamma_3} & \frac{-l_3\cos(\beta_3+\gamma_3)}{\cos\gamma_3}\\
\frac{\sin(\alpha_4+\beta_4+\gamma_4)}{\cos\gamma_4} & \frac{-\cos(\alpha_4+\beta_4+\gamma_4)}{\cos\gamma_4} & \frac{-l_4\cos(\beta_4+\gamma_4)}{\cos\gamma_4}
\end{bmatrix}\begin{bmatrix}\dot{x}_R\\ \dot{y}_R\\ \omega_R\end{bmatrix} \tag{5}$$

The Jacobian matrix for the inverse kinematic equation of the system is represented by the equation:

$$\mathbf{J}=\frac{1}{r}\begin{bmatrix} \frac{\sin(\alpha_1+\beta_1+\gamma_1)}{\cos\gamma_1} & \frac{-\cos(\alpha_1+\beta_1+\gamma_1)}{\cos\gamma_1} & \frac{-l_1\cos(\beta_1+\gamma_1)}{\cos\gamma_1} \\ \frac{\sin(\alpha_2+\beta_2+\gamma_2)}{\cos\gamma_2} & \frac{-\cos(\alpha_2+\beta_2+\gamma_2)}{\cos\gamma_2} & \frac{-l_2\cos(\beta_2+\gamma_2)}{\cos\gamma_2} \\ \frac{\sin(\alpha_3+\beta_3+\gamma_3)}{\cos\gamma_3} & \frac{-\cos(\alpha_3+\beta_3+\gamma_3)}{\cos\gamma_3} & \frac{-l_3\cos(\beta_3+\gamma_3)}{\cos\gamma_3} \\ \frac{\sin(\alpha_4+\beta_4+\gamma_4)}{\cos\gamma_4} & \frac{-\cos(\alpha_4+\beta_4+\gamma_4)}{\cos\gamma_4} & \frac{-l_4\cos(\beta_4+\gamma_4)}{\cos\gamma_4} \end{bmatrix} \quad (6)$$

The forward kinematic equation is represented as follows:

$$\begin{bmatrix} \dot{x}_R \\ \dot{y}_R \\ \omega_R \end{bmatrix} = \mathbf{J}^+ \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} \quad (7)$$

Where: $\mathbf{J}^+$ is the pseudo-inverse matrix of $\mathbf{J}$.

From there we can calculate the forward kinematics and inverse kinematics for the mobile robot using 4 omni wheels as follows:

$$\begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} = \frac{1}{r}\begin{bmatrix} \frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & -l_1 \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & -l_2 \\ -\frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & -l_3 \\ -\frac{\sqrt{2}}{2} & -\frac{\sqrt{2}}{2} & -l_4 \end{bmatrix} \begin{bmatrix} \dot{x}_R \\ \dot{y}_R \\ \omega_R \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} \dot{x}_R \\ \dot{y}_R \\ \omega_R \end{bmatrix} = \frac{r}{4}\begin{bmatrix} \sqrt{2} & \sqrt{2} & -\sqrt{2} & -\sqrt{2} \\ -\sqrt{2} & \sqrt{2} & \sqrt{2} & -\sqrt{2} \\ -1/l_1 & -1/l_2 & -1/l_3 & -1/l_4 \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \end{bmatrix} \quad (9)$$

These are the equations used for the design and synthesis of controllers for the 4-wheel omni robot later.

3. Design and synthesis of controller

3.1. Structure diagram of system hardware

Based on the design requirements and the selected robot model, the authors proceeded to calculate, select components, manufacture, assemble and obtain the model as shown in Figure 4.

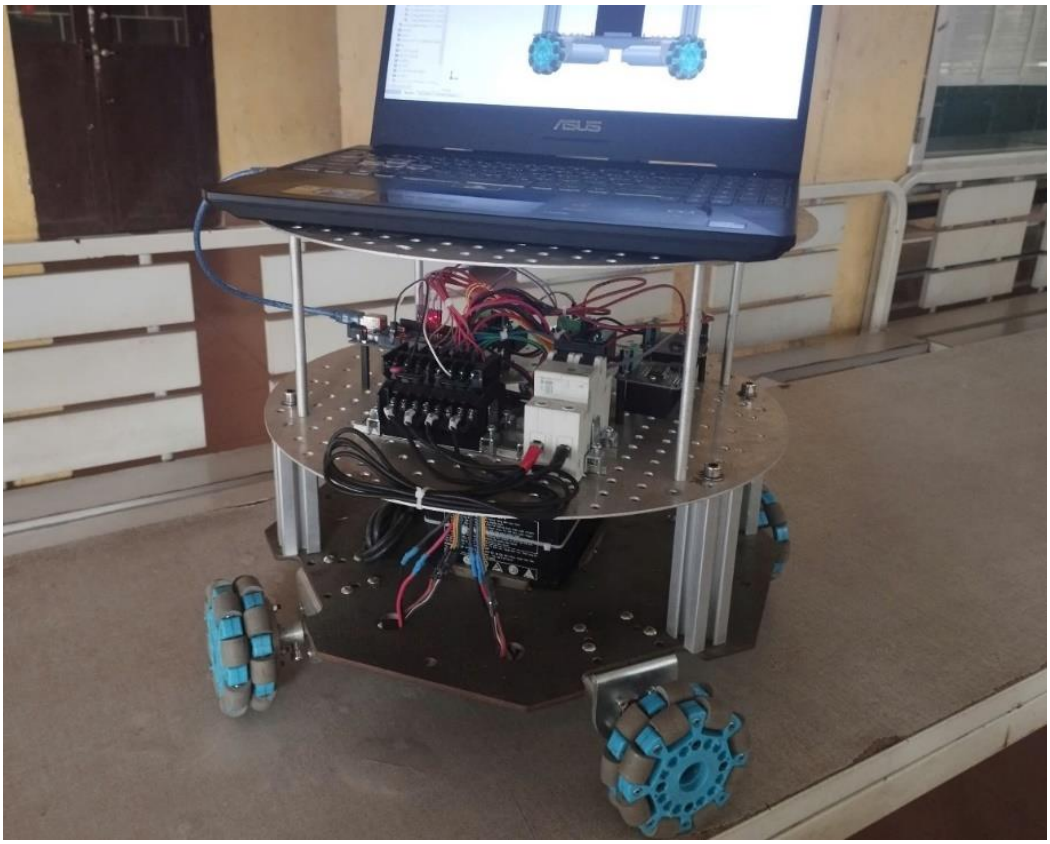

Figure 4. Model of mobile robot using 4 omni wheels

The drive part of the robot model is powered by four DC motors with encoder sensors, receiving voltage from BTS7960 power units. These power units are controlled by Arduino Mega 2560 board. The block diagram of the robot hardware control system is illustrated in Figure 5. Image processing algorithms are implemented on a personal computer, where the output of the image processing program is the deviations of the object center position compared to the image center in the two directions X and Y. From these deviation values, the software program will calculate the set speed to each motor.

These set velocity values will be transferred to the Arduino Mega 2560 board via ROS to hash the control pulses of the 04 motors.

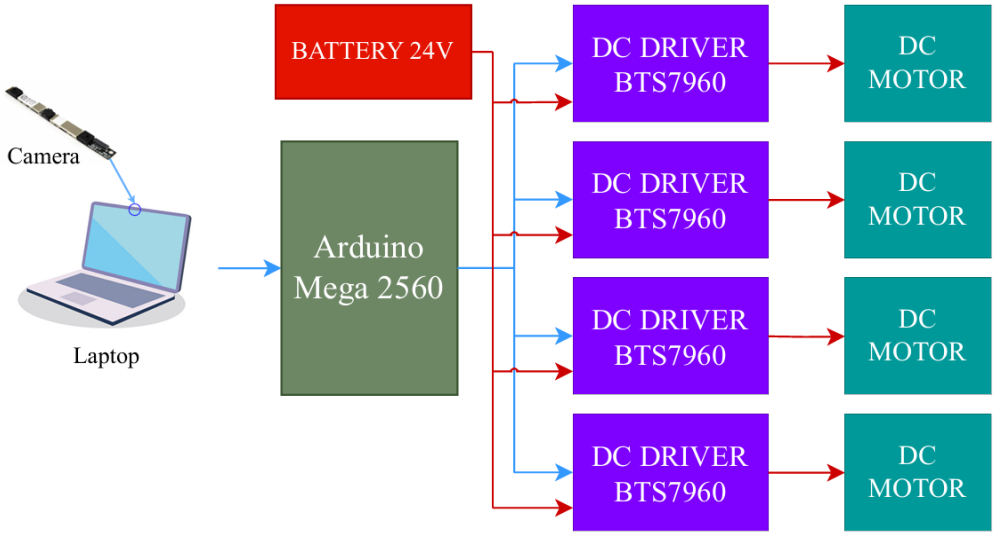

Figure 5. Connection diagram of hardware system on robot

Based on the robot hardware connection diagram, the robot control system can be divided into 2 layers:

- Lower Layer Control System: This layer includes the Arduino Mega 2560 controller and the BTS7960 power supplies;
- Upper Layer Control System: This layer consists of a laptop connected to a camera, responsible for implementing image processing algorithms, calculating the desired velocity for the four wheels, and transmitting this information to the Arduino board using the communication environment provided by ROS.

The two layers of the hardware system are organized into three layers within the robot model as illustrated in Figure 4. This structure serves as a foundation for the authors to further research and develop a controller for the robot model.

The use of Arduino for generating pulses to control actuators has been widely researched and published by many organizations and individuals. Therefore, in the content of the article, the authors focuse on presenting the results of implementing image processing algorithms and synthesizing controller on the upper layer.

3.2. Algorithm flowchart

To enable the robot to follow humans in various tasks such as transportation and assisting the disabled, three primary tasks must be addressed:

- Object detection task;
- Object tracking task;
- Calculate the set velocity for 4 wheels.

For object detection, several advanced techniques are being used such as: YOLO, SSD, Faster R-CNN. However, when applied to the task of controlling a robot to move and follow a person, the authors found that the YOLO algorithm is a suitable choice due to the algorithm's real-time processing ability.

In terms of object tracking, various modern techniques are employed, such as Deep SORT, StrongSORT, and ByteTrack. After careful research and evaluation, the authors selected the ByteTrack algorithm for deployment in the controller, as it demonstrates superior speed and a greater ability to handle real-life scenarios compared to other object tracking algorithms.

Based on the above analysis and selection of object detection and tracking algorithms, we have an algorithm flowchart for the entire control system as shown in Figure 6.

Starting the algorithm, the image captured from the camera will be sent to the image processing module. Here, through the process of applying the object detection algorithm YOLOv8 and the object tracking algorithm ByteTrack, the object center position on the frame will be obtained. The deviation calculation module will calculate the deviation of the object center compared to the frame center. These two modules are processed on the ROS2 environment to ensure real-time. Then the deviation values in the two directions X and Y will be sent to the ROS environment via ros1_bridge. From there, the "Calculate the wheel set velocity" module calculates the set velocities for the 4 DC motors through the deviation of the object's center with the frame center and the inverse kinematic equation. The set velocities after being calculated are sent down to the Arduino Mega 2560 board via rosserial. The motor control module uses the PID algorithm to output a signal to control the motor velocity according to the set velocity. The algorithm runs in a loop until it stops when there is an exit command.

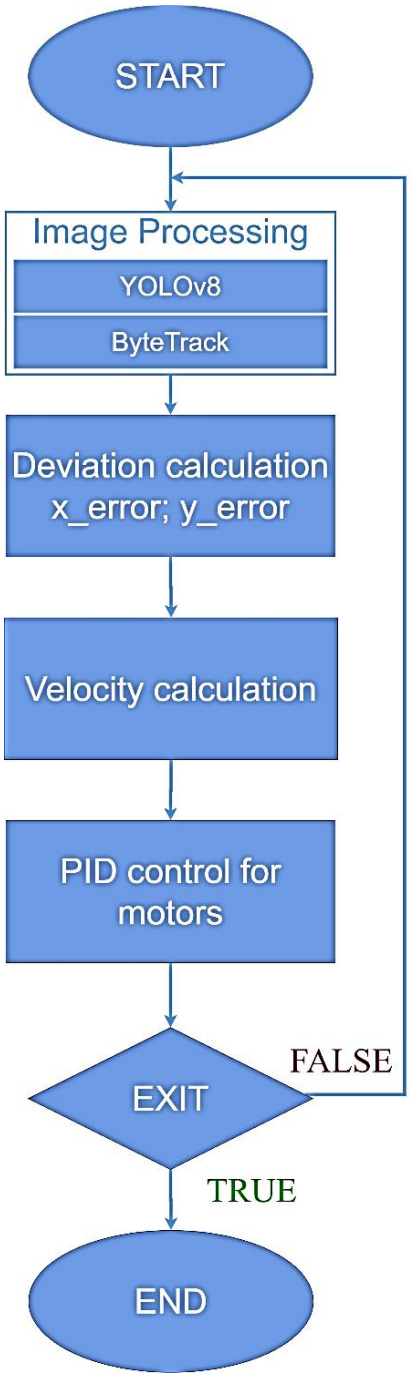

Figure 6. Algorithm flowchart

Thus, with the combination of the two algorithms mentioned above, the program calculates the error of the tracked object center with the fixed coordinate system of the frame. Here, the error in the X axis (x_error) is calculated as the error between the tracked object center and the frame center (coinciding with the robot middle axis). This error is used to calculate the robot deviation angle from the tracked object. The error in the Y axis (y_error) is calculated by the lower edge of the tracked

object frame with the horizontal line corresponding to the pixel value y = 475 [11]. The y error is used to determine the relative distance of the robot from the object, serving to calculate the translational velocity of the robot. This value can be customized so that the robot maintains a suitable distance from the object being tracked.

When ROS receives the error values from ROS2, the program starts calculating the angular velocities for the wheels from the two error parameters. First, we calculate the linear velocity and angular velocity of the robot according to the formula:

$$\begin{cases} v = \dot{x}_R = k_y \cdot y_error \\ \omega = k_x \cdot x_error \end{cases} \quad (10)$$

with k_x, k_y being optional gain coefficients to set the robot velocity limit selected through the experimental process on the robot model with the appropriate alignment to the task requirements. From there, substituting into equation (8), we get the set velocity for 4 wheels according to the following deviation:

$$\begin{cases} \omega_1 = \frac{1}{r}\left(\frac{\sqrt{2}}{2} k_y y_error - l k_x x_error\right) \\ \omega_2 = \frac{1}{r}\left(\frac{\sqrt{2}}{2} k_y y_error - l k_x x_error\right) \\ \omega_3 = \frac{1}{r}\left(-\frac{\sqrt{2}}{2} k_y y_error - l k_x x_error\right) \\ \omega_4 = \frac{1}{r}\left(-\frac{\sqrt{2}}{2} k_y y_error - l k_x \times x_error\right) \end{cases} \quad (11)$$

The set velocity for the 4 motors is sent down to the Arduino Mega 2560 via the rosserial package to control the actuator motors to move the robot to follow the specified object.

4. Experimental results

The image processing program is implemented using Python 3.8, incorporating the YOLOv8 module and the ByteTrack algorithm within a ROS2 environment on a personal computer. The following results were achieved:

Figure 7. Result of object recognition and ID assignment for an object to be tracked

Based on Figure 7, it is evident that the YOLOv8 algorithm has successfully determined the center of the object (indicated by the red dot) and the ByteTrack algorithm has assigned ID = 1 to the object that the robot wants to follow.

When multiple objects appear in the frame, the program generates the result as illustrated in figure 8.

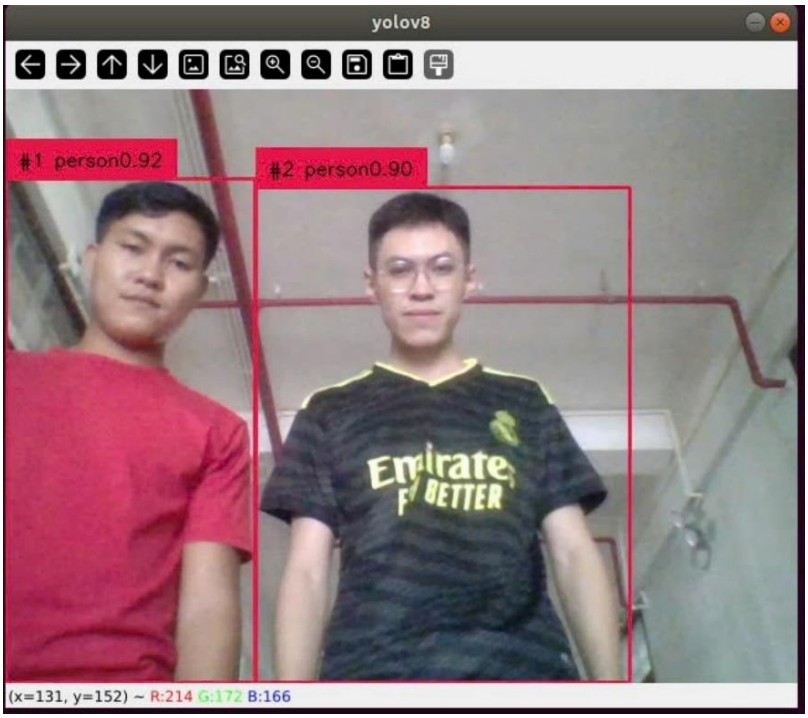

Figure 8. Result of recognition and ID assignment for multiple objects

As shown in Figure 8, when 2 objects appear in a frame, the program detects and assigns each object a different ID (ID = 1 and ID = 2).

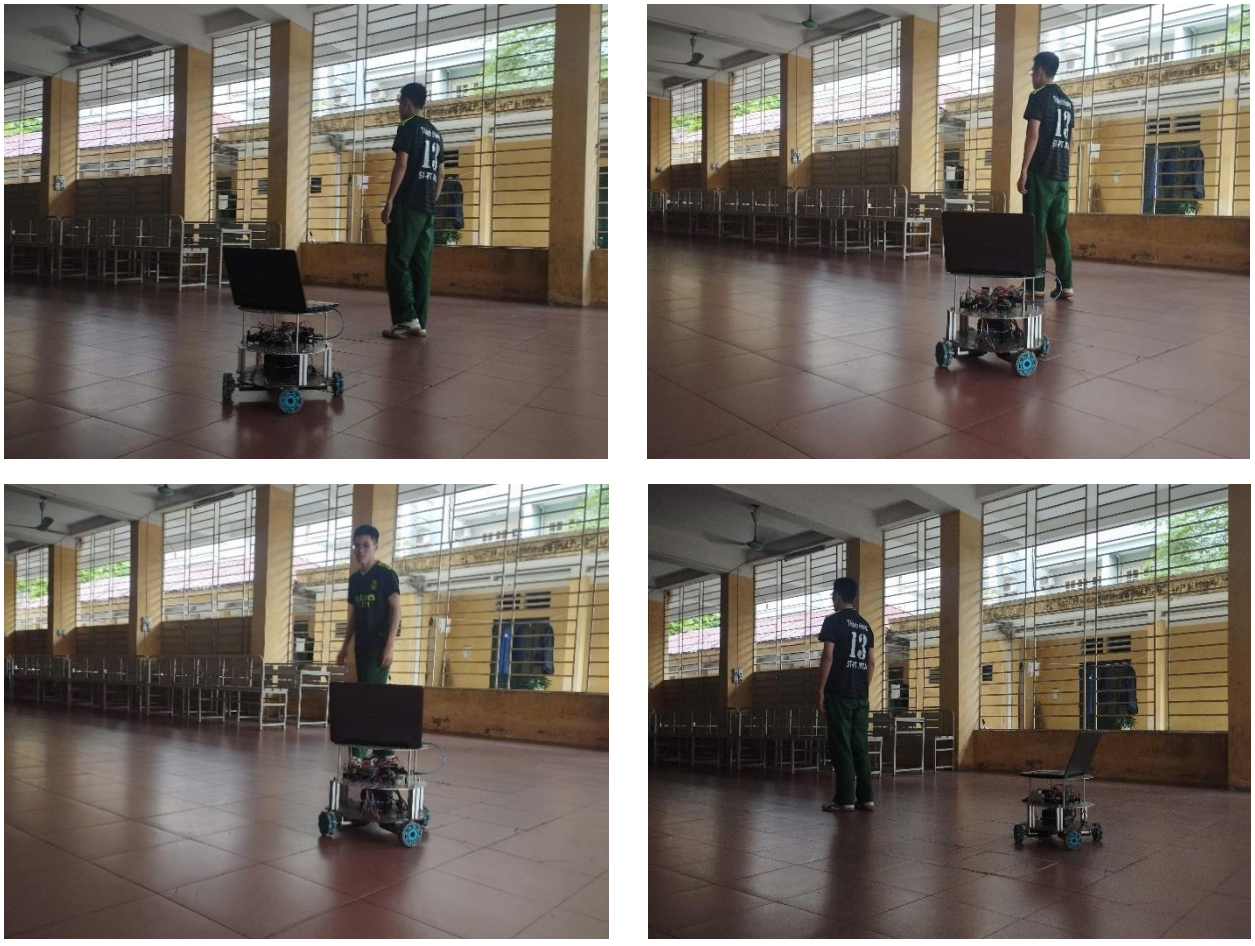

Figure 9. Robot moves to follow the object

The experimental results of robot tracking the object are shown presented in Figure 9. The tracking result is satisfactory when the object moves at a speed of less than 0.6 m/s. Along the Y axis, the robot maintains a relatively good distance, however, along the X axis, the robot's tracking angle is not good yet, there is still a phenomenon of oscillation (shaking) around the main axis. The reason for the above phenomenon is due to the limitation of computing resources of personal computers, the parameters of the PID motor controller have not been optimally selected, and the influence of the transmission speed between the Laptop and Arduino. These disadvantages will be overcome by the authors in subsequent studies.

Experimentally, when the object is hidden from the camera's view (<4s), the proposed algorithm gives positive results: the robot correctly re-detects the object's ID and follows it. This is necessary for the real-world object tracking task.

5. Conclusion

The integration of mechanical design solutions utilizing four omni-wheels and advanced image processing technology represents an effective approach to developing transportation robots for use in warehouses, factories, restaurants, hospitals, and similar environments. This combination yields positive test results, effectively mitigating some of the limitations observed in previously researched and developed robots.

Experimental findings demonstrate that the robot operates smoothly, without shaking, and can successfully track the object even in the presence of noise, such as when the object temporarily disappears from the frame or becomes obscured.

The research outcomes presented in this paper have significant implications for the development of transportation robots in logistics, as well as for medical robots aimed at assisting individuals with disabilities and aiding medical staff in the transportation of medications and essential supplies.

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ADDRESSING DATA CONSISTENCY IN HIGH-LOAD DISTRIBUTED SYSTEMS: IMPLEMENTATION CHALLENGES AND SOLUTIONS

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ОБЕСПЕЧЕНИЕ СОГЛАСОВАННОСТИ ДАННЫХ В ВЫСОКОНАГРУЖЕННЫХ РАСПРЕДЕЛЕННЫХ СИСТЕМАХ: ПРОБЛЕМЫ РЕАЛИЗАЦИИ И РЕШЕНИЯ

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ABSTRACT

This article presents a review of best practices for ensuring data consistency in high-load distributed systems (HLDS). It highlights the importance of this task in the context of rapidly growing data volumes. Various consistency models such as strict, sequential, weak, and causal are analyzed. Methods and approaches for ensuring consistency are studied. Examples of successful application of these approaches in the practice of leading international companies are provided. Methods for solving typical problems arising during the implementation of consistency in HLDS are discussed.

АННОТАЦИЯ

В статье представлен обзор лучших практик обеспечения согласованности данных в высоконагруженных распределенных системах (HLDS). Подчеркивается важность этой задачи в условиях быстрорастущих объемов данных. Анализируются различные модели согласованности, такие как строгая, последовательная, слабая и причинная. Изучаются методы и подходы к обеспечению согласованности. Приводятся примеры успешного применения данных подходов в практике ведущих международных компаний. Обсуждаются методы решения типичных проблем, возникающих при реализации согласованности в HLDS.

Keywords: data consistency, high-load distributed systems, system scalability, data management, application architecture optimization, NoSQL, NewSQL, Kafka, CAP theorem.

Ключевые слова: согласованность данных, высоконагруженные распределенные системы, масштабируемость системы, управление данными, оптимизация архитектуры приложений, NoSQL, NewSQL, Kafka, ZooKeeper, теорема CAP.

Introduction

In the contemporary world, data has emerged as a new 'currency', as it enables the generation of substantial volume of insights that businesses can leverage to both increase their revenue and improve the efficiency of their processes [1]. However, as the volume of data increases, software systems must address challenges related to concurrency management, latency reducing, data replication handling. Distributed systems, which consist of a number of independent nodes working together to provide a unified business service, have become critical part for the operation of modern cloud-based applications, including e-commerce platforms, social networks, and banking services [2]. Ensuring consistency in high-load scenarios—characterized by frequent data updates from multiple sources - often conflicts with other system properties such as availability and partition tolerance, as articulated by the CAP theorem [3].

The primary goal of this study is to explore and analyze various techniques for addressing data consistency in high-load distributed systems (HLDS), develop a framework for consistency model evaluation and a set of recommendations for software developers and architects designing high load architectures.

The tasks of this study were to **identify and articulate the primary challenges** associated with maintaining data consistency in distributed systems operating under high-load conditions. The challenges include issues related to concurrency, network latency, and partition tolerance; **synthesize findings from existing research** and analyzing emerging trends in data consistency techniques; **evaluate and classify consistency models** such as strong consistency, eventual consistency,

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causal consistency, focusing on their theoretical foundations and practical implications in high-load scenarios; **provide actionable insights and recommendations** for practitioners and researchers, providing best practices for designing distributed systems that effectively balance data consistency, availability, and performance (in accordance to CAP theorem) under high-load conditions.

The relevance of this work is justified by presence of technical challenges associated with the implementation of scalable and fault-tolerant architectures for data-intensive business systems, such as e-commerce platforms, financial services, online banking, and social networks. The challenges require well-reasoned solutions.

The theoretical significance of this study lies in its provision of a comprehensive framework for the evaluation and comparative analysis of various consistency models, systematically assessing their strengths and weaknesses. Furthermore, this study can serve as a reference for teaching concepts related to data consistency, system design, and performance optimization. The practical contribution of this research includes the formulation of a set of recommendations, best practices, and guidelines for practitioners and researchers engaged in the field of distributed systems, particularly in the design of systems that prioritize both performance and data integrity.

Materials and Methods

To investigate and evaluate various methods for ensuring data consistency in distributed software systems and to achieve the stated goals, this study uses both theoretical and practical approaches. In order to build up a holistic and comprehensive understanding of the topic addressed in this research; the following steps were undertaken:

- identified the core concepts such as the CAP theorem (Consistency, Availability, and Partition Tolerance), as well as various consistency models such as strong, eventual, causal, and hybrid consistency models.
- confirmed theoretical conclusions and obtained practical recommendations by comprehensive review of pertinent academic journals, conference proceedings, and technical reports was conducted across various databases, including IEEE Xplore, ACM Digital Library, and Google* Scholar [4]. The key terms used in the search included "data consistency, "consistency models, "distributed systems, "high-load environments, and "scalability".
- studied practical application of various techniques for ensuring consistency, including an analysis of how each model addresses the challenges presented by specific scenarios and use cases associated with each model.

The following stages of the research were conducted:

1. The data acquired from theoretical sources and practical use cases were systematically processed and analyzed. The inclusion criteria for the sources stipulated that the studies must be current and published within the last three-four years, specifically focusing on insights into data consistency techniques in distributed systems. Both theoretical and empirical studies were reviewed to identify emerging trends and best practices.

2. The findings were synthesized to construct a cohesive narrative regarding the current state of research on data consistency in high-load distributed systems. The key themes identified include: The evolution of consistency models in response to the growing volume of data; The significance of hybrid consistency models in attaining a balance between performance and correctness.

3. A comparative framework was established to assess the efficacy of various data consistency techniques under high-load conditions. This framework encompassed criteria including: **a.** the evaluation of the influence of each technique on system latency and throughput; **b.** the assessment of scalability involves evaluating the capacity of various techniques to manage growing data volumes and increasing user demands; an examination of the effectiveness of conflict resolution mechanisms in upholding the consistency.

4. A comprehensive set of recommendations was developed based on the results obtained. These recommendations are tailored to guide the selection of the optimal consistency strategy, taking into account the specific requirements of the architecture and the most efficient utilization of resource capabilities.

The proposed comparison framework enables software developers, architects, and Chief Technology Officers (CTOs) to make informed and structured decisions. For instance, they can determine whether to implement strong consistency, which ensures immediate correctness, or eventual consistency, which prioritizes availability and speed, based on the specific requirements of the application. Additionally, the framework facilitates the evaluation of trade-offs, such as latency versus consistency, cost versus performance, and complexity versus flexibility. It also aids in risk mitigation by assessing how different databases manage network partitioning and whether the system can degrade gracefully during failures. Furthermore, the framework promotes support of performance and scalability optimizations. Additional advantage is keeping consistency across teams. This consistency is crucial for long-term maintainability at an appropriate level. For example, when selecting between various open-source libraries or frameworks, a comparison based on active development and community support can help ensure that the project is not impeded by the use of unsupported or outdated technologies.

The next step in the development of the comparison framework must consider additional factors that influence economic efficiency, including the learning curve of the software engineers, costs of technical resources, and other relevant variables for calculation. This approach will facilitate the creation of a more accurate and effective tool for decision-making in the domain of data consistency.

Results, and Discussion

Distributed systems have become widespread in software solutions for commercial companies due to their scalability, reliability, significant potential for costs reduction, and handling the ever-growing volumes of data. The primary consumers of these solutions are so called data-intensive applications such as e-commerce platforms, social media networks, or cloud service

providers, which need to accommodate millions of users and transactions [5]. Unique characteristics of the distributed systems make them essential for businesses that eager to innovate, grow, and compete in a digital-first economy.

A distributed system is a collection of autonomous computing elements that appears to its users as a single coherent system. These types of system have become widespread due to establishment of microservice architectures.

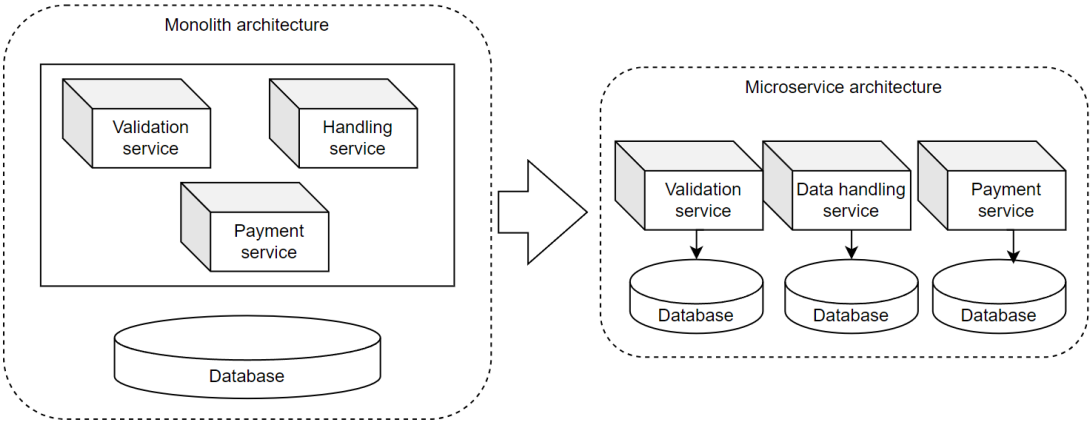

Figure 1. Transition from the monolith to the microservice architecture

With a set of aforementioned advantages of distributed systems, they also come with several disadvantages and challenges. These downsides can add complexity and cost to system design, maintenance, and operation. Here are some key disadvantages of distributed systems [6]:

- Network related issues
- Fault detection and diagnosis challenges
- Security related issues
- Increased maintenance costs
- Higher resource requirements
- Data consistency challenges

One of the most important goals of a distributed system is to allow its users to get an access to resources. It can be implemented in a cooperative way, as in the case of communication channels or in competitive way when a number (> 2) of independent users / clients want to retrieve the same file server or the same tables in a shared database. In instances of concurrent resource utilization, it is essential that each user remains unaware of the simultaneous access by others to the same resource. This phenomenon is referred to as concurrency transparency. A critical consideration in this context is ensuring that concurrent access to a shared resource maintains the resource in a consistent state. Consistency can be attained through the implementation of locking mechanisms, which grant users exclusive access to the desired resource in a sequential manner. A more sophisticated approach involves the utilization of transactions; however, the implementation of transactions in a distributed system can be challenging, particularly when scalability presents a concern [7]. It often takes place in building transaction-intensive solutions like payment platforms [8].

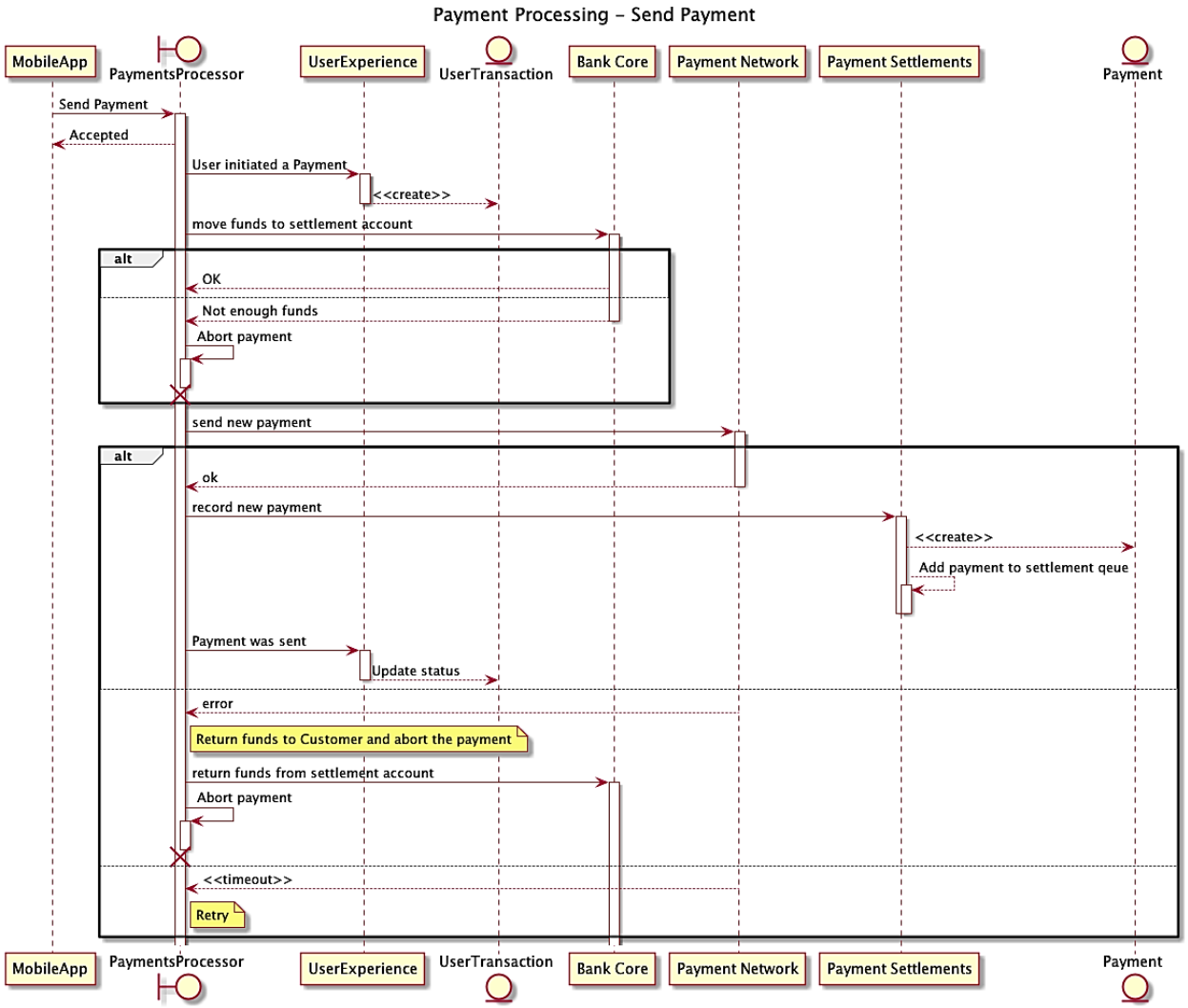

Figure 2. Transaction-intensive solitons present significant challenges in maintaining data consistency due to their inherent complexity

Understanding and applying best practices for maintaining data consistency is becoming an important aspect for ensuring the stability and efficiency of high-distributed systems (HDS) [9]. The selection of architectural solutions and technologies that facilitate a balance between consistency and availability is crucial for the system's capacity to adapt to evolving usage conditions.

Data consistency models are a set of principles and guarantees that define the behavior of a system when reading and writing data. They provide predictability and reliability in a distributed computing environment and define how and when changes made in one place become visible to other parts of the system. There are five main criteria that must be evaluated for developing data sharing in distributed systems [6]:

- concurrency (the extent to which conflicting read/write access is permissible)
- consistency (preservation of the update dependency and stale read data tolerance)
- availability (the access method to the replica is their absence) visibility (how should we have a global view, when the local changes have been applied on the replicated data)
- isolation (when the remote updating must be observed locally)
- These criteria represent a set of requirements to a consistency model appropriate to the system and in accordance to the CAP theorem [10]. Based on these requirements many consistency models were invented and classified (Figure 3) [7] but only few types of them found widespread adoption:
- **strict consistency (linearizability)** assumes that if a write occurs before a certain point in time, then any subsequent read after that point will see that write. Achieving strict consistency is quite difficult, especially when high availability and partition tolerance are required
- **sequential consistency** has less stringent requirements and guarantees that if a write is seen as complete, then all subsequent reads will see the result of that write [11], but does not require that changes be immediately visible to all nodes
- **weak consistency** provides even more flexible guarantees by not requiring immediate or sequential visibility of changes. Instead, it guarantees that if no new writes are made, then eventually all reads will return the latest value. This greatly simplifies its implementation,

where latency and network partitioning are common [12], but introduces an element of uncertainty into the system's behavior, making it less predictable for users and developers

- **causal consistency** ensures that operations that have a causal relationship will be visible in the appropriate order.

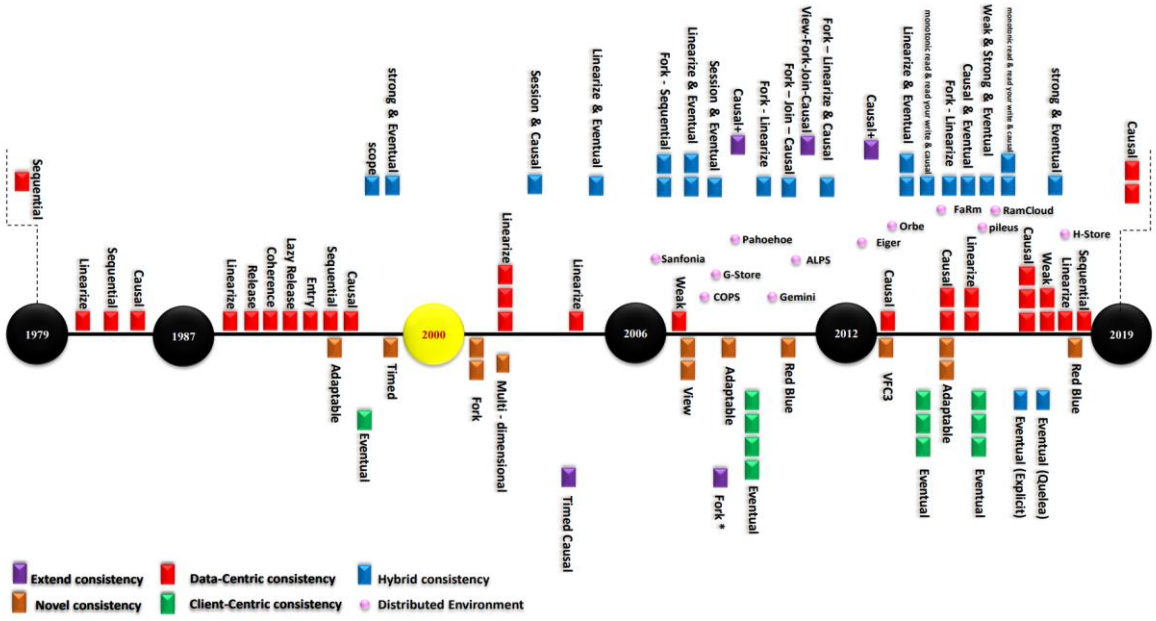

Figure 3. Classification of different consistency models used in distributed systems

The consistency model is largely determined by the specifics of the application. Developers must carefully weigh the requirements for availability and timeliness of information to find a balance for a system development. The following figure demonstrates visual representation of parameters of the consistency models:

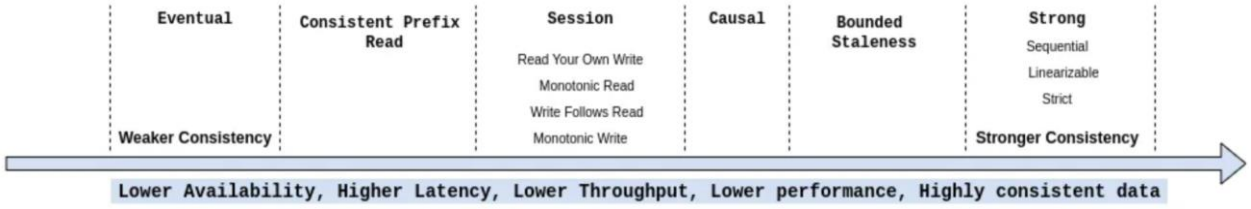

Figure 4. The characteristics of consistency models are dependent on their respective types

There are methods and approaches to ensuring consistency. To ensure data consistency, various methods and approaches are used, each of which has its own characteristics, advantages and areas of application (Table 1).

Table 1.

Features of the application of consistency assurance methods

Method/Approach	Peculiarities	Advantages	Application areas
Two-phase commit (2PC)	Two phases: preparation and confirmation /rollback.	Guarantee of transaction atomicity.	Distributed transaction systems.
Three-Phase Commit (3PC)	Adding a pre-phase to 2PC to reduce blocking.	Improved fault tolerance.	Distributed systems with high availability requirements.
Vector clock	Tracking causal dependencies between events [13].	Allows for the implementation of causal consistency.	Systems, where the sequence of events is important.
Data versioning [14]	Saving the history of changes to objects.	Simplifying conflict resolution.	Systems with frequent data changes.
Resolving conflicting replicas	Mechanisms for merging changes to achieve consistency.	Flexibility in handling conflicts.	Systems with active replication.

Each of these methods and approaches plays a crucial role in maintaining data consistency within the developed system. By integrating various mechanisms and considering the specifics of a particular application or service, it is possible to identify the optimal balance among consistency, availability, and efficiency, thereby enhancing the system's reliability and operational effectiveness. The implementation of microservice architecture offers significant opportunities for the application of these technologies.

Problems of implementing consistency and ways to overcome them. In the process of implementing consistency in the system, developers face a number of problems, including the complexity of data management in conditions of high availability and fault tolerance [15]. It is necessary to ensure the scalability of the system while maintaining strict requirements for data consistency, which requires careful planning and optimization of the architecture. Table 2 presents typical problems when implementing consistency and possible solutions:

Table 2.

Problems of implementing consistency and ways to solve them

Problem	Description	Solution methods
Delays due to rigid consistency [15]	Striving for absolute consistency increases latency due to the need to synchronize data between nodes.	Applying consistency models tailored to the specific requirements of the application, such as sequential or causal consistency.
Concurrency and Lock Management	Simultaneous access to data may result in blocking and slowdowns in the system.	Use of optimistic and pessimistic blocking methods and conflict resolution algorithms.
Difficulty of scaling	System expansion can make it more difficult to manage data consistency.	Data partitioning and replication, using geographically distributed databases to improve scalability and availability [17].
Network partition tolerance	Network failures may prevent data synchronization between nodes.	Using partition-tolerant algorithms such as Paxos or Raft to ensure consistency even under network problems [18].
Ensuring Consistency in Microservice Architecture	Microservices increase the complexity of data management and consistency.	Create a centralized state management service or use event-driven approaches to synchronize data between microservices.

This is not an exhaustive list of potential methods for addressing common consistency issues; however, it outlines fundamental strategies that help to the develop reliable and effective distributed systems.

Conclusion

Ensuring data consistency in the distributed systems is a complex task that requires a comprehensive approach and a deep understanding of the theoretical foundations and practical aspects from developers and system architects. The choice of the optimal consistency model is a key factor in determining the strategy for working with data in the developed system. Depending on the specifics of the application and the requirements for reliability and performance, it may be necessary to use strict, causal or sequential consistency. The success of the implementation is significantly influenced by the selected technologies and tools, including NoSQL and NewSQL [19] databases, messaging brokers and coordination service such as Apache Kafka and Apache ZooKeeper respectively, which provide powerful capabilities for creating scalable and reliable systems [20]. Finding a balance between performance and consistency requires careful consideration from developers and can be achieved through trade-offs aimed at optimizing the system for specific tasks. An important part of the work is writing strategies to solve common problems such as latency and blocking management, scalability, and resilience to network partitioning is key to creating efficient and reliable platforms. Analysis of successful examples, such as Amazon DynamoDB and Google * Spanner [21], though not presented in this study, shows that with a reasonable choice of consistency models, as well as with the effective application of modern approaches to data management, it is possible to achieve a high level of reliability and performance that meets application requirements. Successful implementation of consistency requires from developers not only technical knowledge and skills, but also a deep understanding of the specifics of the application, which allows finding flexible and effective solutions for each specific case.

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**(По требованию Роскомнадзора информируем, что иностранное лицо, владеющее информационными ресурсами Google является нарушителем законодательства Российской Федерации – прим. ред.)*

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ANALYSIS OF OPTIONS FOR USING AI TO PROTECT WEB RESOURCES

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АНАЛИЗ ВАРИАНТОВ ИСПОЛЬЗОВАНИЯ ИИ ДЛЯ ЗАЩИТЫ ВЕБ-РЕСУРСОВ

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ABSTRACT

The issues of data protection when working in a web environment have long been in the forefront. A large number of technologies and methods for implementing websites and web services, a huge number of network users, open transmission protocols - these and many other factors have made the global network a favorable environment for intruders. In order to protect against them, developers use various approaches to ensure the security of their applications, and artificial intelligence is today considered one of the promising technologies in the field of information security. In this regard, consideration of the capabilities of AI in matters of ensuring the protection of web applications is relevant.

АННОТАЦИЯ

Вопросы защиты данных при работе в веб-среде уже давно вышли на первое место. Большое число технологий и методов реализации веб-сайтов и веб-сервисов, огромное количество пользователей сети, открытые протоколы передачи – эти и еще множество факторов сделали глобальную сеть благоприятной средой для злоумышленников. С целью защиты от них разработчики используют различных подходы обеспечения безопасности своих приложений, и искусственный интеллект сегодня считается одной из перспективных технологий в сфере ИБ. В связи с этим рассмотрение возможностей ИИ в вопросах обеспечения защиты веб-приложений является актуальной.

Keywords: information security, web application protection, artificial intelligence, ensuring information security.

Ключевые слова: информационная безопасность, защита веб-приложений, искусственный интеллект, обеспечение информационной безопасности.

Artificial intelligence is increasingly used today to solve a wide variety of problems in many areas of human activity, primarily in areas such as information security and web development. The use of AI here has allowed us to develop new approaches to solving problems, improve user experience, and obtain new services and mechanisms. Applications accessible via the Internet have always been an attractive target for intruders who could use a variety of attack vectors and techniques to implement them. For this reason, it has always been considered important to ensure their security at a high level. Speaking about the use of artificial intelligence mechanisms in the context of ensuring the information security of web applications, the main goal in this case will be, first of all, ensuring a high level of protection.

Today, information security solutions based on artificial intelligence mechanics allow solving a wide variety of tasks, such as preventing cyberattacks and data leaks, providing access control and management in conjunction with monitoring user behavior and recording unauthorized operations. In addition, this type of solution can search for vulnerabilities in program code and application operation, analyze and block unwanted actions, etc. This is only a short list of AI capabilities. Let us present the most common areas of artificial intelligence use in web application security at the current time. They are presented in Figure 1.

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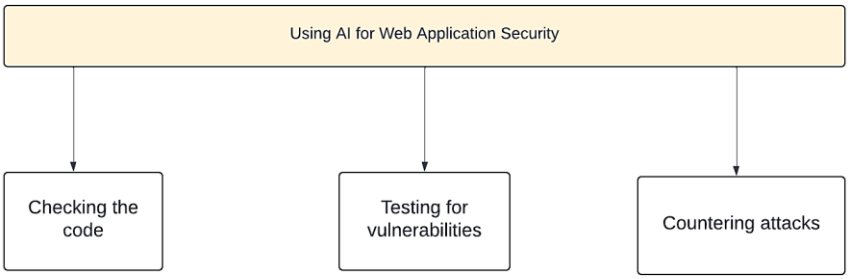

Figure 1. Directions for using AI in web application security

Let's consider the presented approaches to ensuring the security of web applications using AI in more detail.

Code checking for vulnerabilities is usually performed at the testing stage, but in the case of using AI, this will become possible even at the writing stage. It has long been noted that AI can help in a variety of areas of development, including the web. Its role can be quite diverse - from checking for errors in the code text, to checking the code for vulnerabilities. The complexity of checking the code of this type of application is directly related to their architecture, shown in Figure 2.

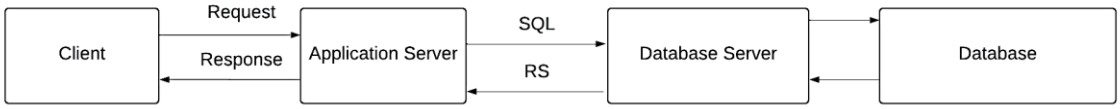

Figure 2. Web application architecture

A typical web application includes a client and a server part, and the latter in turn can consist of several server solutions. This complicates the procedures for monitoring vulnerabilities in the code, especially when working in a team, when different developers work on each part of the service. In this situation, the use of AI will be a fairly justified solution, and special AI training programs can be used for this, as well as a single knowledge base can be formed. Its use will subsequently provide developers with mechanisms for training artificial intelligence, which will receive information regarding all typical errors and vulnerabilities and will be able to warn developers about their presence directly at the stage of writing the program code, structuring the identified vulnerabilities into various levels of danger. As an example of systems that provide control over work with code based on AI, we can present the AI assistant "Ghostwriter" as part of the IDE Replit, functioning in the format of a chat bot. In addition to the typical functions of providing auto-completion of the code, this assistant performs a check "on the fly", indicating errors and potential vulnerabilities. Another solution is the CodeWhisperer assistant, which analyzes the code as it is written and provides the necessary recommendations for its improvement, as well as eliminating potentially vulnerable points in terms of security.

The next direction is the use of artificial intelligence in web application testing. In desktop testing, AI has already begun to be used by major software developers to implement automatic testing mechanisms - AI develops test scenarios and also executes them independently. This allows identifying the maximum percentage of existing errors and generating structured reports.

Speaking about web applications, they require mandatory serious testing and debugging procedures. The use of artificial intelligence will allow high-quality automation of these processes, and in this case, identify both errors related to the functionality of products of this class, and identify vulnerabilities in relation to their security. The final result of using AI in testing web resources is an increase in the stability and quality of their functioning in combination with a high level of reliability and protection. As an example of a system that simplifies the testing and debugging processes from a security point of view, developers can use various tools. One example is the GPT Pilot assistant, which performs unit tests at the development stage, providing the results to developers and testers, and leaving them with full control over the decisions made.

The above options relate to the processes of developing and debugging applications operating in a web environment. However, this is not enough, especially for large solutions. Additional protection should be provided for the application itself and its environment - the server operating system and the platform on which everything is located. And in this case, a special complex is used aimed at protecting web applications, called a web application firewall (WAF). It is a complex system of protection against various categories of attacks from outside, while ensuring the availability of the web application for ordinary users. Figure 3 shows the principle of WAF operation.

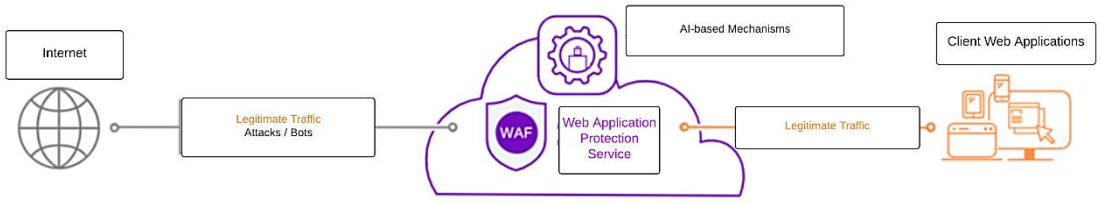

Figure 3. WAF operating principle

The functioning of WAF involves control and protection in a number of areas:

- checking the transmitted information for compliance with protocols;
- control of transmitted traffic;
- signature analysis;
- protection against code injections, as well as XSS and DDOS attacks;
- performing reputation analysis.

The basis for the functioning of firewalls for web applications is the use of mechanisms for studying the behavior of applications and users. This allows you to identify not only external attacks during the operation of applications, but also to determine possible vulnerabilities that were not detected during the development and testing of this application. To do this, the protection system not only controls access to applications, but also tracks the data entered into fields and forms, checks data entry, transmitted traffic, created cookies. All this together allows you to build a picture of the application's behavior, which has long been actively implemented using AI, and is even implemented in many modern WAFs. Through the use of machine learning, security specialists promptly receive alerts regarding all deviations in behavior. More advanced AI-based systems can make decisions on their own regarding operations and procedures that need to be performed in the event of deviations in behavior or detection of a threat. The presence of self-learning mechanisms allows you to accumulate your own knowledge base, with the help of which AI can quickly identify the emergence of threats, while avoiding false positives. Nemesida WAF and Continent WAF are striking examples of firewalls for web applications based on the use of AI. Their developers claim to detect 99.9% of all attacks on web applications and the ability to identify vulnerabilities in the operation of systems, which are high indicators of the functioning of this type of applications.

In conclusion, it is important to note that AI has made a significant contribution to the development and protection of web applications. It provides benefits of both financial and labor nature - reducing the amount of information processed manually. This allows developers and testers to implement applications with a minimum amount of possible vulnerabilities in their composition. AI also performs a significant amount of work for information security specialists. It will not replace them completely, but will become a powerful tool that simplifies their work and takes it to a new level.

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AUTOMATED TESTING OF WEB APPLICATIONS WITH MULTI-TIER ARCHITECTURE

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АВТОМАТИЗИРОВАННОЕ ТЕСТИРОВАНИЕ ВЕБ-ПРИЛОЖЕНИЙ С РАЗНОУРОВНЕВОЙ АРХИТЕКТУРОЙ

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ABSTRACT

The article highlights the topical issues related to conducting automated tests of web applications that have a multi-tier architecture. In the course of the research two main ways that allow automating tests of web applications are described. It is noted that includes automatic testing and highlights the features of multi-tier applications, which should be considered when choosing the means of conducting tests. The cycle of automatic testing is presented separately and its main stages are briefly described.

АННОТАЦИЯ

В статье освещаются актуальные вопросы, связанные с проведением автоматических тестов веб-приложений, которые имеют разноуровневую архитектуру. В процессе исследования описаны два основных способа, позволяющих автоматизировать тесты веб-приложений. Отмечены основные виды автоматического тестирования и выделены особенности многоуровневых приложений, которые следует учитывать при выборе средств проведения тестов. Отдельно представлен цикл автоматического тестирования и кратко описаны его ключевые этапы.

Keywords: test, web application, automation, architecture.
Ключевые слова: тест, веб-приложение, автоматизация, архитектура.

Testing is one of the most important aspects of developing reliable and quality software systems.

When it comes to multi-tier web applications, the testing process becomes even more complex due to the complex interactions between different elements, the need to ensure seamless integration, and end-to-end functionality. Testing web applications occupies one of the main places in their development process, and the damage caused by poor performance to the base level of an organization emphasizes the need to conduct it properly [1].

A quarter of users leave a web page that takes four seconds to load, and "Black Friday" serves as an example of how many millions can be lost to poor web application performance.

Obvious is the fact that realistic testing cannot simply be based on a large number of repeated tests using little diverse data. Instead, tests should reflect the full range of actions that users can take towards the system in production, and the full range of possible workloads. Therefore, given that the complexity of web applications is rapidly increasing as are the requirements for their reliability and security, the automation of software systems tests is of particular relevance today.

Automated testing is one of the fastest-growing segments of the software industry. According to one of the McKinsey studies, the expected annual growth will be 16.4 % from 2024 to 2027. Today, virtually 100% of companies use test automation in one capacity or another [2].

Test automation has countless benefits. It helps companies significantly increase test coverage, detect and fix bugs faster, accelerate release schedules, and save money by creating reusable tests that deliver reliable results.

Nevertheless, automation is not necessarily a process without downsides. Especially when it comes to web applications with a multi-tier architecture where the implementation is distributed across different layers and runs on different machines. For this reason, to test the overall behavior of web applications, through-testing methods supported by robust automation are needed.

Thus, the relevance and practical importance of the identified issues predetermined the choice of the topic of this article.

The description of the best automated tools for testing web applications devoted their works to A.V. Tkachev, D.V. Irtegov, A.V. White,

Библиографическое описание: Ukhlivanov S. AUTOMATED TESTING OF WEB APPLICATIONS WITH MULTI-TIER ARCHITECTURE // Universum: технические науки : электрон. научн. журн. 2024. 10(127). URL: *https://7universum.com/ru/tech/archive/item/18300*

O.A. Mitrofanova, N.A. Dubinina, V.O. Fedorov, M.S. Shilkina.

Algorithms for creating and running automated tests using the Automated Test Framework are reviewed by B.F. Latypov, T.R. Ziyazetdinov, A.R. Mukhetdinov, O.N. Vybornova, A.N. Ryzhikov.

At the same time, considering the fact that web application testing is a complex process as its difficulties are multiplied by all the distributed system components interacting with the application, the issues of organizing an efficient automation of the testing process require more detailed elaboration and in-depth analysis. So, for example, the development of an automation test infrastructure with a multi-level architectural approach deserves special attention.

So, the purpose of the article is to consider the features of automated web application testing with a multi-tier architecture.

First of all, it is essential to note that web application testing automation implies using software to perform automated tests that allow you to identify bugs in the application's performance. Test automation gives you the ability to repeat tests multiple times, using a framework to ensure each test step is executed. Moreover, it is possible to constantly run automated tests as software updates are released, which ensures that there are no new bugs in the web application [3].

Currently, two main ways can be distinguished to automate web application tests with a multi-tier architecture.

1. Using a task launcher, such as Grunt or Gulp, or npm scripts to start tests and clean up code during the build process. This is an effective way to solve, for example, tasks such as linting and minifying code, adding CSS prefixes, or transposing nascent JavaScript features for maximum cross-browserability.

2. Applying a browser automation system, such as Selenium, to run certain tests in installed browsers and return results, alerting to failures as they occur. Commercial cross-browser testing applications like Sauce Labs and BrowserStack are based on Selenium but allow remote access to their settings with a simple interface, eliminating the need to set up your own testing system.

The different types of automated web application testing include functionality testing, usability, cross-browser compatibility, performance testing under load and stress, and accessibility testing. However, for multi-tier applications, it is critical to thoroughly understand the system architecture before proceeding with testing. This involves defining the different levels or layers (e.g., representation, business logic, data access), the communication channels between them, and the technologies involved [4]. A clear understanding of the system architecture will help you plan and prioritize more effectively when testing.

In Fig. 1 presents the automatic testing cycle of web applications with a multi-tier architecture on the example of the Shadow DOM framework

Figure 1. Automatic testing cycle of web applications with multi-tier architecture

Let us consider in more detail the main stages of the cycle presented in Fig. 1 . 1

1. Web UI scanning automatically creates complete page objects and implementation code in C#, Java, Javascript, VB Script, Python, and other languages.

2. Application Scanner automatically identifies CSS roots and IDs, saving time from writing complex and repetitive element locators.

3. "Fast Modeling" without delays converts scanned items into logically complete models by defining the equivalence classes associated with each scanned item.

4. Automated coverage algorithms generate the smallest set of test scenarios needed to thoroughly test the simulated web application, detecting defects earlier and spending fewer resources to fix them.

5. Exporting optimized test cases to test management tools such as Zephyr, Azure DevOps, and ALM/Octane creates a connection to them by automatically updating test cases after test execution.

6. Test Scenario Generation embeds dynamic test data features into each test, automatically deploying automation code to Git repositories and running CI/CD processes to execute tests.

7. Updating central models re-generates and synchronizes automated test scenarios and test cases, providing comprehensive automated testing in short iterations.

Summarizing the results of the conducted study, note that an automated web application testing system with a multi-tier architecture allows to quickly and efficiently administer all components of the system, receive information messages and carry out analysis of changes, errors, server part resources and optimize the overall performance of the project. One of the most important areas of development of test automation tools is to support the test suite in an up-to-date state when the web application changes, as well as to expand the types of tests.

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MECHANICAL ENGINEERING AND MACHINE SCIENCE

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ROTOR SUPPLY FOR PNEUMOTRANSPORT DEVICE

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ИСТОЧНИК ПИТАНИЯ РОТОРА ДЛЯ ПНЕВМОТРАНСПОРТНОГО УСТРОЙСТВА

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ABSTRACT

During the pneumatic transportation of raw cotton stored in the territory of cotton mills, the clogging of the device increases. To overcome these problems, a vacuum-loaded discharge pipe separating the cotton raw material is connected to the pipe by an external pneumatic conveying system.

Due to the constant increasing of the cotton's volume stored in cotton mills, it can lead to damage to the natural properties of raw cotton in pneumatic conveying devices. Therefore, it is necessary to ensure a uniform flow of raw cotton in pneumatic transportation.

АННОТАЦИЯ

При пневматической транспортировке хлопка-сырца, хранящегося на территории хлопкопрядильных фабрик, засорение устройства увеличивается. Для устранения этих проблем к трубопроводу внешней пневмотранспортной системой подсоединен вакуумированный отводящий патрубок, отделяющий хлопковое сырье.

Из-за постоянного увеличения объема хлопка, хранящегося на хлопкопрядильных фабриках, это может привести к нарушению естественных свойств хлопка-сырца в пневмотранспортирующих устройствах. Поэтому необходимо обеспечить равномерный поток хлопка-сырца при пневмотранспорте.

Keywords: pneumatic conveying, raw cotton, fiber grade, mass, adjustment, device, hopper, deformable, strain gauge.

Ключевые слова: пневмотранспорт, хлопок-сырец, сорт волокна, масса, регулировка, устройство, бункер, деформируемый, тензодатчик

In this article H.A. Ziyayev and O. Ishmuratov, we have analyzed the flow of cotton in the pneumatic conveying device, which not only prevents the cotton from falling out of the drum cells, but also clogs the cotton. Hence, it is necessary to improve the equipment to transfer the raw cotton to the next process. It is known that overcoming these problems is very important to ensure sustainable efficiency in cotton mills.

A high-pressure fan VTS 8 is used in the yard pneumatic conveying system at cotton ginning factories, which ensures the transfer of 12-15 tons of raw cotton per hour from the storage facilities to the drying and refining shop at a distance of 140-170 m. Due to the constant increase in the volume of cotton stored on the territory of cotton factories, it is necessary to increase the radius of action of pneumatic installations to 200-250 m. To this, it is impractical to use a high-pressure fan of higher power or a series connection of two conventional fans, since the resulting high vacuum leads to an increase in energy consumption. Therefore, in practice, the issue of increasing the radius of action of pneumatic installations is often solved by arranging two independent installations, one of which works at the transshipment point, and the other from it supplies raw cotton to production. The disadvantage of this solution is that stationary transshipment installations impede the rational laying of pneumatic lines, which ultimately leads to an increase in energy consumption.

An increase in the radius of action of yard pneumatics can be achieved by using a mobile transfer station. However, in the ginning industry there is still no industrial design of such an installation, so many ginneries create them themselves. The most widespread is a suction-type transfer pneumatic unit, complete with a separator, a fan and two cyclones TSP-3 for collecting dust and litter. Due to the low efficiency of single-stage exhaust air purification, a significant amount of dust and free fiber is emitted into the atmosphere, polluting

Библиографическое описание: Mekhmonaliyev L. ROTOR SUPPLY FOR PNEUMOTRANSPORT DEVICE // Universum: технические науки : электрон. научн. журн. 2024. 10(127). URL: *https://7universum.com/ru/tech/archive/item/18323*

the air and creating unsanitary conditions on the territory of the plant. Thin air purification from dust in the areas of raw cotton transshipment due to the installation of effective dust collectors requires large capital expenditures.

To check the operability and establish the technical characteristics of the rotary feeder, it was tested on an experimental pneumatic unit. In the course of the research, the stability and reliability of the operation of a pneumatic unit with a new feeder was assessed at different productivity for raw cotton. The test results showed that the use of rotary feeders will ensure the stability and cost-effectiveness of the operation of the suction-injection transfer units.

Table 1.

Results

Feeder body diameter, mm.....	920
The gap between the blade drum and sidewalls, mm.....	8-10
Blade drum rotation frequency, rot/min.....	37,5
Number of blades, pcs.....	7
Raw cotton throughput, t/h …….	12-15
Resistance of the feeder in clean air, Pa …….…..	350
Installed power, Kw …….....	2,8

To clarify a number of issues related to the establishment of the optimal operating mode of the feeder, its economic efficiency, advantages in comparison with a vacuum valve and the effect on the quality of raw cotton and seeds, it is planned to manufacture an experimental model of a mobile transfer unit with a suction-injection action with the described rotary feeder.

Discussions

Analyzing the article, we propose that the proposed device be installed in used separators during the transportation of seed cotton to the production shops by air in ginneries. This device allowed to effectively clean the seed cotton from fine contaminants without any damage, without excessive costs, while separating the cotton from the air.

The vacuum-wheel dropper blades in the device are placed at an oblique net surface at a distance along its length.

The task is performed as follows. Unlike the separators used, the vacuum-wheel dropper has a special net surface along the length of the blades, which allows the separation of fine impurities from the seed cotton from the separator working chamber into the vacuum wheel dropper. The waste side pockets are fitted with waste collection pockets. It is possible to expel contaminants through these pockets. The purpose of proposing the device to place the net surfaces at an angle is to create an opportunity to clean the contaminants in the cotton pieces falling into the vacuum wheel dropper without consuming additional energy.

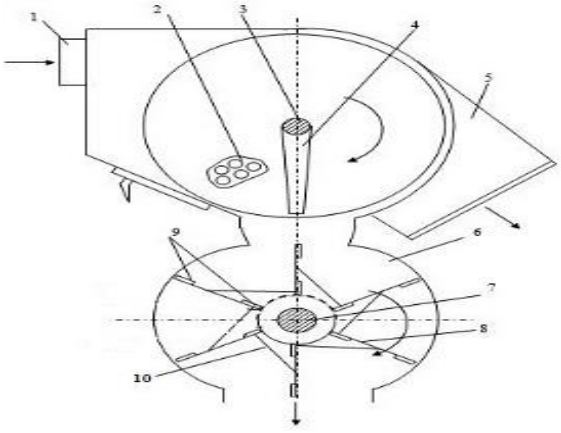

Figure 2. General view: 1 inlet pipe, 2 net discs located on the side walls of the separation chamber, 3 shafts, cotton scrapers attached to the net surfaces attached to 4 shafts, 5 dust suction pipes, 6 workers vacuum-wheel dropper parallel to the chamber, 7-vacuum-wheel dropper shaft, 8-blade, elastic part attached to the edge of the 9-blade, 10-net surface placed at a distance of 10 inclines

Conclusion

Due to the constant increasing of the cotton's volume stored in cotton mills, it can lead to damage to the natural properties of raw cotton in pneumatic conveying devices. Therefore, it is necessary to ensure a uniform flow of raw cotton in pneumatic transportation.

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ANALYSIS OF BURNING TIME AND STRENGTH OF CHARCOAL BRIQUETTES BASED ON TREE LEAF RESIN

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АНАЛИЗ ВРЕМЕНИ ГОРЕНИЯ И ПРОЧНОСТИ ДРЕВЕСНО-УГОЛЬНЫХ БРИКЕТОВ НА ОСНОВЕ СМОЛЫ ИЗ ЛИСТЬЕВ ДЕРЕВЬЕВ

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ABSTRACT

This article presents the results of research focused on the briquetting of coal powder, specifically examining its burning time and durability. Tree leaf resin was selected as the binding agent, and a piston press device was recommended for compressing the coal powder along the horizontal axis. Experimental studies were conducted to produce briquette products and substantiate their parameters within the recommended briquetting design. During the experiments, various parameters were varied, including the concentration of the fermented resin solution (10%, 15%, and 20%), the amount of water added (10%, 15%, and 20%), the number of revolutions of the curved mechanism (20, 25, and 30 rpm), and the diameter of the working chamber (15, 20, and 25 mm). The results indicated that at the lower load limit, the burning time of the briquette increased from 86 to 110 seconds, while at the upper load limit, it rose from 95 to 124 seconds. Additionally, the strength of the briquette was found to increase from 0.11 to 0.53 H/cm². The experimental data were mathematically analyzed, and an empirical equation for determining the strength of the briquettes was proposed.

АННОТАЦИЯ

В данной статье представлены результаты исследований, посвящённых брикетированию угольного порошка с целью определения времени его горения и долговечности. В качестве связующего материала была выбрана смола, полученная из листьев деревьев, и рекомендовано использование поршневого прессового устройства для прессования угольного порошка вдоль горизонтальной оси. Проведены экспериментальные испытания, направленные на получение брикетов и обоснование их параметров в рекомендованной конструкции брикетирования. В ходе исследований варьировались параметры: концентрация ферментированной смолы в растворе (10%, 15% и 20%), количество добавляемой воды (10%, 15% и 20%), число оборотов кривого механизма устройства (20, 25 и 30 об/мин) и диаметр рабочей камеры (15, 20 и 25 мм). Результаты показали, что при нижнем пределе нагрузок время горения брикета увеличивалось с 86 до 110 секунд, а при верхнем пределе – с 95 до 124 секунд. Также установлено, что прочность брикета возросла с 0,11 до 0,53 Н/см². Данные экспериментов были подвергнуты математической обработке, и предложено эмпирическое уравнение для определения прочности брикетов.

Keywords: briquetting, coal powder, burning time, durability, binder, leaf resin, piston pressing device, briquette strength, empirical equation.

Ключевые слова: брикетирование, угольный порошок, время горения, долговечность, связующее средство, смола листьев, поршневое прессовое устройство, прочность брикетов, эмпирическое уравнение.

Introduction

The global advancement of high-quality coal briquette fuel technology and briquetting devices is of paramount importance in the context of sustainable energy production. This development involves the optimization of various technical parameters to enhance product durability, increase burning efficiency, and maximize heat output while minimizing ash generation and energy consumption during combustion [1]. The effective briquetting of coal powder necessitates the modernization of traditional technologies, consideration of the infrastructural characteristics of production facilities, and the selection of cost-effective binding additives [2].

Recent research has underscored the significance of employing innovative briquetting methods that focus on rationalizing the production process. This includes

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the evaluation of binders that facilitate mechanical activation, structural modification, and the enhancement of surface energy in briquettes, which are critical for improving the fuel's strength and structural properties [3]. Such advancements not only contribute to the overall efficiency of the briquetting process but also align with global sustainability goals by producing cleaner-burning fuels.

Significant scientific and research efforts have been undertaken in countries such as Canada, the United States, Russia, China, Ukraine, and Belarus, among others, to enhance fuel briquette production technologies [4]. However, challenges remain, particularly in the development and implementation of low-cost binders and energy-efficient construction designs that are conducive to the briquetting of coal dust. Addressing these issues is essential for improving the economic viability of briquette production and for promoting the widespread adoption of briquette fuels as an alternative energy source [5].

Methods

It is known that the development of a new method of production of coal briquettes with the help of a binder requires the selection of types of binder products that ideally satisfy all the requirements at the same time. In this case, the low cost of the required binder, the ability to increase the combustion heat of the obtained agglomerated fuel, and the ability to give high mechanical strength to the briquette are of great importance.

Today, coal mining, their transportation and supply of high-quality fuels for consumers, as well as industries dealing with coal fuels, are one of the main sectors. The coal industry includes the processes of coal mining (in some cases enrichment, briquetting) and delivery to consumers. The most preferred and effective method of coal mining is open pit mining. If the coal deposits are located in a pit, it is mined in a closed (mine) method. Open methods are mainly used in the coal industry of Uzbekistan. This method also has its drawbacks. For example, due to being in open basins, the moisture content of the coal is high, and it decomposes under the influence of atmospheric heat. This results in the formation of fine coal dust in coal mines. This indicator is around 60%.

The rational use of these generated coal powders by consumers presents several challenges. For example, during loading, transportation and consumer use, a large part of the product remains as waste. Various pressing methods are used in our republic to eliminate emerging problems. These include screw, roller and manual pressing devices. Coal pulverization is achieved by placing it in a certain container, giving it high pressure and adding binders to its composition [6, 7].

Research object

In response to the identified requirements, we conducted a comprehensive scientific investigation to address these challenges. Initially, we examined binders that have shown promise in recent years, evaluating their physicochemical properties. Following this, we performed a systematic four-step analysis of briquetting devices using the MatLab program. The findings from this analysis indicated that coconut waste, paraffin, by-products from oil production, bark from thorny plants, and multi-component resins derived from tree leaves are the most effective binders for coal powder briquetting under the conditions present in Uzbekistan.

Our evaluation of briquetting devices revealed that utilizing an advanced return force during the briquetting process enhances the strength of the compressed product by 1.23 times when compared to methods relying on centrifugal and impact forces [8]. Consequently, based on these analytical results, tree leaf resin was chosen as the binding agent. We also designed a piston press specifically for compressing coal powder along a horizontal axis and developed its construction. Figure 1 illustrates the schematic representation of the pressing device, while Figure 2 provides an overview of the laboratory equipment developed for this purpose.

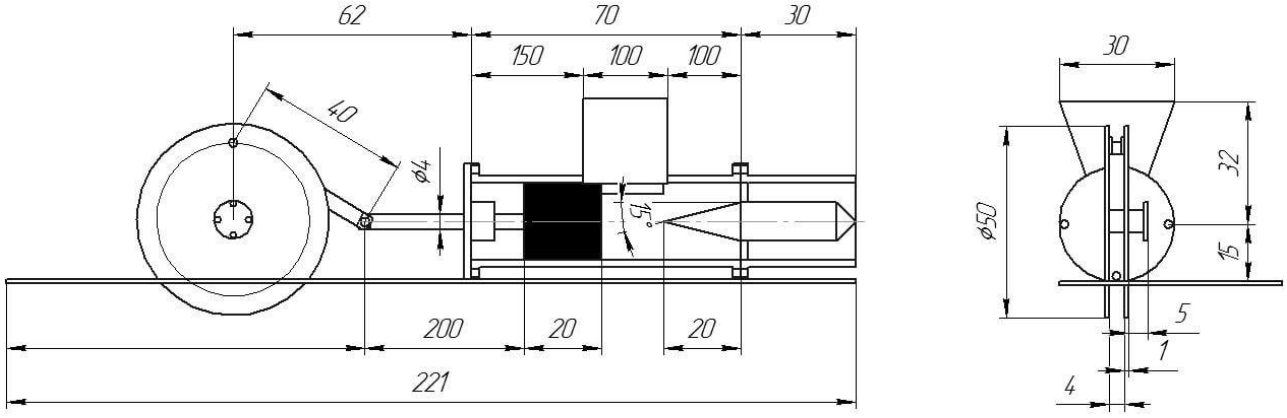


Figure 1. Scheme of the pressing device

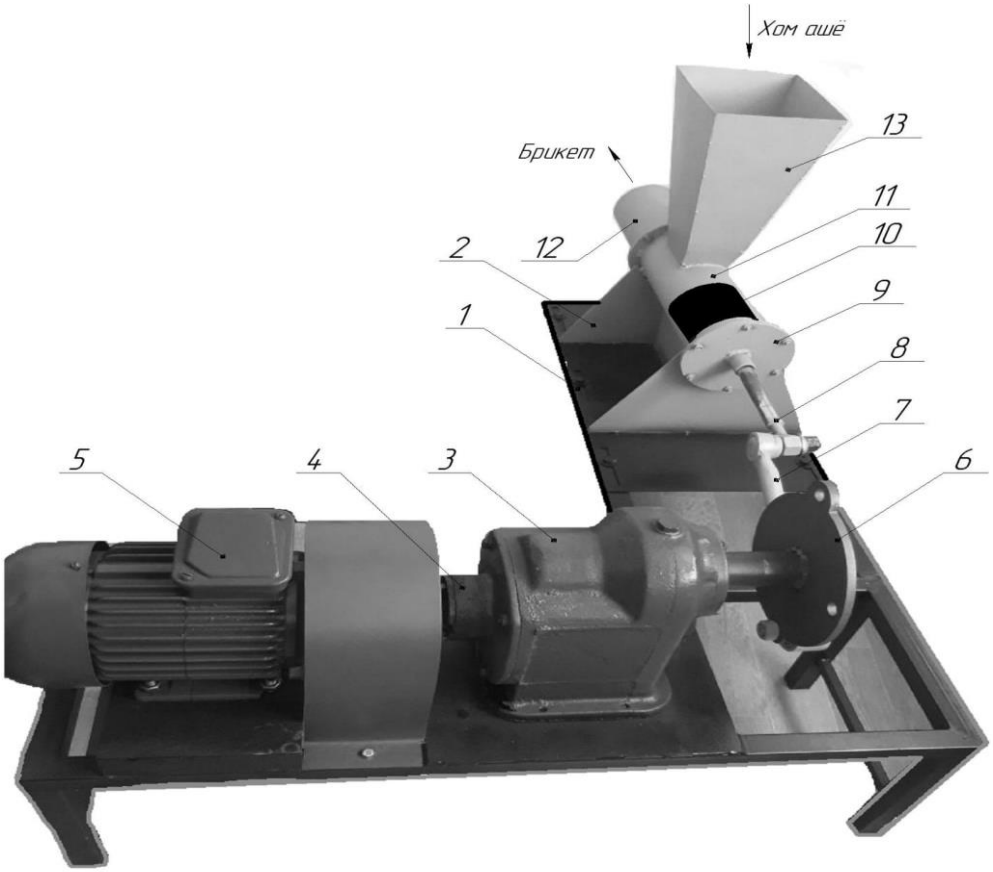


Figure 2. Overview of the laboratory device

This device distinguishes itself from other presses by its ability to incorporate only small amounts of additional binders during the coal powder pressing process. It operates at high pressure, features a straightforward construction, and delivers high efficiency. Coal powder is sourced from storage facilities and sorted to include only particles smaller than 5 mm. Edible fractions are separated from the remaining material, which is then crushed. The sorted coal powder is subsequently dried at temperatures ranging from 80 to 100 ℃ before being conveyed to the pressing station.

The device operates as follows: Initially, the electric motor (1) transmits rotational motion through the clutch (2) to the reducer (3). The reducer then transfers this motion to the drive disk (6) at a 10:1 ratio. The driving disk conveys the movement to the shaft (8) via the crank mechanism (7). As a result, rod (8) moves the piston (10) in a forward and backward motion. The product is fed into the press hopper (13), where, in the piston's first position, coal powder is loaded into the cylinder (11). Once the piston (10) shifts to its second position, it closes off the hopper (13), initiating the pressing operation.

During this operation, the briquetting process occurs within the forming section, the third component of the device. Here, the coal powder is compacted under high pressure within the conical stirrer located inside the cylinder (12). The resulting briquette, which emerges from the forming section, is of a specific length and is subsequently cut to the desired dimensions using specialized automatic cutters [9, 10].

Results

Experimental investigations were carried out to produce briquette products and validate their parameters within the proposed briquetting design. During these studies, several variable parameters were examined, including solutions of fermented leaf waste resin in water at concentrations of 10%, 15%, and 20%. The amounts of water used were also varied at 10%, 15%, and 20%. Additionally, the rotational speeds of the device's curved mechanism were set at 20, 25, and 30 revolutions per minute (rpm), with working chamber diameters of 15, 20, and 25 mm being tested. It was also essential to consider the humidity of the external environment during the research.

The coal powder selected for this study was sourced from the Angren mines. For the experiments, the aforementioned variable parameters included the 10%, 15%, and 20% solutions of fermented leaf waste resin in water, as well as the specified percentages of water and resin mixed for each kilogram of coal powder. The total mass of the binder and powder was established at 10 kg. Following the experiments, the briquette products were air-dried for a period of 48 hours, after which the burning time for each briquette was recorded. The findings from the experiments are summarized in Table 1.

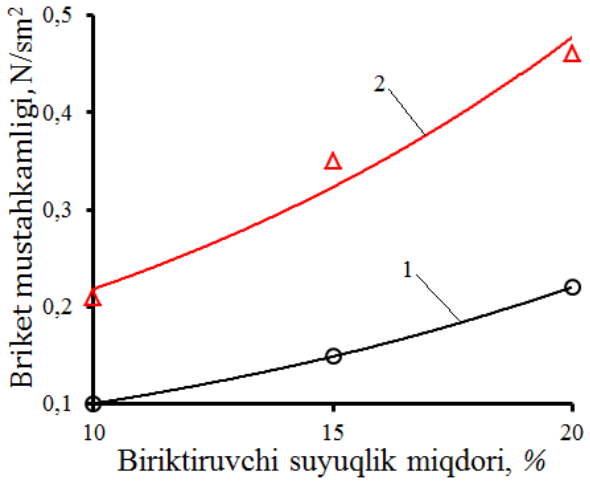
Table 1.

Burning time of briquette product for different values of variable parameters

No.	Working chamber diameter, mm	Amount of water and binder mixture, %	Material moisture, %	The number of revolutions of the Krivaship mechanism, 20 rpm/min	The number of revolutions of the Krivaship mechanism, 25 rpm/min	The number of revolutions of the Krivaship mechanism, 30 rpm/min
				Burning time of briquette product, seconds		
When the amount of fermented leaf resin in water is 10%						
1	25	10%	6,29	86	97	108
		15%	6,432	87	98	109
		20%	6,65	87	99	110
2	20	10%	6,65	88	100	112
		15%	6,65	89	101	113
		20%	6,65	90	102	114
3	15	10%	6,65	91	103	116
		15%	6,65	92	104	117
		20%	6,65	94	106	118
When the amount of fermented leaf extract in water is 15%						
1	25	10%	6,5	87	99	111
		15%	6,65	88	100	112
		20%	6,87	89	101	113
2	20	10%	7,02	90	102	115
		15%	7,24	91	103	116
		20%	7,45	92	104	117
3	15	10%	7,6	93	106	118
		15%	7,82	94	107	119
		20%	8,045	96	108	121
When the amount of fermented leaf slime in water is 20%						
1	25	10%	6,65	89	101	114
		15%	6,8	90	102	115
		20%	7,03	91	103	116
2	20	10%	7,18	92	105	117
		15%	7,4	93	106	118
		20%	7,63	94	107	119
3	15	10%	7,78	95	108	121
		15%	8	96	109	122
		20%	8,23	98	111	124

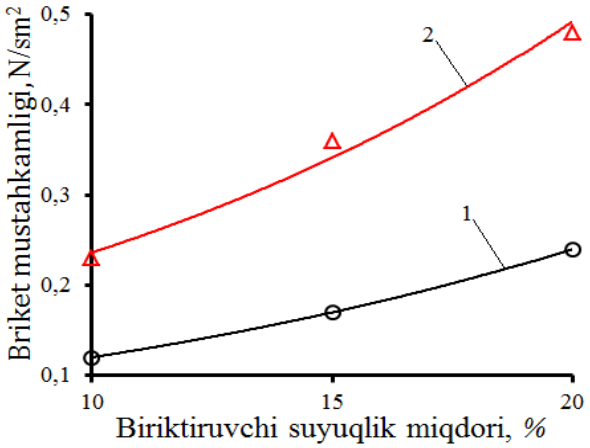
The data illustrated in Table 1 indicate that an increase in the quantity of fermented leaf resin and binder within the coal powder-water mixture leads to higher moisture levels in the final product. This increase in moisture content subsequently prolongs the burning duration of the briquettes. Moreover, both the rotational speed of the crank mechanism and the diameter of the working chamber have a significant impact on combustion time. For instance, at the lower load limits, the burning duration of the briquettes extended from 86 seconds to 110 seconds as the product's moisture content shifted from 6.29% to 6.65%. Similarly, at the upper load limits, the burning time rose from 95 seconds to 124 seconds with an increase in moisture from 7.78% to 8.23%. This variation is attributed to changes in the diameter of the working chamber.

Additionally, alterations in the parameters of the working chamber and the bending mechanism also influence the product's durability. Consequently, the study examined how these variable parameters affect the strength of the briquettes. The briquette products produced under various device settings and binder types were evaluated using the laboratory model of the SIB-145 durability testing machine. Each experiment was conducted five times, and the arithmetic mean values were calculated and compared with the theoretical predictions. The multifactorial nature of the experiments was considered, and supporting graphs were created based on the data collected at both the lower and upper limits. The results of Experiment 3 are illustrated in Figures 4 and 5.



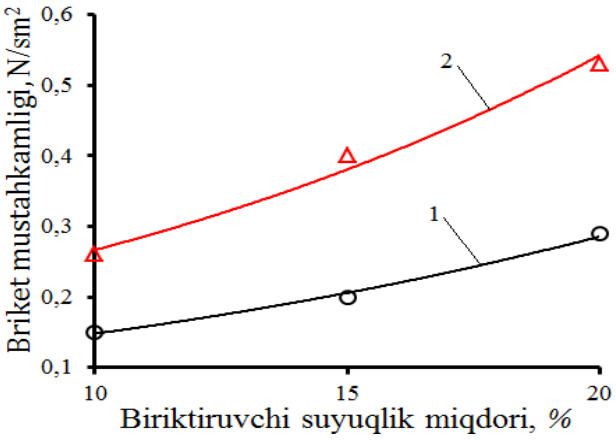
1-When the number of rotations of the crank mechanism is 20 rpm/min;
2- When the number of rotations of the crank mechanism is 30 rpm/min;

Figure 3. Dependence of the amount of binder liquid on the strength of the briquette. When the amount of fermented leaf extract in water is 10%



1-When the number of rotations of the crank mechanism is 20 rpm/min;
2- When the number of rotations of the crank mechanism is 30 rpm/min;

Figure 4. Dependence of the amount of binder liquid on the strength of the briquette. When the amount of fermented leaf extract in water is 15%



1-When the number of rotations of the crank mechanism is 20 rpm/min;
2- When the number of rotations of the crank mechanism is 30 rpm/min;

Figure 5. Dependence of the amount of binder liquid on the strength of the briquette. When the amount of fermented leaf extract in water is 20%

It can be seen from the graphical relationships presented in Figures 3, 4 and 5 that the amount of fermented leaf resin and binder in water, the amount of coal powder, and the number of twisting mechanisms increase the strength of the product. In addition, the diameter of the working chamber has a significant effect on the durability of the product. For example, when the diameter of the working chamber changes from 15 to 25 mm at the lower limit of the loads, the strength of the briquette drops by 0.46 to 0.1 H/cm^2. At the upper limit of the loads, when the diameter of the working chamber changes from 15 to 25 mm, the strength of the briquette drops from 0.53 to 0. A decrease of 15 H/cm^2 was observed.

The graphical relationships presented in Figures 3, 4 and 5 can be expressed by the following regression equations determined by the method of least squares [11,12].

The slope of the material discharge part of the nozzle is R=15°

When the amount of fermented leaf resin in water is 10%;

In the download below:

$$y = 0,0456e^{0,0788x} \qquad R^2 = 0,9997 \quad (1)$$

At high load:

$$y = 0,0997e^{0,0784x} \qquad R^2 = 0,9703 \quad (2)$$

When the amount of fermented leaf resin in water is 15%;

In the download below:

$$y = 0,06e^{0,0693x} \qquad R^2 = 1 \quad (3)$$

At high load:

$$y = 0,1132e^{0,0736x} \qquad R^2 = 0,9844 \quad (4)$$

When the amount of fermented leaf resin in water is 20%;

In the download below:

$$y = 0,0765e^{0,0659x} \qquad R^2 = 0,9946 \quad (5)$$

At high load:

$$y = 0,1308e^{0,0712x} \qquad R^2 = 0,9855 \quad (6)$$

As a result of processing the empirical formulas obtained as a result of the research, the equation for theoretical determination of briquette strength was recommended, H/cm^2;

$$\sigma_{\text{br. str.}} = 0,1123e^{0,06((q_1-q_2)/q_1 \cdot 100)} \quad (7)$$

The results of the study differ from the theoretical calculation results by 3.75% and do not exceed. The quantities in equation (7) are 10, 15 and 20% solution of leaf waste tar in water, water content is 10, 15 and 20%, the number of revolutions of the device crank mechanism is 20, 25 and 30 rpm/min and the diameter of the working chamber is 15, 20 and 25 mm. is meaningful when it is between

Within the specified limits, the difference of the research results according to equation 7 does not exceed 4% on average compared to the calculated results, which means that the obtained experimental results are correct. Equation (7) can also be used in engineering calculations and in the selection of rational operating modes and parameters of the apparatus.

Conclusions

In summary, the developed device offers a viable solution to the challenges of supplying consumers with solid fuels that possess high durability, combustibility, and specific porosity. In our country, numerous tree branches are burned without being utilized, while the stems of annual plants are either left in the fields or similarly incinerated. Even when these materials are employed as fuel, they yield less heat due to their dispersed and low-density state.

The production of fuel briquettes not only enhances the efficient utilization of organic materials' thermal energy but also mitigates the release of various toxic gases that typically result from their improper combustion. When fuel briquettes are burned, no toxic gases are emitted.

These points underscore the importance of effectively utilizing various types of wood and annual plant stems in the Republic of Uzbekistan. As we look to the future, it is crucial to recognize that natural fuel reserves, such as oil, gas, coal, and fuel oil, are finite. Thus, addressing this issue is essential not only for our republic but also for the entire planet.

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PROCESSES AND MACHINES OF AGROENGINEERING SYSTEMS

EVALUATION OF THE TECHNICAL AND ECONOMIC EFFICIENCY OF CENTRIFUGAL PUMPS AT IRRIGATION PUMPING STATIONS

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ОЦЕНКА ТЕХНИКО-ЭКОНОМИЧЕСКОЙ ЭФФЕКТИВНОСТИ ЦЕНТРОБЕЖНЫХ НАСОСОВ НА ОРОСИТЕЛЬНЫХ НАСОСНЫХ СТАНЦИЯХ

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ABSTRACT

The article examines the efficiency improvement of D6300-27 centrifugal pumps in irrigation systems by optimizing blade angles. The study compares 28 and 30-degree blade configurations, showing that the 30-degree angle reduces power consumption and enhances energy savings. The research highlights the economic benefits of this modification, with calculations of annual energy savings for multiple pumping stations.

АННОТАЦИЯ

В статье исследуется повышение эффективности центробежных насосов Д6300-27 в оросительных системах путем оптимизации углов лопаток. Сравниваются конфигурации лопаток с углами 28 и 30 градусов, показано, что угол в 30 градусов снижает потребление электроэнергии и увеличивает экономию. Исследование подчеркивает экономическую выгоду этой модификации с расчетами годовой экономии энергии для нескольких насосных станций.

Keywords: pumping station, water source, water supply canal, blade chamber, pump impeller, suction and discharge pipelines.

Ключевые слова: насосная станция, источник воды, канал подачи воды, лопастная камера, рабочее колесо насоса, всасывающий и напорный трубопроводы.

Introduction

In the design of irrigation pumping stations, various blade options for centrifugal pumps with technically equal performance can be determined, fully ensuring the operating mode for water pumping and pressure. The degree of acceptability and cost-effectiveness of the planned structures is based on technical and economic calculations. In the practice of water construction, the method of comparing economic efficiency is used to determine whether the technical solution of one option is more effective than another [1].

Main Part

The calculation of the economic efficiency of centrifugal pumps D6300-27 was carried out by introducing a modernized impeller into the centrifugal pump. The study established the current parameters of the D6300-27 pump: water flow rate Q = 6033 m³/h, pressure H = 14 m. The electric motor used for power generation is of the SD13-42-10 type, with a power output of N = 400 kW and a rotational speed of n = 1000 rpm.

Based on the research and design developments aimed at reducing cavitation erosion in centrifugal pumps, various "impact angles" of the impellers and blades were calculated and improved. Specifically, designs with angles of 28 and 30 degrees were explored. The most suitable impeller design is one with backward-curved blades, meaning the blades are turned against the direction of the flow. This type of impeller blade significantly increases the pump's efficiency, accelerates the conversion of kinetic energy into potential energy in the flow part, and reduces cavitation phenomena [2].

The cost of electrical energy used for water transmission in irrigation pumping stations, along with staff salaries, repair costs, depreciation deductions, labor protection, and lubrication material expenses, is referred to as the annual operational costs (E) [3].

To determine the annual cost of electricity in centrifugal pumps at irrigation pumping stations, the actual pressure Hi, water flow rate Qi, and efficiency ηi of the pumps during each water transmission period are taken from the pump characteristics. The power of the pumping station for each period ti is calculated using the following formula (in kW):

$$N_i = \frac{9{,}81 \cdot \Sigma Q_i H_i}{\eta_{i,i}\ \eta_{\partial\hat{a},i}};$$

Here is the translation:

Here, $\eta_{\partial в,i}$ represents the efficiency of the electric motors during different water transmission periods; ΣQi is the total water transmission of the operating pump units during each period t_i, measured in m³/s.

The total amount of electrical energy consumed during the year (kWh) is calculated as follows:

$$\Sigma E = (N_1 t_1 + N_2 t_2 + \ldots + N_n t_n)\ 24;$$

Here is the translation:

Here, N_1, N_2 …N_n are the powers of the pumping station during different water transmission periods (kW); t_1, t_2 … t_n are the water transmission periods of the pumping station, measured in days:

The annual cost of consumed electrical energy (in soums) is calculated as follows:

$$C_{эн} = (\Sigma E + 0{,}02\ \Sigma E)\ S;$$

Here, S is the price of electrical energy in kWh, in soums; 0.02·E is the amount of electrical energy consumed by the station for its own needs, in kWh.

As a result of the research, while maintaining the nominal characteristics of the D6300-27 pump, improvements to the pump's impeller were made. Testing revealed that when the impeller blades are at an angle of 30 degrees, the pump consumes 396 kW of power, resulting in a difference of 4 kW. The average annual operation of this pump, taking into account maintenance and other types of work, is 3381.8 hours with a utilization factor of k=0.77.

183 days/year x 24 hours т x 0,77 = 3381,8 motor hours/year.

The calculation of costs includes 1 kWh = 1000,0 sum (as of July 1, 2024).

Additionally:

400 kW x 3381,8 motor hours/year x 1000,0 sum = 1 055 121 600 sum/year.

396 kW x 3381,8 motor hours/year x 1000,0 сум = 1 041 594 400 sum/year.

The annual cost savings on energy is 13,527,200 soums/year.

Table 1.

Comparative Table of Annual Energy Savings

№	Pump Names	Electric Motor Brand	Blade Angle (degrees)	Power Consumption (kW)	Utilization Factor	Annual Operating Hours	Electricity Tariff (sum)	Electricity Costs (sum)
1	D6300-27	SD13-42-10	28	400	0,78	3381,8	1000	1 055 121 600
			30	396	0,77	3381,8	1000	1 041 594 400

As a result of implementing this pump design, the economic efficiency is calculated to reduce electricity consumption by 0.05% per year.

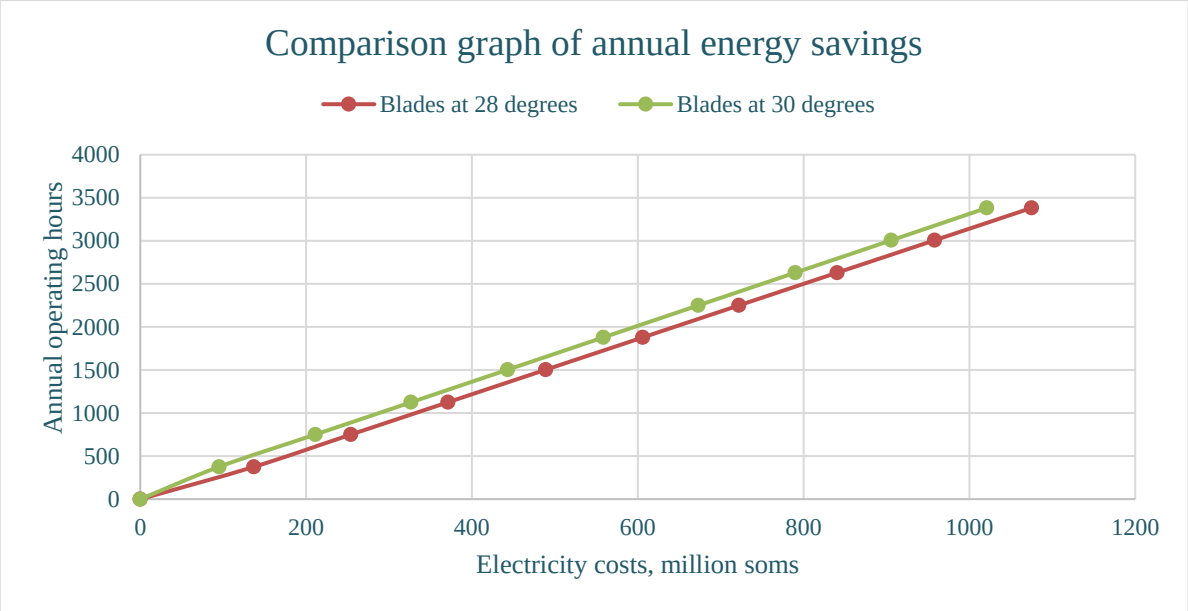

Figure 1. Annual Electricity Savings Graph

In the Andijan region, there are 16 existing D6300-27 pumps, and if the impeller blades of these pumps are operated at an angle of 30 degrees, the following calculation applies:

4 kW×16×3381.8 hours/year×1000.0 soums= 216,435,200 soums/year

The expected annual economic benefit from electricity costs is approximately 216,435,200 soums.

Conclusion

Evaluating the technical and economic efficiency of centrifugal pumps allows for the following conclusions:

In assessing the technical and economic efficiency of irrigation pumping stations, it is essential to monitor the electrical energy consumed by the pump, implement measures to save electricity, and improve the main performance indicators of the pump.

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METHODOLOGICAL ISSUES OF CREATING AN ASSESSMENT MAP OF THE TOURISM POTENTIAL OF THE TASHKENT REGION OF UZBEKISTAN

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МЕТОДИЧЕСКИЕ ВОПРОСЫ СОЗДАНИЯ ОЦЕНОЧНОЙ КАРТЫ ТУРИСТИЧЕСКОГО ПОТЕНЦИАЛА ТАШКЕНТСКОЙ ОБЛАСТИ УЗБЕКИСТАНА

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ABSTRACT

This article discusses the issues of creating assessment maps of the tourism potential of the Tashkent region of the Republic of Uzbekistan. The analysis of the role of tourism at the regional level is considered from the point of view of opportunities for its development in the territory. This study is aimed at geoinformation mapping of tourism potential, depending on a number of factors affecting the development of the industry in the region. Based on the information obtained from the analysis of existing opportunities, the issues of using geoinformation systems to identify the territorial distribution of opportunities and limitations of tourism development in the region have been resolved. The article also discusses the issues of developing a geodata database for spatial analysis. Visualization of 3 thematic maps is aimed at determining the tourist potential of the territory of the Tashkent region. On the basis of geo-information extracted from spatial and non-spatial data, criteria for assessing tourism potential have been developed and a three-stage scale has been adopted. The tourism potential assessment map was created by spatial analysis of geodata of selected factors. The result is a spatial assessment of regions with high, medium and low potential in terms of tourism development opportunities. The map of the assessment of the tourist potential of the region can be used to find ways to eliminate them and plan the development of the territory.

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АННОТАЦИЯ

В данной статье рассматриваются вопросы создания оценочных карт туристического потенциала Ташкентской области Республики Узбекистан. Анализ роли туризма на региональном уровне рассмотрен с точки зрения возможностей его развития на территории. Данное исследование направлено на геоинформационное картографирование туристического потенциала в зависимости от ряда факторов, влияющих на развитие отрасли в регионе. На основе информации, полученной в результате анализа существующих возможностей, были решены вопросы использования геоинформационных систем для выявления территориального распределения возможностей и ограничений развития туризма в регионе. В статье также рассматриваются вопросы разработки базы геоданных для пространственного анализа. Визуализация 3-х тематических карт направлена на определение туристического потенциала территории Ташкентской области. На основе геоинформации, извлеченной из пространственных и непространственных данных, были разработаны критерии оценки туристического потенциала и принята трехступенчатая шкала. Карта оценки туристического потенциала была создана путем пространственного анализа геоданных по выбранным факторам. Результатом является пространственная оценка регионов с высоким, средним и низким потенциалом с точки зрения возможностей развития туризма. Карта оценки туристического потенциала региона может быть использована для поиска путей их устранения и планирования развития территории.

Keywords: Tashkent region, Uzbekistan, Tourism potential, assessment map, GIS.
Ключевые слова: Ташкентская область, Узбекистан, Туристический потенциал, оценочная карта, ГИС.

Introduction. The state strategy of Uzbekistan, planned until 2030, presents a sequence of works to further increase the potential of tourism. According to this strategy, by 2030 it is planned to increase the number of foreign tourists by 15 million, increase the number of domestic tourists to 25 million, and increase the number of visitors in the field of pilgrimage tourism by 3 times. Tourism development programs involve the creation of large tourist clusters, an increase in the number of guest places by at least 2 times, the construction of 25 cable cars in the highlands, and an increase in the number of tourist settlements to 175. As part of the planned work, 2 girder roads were built and commissioned in the tourist mountain areas of Zamina and Navoi at the end of 2023 and the first quarter of 2024. According to this Program, the key factors and necessary prerequisites for future development are highlighted, as well as the main mechanisms contributing to the development of the industry. One of the important tasks is to increase the potential of the territories. In the development of the economy of the Republic of Uzbekistan, the tourism sector is of great importance due to its impact on employment, an increase in the inflow of currency into our country, an increase in the moral level of people, and an improvement in the activities of economic and social organizations. In Uzbekistan, this indicator is implemented by comprehensive measures to ensure the safety of life and health of tourists and guides in hotels while visiting tourist sites. According to official statistics, the number of tourists who visited Uzbekistan in 2014 amounted to more than 1 million, in 2023 this number exceeded 5 million. The number of foreign tourists reached 80% of the previous level after the pandemic period. In Europe and the Middle East, the recovery rate compared to the first quarter of 2023 was 66%. The opportunities between tourism and international development have long been recognized. Tourism is considered [Gössling & Scott, 2024] not only as a service sector, but also as a reflection of the internal and external relations of the state, an economic and social resource. [Korstanje, 2024] notes the role of global tourism in the pace of its development in countries in the immediate vicinity, which illustrates new patterns in the behavior of travelers. While in the 1950s, Birzhakov points out [2000], tourism was seen as a modernization strategy designed to help newly independent countries create jobs and earn foreign currency, in the 1970s and 1980s tourism was widely criticized by sociologists as an industry dominated by large corporations. But from the late 1980s to the present, some scientists [Gössling & Scott, 2024; James et al., 2023] have focused on the possibilities of achieving more equitable and sustainable tourism development. Analyzing the research on the role of tourism on a global scale, attention is drawn to the desire to find solutions to existing social and economic problems. Researchers [Scheyvens, 2024; Sharma & Martini, 2024; Uhodnikova, 2024] emphasize the connection of tourism with other development paths. According to d'angella, De Carlo [2024], tourism is a tool for addressing sustainable development issues. Rogerson, Rogerson [2024] emphasize the importance of exploring the potential of tourism, providing products, services or interests also for a small group of people as the antithesis of mass tourism. The geography and cartography of tourism helps to study the tourism potential of each country depending on its geographical location [Gulyamova et al., 2023] and, as the researchers emphasize [Dube, 2024; Guia, 2024; Klepej, 2024], use it in the development of the industry in connection with changing conditions caused by climate change. According to [Rickly et al., 2023], the close dependence of tourism research on the concepts of tourism geography determines the potential for future empirical and conceptual research. The spatial aspect of tourism research makes it possible to identify the potential for its development. An example is the study [Blanco-Romero, Blázquez-Salom, 2023] of Spain, which reveals the uneven spatial distribution of tourism and an unused resource in rural areas. The development of an algorithm or methodology for evaluating the effectiveness of strategic and territorial planning health systems at all levels of government, as shown by [Panin et al., 2023], demonstrates the advantages of geoinformation analysis. The possibilities of geoinformation modeling in research

[Tikunov, Gaidukov, 2023; Tikunov et al., 2023] are an effective tool in forming an assessment of the socio-economic conditions of the territory's development. Geoinformation research according to researchers [Panin et al., 2014; Stelmach, 2016] are the main mechanism for planning the organization of tourist zones and tourist sites and an instrument for effective management of recreational and tourist activities. The need to improve scientific geoinformation approaches in tourism research is noted by researchers [Mironova, 2023; Miadzelets, Luzhkova, 2022; Tukhliev, 2020]. Miadzelets, Luzhkova [2022, p. 84] point to "a methodological and substantive deficit that prevents the solution of environmental and educational tasks of protected areas", and "the lack of a unified information technology platform that ensures integration into a centralized data system in Uzbekistan" was noted by Tukhliev [2020, p.35]. New opportunities for geoinformation research have emerged due to the development of the Internet and mobile platforms. Their role as "a means of creating and sharing content through one or more ways of interacting with space, place and the environment" is pointed out by Mingming Cheng [2024]. As a source of geodata, online platforms also provide tools for researching the conditions of tourism development. Panin et al. [2014, p. 573] emphasize the expediency of using GIS technologies as an information resource and mass media about unique and extremely significant territories from the point of view of tourism development. Among the factors determining the development of tourism and its potential, a special place is occupied, as indicated by Mertena & Kaaristo [2024] the interdependence between tourism, transport and mobility.

In order to demonstrate the tourist opportunities and geographical uniqueness of the territory of the Republic of Uzbekistan, this study aims to study the socio-economic conditions of tourism development using the example of the Tashkent region. Based on spatial and non-spatial information, the article discusses the use of geoinformation mapping to develop a system for assessing tourism potential. The following are selected as the main factors of tourism development: 1) accommodation of tourist facilities, 2) tourism infrastructure, 3) demographics of the region. Based on the extracted geoinformation, a three-stage rating scale was developed. According to this scale, regions with high, medium and low potential in terms of tourism opportunities were allocated to the territory of the Tashkent region.

Materials and methods. The main data sources for geoinformation mapping are the materials of the Tashkent Regional Statistics Department of the Agency for Statistics under the President of the Republic of Uzbekistan and the Tashkent Regional Tourism Department. Using the experience of studying the natural and geographical aspects of the Tashkent region for recreational tourism [Gulyamova et.al ., 2023], this study uses the approach of calculating the main indicators based on geodata and assessing the location of tourist facilities, infrastructure and employment of the population as the main socio-economic factors of tourism development. Geodata of outsourcing OpenStreetMap, Google * EarthPro, and Yandex Map are used as the basic basis for geoinformation mapping and storage of geometric elements (Fig. 1).

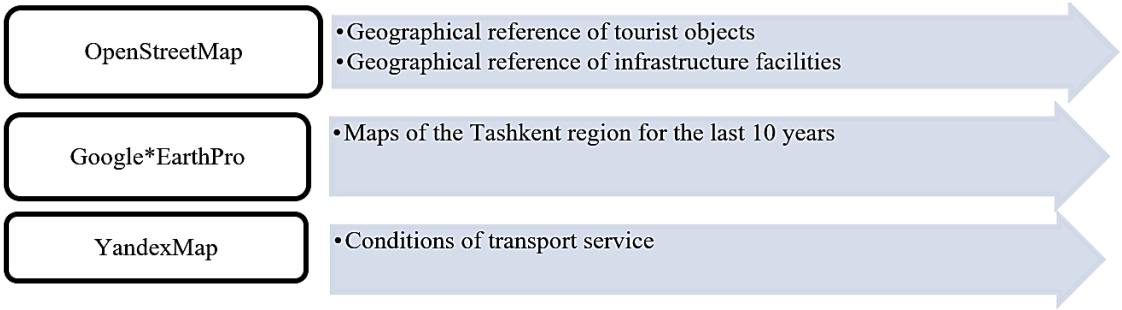


Figure 1. Using Online Geodata

The study is aimed at studying the socio-economic opportunities of tourism in the Tashkent region, for which the tasks are set: ¬ Formation of a database using geoinformation systems using existing data. Development of relevant analytical cartographic data. Development of a capacity assessment system. ¬ Spatial analysis for the assessment of the territory. ¬ Visualization of the analysis results. Based on the objectives of the study, information on tourist resources and demography posted on the official website of the Statistical Office of the Tashkent region and data published in the statistical demographic collection for 2023 were used. Data were collected by region, and for the purposes of analysis and evaluation, indicators for the last 10 years were used. The formation of the database is based on three main indicators: 1. By demography and social status: data on the population of the districts; the age of the population; the number of unemployed; changes in the number of urban and rural residents by year; the proportion of people employed in the tourism business. 2. On the development of tourism: the number of jobs created in the tourism sector; the number of foreign and local tourists who visited the territory; the amount of income received from the tourism sector over the past 10 years. 3. Tourist infrastructure: provision of transport; number of consumer services; number and types of tourist facilities. Based on the collected demographic data on the population of the districts of the Tashkent region for 2013-2023 (Table 1), a database was created for spatial analysis and creation of planned maps of population

dynamics (Fig.2). Data on the tourism sector of the Tashkent regional Department of the Ministry of Tourism and Cultural Heritage of the Republic of Uzbekistan for 2023 in the context of administrative districts served as the basis for studying the territorial features of the development of this industry and creating a system for assessing the potential of tourism.

Table 1.

Population, thousand people, 2014 - 2023

Year / Districts	2023	2022	2021	2020	2019	2018	2017	2016	2015	2014
Akkurgan	110	108	106	105	103	102	101	100	98	97
Akhangaran	109	107	97	96	94	93	128	127	126	124
Bekabad	163	160	160	157	155	153	151	149	146	144
Bostanlyk	175	173	171	169	167	166	164	163	162	161
Buka	133	130	128	126	124	122	120	119	117	116
Zangiata	167	167	195	198	195	193	366	362	357	353
Kibray	173	172	202	200	198	195	193	190	189	187
Nizhnechirchiksky	114	112	110	108	106	105	104	103	102	101
Parkent	175	172	158	155	152	149	147	145	142	140
Pskent	102	104	102	101	99	98	97	96	95	95
Srednechirchiksky	135	133	143	149	147	144	187	185	182	180
Chinaz	143	139	136	134	132	130	128	126	124	123
Verkhnechirchiksky	137	135	139	135	133	131	129	127	125	123
Yangiyul	197	192	210	210	207	203	260	256	253	250
Tashkent	193	188	183	180	178	-	-	-	-	-

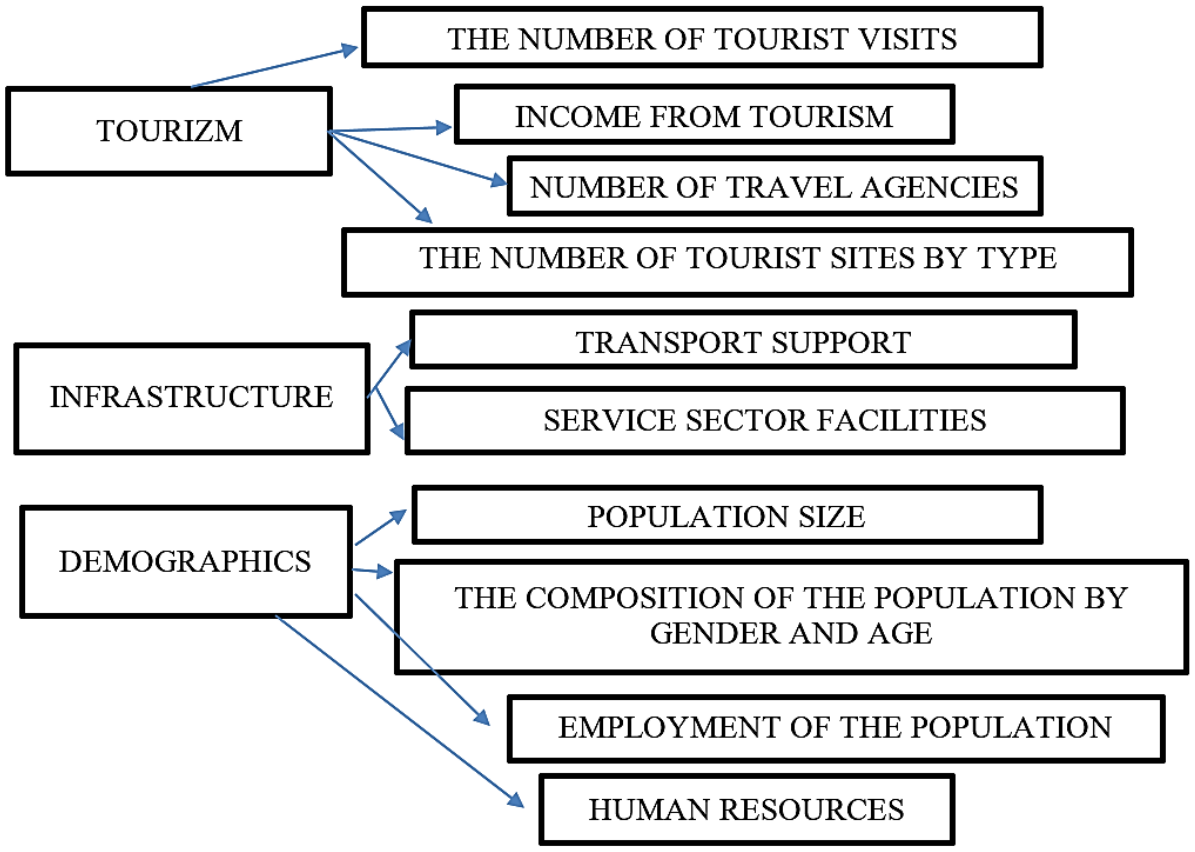


Figure 2. The scheme of database development

In accordance with the specifics of the study, data on the territory is stored in the vector format of the area, transport lines – in the linear vector format, tourist sites – in the point format.

Results and discussion. When assessing the tourism potential of the Tashkent region, criteria have been developed to create an assessment map of the tourism potential of the region. The following indicators have been identified to assess the tourism potential:

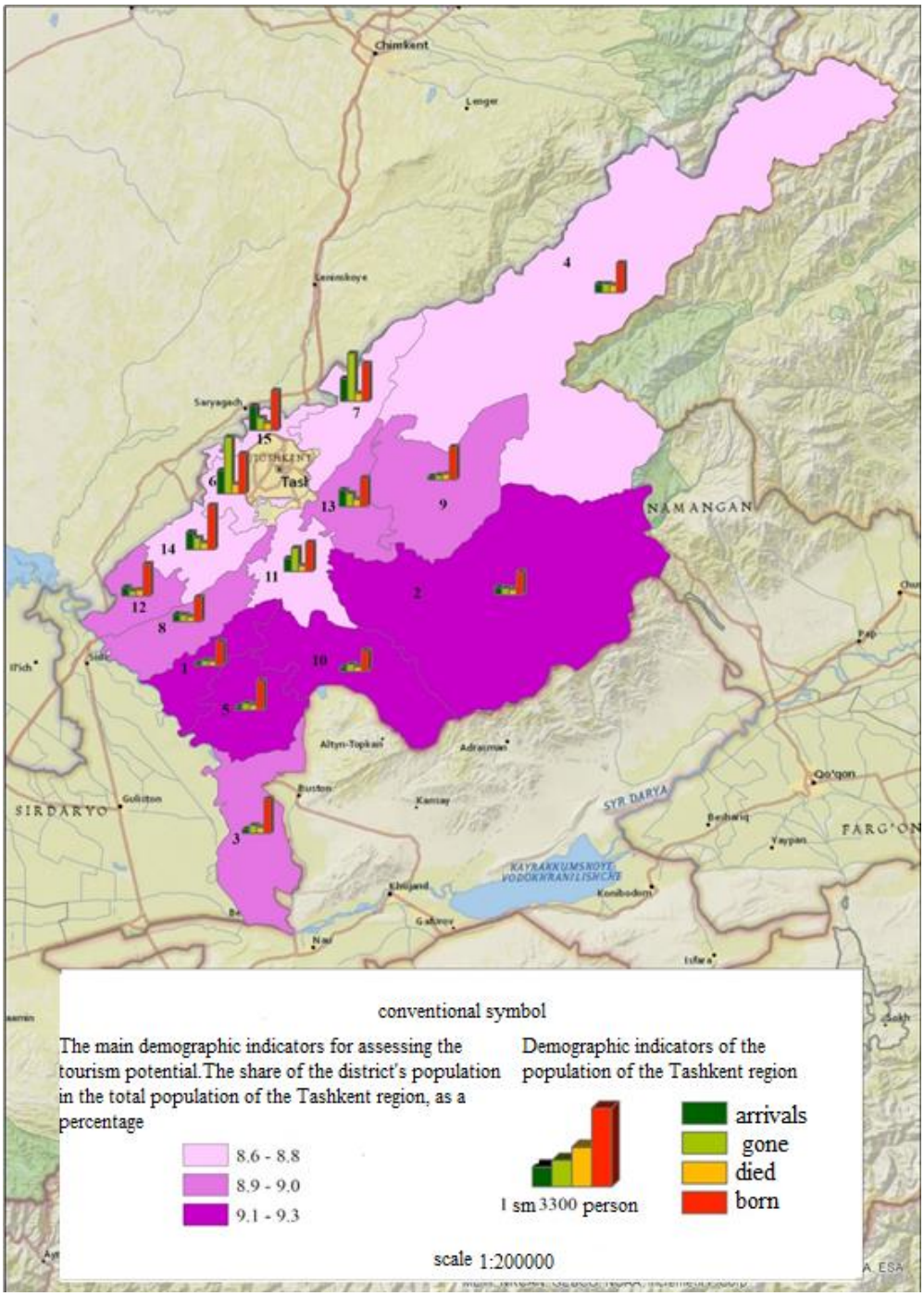
1. Population growth dynamics
2. The share of the working-age population
3. The share of people employed in the tourism business
4. The number of jobs in tourism
5. The distance from the object to Tashkent
6. Distance from the object to the nearest regional center
7. The density of tourist facilities per 1 sq. km
8. Distance between tourist sites
9. Location of objects relative to communication routes

Demographics and workforce. One group of indicators consists of data on demography and labor resources, as one of the main criteria for the potential of tourism development: 1. The share of the district's population in the total population of the Tashkent region (in %), demographic indicators of natural movement (people), internal migration (people) (Fig.3). 2. Labor resources, the share of unemployed to the total number of employed in the economy (thousand people) (Table 2).

Table 2.

Main demography indicators for assessing the tourism potential of the Tashkent region

Districts	The population employed in the economy			Unemployed	
	total, thousand people	Engaged in tourism		thousand people	%
		thousand people	%		
Bostanlyk	80,0	0,841	1.05	7,7	8,8
Zangiota	83,5	0,687	0.83	7,3	8,7
Akkurgansky	48,6	0,441	0.9	4,5	9,2
Akhangaran	38,3	0,363	0.95	3,7	9,1
Parkent	69,0	0,542	0.78	6,2	9,0
Nizhne chirchiksky	51,0	0,339	0.66	4,6	9,0
Bukinskiy	55,2	0,390	0.71	5,2	9,3
Kibray	83,8	0,499	0.60	7,2	8,6
Verkhnechirchiksky	57,3	0,401	0.70	5,1	8,9
Tashkent	81,4	0,475	0.58	7,0	8,6
Yangiyul	93,1	0,471	0.51	8,1	8,7
Chinaz	57,2	0,297	0.52	5,2	9,0
Pskov	45,6	0,218	0.48	4,2	9,2
Bostanlyk	66,6	0,283	0.42	6,0	8,9
Zangiota	61,4	0,215	0.35	5,4	8,8

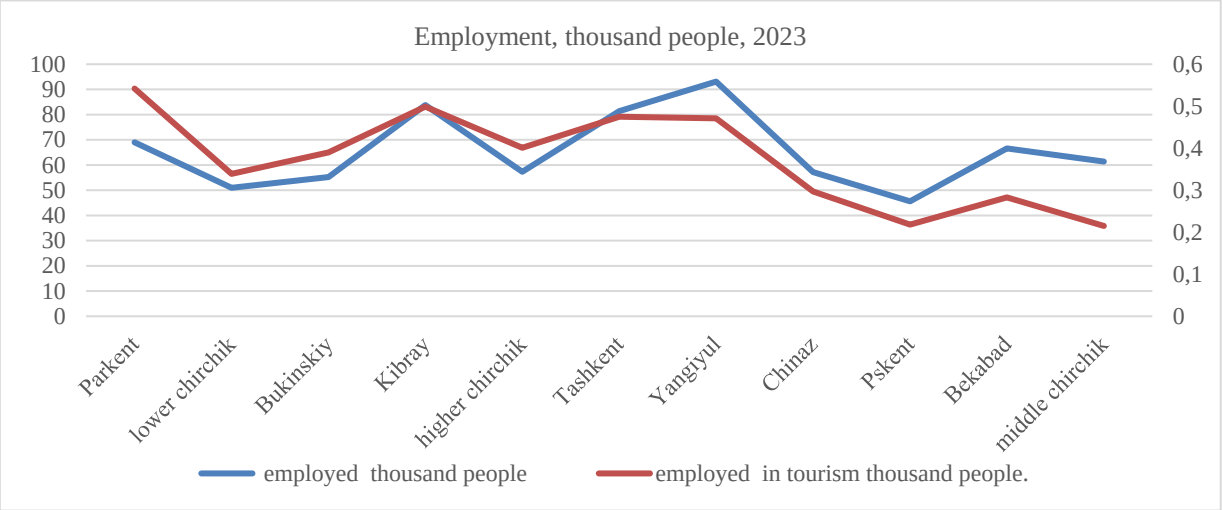


Source: compiled by authors according to the official data of the Tashkent Regional Department of the Agency on Statistics under the President of the Republic of Uzbekisstan.

Note: numbers on the map indicate the districts

Figure 3. Map of demography of Tashkent region.

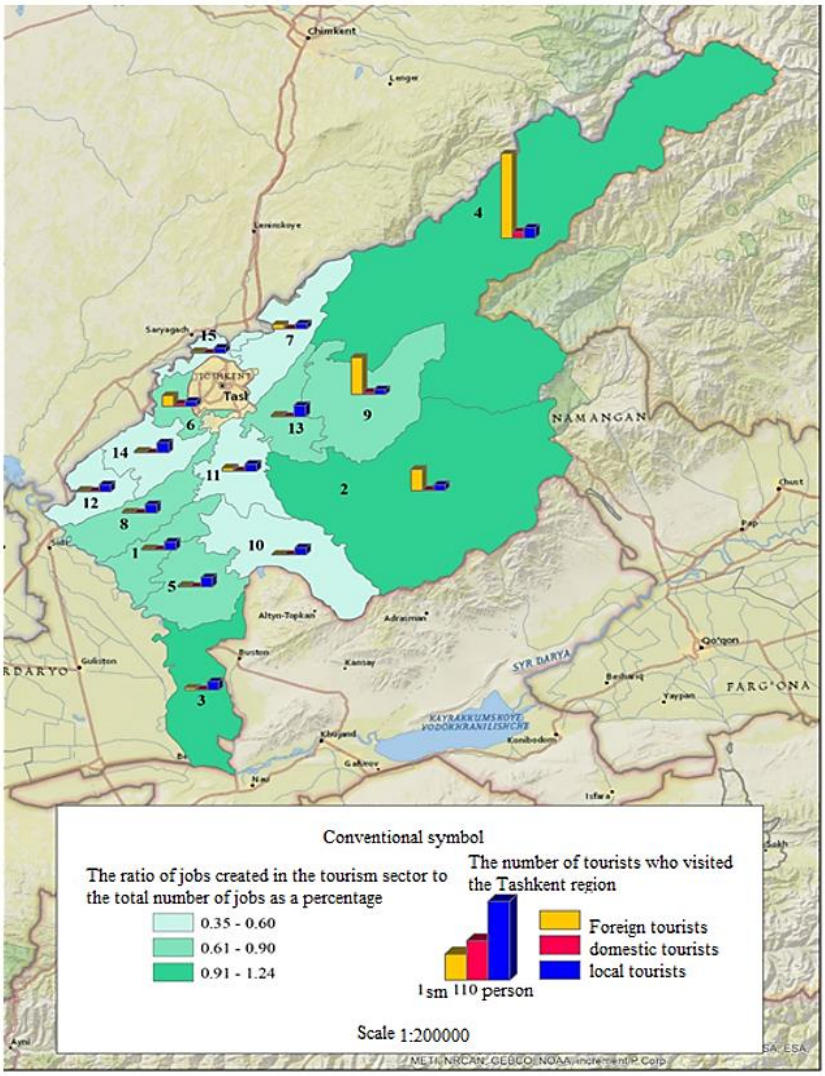
Note: on the maps, the numbers indicate the areas: 1. Akkurgan; 2. Akhangaran; 3. Bekabad; 4. Bostanlyk; 5. Buka; 6. Lower Chirchik; 7. Zangiata; 8. Higher Chirchik; 9. Kibraysky; 10. Parkent; 11. Pskent; 12. Middle chirchik; 12. Chinaz; 13. Yangiyul; 14. Tashkent. The results of calculations of the distribution over the territory of some indicators are shown in Fig. 4



Source: compiled by authors according to the official data of the Tashkent Regional Department of the Agency on Statistics, 2023.

Figure 4. Employment in the tourism

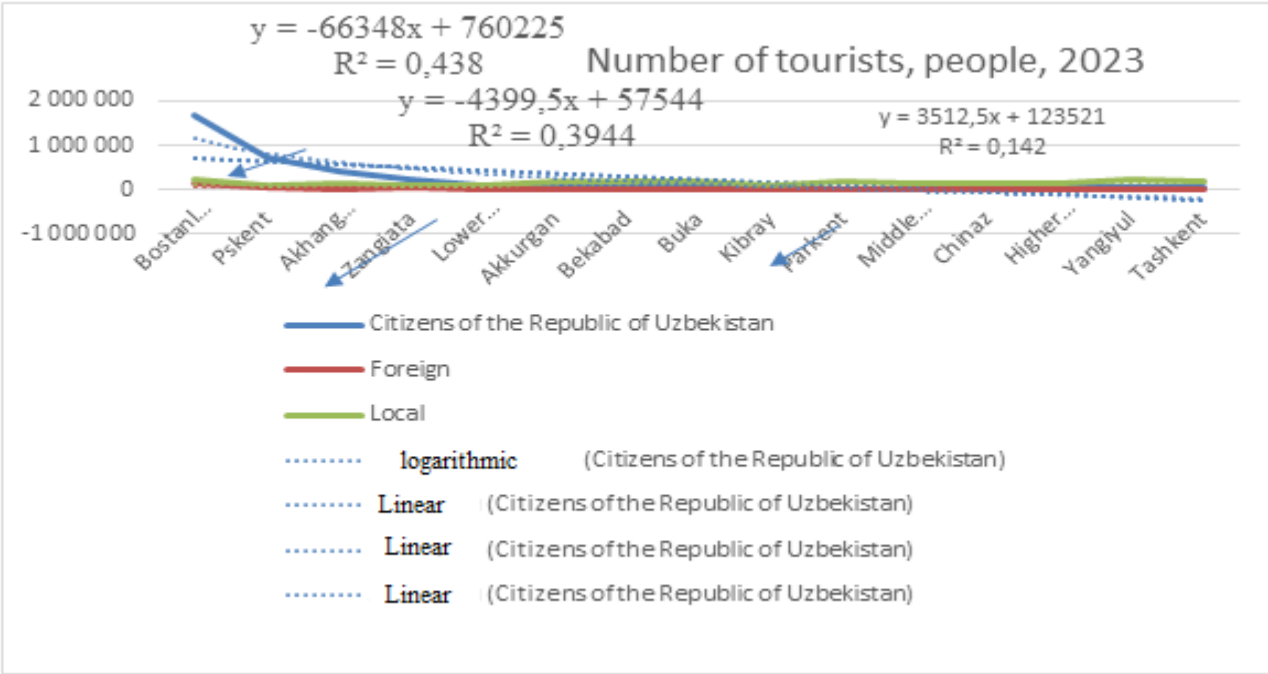
An essential indicator for assessing the potential of tourism development is the ratio of jobs created in this industry to the total number of jobs, in % (Fig. 5).



Source: compiled by authors according to the official data of the Tashkent Regional Department of the Agency on Statistics under the President of the Republic of Uzbekisstan. Note: numbers on the map indicate the districts

Figure 5. Map of employment in tourism of Tashkent region

One of the indicators of tourism potential is the number of visits to tourist sites: 1) The number of foreign, 2) domestic (from other regions of Uzbekistan), 3) local (residents of the Tashkent region) tourists who visited tourist sites of the Tashkent region (people) in 2023 (Table 3). Mathematical and statistical analysis of data on tourist visits to certain areas shows that the spatial distribution of these data is significantly uneven (Fig. 6). It is noteworthy that tourists from other regions of the Republic of Uzbekistan predominate in the number of visits. The number of tourists from abroad and residents of the Tashkent region is insignificant. In 2023, the number of local tourists who visited Bostanlyk district of Tashkent region for the purpose of tourism amounted to 1,677,169 people, which is the highest figure in the region, the number of foreign tourists - 125,336, the number of local tourists - 208,957 people. This area is located in a foothill and mountainous area, characterized by a variety of natural landscapes and a comfortable climate. The Parkent and Akhangaran districts are also located in similar natural and climatic conditions and are mainly the object of recreational tourism. The Zangiata area is the most visited by tourists as an object of rapidly developing pilgrimage tourism. These three districts differ significantly from other districts and have high potential for further development and investment in this industry.



Source: compiled by the authors based on the materials of the Tashkent Regional Department of the Committee for Tourism under the Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan

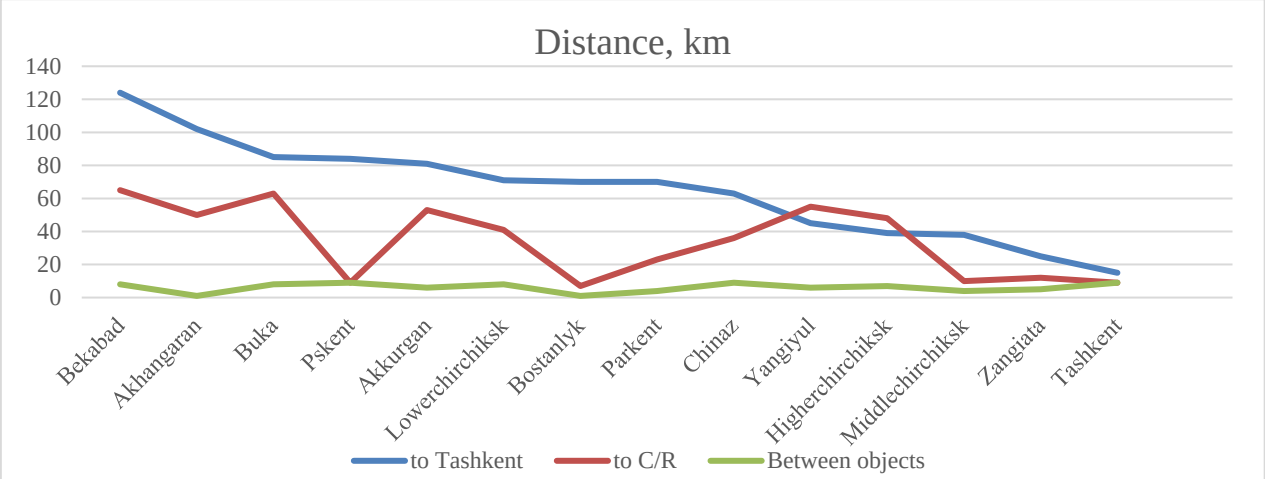
Figure 6. Number of visits to tourist sites in the Tashkent region in 2023

Accessibility of tourist facilities. The next group of indicators characterizing the potential of tourism is related to the possibilities of transport accessibility, the placement of facilities on the territory: 1. The "Distance" indicator: 1) the distance to the city of Tashkent; 2) the distance to the center of the district; 3) the distance from one object to another object; 4) the distance to the communication routes using the spatial analysis method. 2. The indicator "Density of objects": 1) the number of tourist sites in an area of 1 sq. km. Online information about the distance and the conditions of transport were obtained with the help of online services Google *, Bing and OpenStreetMap. In order to calculate how much time tourists, spend on the road during their trip, the distance between the district centers of the Tashkent region and the city of Tashkent was analyzed. According to calculations, the distance to Tashkent from the district centers of the Tashkent region is divided into 3 groups: 1) less than 30 km; 2) 30-100 km; 3) more than 100 km. The average distance from tourist sites to the nearest regional center is 11 km. There are three main groups of accommodation relative to the district center: 1) less than 10 km; 2) 10 – 50 km; 3) more than 50 km. The average density of tourist facilities in the territory was 5 units per 1 sq. km. Three main groups: 1) 4 – 5; 2) 2 – 3; 3) 1. The distance between objects is represented by 3 groups: 1) less than 1 km; 2) 1-5 km; 3) more than 5 km.

Table 4.

Indicators of access for visiting tourist sites

Districts	Distance, km		
	To Tashkent	To the district center	Between objects
Bekabad	124	65	8
Akhangaran	102	50	1
Buka	85	63	8
Pskent	84	9	9
Akkurgan	81	53	6
Lowerchirchik	71	41	8
Bostanlyk	70	7	1
Parkent	70	23	4
Chinaz	63	36	9
Yangiyul	45	55	6
Higherchirchik	39	48	7
Middlechirchik	38	10	4
Zangiata	25	12	5
Tashkent	15	9	9



Source: compiled by the authors

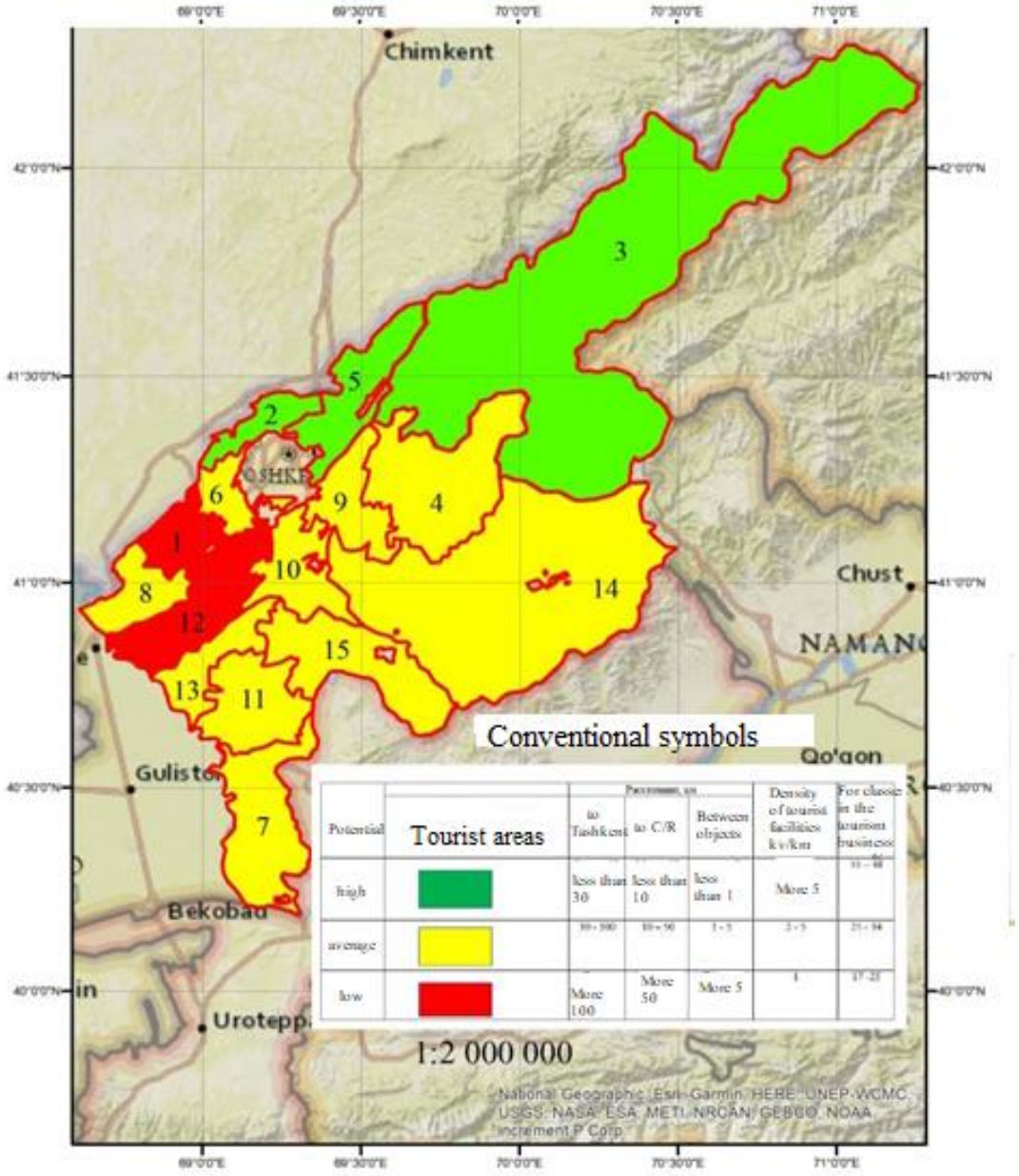
Figure 7. Accessibility of tourist sites

Based on the fact that the goal was to create a 3-point system for assessing the potential of tourism, 3-step scales were adopted for calculations and visualization to build appropriate maps. This makes it possible to simplify the process of allocating territories with similar conditions and drawing up an assessment map by combining maps of the region's population, the dynamics of the development of the tourism sector, and the placement of tourist infrastructure facilities. To assess the potential of tourism, a 3-point scale has been adopted, which takes into account a number of main factors affecting the development of tourism (Table 5).

Table 5.

Indicators of potential for visiting tourist sites

Potential	Distance, km			The density of tourist facilities, 1 / sq.km	The share of people employed in the tourism business, %
	To Tashkent	To the center of the district	Between objects		
High	Less than 30	Less than 10	Less than 1	More than 5	35 – 48
Medium	30 – 100	10-50	1-5	2 – 5	25 – 34
Low	More than 100	More than 50	More than 5	1	17 – 24



Source: compiled by authors

Figure 8. Map of assessment of tourism capacity of Tashkent region

Conclusions. As a result of the conducted research, it was possible to solve a number of tasks: 1) Integrate non-spatial statistical data and geodata from open sources posted on the Internet to form a database on tourism in the Tashkent region. 2) To develop a system of potential assessments based on the analysis of the spatial distribution of the main factors determining the potential of tourism development: a) demographics and labor resources: b) facilities visited by tourists; c) accessibility of facilities. 3) Using the methods of spatial analysis and mathematical statistics, identify areas with high, medium and low potential. 4) The received map was compiled for the first time for the Tashkent region. Its practical significance lies in the fact that a methodology has been proposed based on the analysis of a large number of data, areas for which there are reserves for tourism development have been identified. The scientific significance lies in the use of geoinformation mapping to create an assessment map of tourism based on the developed system of indicators.

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**(По требованию Роскомнадзора информируем, что иностранное лицо, владеющее информационными ресурсами Google является нарушителем законодательства Российской Федерации – прим. ред.)*

THE RESISTANCE OF PRE-STRESSED FORMWORK-FREE FLOOR SLABS TO THE ACTION OF SHORT-TERM STATIC LOADS

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РАБОТА ЖЕЛЕЗОБЕТОННЫХ ПРЕДВАРИТЕЛЬНО НАПРЯЖЕННЫХ ПЛИТ ПЕРЕКРЫТИЙ БЕЗОПАЛУБОЧНОГО ФОРМОВАНИЯ ПРИ НАГРУЖЕНИИ КРАТКОВРЕМЕННОЙ СТАТИЧЕСКОЙ НАГРУЗКОЙ

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ABSTRACT

The article presents the results of experimental research on the strength and deformation of concrete with a strength class of B30 under short-term compressive loads, which relate to floor slabs of various lengths. An analysis of the results of full-scale tests of restressed multi-hollow slabs, reinforced with high-strength reinforcing wire of class Bp1400, is conducted in terms of load-bearing capacity, crack resistance of normal sections, and deformability under short-term static loading. For a comprehensive analysis of the behavior of restressed formwork-free floor slabs under short-term static loading, it is necessary to consider concrete stress-strain diagram parameters: average compressive strength, initial elastic modulus, and ultimate deformations. The question of assessing the reliability of the slabs is a complex probabilistic problem, especially when considering the seismic activity of the construction area and the variability of the properties of the concrete used and the characteristics of the reinforced concrete structure as a whole.

АННОТАЦИЯ

Представлены результаты экспериментальных исследований прочности и деформаций бетона класса по прочности на сжатие B30 при действии кратковременной сжимающей нагрузки, относящихся к плитам перекрытий различных длин. Выполнен анализ результатов натурных испытаний предварительно напряженных многопустотных плит, армированных высокопрочной проволочной арматурной проволокой класса Bp1400, по несущей способности, трещиностойкости нормальных сечений и деформативности при нагружении кратковременной статической нагрузкой. Для глубокого анализа работы предварительно напряженных плит перекрытий безопалубочного формования при нагружении кратковременной статической нагрузкой следует учитывать параметры диаграммы "напряжение-деформация" бетона: средняя прочность бетона на сжатие, начальный модуль упругости и предельные деформации. Вопрос оценки надежности плит является сложной вероятностной задачей, особенно если учесть сейсмоактивность районов строительства и изменчивость свойств используемого бетона и характеристик железобетонных конструкции в целом.

Keywords: concrete, strength, crack resistance, stiffness, plate, reinforcement, high-strength reinforcing wire.
Ключевые слова: бетон, прочность, трещиностойкость, жесткость, плита, арматура, высокопрочная арматурная проволока, перекрытие.

The objective of this work is an experimental study of the stress-strain state and an assessment of the strength, rigidity and crack resistance of typical reinforced concrete floor slabs of bench-type formwork-free formation under short-term static load.

To achieve this objective, the following tasks are solved sequentially:

1. Experimental study of the strength and deformability of concrete used for the manufacture of floor slabs;
2. Control of the technology of manufacturing floor slabs under production conditions according to the technical regulations for the manufacture of concrete samples for experimental studies;
3. Conducting standard tests of floor slabs under short-term static load in accordance with the requirements of current regulatory documents;
4. Processing and analysis of experimental research data to prepare a conclusion on the results obtained and assess the strength, rigidity and crack resistance of floor slabs of bench-type formwork-free formation.

Introduction. The system of any multi-story reinforced concrete frame building is formed by vertical load-bearing structures (columns, panels) connected into a unified spatial system with horizontal load-bearing structures (floor slabs). The load-bearing elements in these buildings include the reinforced concrete frame consisting of columns, beams, and foundations, as well as vertical stiffness elements in the form of reinforced concrete diaphragms and horizontal elements.

The floor slabs of multi-story frame buildings can be precast, cast-in-place, or a combination of both. Precast beam floor slabs typically consist of hollow panels supported by the frame's beams.

Approximately 60% of the total consumption of reinforced concrete structures is attributed to floor slabs. Therefore, it is essential to pay the most attention to their rational structural design. To reduce the weight of the slabs, they are designed with circular or oval voids and are often pre-stressed.

Precast restressed concrete multi-hollow slabs with high-strength wire reinforcement (referred to as slabs) are manufactured on forming stands using a continuous formwork-free technology. According to this technology, longitudinal reinforcement is laid on the stand, secured at both ends, and tensioned using a hydraulic jack. Concrete placement is done using a forming unit, which involves the sequential placement of a rigid concrete mix that includes provisions for fixing the tensioned reinforcement wires in their design positions. After forming, the slabs are subjected to heat treatment and covered with polyethylene film to protect the surface. The concrete ribbon is then cut into slabs of the required length using diamond saws. This technology is used to produce multi-hollow slabs with a thickness of 22 cm, a width of 120 cm, and lengths up to 12 m, designed to support various loads.

Properties of materials and testing methods. In the experimental research, heavy concrete specimens were prepared using Portland cement of grade PC400D20 from the "Kyzylkumcement" joint-stock company with an activity of 38.2 MPa.

As coarse aggregate, granite crushed stone from the "Nerudnik" quarry with a particle size of 5-20 mm, conforming to GOST 8267 "Crushed Stone and Gravel from Dense Rocks for Construction. Technical Specifications", was used. The granite crushed stone has the following properties:

•Bulk density: 1380 kg/m^3

•Void volume: 38%

•Water absorption after 1 hour: 1.4%, after 48 hours: 1.8%.

As fine aggregate, quartz sand from the "Nerudnik" quarry, complying with GOST 8736 "Sand for Construction. Technical Specifications", was used. The sand has the following properties:

•Specific gravity: 2.62 t/m^3

•Bulk density: 1470 kg/m^3

•Fineness modulus: 2.8.

The concrete mix for class B30 concrete used to manufacture the slabs had the following composition:

•Cement: 480 kg/m^3

•Sand: 680 kg/m^3

•Crushed stone: 1080 kg/m^3

•Water: 210 liters/m^3

The workability of the concrete mix was 50-60 seconds according to for each composition.

To determine the strength and deformation characteristics of the concrete, concrete cubes with edge sizes of 100 mm and prisms with dimensions of 100x100x400 mm were manufactured simultaneously with the slabs, using the same concrete mix. The tests on cubes and prisms were conducted at the age of 28-30 days in a hydraulic press IGM-1000 in accordance with GOST 10180 and GOST 24452.

During the prism tests, the load was applied in increments of 10% of the expected ultimate load. The modulus of elasticity of concrete was determined under a load of 30% of the ultimate load. Based on the results of these tests, the prism compressive strength, initial modulus of elasticity, and ultimate compressibility of the concrete for each grade were determined.

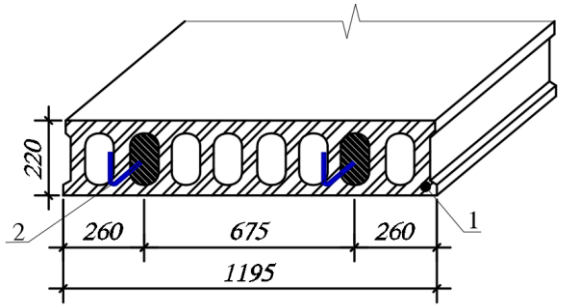
To determine the mechanical properties of the reinforcing wire, samples were tested according to the requirements of GOST 12004. These tests were also carried out using a hydraulic press IGM-1000.

The prestressed reinforcement is made of high-strength wire of class Bp1400 from the Beloretsk Metallurgical Plant (Russian Federation), characterized by a tensile strength of 1800-1820 N/mm^2 at 7% elongation, and an elastic modulus Es=196,000 MPa, in accordance with the requirements of GOST 7348 "Wire of Carbon Steel for Reinforcement of Prestressed Concrete Structures. Technical Specifications".

In accordance with [1], the load-bearing capacity of multi-hollow slabs was assessed through full-scale tests, checking strength, stiffness, and crack resistance of normal sections under the action of control uniformly distributed loads in accordance with the regulatory documentation.

The criteria for assessing load-bearing capacity include allowable deflections under control loads based on stiffness, crack width, and the load-bearing capacity with a strength safety factor [1] depending on the nature of failure of the tested reinforced concrete structure.

Results and discussions. High-strength prestressing reinforcement is used, consisting of 5mm diameter wire of class Bp1400, which is placed in the upper and lower zones of the slab within the spaces between voids. For all slab sizes, the upper zone reinforcement consists of 4 ∅ 5mm Bp1400 wire each. Heavyweight concrete of class B30 is used for all slab sizes. The design dimensions of these slabs are chosen to ensure their interchangeability with typical multi-hollow (six-hollow) floor slabs with a thickness of 22 cm (see Figure 1).



1 - floor slab; 2 - anchor projections.

Figure 1. Cross-section of the floor slab with oval voids

One of the drawbacks of these slabs compared to typical ones is that during their formation, there is no opportunity to create keying slots (indentations) along the side faces and anchor protrusions on their ends, which are intended for carrying out seismic measures. Therefore, the formation of indentations is carried out after molding with fresh concrete, and anchor protrusions are installed after the slabs have been heated in the factory or on the construction site during their installation.

Currently, such slabs are produced by many enterprises in the republic. The LLC "BINOKOR TEMIR-BETON SERVIS" produces similar slabs according to working drawings [2] on equipment imported from abroad.

As is well known, the quality and reliability of reinforced concrete products are generalized indicators that are evaluated by a set of characteristics dependent on many technological and structural factors. The reliability of such structures should be based on their trouble-free operation, i.e., on the preservation of their functionality throughout the prescribed service life. In the context of this work, tests were conducted to determine the concrete strength using both destructive and non-destructive methods, as well as the structural parameters of the slabs.

The determination of concrete strength was carried out by testing experimental concrete cubes with edge dimensions of 10 cm on a hydraulic press at 28 days of age and by using the method of elastic rebound of concrete slabs with the ONIKS-2.53 device [3]. In each case, six tests were conducted to ensure the consistency of the results.

The testing scheme of the slabs corresponded to the design scheme of the slab, representing a freely supported beam with a uniformly distributed load created by individual concrete weights (see Figure 2). These tests, in line with the set goal, were carried out until the load corresponding to the evaluation of crack resistance and stiffness of the slabs was reached. The deflection of the slabs was measured using the N.P. Maximov system with a dial gauge, taking into account the settlement of the supports measured with 0.01 mm dial indicators. The crack width was measured using the MPB-24 device.

Figure 2. Testing process of the floor slab

As is well known, the bond between the reinforcement and the concrete, not less than the strength of the concrete itself, ensures the reliability of restressed slabs. For this purpose, the concrete of such slabs must possess the necessary strength and density, which is achieved by appointing its optimal composition and proper placement and compaction of the concrete mix. If, for any reason, the transfer strength is reduced, there is a risk of increasing the length of the stress transfer zone and reducing the crack resistance of the support sections of the slab. In the slabs, after the release of tension, the wire tends to return to its initial position, resulting in a process of rapid creep of concrete around it, leading to the densification of the concrete structure. As a result, the concrete in the contact zones becomes denser and stronger compared to the peripheral layers. This is evidenced by the fact that after cutting the slabs, there is no slippage of the wires from both ends of the slab.

Table 1.

The test results for determining the strength and deformation of the concrete slabs

Designation of Samples	Cubical strength, R, MPa	Prism strength, R_b, MPa	Initial modulus of elasticity $E_b \times 10^{-3}$, MPa	Ultimate compressibility $\mathcal{E}_b \cdot 10^{-5}$
Class of Concrete slabs PB47.12-6	40.6	32.0	28.8	235
Class of Concrete slabsPB60.12-8	39.8	31.0	29.2	242
Class of Concrete slabs PB72.12-8	42.2	33.2	29.6	230
Class of Concrete slabs PB90.12-8	40.4	31.8	28.0	225
Class of Concrete slabs PB89.12-8	41.1	32.5	28.6	230

The data in Table 1 show that, based on the test results, the composition of concrete used in production conditions is relatively homogeneous in structure with minimal deviations.

As indicated by the data in the table, the modulus of elasticity of concrete is related to its strength, and its actual values are typically evaluated through a straightforward dependency. Such a relationship is commonly accepted in normative documents for the design of reinforced concrete structures [4, 5]. One of these dependencies in the form of a regression equation is as follows:

$$E_b = -0.0064 \cdot R_b^2 + 0.831 \cdot R_b + 13.9907 \quad (1)$$

The ultimate compressibility of concrete under compression is typically assumed to be 200×10^{-5} when calculating the crack resistance of reinforced concrete structures. However, its actual values vary within fairly wide limits and linearly increase with the increase in prism strength [6], which can be expressed by the following regression equation:

$$\varepsilon_b = -0.00013 \cdot R_b^2 + 0.02649 \cdot R_b + 1.5459 \quad (2)$$

Where: R_b is the prism strength of concrete, in MPa.

As the results of the comparison between the calculated and experimental values of the modulus of elasticity and ultimate compressibility of the concrete slabs, computed using equations (1) and (2), show, the difference on average is 18% and 2.5%, respectively. This indicates that for the calculated determination of the modulus of elasticity of concrete slabs in the formula (1), an additional factor is needed to be included, such as the specific content of cement paste in the concrete mix or another parameter that characterizes the structural characteristics of such concretes.

The resistance of concrete for calculations is determined according to the current norms for the design of reinforced concrete structures [4, 5], based on the values of the normative resistance obtained by non-destructive methods before testing the slabs. With data on the strength of concrete in individual sections (at least six), it is possible to estimate it using statistical methods. The normative value of concrete strength is calculated using the formula:

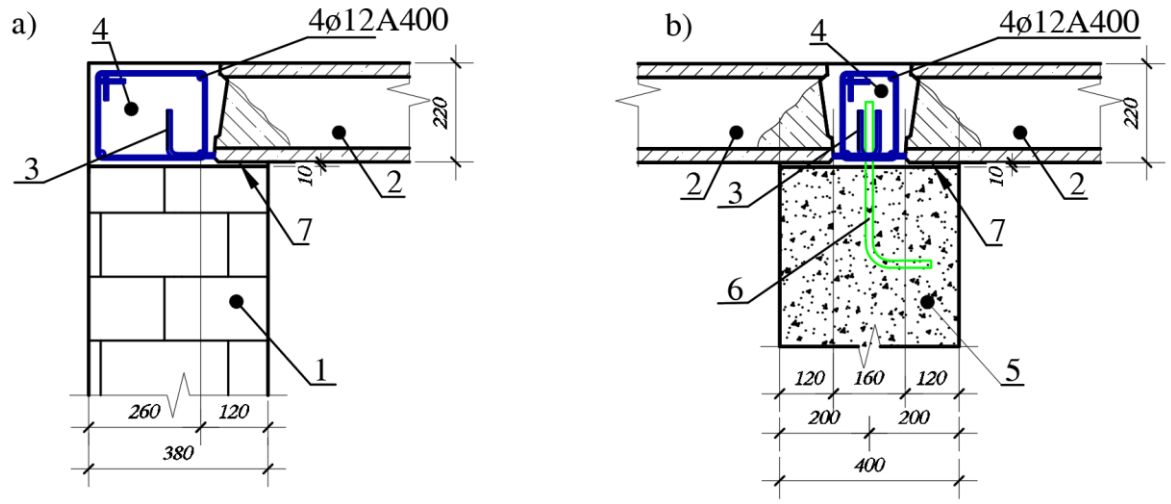
$$R_n = R_m - \alpha \cdot S_R, \text{ MPa} \quad (3)$$

Where:
R_m- average actual strength of the concrete structure;
S_R- root mean square deviation of test results;
n- number of measurements;
α- coefficient determined from the expression.

$$\alpha = 3.62\left(1 - \frac{2.52}{n}\right) \quad (4)$$

The calculation also includes coefficients for the concrete working conditions, as specified in the standards [5]. Depending on the obtained concrete strength class under compression by interpolating the tabular values provided in the standards, the calculated resistance of the concrete is determined.

Structural solutions for the supports of floor slabs on brick walls and reinforced concrete girders of buildings, taking into account seismic measures, are shown in Figure 3.



1 - brick wall; 2 - floor slab; 3 - anchor projections; 4 - seismic belt; 5 - reinforced concrete girder; 6 - anchor pins of the girder; 7 - cement-sand mortar M100.

Figure 3. Support details of floor slabs on brick walls (a) and reinforced concrete girders (b)

To withstand seismic forces, a rigid diaphragm is created on all levels of the floor slabs by installing monolithic reinforced concrete inserts between the lateral edges of the slabs, followed by anchoring them into the seismic belts of the buildings [2, 7, 8, 11].

Table 2.

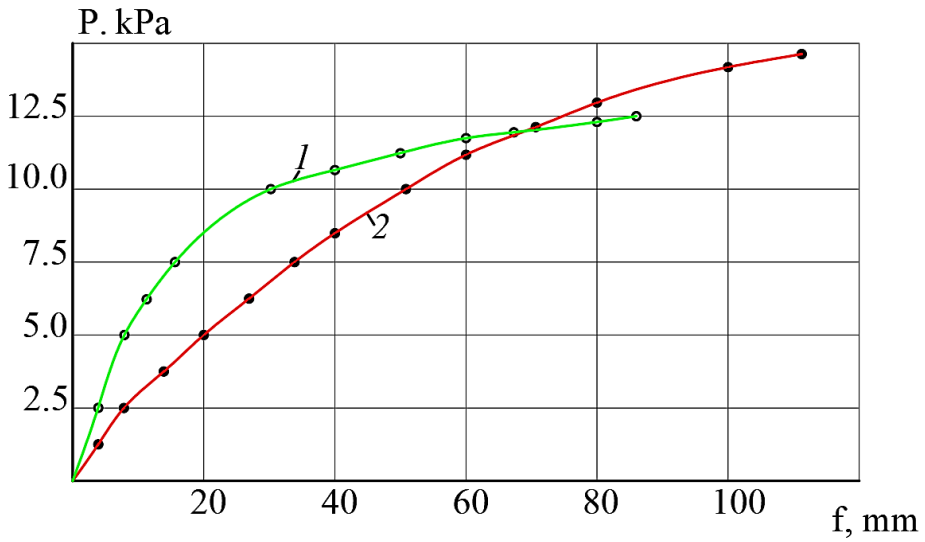
The characteristics of the multi-void slabs designed for testing are provided

Class of slabs	Dimensions, mm	Concrete class	Amount of reinforcement (reinforcement percentage)	Concrete strength of the slab on the day of testing, MPa
PB47.12-6	Cross section 220x1200, length 4700	B30	4ø5Bp1400 + 9ø5Bp1400 (0.12)	40.3
PB60.12-8	Cross section 220x1200, length 6000	B30	4ø5Bp1400 + 17ø5Bp1400 (0.20)	43.1
PB72.12-8	Cross section 220x1200, length 7200	B30	4ø5Bp1400 + 39ø5Bp1400 (0.40)	41.0

Class of slabs	Dimensions, mm	Concrete class	Amount of reinforcement (reinforcement percentage)	Concrete strength of the slab on the day of testing, MPa
PB90.12-8	Cross section 220x1200, length 9000	B30	4ø5Bp1400 + 45ø5Bp1400 (0.46)	39.8
PB89.12-8	Cross section 220x1200, length 8900	B30	4ø5Bp1400 + 42ø5Bp1400 (0.43)	41.1

During the testing of the slabs, the load was applied in steps, with each step constituting 10% of the design load, and there was a 10-minute hold at each step. After reaching the design load, there was a 1-hour hold to observe the processes of rapid creep of the concrete.

Figure 4 shows characteristic load-deflection graphs obtained during the testing of the floor slabs. Based on these graphs, it can be concluded that the deflection of the slabs increases as the load is raised, but as it approaches the ultimate load, there are no significant deformations indicative of concrete creep.



1-stamp PB60.12-8, 2-stamp PB90.12-8.

Figure 4. Typical load-deflection (deflection + bending) curves

The values of deflection under the design load for all tested floor slabs do not exceed the limits specified in the design documentation [2]. When subjected to the design loads, no cracks appeared in the tension zone of any of the floor slabs. Cracks with a crack width of 0.05 mm were only observed when loads exceeded the design load by 30-40%. This condition can be explained by the possibility that the strength of the floor slabs in the tension zone might be slightly higher compared to the compressive zone. This is due to the formation of a dense structure of rigid concrete mixture in these zones, achieved by the pressure applied by the pons (void formers) of the molding machine during the vibration compaction process.

Under the action of the design load, no slippage of the working reinforcement was observed at the edges of the slabs. This provides confidence in the reliability of the bond between high-strength wire and concrete under load in pre-stressed continuous formless floor slabs. This is facilitated by the high strength of the concrete itself, as well as the adhesion of the reinforcement to the concrete, the frictional forces between the reinforcement and concrete caused by shrinkage deformations, and the mechanical interlocking of the reinforcement in the concrete due to its surface shape.

During strength testing, the load-bearing capacity of the floor slabs was ensured at control loads with a safety factor of 1.6. Under these conditions, cracks with a crack width of 0.2-0.25 mm were observed at the level of the restressed reinforcement. Further increase in the load led to a significant increase in deflection and the opening of cracks in the slabs up to 1.0-1.5 mm, with simultaneous yielding of the reinforcement without fracturing the concrete in the compressive zone of the structure. Based on the test results, the tested floor slabs met the requirements specified in [1] and complied with the current standards [9].

The results of the experiments allow establishing the influence of the percentage of reinforcement of floor slabs on their load-bearing capacity. For slabs with a low percentage of reinforcement (1.2% and 2.0% for slabs with lengths of 4700 mm and 6000 mm, respectively), the height of the compressed zone is small before failure. For slabs with lengths exceeding 7200 mm (reinforcement percentage over 4%), the height of the compressed concrete zone increases, indicating that the

reinforcement is not fully utilized (and stress in it does not reach the yield point). This condition confirms that the reinforcement is in the elastic stage when the floor slabs reach the ultimate state of load-bearing capacity. In connection with this, it can be noted that the incomplete utilization of the calculated resistance of high-strength wire reinforcement can lead to an inaccurate determination of the nature of the failure of the formwork-free floor slabs and their over-reinforcement.

All floor slabs exhibited flexural failure characteristics along normal cross-sections. The results of the comprehensive tests allow for the determination of the actual load-bearing capacity of the slabs and the operational loads. These factors are considered during the development of detailed drawings for pre-stressed multi-void formless floor slabs intended for use in construction in seismic zones [2, 10]. To fully realize the structural characteristics of such slabs under operational conditions and the impact of forces acting along their perimeter in longitudinal and transverse joints, the requirements outlined in the design documentation and current standards [2, 9] must be strictly adhered to.

Conclusion. The results of experimental studies on the strength and deformability of concrete with a compressive strength class of B30 and tests of multi-void formless floor slabs under short-term loads provide a basis for the potential use of concrete with a class of B25 to manufacture such structures under design loads of 4.5 kPa and 6.0 kPa. Additionally, the use of wire reinforcement as restressed reinforcement is in line with the recommendations of current standards for designing reinforced concrete structures. Forming re-stressed concrete floor slabs without the need for molds using a concrete mix with an optimal composition and proper consistency allows for the production of concrete with a strong and dense structure, ensuring a guaranteed concrete class for compressive strength. However, it is essential to take into account the actual strength of the concrete used in the construction by determining it through non-destructive testing.

Selective tests conducted on mass-produced and experimental floor slabs subjected to static loading have shown that they meet the requirements of regulatory documents in terms of stiffness and crack resistance and possess sufficient strength. To ensure the reliable and successful use of such floor slabs, strict adherence to the structural solutions and installation guidelines is necessary, especially concerning the implementation of seismic measures as outlined in regulatory documents.

For a reliable assessment of the operational reliability of pre-stressed floor slabs with high-strength wire reinforcement, which is a complex probabilistic problem, it is necessary to continue comprehensive experimental and theoretical research in this direction to obtain and accumulate new results.

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